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THE TWENTY-FOUR HOUR WORKDAY: PROCEEDINGS OF A SYMPOSIUM ON VARIATIONS IN WORK-SLEEP SCHEDULES

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The function of this symposium was to bring together workers in three areas that in one way or another, are concerned with a common problem: variations in work-sleep schedules. These three areas are (1) shift work, (2) sleep, and particulary that area concerned with sleep loss and the fragmentation of sleep schedules, and (3) biological rhythms. In addition to social and health problems, which were covered in this symposium, shift work inevitably changes sleep; sleep problems are a major complaint of shift workers. Any variation in work-

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PREFACE

In 1975, the National Institute for Occupational Safety and Health (NIOSH) sponsored a two-day symposium on Shift Work and Health. As a reflection of NIOSH's continuing concern over the possible influence of shift work on health and well-being of the worker, NIOSH, with the Office of Naval Research (ONR), cosponsored a conference concerned with Variations in Work-Sleep Schedules: Effects on Health and Performance, in San Diego, California, September 19-23, 1979. These proceedings are the papers presented at the conference.

The function of this symposium was to bring together workers in three areas that, in one way or another, are concerned with a common problem: variations in work-sleep schedules. These three areas are (1) shift work, (2) sleep, and particularly that area concerned with sleep loss and the fragmentation of sleep schedules, and (3) biological rhythms. In addition to social and health problems, which were covered in this symposium, shift work inevitably changes sleep; sleep problems are a major complaint of shift workers. Any variation in work-sleep schedules immediately involves, in a complex fashion, the basic biological rhythms.

Workers in each of the above areas have yearly conferences and, in some instances, there are papers at each meeting concerned with all these areas, but never has there been a meeting where the common interests, problems, and goals of the three areas have been explored in depth. It was hoped that from the focused interaction of researchers in the three fields, there would be a consensus as to the major areas of agreement and as to the direction of future research.

Shift work (such as watch or duty schedules of the military) has always been an integral part of most military operations, but shift work in the civilian sector has become a major factor only in the last 20 years. For example, in France the percent of shift work done has risen from 10.3% of the total work force in 1957 to 22% in 1974. In some industries such as metal processing, petrochemical, automobile, and textile, the proportion of shift workers is over 50%.

In the United States, the 1977 Bureau of Labor statistics indicated that over 13.5 million people, 18% of the work force, were working full- or part-time on evening or night shifts. Over a 3-year period, 1974-1977, those working full night shifts, 12:00-6:00 am, increased 13%. In Great Britain, the increase in full-time night work in manufacturing, since World War II, is estimated at about 1% per year. The increase has been greater in industries that make vehicles and chemicals.

Three reasons have been advanced to account for this increase in shift work: (1) social (provision of "round the clock" services, e.g., medical care, transportation facilities, and security); (2) technological (continuous process operations, e.g., steel production, petrochemical refineries); and (3) economic (optimal use of invested capital, e.g., costly machinery). It is likely that each of these three factors will continue to operate to further increase the proportion of workers involved in shift work. While the introduction of shift work may add to the quality of life of society as a whole, it cannot be overlooked that shift work disturbs the lives of the individual workers, and that of their families. One of the purposes of this conference was to determine the current state of our knowledge on the effects of the variations in work-sleep schedules brought about by shift work on the individual worker and in his relationships to his family and society. Borrowing the frame of reference used for evaluating research studies involving human subjects, the question can be phrased, "Do the benefits from shift work to society in general outweigh the risks to the individual shift worker?"

In addition to the above question, the participants were asked to explore alternatives to current practices. For example, is there an alternative to the traditional shift-work schedule? What is the minimal amount of sleep, and in what amounts should this sleep be obtained when spaced over a 24-hour period, to maintain effective sustained performance over several days, and perhaps weeks? There have been reports of effective functioning with only 2 to 3 hours of sleep in every 24, and recent studies from the Naval Health Research Center sleep laboratories have indicated average sleep time can be reduced by 1 to 2 hours with no impairment on waking mood or performance. Yet to be determined is whether personnel can continue to effectively perform if 1, 2, or 3 hours of sleep (naps) are allowed once in every 4-, 6-, 8-, 10-, or 12-hour period. What are the limits in the variation of work-sleep schedules?

There is no longer any question that time of day is a factor in feelings of well-being, effective performance, and in the efficacy as well as toxicity of many drugs. Accident rates go up and productivity goes down in the early morning hours when body temperature is low. Clearly, time of day must be considered in any variation in work-sleep schedules. Less certain, however, is the strategy for minimizing the effects of changes in biological rhythms, and, in fact, whether there is ever a complete adaption in some rhythms to variations in work-sleep schedules. Should there be a fixed shift in work schedules or should there be rapidly rotating shifts on the assumption that there is never a complete adjustment in rhythms anyway? Are there health risks incurred due to prolonged or rapid shifts in biological rhythms? Is there a balance between the social needs of the shift worker and the optimal schedule in terms of biological rhythms? Also relevant are the effects of jet travel across many time zones, which is of concern to both military and civilian air crews.

The success of any symposium rests with the participants. In this instance, the participants were some of the leading researchers from the United States, Japan, and Western Europe, in the areas of sleep, shift work, and biological rhythms. The relatively large number of Western European participants reflects the active interest of labor and government in these countries in shift work, which is reflected in their active research programs. To the participants, the organizers express their appreciation for their contributions. We also wish to express our appreciation to Donald P. Woodward, Ph.D., of the Office of Naval Research, for his support, and to Michael A. Colligan, Ph.D., of the National Institute for Occupational Safety and Health, who contributed to the symposium as a NIOSH sponsor, a participant, and as an editor of the proceedings.

Many participants requested that their contributions to these proceedings include statements acknowledging the assistance of numerous individuals in their research. The editors reget that space limitations do not allow individual recognition of each of these contributions. On behalf of the authors, the editors wish to extend their special thanks to all of these people. When available, acknowledgment of grant or contract support has been recorded at the end of the reference sections of individual papers.

The camera-ready copy for these proceedings was prepared at the Department of Psychology of the Illinois Institute of Technology. We wish to express our special appreciation to the IIT Managing Editor for these proceedings, Sylvia N. VanBerschot, Ph.D. Her dedication to these proceedings guaranteed completion of an excellent camera-ready copy. Finally, a word of appreciation to Kim VanBerschot, Dennis R. Armstrong, Elizabeth A. Byrnes, Paul M. Canning, and Pamela D. Williams for spending countless tedious hours typing or proofing the manuscripts. Their sincere interest in the dissemination of the research presented at this symposium added great impetus to their activity.

The Editors

CONTENTS

KEYNOTE ADDRESS

SECTION I: BIOLOGICAL RHYTHMS

SECTION II; SHIFT WORK

SECTION III: SLEEP OF THE SHIFT WORKER

SECTION IV: ALTERED SLEEP SCHEDULES

CONCLUSIONS

WORK/REST SCHEDULES: ECONOMIC, HEALTH, AND SOCIAL IMPLICATIONS

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The organizers of this meeting cleverly invited me to give this opening address many months ago when the honor of the invitation readily overrode the precautions which should accompany the acceptance of such an honor. The impressive roster of participants, the complexities of their topics and their outstanding contributions of the past made apparent the problems of an adequate introduction as the time for the address approached.

Fortunately, I had some guidance in my dilemma. The organizing Chairman gave me a topic: "Work/Rest Schedules: Economic, Health and Social Implications." Further, he designated the talk as a keynote address. Since, in my times of speaking I had never had the task of delivering a keynote address, I turned to my dictionary. I found "keynote address" handily defined: "an address designed to present the issues of primary interests to an assembly and often to arouse unity and enthusiasm." While I suspect that the trailing additions of "unity" and "enthusiasm" are primarily referent to political conventions rather than scientific assemblies, they are reasonable virtues and I shall certainly not try to avoid them. At the least I shall try to follow the advice of the English novelist, Thackery: "to make new things familiar - and familiar things new."

First, I shall try to extend an apparent and obvious underlying "unity" in our mutual commitment to research as the sine qua non in our approach to the understanding of work/rest schedules and their consequences. I shall point up the remarkable, symbiotic convergence of three disciplinary areas: sleep research, chronobiology and performance research in this research arena of work/rest schedules. I shall urge and applaud onward their unity and call for an enhanced collaboration in mutually beneficial efforts.

Secondly, I shall project from these foundations and their ever increasing findings, some of their "economic, health and social implications" relative to work/rest schedules.

Biological Rhythms, Sleep and Performance Research

We are gathered together around a common topic of concern--work/rest schedules. However, like all good causes or complex tasks we are drawn from different interests and areas of competence. In this instance, three core areas are clearly identifiable; chronobiology, sleep, and performance research. It is my contention that, while these disciplines have emerged essentially independently in their origins and are marked by differences in emphases, conceptual schema and procedures, they are necessarily interdependent in a comprehensive approach to work/rest schedules.

Let us look more specifically at these research areas. The biological rhythm and sleep areas share two common characteristics, their recency of development and their interdisciplinary character.

Human history, folklore, and curiosity have long been responsive to sleep and to the rhythmic aspects of nature. The seasons, the tides, the successive presence of sleep form the very warp of mankind's existence. A striking quotation recognizing both the place and the presence of sleep and its circadian character can be found as early as 300 B.C. in the Hippocratic writings collected in the Book of Prognostics (Adams, 1939):

> The patient should wake during the day and sleep during the night. If this rule be altered it is so far worse: but there is little harm provided he sleep in the morning for the third part of the day; such sleep as takes place after this time is more unfavorable... (p. 47).

However, the essentials of the current developments of both chronobiology and sleep research and their momentum began in the 1950's. A few significant items should suffice to remind us of that recency. For sleep research the presence of the "activated" sleep or the rapid eye movement period was explicated in the 1950's, the first symposium on sleep, the CIBA symposium, was published in 1961, Kleitman's revision of *Sleep and Wakefulness* appeared in 1963. For biological rhythm research Harker's *Diurnal Rhythms* was published in 1959, the crucial Cold Spring Harbor symposium occurred in 1960, the term "circadian rhythms" was introduced by Halberg in 1959 and Cloudsley-Thompson's book *Rhythmic Activity in Animal Physiology and Behavior* appeared in 1961. Both areas have experienced an exponential expansion of research activities into the present.

Both, as emergent fields, drew their active participants from already established disciplines and their research was dispersed across an enormous range of journals. Though the biological rhythm researchers were more heavily drawn from the biological scientists and the sleep researchers from medicine, both groups involved biologists, pediatricians, physiologists, psychiatrists, endocrinologists, neurologists, biochemists and the ubiquitous psychologists. Indeed both involved the entire broad range of the life sciences.

The performance researchers do not share this history. This research area has a longer continuous history which extends from the psychophysical research in the early 1800's and mental abilities testing of the later 1800's into human factors research of today. It has been primarily a development within psychology.

More critically, the primary foci of these areas have been clearly different. Simply, biological rhythm research has been concerned with time as an independent variable in relation to a broad range of biological events, sleep research has primarily focussed on the phenomenon of sleep as both a dependent and independent variable and performance research has taken behavior as its dependent variable relative to a wide range of independent variables.

These different concentrations have developed independently valuable findings, concepts and procedures that are usefully transferable beyond their own specific domains. Let me cite some obvious ones.

Biological rhythms research as a result of its focus on time as a variable, has stimulated measurement of variations across time series. In the process, it has identified a wide and important range of behavioral and physiological events which show systematic variations across time. Most importantly it has emphasized an alternative model for the determination of biological variations. It has proposed and demonstrated that significant variations may be a function of timing systems in contrast to homeostatic or feedback systems such as those operative in "drive/motivation" or restorative models, the organism's historical determinants of the "learning" models or environmentally evoked models of "reflex" action.

Sleep research has focussed on the measurement of sleep phenomena and their mechanisms. As a consequence it has developed sensitive measures of sleep and described its normative characteristics and variations thereof. There have been increasing capabilities in the prediction of the influence of precursor and concomitant environmental and behavioral variations as they modify sleep, including the effects of variations in sleep patterns and structure as these influence other dependent variables including performance.

In its long history of behavior measurement, performance research had developed a vast range of sophisticated "tests" including measures of sensory sensitivities, motor skills, mental abilities and psychological traits, attitudes and moods. Beyond these "tool" or technique contributions there have been significant advances in measurement procedures in such areas as psychophysics, scaling and research designs as well as in the methodological considerations of reliability, validity and the organization of behavior through factor analysis and classification procedures.

These research areas and their developed procedures and concepts find focus in the area of work/rest schedules. The human system has many of its properties, including sleep and performances, organized in a circadian system. A change in work/rest schedules is an exogenous imposition on this endogenous organization. There are consequent variations in the rhythmic systems, including sleep, and a vast set of performances as they occur in modified time periods.

Individual research efforts must, of course, emphasize particular aspects —certain elements of sleep, certain varied time schedules and biosystems, certain performance dimensions. However, this is a complex and interdependent process and a comprehensive understanding of work/rest schedules will be ultimately dependent upon all three areas.

I suspect, indeed I fervently hope, that to this point my comments have been a reminder—a review—a reaffirmation of what we all can agree upon. At best they simply make more explicit what implicitly your own efforts and time will achieve in the cross-fertilization of our various perspectives.

But let me turn to broader considerations. My assigned title included the topics, "Economic, Health and Social Issues." Certainly, our findings and our research must be ultimately embedded in the broad matrix of reality to be of use. No matter how accurate and scientifically impeccable our findings may be, if they remain entombed in speciality journals, they will constitute mere "adult show and tell games" among ourselves or will be still-born from an immaculate conception between our computers and our typewriters.

However, even with a commitment beyond "knowledge for knowledge" sake--even with a strong desire and active effort to translate and to transfer our findings into active utilization--it behooves us to recognize the complexities surrounding the context where utility meets the reality of alternative and opposing demands. In the "real" world, significant "ifs" are seldom followed by simple "then that's". Rather "if" is more often "if it were possible" and "that" is more often a set of interactive and often conflicting consequences.

Economics and Shift Work

My comments on "Economics and Shift Work" will be brief and limited. Primarily, I offer them only as an object lesson in humility rather than an analysis of economic factors. That is a task which I found certainly exceeded my competence.

I began my foray into this domain in my usual simplistic way. I began with obtaining a piece of data. I found that data in an article in the AFL-CIO American Federationist (Zalusky, 1978):

> A 1975 survey of 1,514 major private sector labor agreements showed 80% (a total of 1,214) had shift premiums of some type. A money differential was paid in 78% of these, 12% use the shorter hours for the same money as a premium, 6% combined shorter hours with a premium rate and 4% were in a miscellaneous category...the second shift average was 16 cents per hour and 21 cents per hour for the third shift. When a percentage form of shift premium was used...the average second shift premiums was 8% while the third shift premium was 10% (p. 4).

"Ah ha," I said, "Shift work, using the most manageable figure, adds nearly 10% to production costs. Certainly an economic factor".

Slight pause. "But three times as many units are being produced per 24 hours and/or start up times are eliminated and/or, if this were a construction project, completion time would be reduced, etc." It was clearly more complex than my simple labor cost figures displayed.

I retreated to my first line of defense against ignorance--the library. There I had the good fortune to find a ten year study by the Department of Applied Economics of Cambridge University entitled, "The Economics of Capital Utilization--A Report on Multiple Shift Work" (Morris, 1964). This is an empirical study of British manufacturing. It involved more than 54,000 establishments. There were more than two and a quarter million shift workers "discovered". The purpose of the study was to assess in detail the economics of shift work. Specifically, it was an effort to develop a theoretical model which would permit an economic decision, relative to the impact of shift work, on profits.

This is a tightly packed consideration. One cannot simply summarize this elaborate analysis. Most of the primary factors which determine the economic efficiency of shift work extend well beyond our purview which focusses on the worker. The listing of a few of these can reflect some of the extensity and complexity of these considerations:

- Demand for units of production. It is of little use to produce more units than the market can handle.
- Level of automation. In labor intensive systems, shift work may, in fact, increase costs per unit production.
- Capital costs per equipment unit. This involves a complex relation to initial costs, operative costs, wear and tear, depreciation, absentees, and capital depreciation "write offs". In general, the higher the unit operative costs the greater the effectiveness of shift work.

Even in the area of our primary domain--the worker--the critical economic factor is the wage differential paid. And while negative aspects, "health", "social disruptions", and "attitudes" will partially contribute to a wage differential, more salient factors, in economic terms, will be such variables as:

- the size of the labor pool.
- the strength of the union in negotiating wages.
- the base wage level of the day shift.
- the profit margin increase associated with a shift schedule.

I emerged then from my brief foray into the economics of shift work in due and unusual state of humility.

To recognize that a decision about a work/rest schedule will be significantly determined by economic consideration rather than a statistical level of significance findings is, I believe, properly deflating. It can minimally have the benefit of making one more courteous in demands for attention. It has sharply reduced my frustrations when I note that my precious findings are not immediately valued for themselves alone but relative to other grounds. And certainly courtesy and reduced frustrations are desirable ends.

Health and Shift Work

Let me turn to the second aspect of my specific concerns, "Health". It is my contention that, relative to work/rest schedules, we must be cautious in focussing on or confining our concerns to a narrow concept of "health", viz., demonstrable physical illness.

I hasten to add, I am not denying the importance of health factors. I am not so naive as to fail to recognize the specter of illness or the hope of health as powerful motivational forces. It is clear that if anyone can tie their independent variable to a threat of reduced mortality, be it cancer, heart damage or what have you, the doors to the treasury are open and the champions of protection are manifold.

However, I urge caution in our excessive dependence upon "health" as our primary justification. I do so for several reasons. First, as scientists we must respect data and these, relative to health, are discouraging. At the International Symposium on Night and Shift Work in 1969 (Swenssen, 1970), Thiis-Evensen concluded from his extensive studies of more than 9,000 employees over a number of years that: "Thus, there are no probable grounds indicating that shift work in itself is harmful to health: (p. 81)." Two recent studies begin their search for shift work health effects by noting: "Research on the effects of shift work on health has been rather inconclusive (Åkerstedt & Torsvall, 1978)" and "There is no objective evidence, in the majority of studies, that shift work affects health to a significant degree (citations)". Neither is it evident that the form of work scheduling has a significantly higher health risk than permanent day work (8 citations): (Koller, Kundi, & Cervinka, 1978). Our own data then clearly dictate that we should not make a simple linkage between health and work/rest schedules as a raison d'etre of our concerns.

Secondly, the nature of our independent variable--schedules-- and the dependent variable of health suggests that where relations exist they will be tenuous, subtle and limited. The proximal causes are intrusive, direct and physically identifiable--carcinogens, bacteria, and system anomalies, etc. The distal causes lie in the complex domains of psychological and behavioral variables, and are comprised of interactive influences of bad habits and attitudes, psychological stress and social concomitants which ultimately increase susceptibilities to proximal causes or chronically result in wear and tear on systems.

Some of the complexities inherent in such relationships are seen in the early classical study of Bjerner, et al. (1948). Table I displays some data from that study. Note that there is essentially no difference between day workers and current shift workers. However, current day workers who were former shift workers show higher health complaints. Bjerner notes further qualifications. Those shift workers who reported "sufficient sleep" has lower gastritis rates and, further, the higher levels of gastritis were primarily seen in workers over 40 years of age.

Table I

Relations Between
Shift Work and Stomach Disorders

Shift History	% Consulting Physicians	% Hospitalized
Day Work-never on Shifts	18.2	8.6
Day Work-formerly Shifts	29.1	13.7
Present Shiftwork	22.5	9.7

Adopted From: Bjerner, B., Holm, A. and Swenssen, A. (1948).

The recent study of Koller et al. (1978) of workers who had "dropped out" of shift work when compared with day worker and current shift workers showed similar complexities. While "attitude" questionnaire responses showed substantial differences, reported use of "doctors' consultations" or "hospitalization" showed no differences, although the "drop-out group" reported a higher use of drugs at the .05 level. Similarly, Akerstedt and Torsvall (1978) found substantial questionnaire differences relative to seven different schedules which included groups which continued on their shift periods, a non-change day group and the changes in shift schedules groups. Only one group showed a change at the .05 level of confidence in the number of "sickness" absences over a five month period. These paradoxically, were in workers going from a night shift to a day shift.

Practically, then, to tie shift work to the tenuous variable of health courts the danger of limited findings from indirect influences, embedded in a tangle of alternative interactive variables.

This, of course, is not a plea to abandon health as a concern. Such studies must be done and may yield certain "risk" type individuals or groups for selection purposes. However, they are unlikely to show substantial effects on the total population. Rather, it is a plea that we do not make health our Holy Grail and within our concerns with health we focus our efforts appropriately. I agree with the statement by Mott, Mann, McLoughlin, and Warwick, (1965) in their review of shift work and physical health: "Much of the difficulty...arises from a lack of theory that could spell out the specific connection between job hours and ailments. Too often (there is) no effort to provide hypotheses about the direction of the differences expected and the reasons for the differences" (p. 72).

Nor is this a plea that we abandon efforts or hope for justifications of our efforts. We all readily recognize that research is expensive, that research support is limited and justifications are the prime determinants of priorities. More so than the neatness of the research design or the eminence of the researcher. Rather, my call is to seek more proximal effects as justifications and, in turn, to link these to valued justifications.

The most obvious of these is performance decrements. As I noted in my introduction, performance measurement is an old and honorable domain of research and advancing in precision in the measurement of mental and physical functioning. I, at least, perceive substantial empirical and theoretical linkages between this area and sleep and chronobiology, both of which are inherent aspects of work/rest schedules. I advise us to exploit these linkages.

And can there be justification from such findings? Of course, but it must not be simplistic. We are not automatically protected nor justified by the "magic multiplier" argument—a 1% laboratory decrement can be multiplied by 20 million workers. While an established short term memory effect of, say 2% during an "off schedule" period may be an irrelevancy for an assembly line worker, it can be claimed as a disaster for high level diplomacy or in the multithousands of landings involving millions of passengers in air transportation. Where a ten second "lapse" may be considered tolerable in unloading materials from vans they hold terrifying potentials for long distance truckers.

Social Issues

Let me turn to my last assignment, a consideration of "social issues". I suspect that the intent here was that I review the social consequence of shift work with the cataloguing of such factors as effects on family relations, social interactions, and worker's satisfaction. These inherent issues have been far better done than I could possibly manage. They are detailed, for example, in the work by Mott, et al., entitled Shift Work, (1965) which is specifically subtitled, "The social, psychological and physical consequences."

I shall not review these studies but stipulate the summary of their review of the literature: "In aggregate, these studies confirm the position that shift work can and does have effects upon the worker's family relations, his social participation, and his opportunities for leisure activities" (p. 92). And, "Most European and American studies that have probed into worker feelings about shift work agree on one point: few workers like shift work, many dislike it strongly, and many others have learned only to live with it" (p. 24). These general conclusions have been reaffirmed by the recent studies of Åkerstedt and Torsvall (1978) and Koller, et al. (1978).

Rather than adumbrate these social and attitudinal consequences of shift work I take this opportunity to comment upon the more fundamental implications of varied work/rest schedules relative to man's nature and his contemporary society. I do not do this merely as a jeremiad about our times—a crying aloud in the wilderness. Rather, it is a sharing of a perspective and concern with you who are the most knowledgeable and authoritative group in the best sense of those words. As such, this perspective, if valid, weighs most heavily in your hands.

The message that I want to convey can be bluntly and simply stated. The difficulties that may be associated with varied work/rest schedules can be interpreted as pathological symptoms of our society rather than signs of inadequacy in the individual worker.

This proposition emerges from the linkages of chronobiology, sleep and performance. I find it increasingly evident that the natural course of human behavior is systematically organized in the "time and tides" of a 24 hour or circadian framework. In short, the work/rest or, more explicitly, the performance/sleep tendencies reflect a fundamental biological rhythm. I do not feel the necessity to argue the proposition before this group.

Accepting this, however, carries with it other conceptual properties inherent in biological rhythms. At a metatheoretical level, at least, such rhythms are conceived of as innate, inherent adaptive systems that have been shaped in the evolution of the species. These are functional systems of natural wisdom which have been hammered out by survival on the particular anvil of the species' environmental niche.

This line of reasoning relative to the development of adaptive biological systems by evolution has been described by Campbell as "evolutionary epistemology" (1975), and has been elaborated and developed by the ethologists such as Frisch, Lorenz and Tinbergen and more recently by the social biologists such as Wilson.

For all these there is a common theme and concern that speaks directly to my concern about shift work and society. Tinbergen (1969) states the matter dramatically, "...the unprecedented degree of power over natural events which we have achieved carries in its wake a dangerous consequence...(we) have changed our environment (including our social environment) out of all recognition. As a result, our behavioral environment is no longer faced with the environment in which this organization was molded and, as a consequence, misfires...the very success of our behavior has led to a situation from which only a better understanding and controlled change of our behavior can extract us" (p. x).

Lorenz has specifically considered the problem of release from extraspecific environmental selection factors under the concept of "intraspecific" selection effects (1974). In this model, the nature of the organism is shaped into an appropriate system by negative feedback from extraspecific environmental factors leading to adaptive survival systems. However, when these extraspecific environmental factors are "brought under control" and/or are replaced by intraspecific factors, the species may become a victim of its own decisions. Specifically in regard to mankind, Lorenz states:

> ...No such salubrious regulating forces are at work in the cultural evolution of mankind. To his detriment, man has learned to govern all the forces of his extraspecific environment, but he knows so little about himself that he is helplessly at the mercy of the workings of intraspecific (factors)...As no biological factor has ever done before, the competition between man and man works in direct opposition to all the forces of nature..." (p. 18).

In our society, the amount of shift work being imposed upon us resembles the "good-news, bad-news" announcement of the airplane pilot when he said: "Ladies and gentlemen, I have two announcements. One is good news and one is not so good. The bad news is that we are lost--we have no idea where we are. The good news is, however, that we have a 200 mile an hour tailwind." Figure 1 shows you data from the US Department of Labor estimates of the number of shift workers in manufacturing in metropolitan centers since 1959. This is a growth rate of 6% per decade and an extrapolation into the beginning of the next century yields a figure in excess of 50%. Or consider these figures. In 1974, the Bureau of Labor statistics reported an estimate of 2.3 million workers whose schedules included the midnight shift; by 1977, three years, this had increased to 2.6 million--an increase of 300,000 persons. They estimate in 1977 over 13.5 million people--18% of the workforce worked on other than day time schedules. In short, there can be no doubt that this is an ever increasing part of our society.

Shift Work in Industrial Settings of the United States

I have previously admitted that I doubt that shift work effects can be defined in disaster terms and hence do not anticipate a growth of a Zero Shift Work movement similar to a Zero Population or an Anti Shift Work movement matching Anti Nuclear forces or even the sympathy of the Sierra Club. However, I do believe we must recognize shift work as yet another instance of the accretion of a system of behavior which is incompatible with the nature of the human organism. I have no doubts that man's biological rhythms, which include sleep and performance, were shaped by extraspecies factors that included time organized in a 24 hour period. Nor do I doubt that the presence and amount of varied schedules of work and rest are determined by intraspecies transient factors such as profit and production of material goods. While elephants may be taught to dance, dogs to sing and lions to leap through hoops of fire, these acts are, minimally, unseemly and are only useful in supporting their enslavement.

Let us try to remember, then, as we serve to make shift work more compatible, that we are homogenizing the twenty-four hours and, arbitrarily, turning persons off and on around tireless machines, continuous processes and insati-

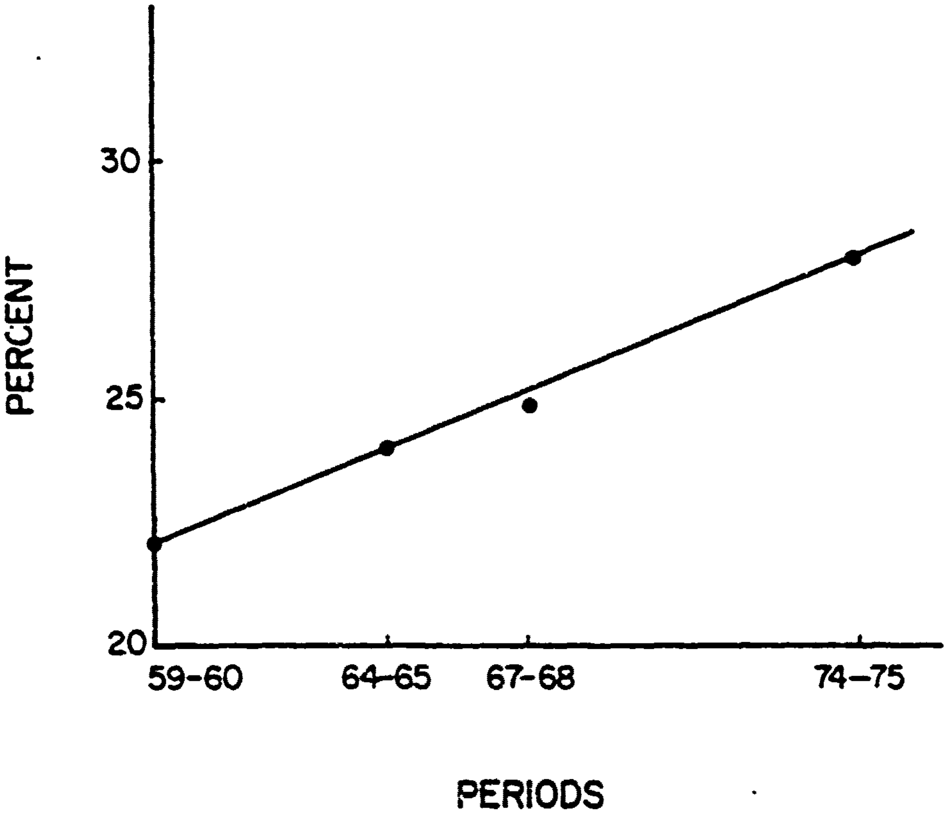

Figure 1. Number of shift workers in manufacturing in metropolitan centers since 1959. (Data from the U.S. Department of Labor estimates)

able output demands. As a consequence, the biological nature of man is being unnaturally bent and all of the accrued adaptive systems such as families and group membership are affected. Moreover, as this continues, the effect will continue into perpetuity since there is no likelihood that man's nature will change to accommodate man's failure to recognize himself as his own worst enemy. Let us at least express our reservations and question our complicity.

The nature of my talk has led me to speak in very general terms in an area of such complexities that highly specialized research is demanded. While I can protectively rationalize my position by recalling the definition of a specialist as one who says more and more about less and less, I can only hope that my comments do not fit the equally tart definition of the generalist who knows less and less about more and more until he knows absolutely nothing about absolutely everything.

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CIRCADIAN RHYTHMS: INTERFERENCE WITH AND DEPENDENCE ON WORK-REST SCHEDULES

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Nearly 100 years ago, the Italian physiologist Ugolino Mosso (1887) raised the question whether the day-night rhythm of rectal temperature could be inverted by working at night and sleeping during the day (Aschoff, 1976). On the basis of measurements made on himself (Figure 1) he came to the conclusion that there was 'une courbe fondamentale de variations automatiques de la température', and that, by shifting his sleep-time by 12 h, he only had succeeded in 'superposer une nouvelle courbe à la première, et à obtenir une courbe résultante de deux phenomènes qui procèdent en direction opposée'. Mosso's experiment marks the beginning of a long series of studies on the adjustability of circadian rhythms and the interaction between the sleep-wake cycle and other rhythmic functions within the organism. In discussing his findings, Mosso anticipates the existence of what now is called an 'endogenous rhythm , and he already points to two characteristic properties of this rhythm. They may be described as its 'rigidity' on one hand, and its 'plasticity' on the other hand. It is to these two aspects of the circadian system that the following chapters mainly are addressed.

The Sleep-Wake Cycle as Part of the Circadian System

Patterns of Rhythms Under a Variety of Conditions

It is well known that 24-h variations of physiological and psychological functions are, in general, not caused by the alternation of sleep and wakefulness, and that they can be observed under conditions of more or less uninterrupted activity as well as continuous bedrest. There is, however, an influence of the sleep-wake cycle and of activity on most of the rhythmic functions, especially on their amplitude. As an example, Figure 2 presents 'standard curves' (solid lines) of the rhythm of rectal temperature, measured in subjects who slept at night and either rested in bed for the full 24h or pursued 'normal' activities during daytime. Each of the two curves is based on data extracted from 6 publiciations and represents the mean of 39 (bedrest) and 46 (activity) subjects, respectively (Aschoff & Wever, 1980). The minima of the curves are the same, but the maxima differ by about 0.22°C, i.e. activity during daytime increases the range of oscillation by 30%. A third curve (dashed line) shows the rhythm obtained during sleep deprivation (2 publications, 28 subjects; cf. Ringer, 1972; and Pöppel, 1968). Here the maximum coincides with that of the standard curve for normal activity, but the minimum is about 0.45°C higher than that measured during sleep; hence, the range of oscillation is even smaller than that seen during bedrest (0.43°C versus 0.73°C). A decrease in the range of oscillation during sleep deprivation as a result of an increase in the night values, has also been found in variables other than body temperature, e.g., in the urinary excretion rhythm of catecholamines (Fiorica, Higgins, Iampietro, Lategola, & Davis, 1968). For comparison, a curve of oral temperature from subjects with daytime activities and sleep at night (6 publications, 126 subjects) is also plotted in Figure 2 (dotted line); its pattern is similar to that of rectal temperature, but the 24-h mean is 0.40°C lower (Aschoff & Wever, 1980).

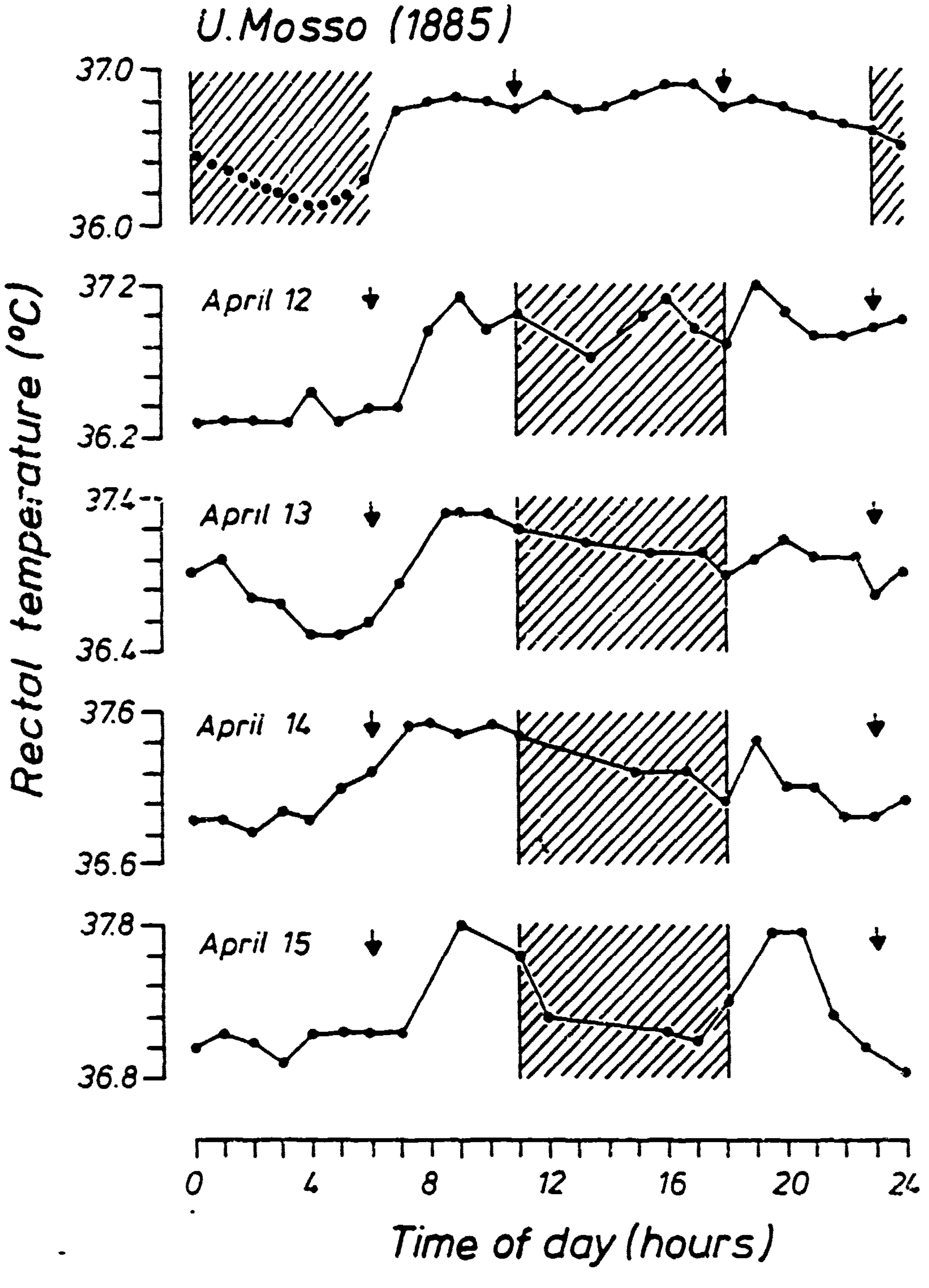

Figure 1. Rhythm of rectal temperature before and after an inversion of the sleep-wake cycle. Shaded area: sleep in darkness. Arrows: meals. (After Mosso, 1887).

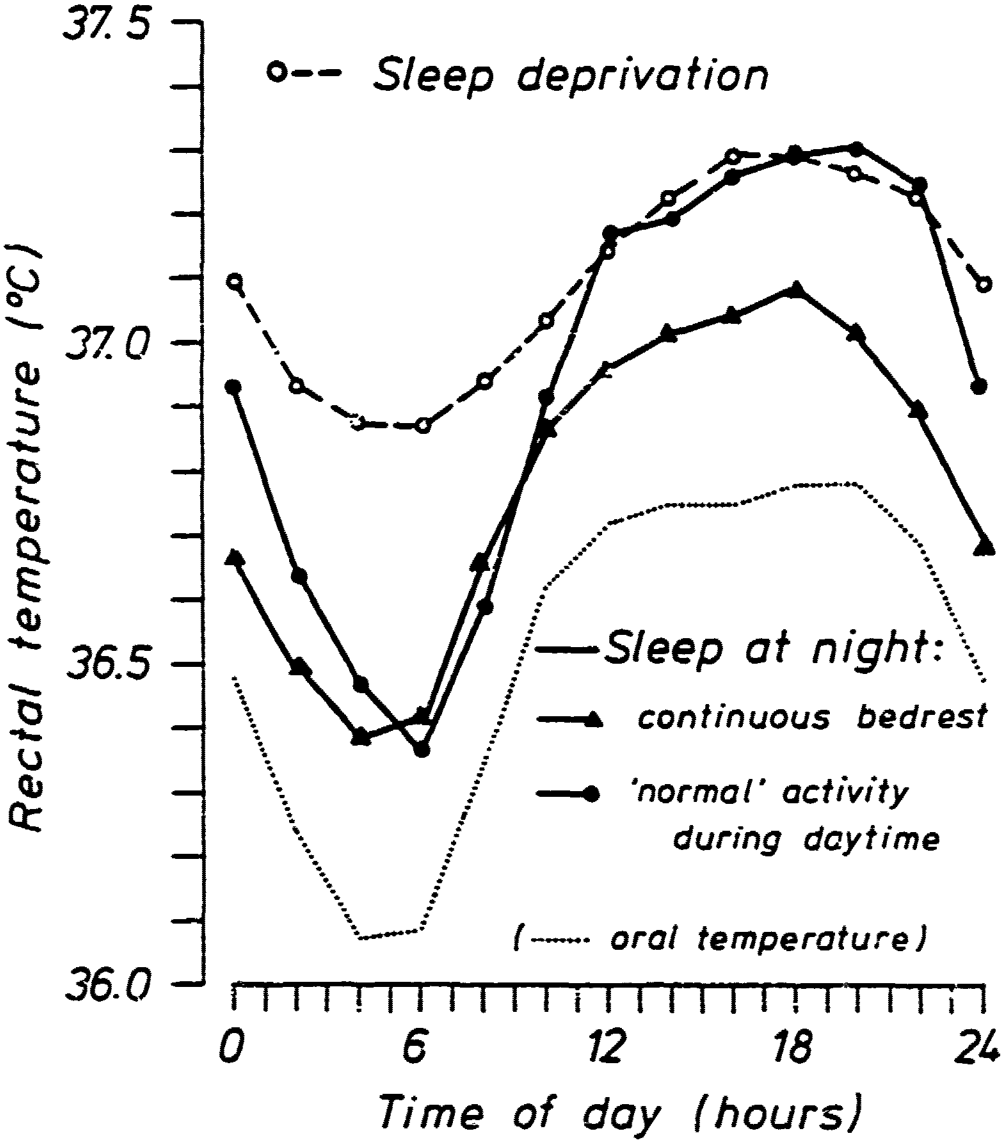

Figure 2. Solid lines: Standard curves of the rhythm of rectal temperature under two conditions, derived from data of six publications each (Aschoff and Wever, 1980). Dashed line: Rhythm of rectal temperature during sleep deprivation (Means of data from Pöppel, 1968, and Ringer, 1972). Dotted line: Rhythm of oral temperature (data from six publications, Aschoff and Wever, 1980).

During prolonged sleep deprivation, a slow but steady decrease in the amplitude of rhythms has been observed in some studies (e.g., Kleitman, 1923), but in others, a substantial reduction was apparent already during the first 24 h without sleep (e.g., Aschoff, Giedke, Pöppel, & Wever, 1972). This is illustrated for rectal temperature in Figure 3 which, in addition, shows that in some (e.g., psychological) functions the range of oscillation may be the same on days with and without sleep. An increase in the range of oscillation during sleep deprivation has been observed in performance rhythms, mainly due to a lowering of night values (e.g., Bugge & Opstad, 1979), and decreases as well as increases in the range of various rhythms during a 72-h vigil (Fröberg, Karlsson, Levi, & Lidberg, 1972; Fröberg, Karlsson, Levi, & Lidberg, 1975). There are, on the other hand, variables such as some hormones (e.g., growth hormone and prolactin) whose secretion seems to be primarily 'triggered' by sleep and which hence do not show a rhythm during the first 24 h of sleep deprivation (Sassin, Parker, Mace, Gotlin, Johnson, & Rossman, 1969; Sassin, Frantz, Kapen, & Weitzman, 1973; cf. the discussion in Aschoff, 1979). In summary, then, the extent to which the sleep-wake cycle influences circadian rhythms, differs widely between variables. Consequences of these differential dependencies will be discussed below.

So far, studies have been mentioned in which the subjects kept to a 24-h routine or had at least some information about the time of day. Therefore, synchronization to 24h could be expected. Quite different conditions are provided by experiments in which subjects have to follow unusual activity-rest cycles such as 4 h on and 4 h off or 16 h on and 16 h off duty. Under those odd schedules, circadian rhythms again persist, as shown in Figure 4 for oral temperature taken from crews on two flying missions (Harris, Hale, Hartman, & Martinez, 1970). In the diagram, the postflight data (thin solid lines) have been complemented by data from the 'standard curve' for oral temperature shown in Figure 2. The range of oscillation measured during the missions is conspicuously smaller than that typical for the control days; however, the reduction in this case does not result from an increase of the minima (as in sleep deprivation), it results instead from a decrease of the day values. No strong conclusion can be drawn with regard to entrainment of the rhythms, because times of day for maxima and minima differ between the three curves and between days; still, no tendency can be seen for a systematic drift of phases during each mission. Such drifts, however, have been conspicuous in an experiment where subjects had to work in a 'flight station mock up' on a 4:2-h work-rest cycle for 15 days (Adams & Chiles, 1963; Chiles, Alluisi, & Adams, 1968). As shown in Figure 5A there was a clear circadian rhythm of computation performance for the whole group of 11 subjects. During the 15 days of the experiment, maxima and minima slowly drifted towards later hours. Similar shifts occurred in the rhythms of pulse rate, axillary temperautre, and skin resistance. Five-day means of the phases of these rhythms are shown in the left diagram of figure 5B.

The shifts are qualitatively similar to shifts observed in a second experiment in which the subjects followed a 4:4-h work-rest cycle (right diagram of Figure 5B). In view of the fact that the human circadian system is inclined towards periods longer than 24 h (Wever, 1979a), the most likely interpretation of these findings is that during the short work-rest cycles entrainment was lost and the rhythms started to freerun. If this is correct, differences could be expected between individuals in their circadian periods and hence a

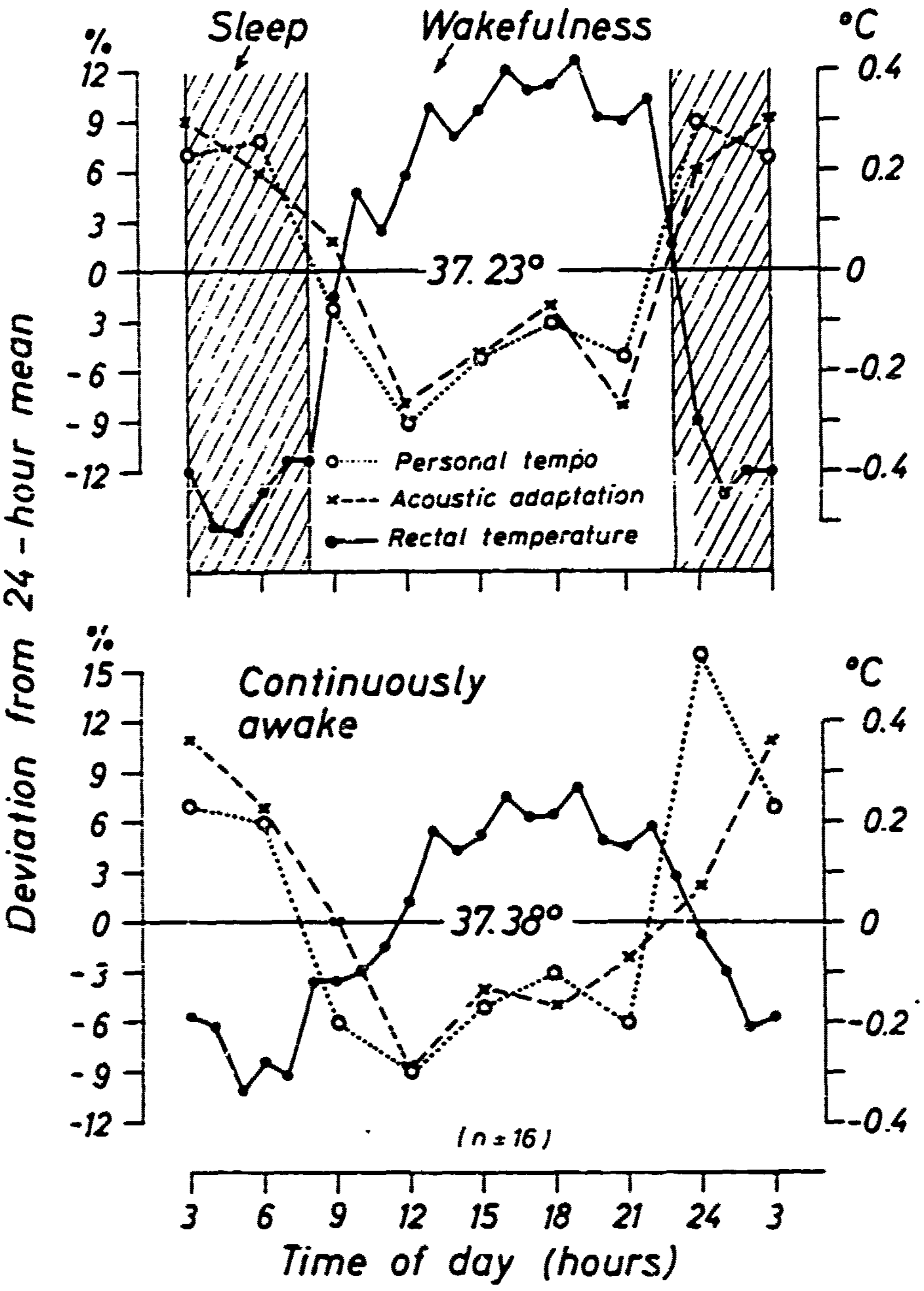

Figure 3. Patterns of circadian rhythms under conditions of normal sleep-wake cycles (above) and under 24-h of sleep deprivation (below). Personal tempo: Preferred speed of tapping. Acoustic adaptation: Comparison of loudness (right versus left ear; 700 Hz tone) after 30 sec adaptation of one ear. (From Pöppel, 1968).

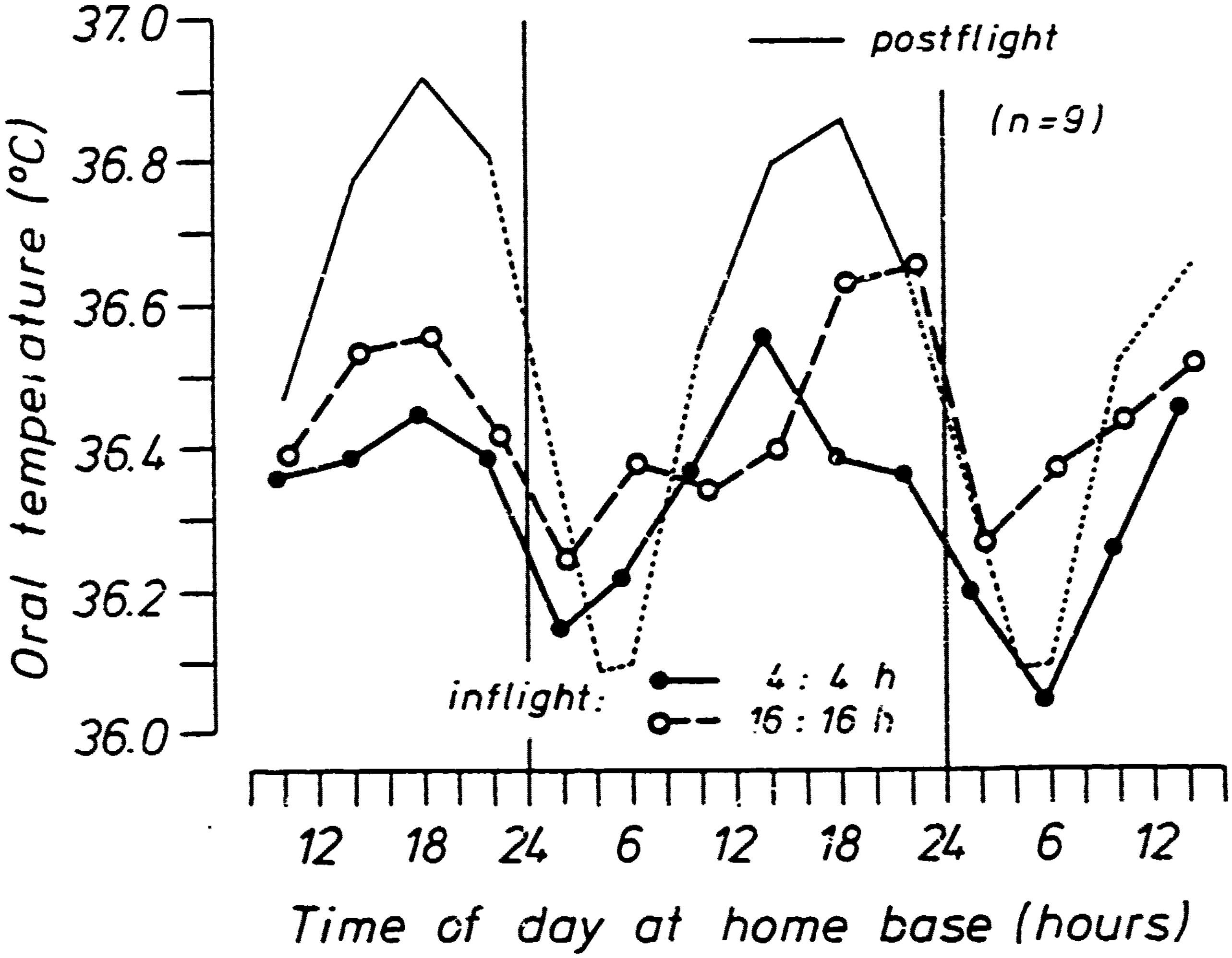

Figure 4. Patterns of the rhythm of oral temperature, obtained from 9 members of a crew during two flight missions with different work-rest schedules. The postflight control data (thin lines) are complemented by data from a 'standard curve' (dotted lines; cf. Figure 2) (After Harris et al., 1970).

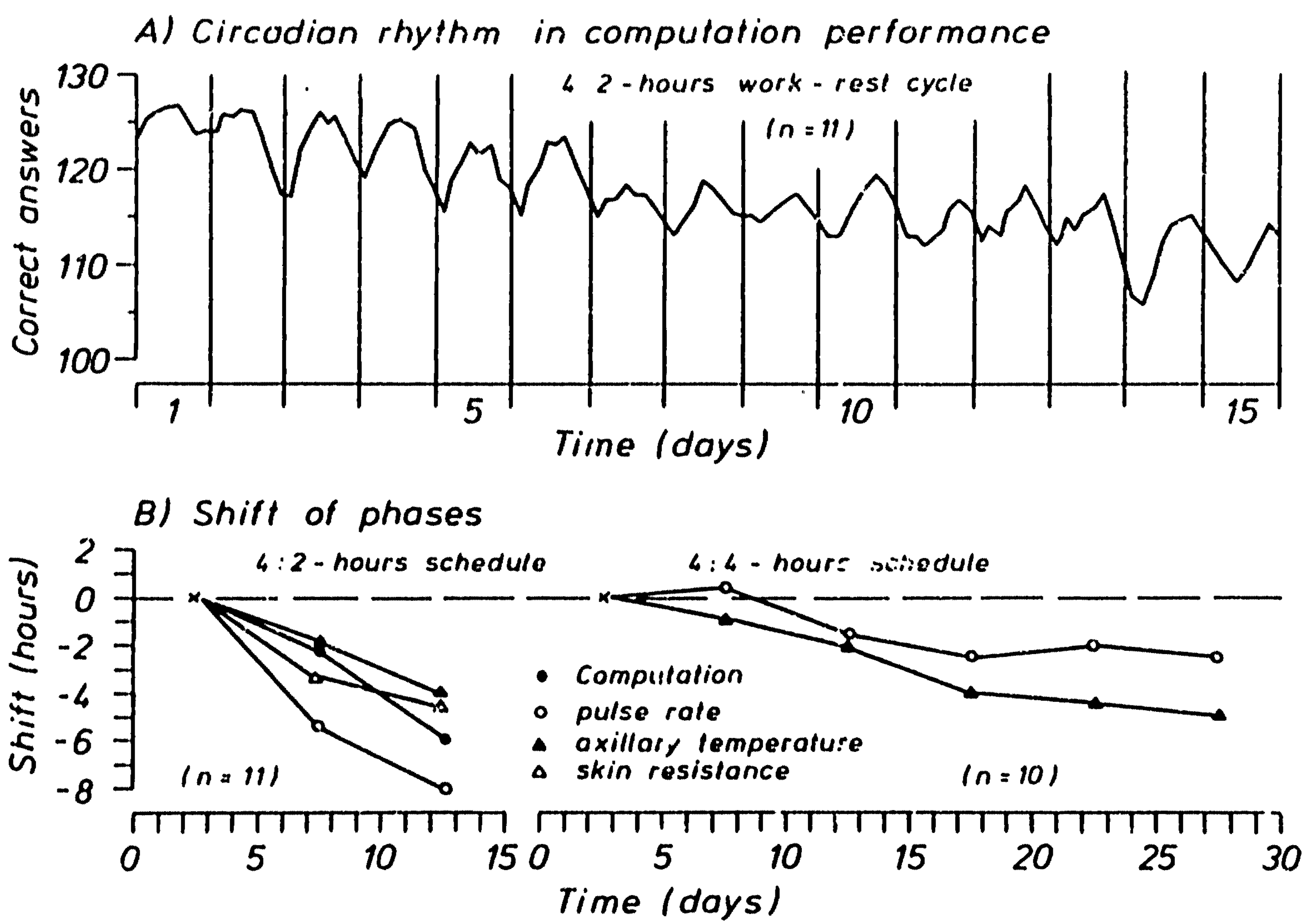

Figure 5. A) Circadian rhythm of arithmetic computation, obtained from a crew of 11 subjects who lived on a 4:2 work-rest cycle. B) Shift of phases of circadian rhythms in crews living either on a 4:2 h (left) or on a 4:4 h work-rest cycle (right). Means from 5 cycles; all phases from the first interval normalized to zero. (Data from Adams & Chiles, 1963).

steady decrease in the rhythm amplitude of the mean values due to interindividual desynchronization. Since this did not happen, mutual entrainment most probably has taken place.

The results discussed above illustrate the ability of the circadian system to remain rhythmic under extremely adverse conditions, and they also demonstrate that environmental entrainment can get lost despite the presence of a behavioral time structure that, in principle, could allow entrainment to 24 h by demultiplication in a 1:4 or 1:3 ratio, respectively (Bruce, 1960). Not surprisingly, such an entrainment has been seen in submarine crews whose schedule required three watches of 3-, 3-, and 2-h duration, separated by 2-h intervals off duty, and which provided a continuous period off duty of 10 to 12 h (Utterback & Ludwig, 1949).

Phase Control and Mutual Interaction

Normally, all the circadian rhythms that can be measured within the organism, are synchronized to 24 h and keep a distinct phase-relationship to the sleep-wake cycle. From this synchrony, and from observations made during the many shift experiments that followed Mosso's first attempt (Figure 1), it often has been concluded that sleep is a major phase determinant for the circadian system. Such a statement ought to be qualified for several reasons: 1) The environment usually contains several zeitgebers which all may contribute to the entrainment of the circadian system. It is not yet clear to what extent various oscillating units can be reached independently by different zeitgebers (cf. the discussion in Moore-Ede & Sulzman, 1980) but there is increasing evidence that e.g., the rhythm of body temperature can be entrained by a zeitgeber while at the same time the rhythm of sleep and wakefulness is freerunning (cf. Figure 81 in Wever, 1979a). Further aspects of such 'partial entrainment' (Aschoff, 1978b) will be discussed below. 2) Each zeitgeber not only influences the primary oscillators (pacemakers) that constitute the circadian system, but also affects the overt rhythms in a more direct way that has no (immediate?) bearing on phase control. Even if such 'masking effects' (Aschoff, 1960) eventually influence the pacemaker, one should be cautious not to infer phase control where only masking has been seen. 3) Rather abrupt changes can be observed in rhythmic functions after waking up and after going to sleep. Many of these effects resemble those of masking by a zeitgeber. For example, body temperature nearly always decreases after a subject has fallen asleep, and it increases, often in an 'anticipatory' mode, whenever the subject becomes active (Aschoff, Fatranska, Gerecke, & Giedke, 1974). As a result, drastic changes may occur in the waveform of the temperature rhythm--but what meaning do they have for phase control?

Despite these qualifying remarks, there is no doubt that the sleep-wake cycle can contribute to the phase control of other rhythms. To support this conclusion, data cannot be used from experiments in which a displacement of sleep-time was accompanied by a shift in zeitgebers (as has been the case in many shift experiments). Two sets of data, however, can safely be considered, a) from experiments in which subjects were exposed to the same zeitgebers but had different sleep-times, and b) from experiments with sleep deprivation. To illustrate the first case, patterns of hormone rhythms obtained from several subjects are summarized in Figure 6 either with respect to local time (left) or after normalization of the data with reference to the various sleep-times

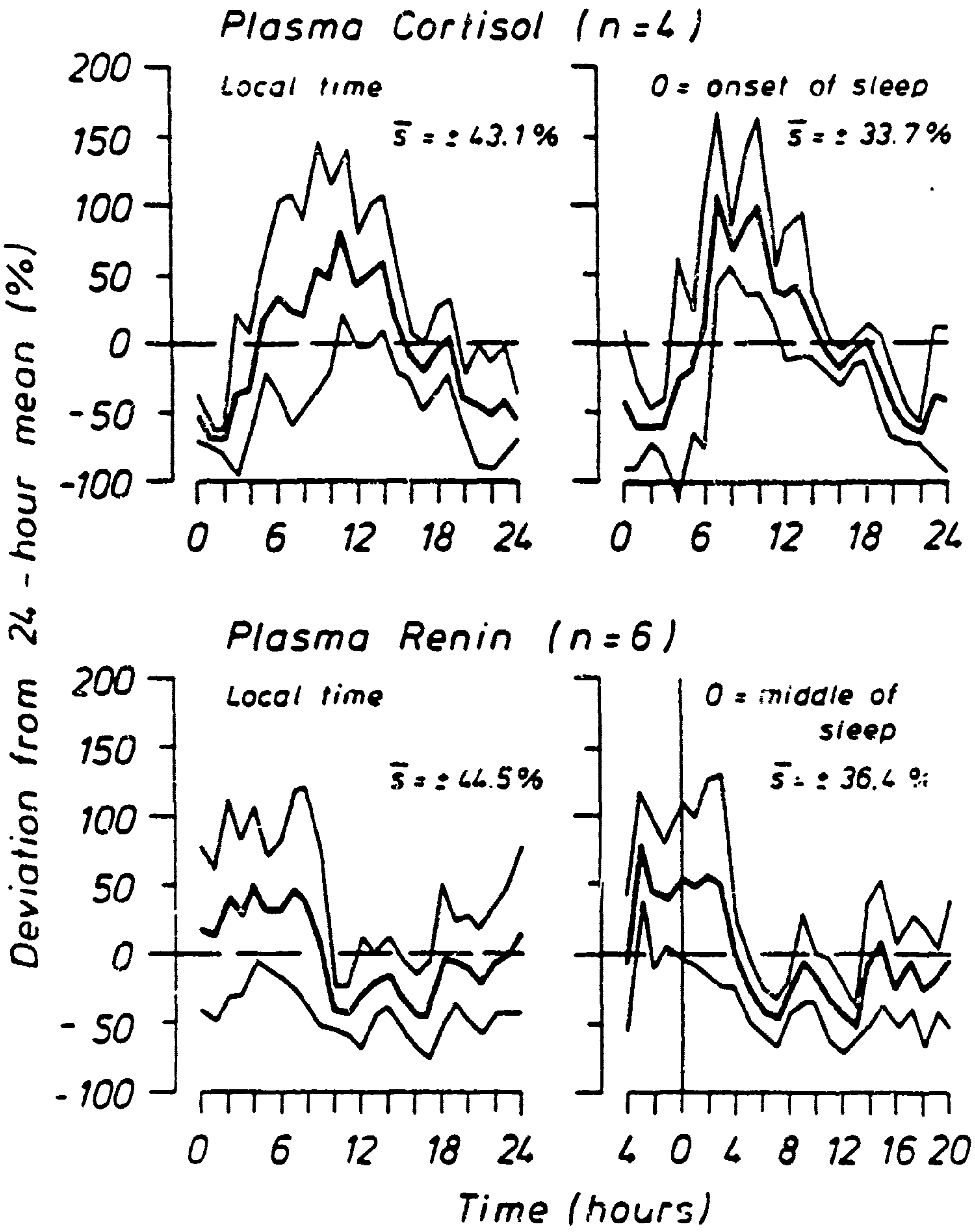

Figure 6. Patterns of the rhythms of plasma cortisol and renin, obtained from subjects with different sleep-times under otherwise similar conditions. Thick and thin lines: Means and standard deviations, respectively. Left: Data averaged according to local time; right: Data averaged with reference to onset of sleep (above) or to middle of sleep-time (below). $\bar{s}$: 24-h mean of the hourly standard deviations. (Data sources: Cortisol Lacerda et al., 1973; renin Breuer et al., 1974).

(right). The latter approach results in a decrease in the interindividual variability as expressed by the overall mean of standard deviation ($\bar{s}$) which indicates phase controlling effects of the sleep-wake cycle. Since it is not yet clear whether sleep per se or a specific event associated with it (e.g., onset of sleep) is of major importance, onset of sleep has been chosen as reference phase for the rhythm of plasma cortisol, and middle of sleep-time for renin; both these procedures not only reduce the variability but also enlarge the range of oscillation because the individual rhythms are now better in phase with each other. Further inquiries into this problem are warranted.

If the sleep-wake cycle exerts phase control, changes in the phase of other rhythms could be expected during sleep deprivation in view of the prevalence of long periods in the human circadian system. Evidence for such an effect has been given by Ringer (1972) who measured various rhythms in 12 subjects in an isolation unit for four days of a rigorous 24-h schedule (with sleep from 23:30 to 7:30), followed by 48 hours of sleep deprivation in constant light. An analysis of the data revealed that during sleep deprivation the phases of all rhythms drifted towards later hours. To demonstrate this, the acrophases of four rhythms of performance and four constituents in the urine, were computed for each subject for days with and without sleep, separately. The frequency histograms of these acrophases given in Figure 7 show that there was a significant phase-delay during sleep deprivation in each of the three groups of variables. It is unlikely that these changes in phase are to be attributed to the concurrent change in illumination because it has been found in other experiments that removal of the light-dark cycle has no influence on the internal phase-relationship within four days (Aschoff, Fatranska, Giedke, Doerr, Stamm, & Wisser, 1971; Giedke, Fatranska, Doerr, Hansert, Stamm, & Wisser, 1974). Similarily, Krieger, Kreuzer, and Rizzo (1969) have seen nearly the same internal phase-relationships in subjects with fixed sleep-times under conditions of a light-dark cycle as in constant light for 21 days. However, the possibility of additional effects of the light-dark cycle cannot be excluded, especially if one takes into consideration the occurrence of partial entrainment of the temperature rhythm by light as mentioned above.

The phrase 'phase control of a circadian rhythm by the sleep-wake cycle' implies a kind of coupling between two oscillating systems, and in addition suggests that the coupling is unidirectional. This point of view that sleep (or activity) influences other, dependent variables is common in the literature; it ignores the equally likely possibility that the rhythm of an autonomous function may act on the sleep-wake cycle. Several observations on rhythms of body temperature and of some hormones suggest that these 'dependent' variables can also become 'determinants' of the phase of sleep and wakefulness. As has been shown by Zulley (1979a, b), duration of sleep-time and hence time of awakening can be predicted from the course of rectal temperature. It is this kind of mutual interaction between its constituents that renders the analysis of the circadian system so intricate.

Especially well documented are interdependencies between the sleep-wake cycle and body temperature. To illustrate the bidirectional mode of this interaction, two sets of data are available. First Mills, Minors, & Waterhouse (1978a) have analyzed the lowering effects of sleep on rectal temperature in subjects who had two sleep-times of 4 h duration each, one from 0:00 to 4:00, the other staggered on successive days over the remaining 24 h. In Figure 8,

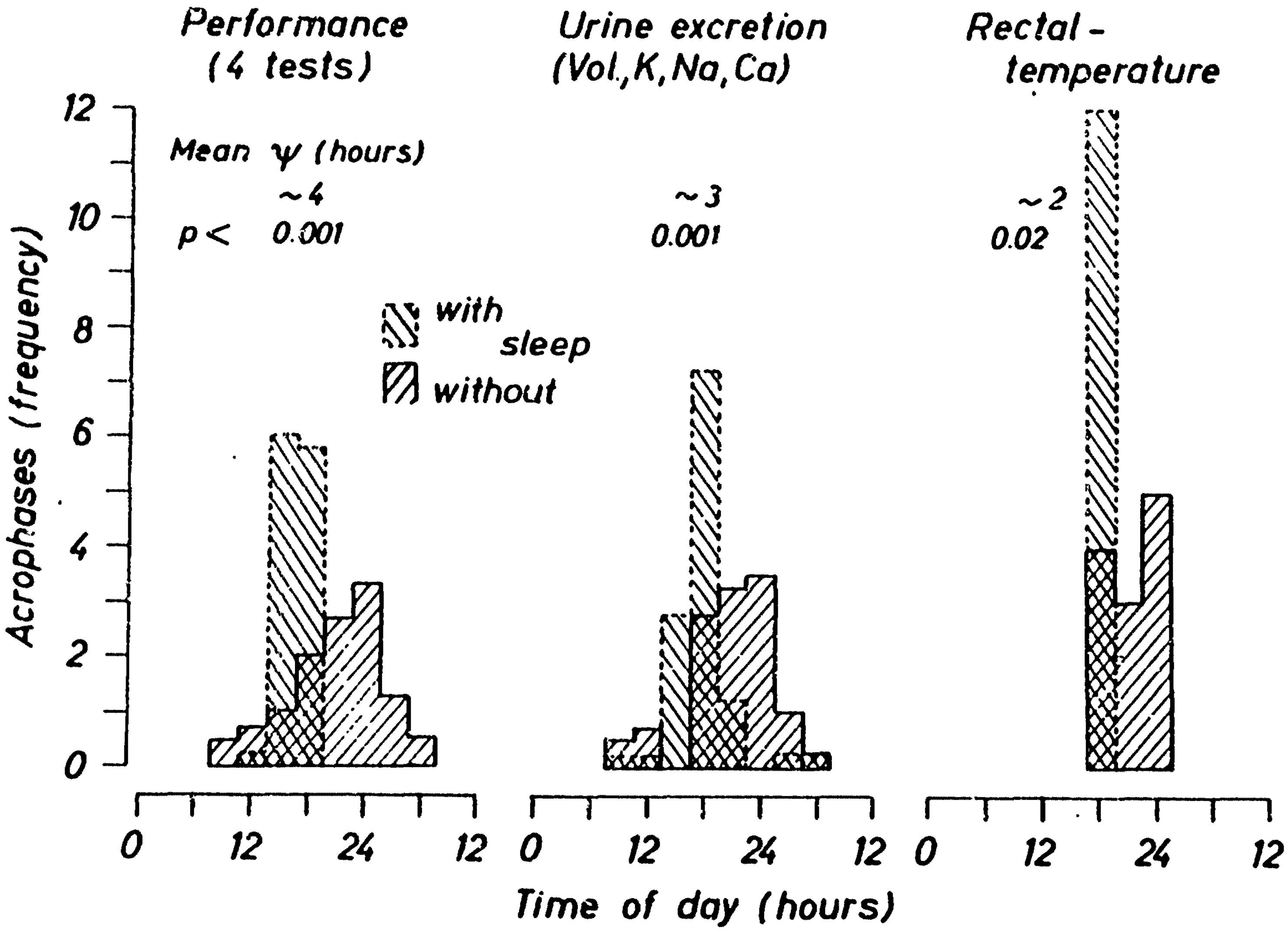

Figure 7. Frequency distribution for times of acrophases, averaged from the rhythms of four performance tasks (left), urine volume and three unrine constituents (middle), and rectal temperature. Mean values from 12 subjects who lived in groups of three in an isolation unit for four days in a light-dark cycle with sleep in darkness, and for two days in continuous light without sleep. ψ : Mean change in phase; p-values given for phase differences between the two conditions. (After Ringer, 1972; from Aschoff, 1978b).

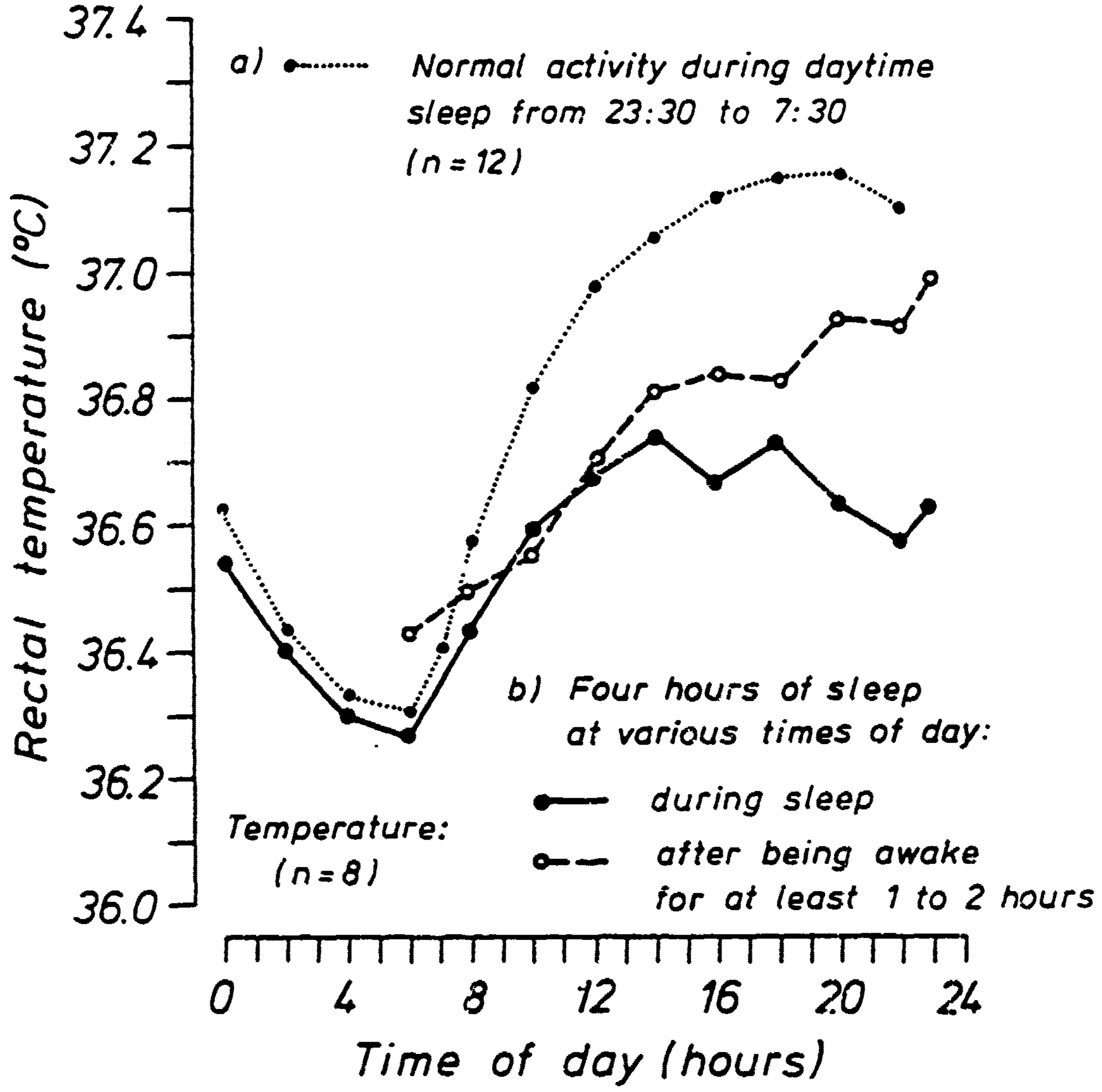

Figure 8. Rectal temperatures measured during 4-h sleep-times (staggered on successive days over 24 h) and after awakening from these sleep-times for at least 1 to 2 hours; a second sleep time was fixed daily from 0:00 to 4:00 (Data from Mills et al., 1978a). Dotted line: Representative curve from subjects with 8 h sleep and normal activities during daytime. (Data from Ringer, 1972).

the solid line represents the mean of the temperatures measured during each sleep-time; the dashed line shows the temperatures measured after the subjects had been awake for at least 1 to 2 h. For comparison, a dotted line is added that represents the course of rectal temperature in subjects who had 8 hours of sleep and were active throughout the rest of the day (Ringer, 1972). If one accepts these latter data as 'control', it is evident that the extent to which temperature drops during 4 h of sleep depends on circadian phase: the decrease is minimal in the morning and reaches maximal values towards late afternoon. Similarily, being awake and active increases rectal temperature very little or not at all in some circadian phases, but quite substantially in others.

In converse to the dependence just mentioned, it could be expected that sleep characteristics depend on the phase of the circadian system at which sleep occurs. In fact, such circadian changes in sleep structure have been observed in subjects who were asked to sleep at different times of day (Webb & Agnew, 1967; Karacan, Finley, Williams, & Hursch, 1979; Moses, Hord, Lubin, Johnson, & Naitoh, 1975; Carskadon & Dement, 1977). In the context of the present discussion, data would be of interest from subjects who spontaneously went to sleep at different phases of the temperature rhythm. Such data are available from experiments performed in the isolation unit under conditions where all zeitgebers and time cues were removed. The following analysis is based on the results obtained from 10 subjects whose circadian systems became internally desynchronized, i.e., who had mean circadian periods of about 25 h in their temperature rhythms and periods of about 32 h in their activity-rest cycles (Zulley, Wever, & Aschoff, 1980). Consequently, the sleep-times of these subjects coincided on each single day with another phase of the temperature rhythm. Onset and duration of sleep were determined for all together 206 sleep-times. These data then were drawn as a function of the phase of the temperature and middle of sleep-time (or onset of sleep, respectively) were used as reference phases. The results are presented in Figure 9. It shows a remarkable dependence of sleep duration on the phase of the temperature rhythm: long sleep-times coincide with the decreasing slope of the temperature curve (hours prior to the minimum), short sleep-times with increasing and high temperatures. Equally striking is the non-random bimodal distribution of onsets of sleep. Of the two maxima in the frequency histogram (upper part in Figure 9), the first one coincides with a phase of the temperature rhythm (about 6 to 7 hours before the minimum) where onset of sleep is most likely to occur in subjects synchronized to 24 h (Aschoff, Gerecke, & Wever, 1967a). The second peak in the histogram approximately coincides with that phase of the temperature rhythm where it is most difficult to stay awake under normal conditions (ref. the 'dogwatch') and at which it is most likely that onset of sleep occurs in subjects whose rhythms are freerunning but remain internally synchronized.

In summary then, it can be concluded that there is a bidirectional interaction between the sleep-wake cycle and other parts of the circadian system, at least as they are represented by the rhythm of body temperature. The modes of this interaction are of major interest for an understanding of the kinetics of the circadian system and the coupling between its constituents (Moore-Ede & Sulzman, 1980), and expecially for an understanding of the phenomena that can be observed in shift experiments in the laboratory, in transmeridian flights, and in shift work. Some of these problems will be dealt with in the following chapter.

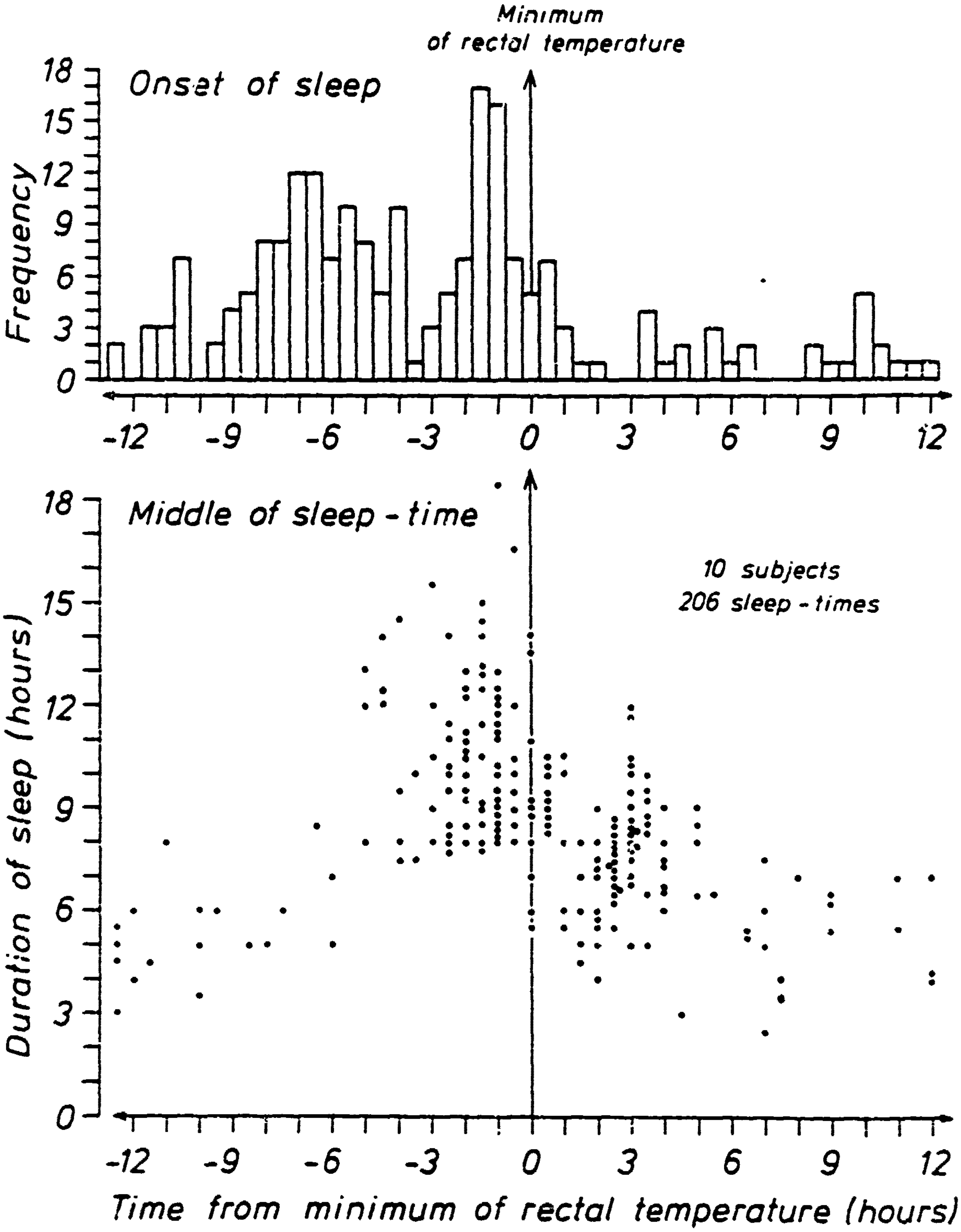

Figure 9. Onset and duration of sleep, taken from 206 sleep-times of 10 subjects who showed freerunning rhythms with internal desynchronization in the isolation unit without time cues. The times for onset of sleep and middle of sleep-time are drawn with reference to the phase of the rhythm of rectal temperature (0 = minimum of rectal temperature). (From Zulley et al., 1980).

Phase Shifts, Flights, and Shift Work

Advance Versus Delay Shifts

Parts of the kinetics that characterize the circadian system after shifts in zeitgebers or displacements of sleep-times are well understood. A few of the principles that have been derived from animal as well as human experiments, can be summarized as follows: a) Due to its inertia the circadian system does not regain a stable phase-relationship (internally as well as externally) until several transient periods have passed. b) During the course of re-entrainment the rate of shift per day varies;this effect can be attributed, at least partly, to the shape of the phase-response curve on which the entraining stimuli act (Aschoff, 1965a). c) The mean rate at which re-entrainment occurs differs between variables, and depends on the direction of the shift. A detailed discussion of these rules has been given elsewhere (Aschoff, Hoffmann, Pohl,& Wever, 1975). There are, on the other hand, several unsolved problems, and observations that need further clarification. This applies especially to conditions of shift work. They are usually characterized by a conflict between zeitgebers to which the circadian system reacts in a complex way. Shifts of zeitgebers in an isolation unit, or transmeridian flights, often produce results that are less difficult to interpret. Certainly, those experiments do not simulate shift work situations; they can, however, serve as tools to study some of the problems involved, and hence shall be discussed first.

In Figure 10 results are summarized from two 6-h shifts in the isolation unit (curves a and c for delay and advance, respectively; data from Wever, 1978b), and from two flights across 6 time zones (curves b and d for westbound and eastbound, respectively; data from Sonderfeld, 1977). For each experiment, the rhythm of rectal temperature is drawn on an abscissa that represents local time before the shift or flight, respectively. To indicate the slow course of re-entrainment, solid small arrows mark the minima of temperature as they occur in each cycle, and dotted arrows the time at which the minima are expected to occur after completion of entrainment. At first sight, the effects of delays and advances differ mainly in one circadian parameter: The range of oscillation remains nearly unchanged during re-entrainment after the delays (upper two curves), but is drastically reduced immediately after the advances (lower two curves). This differential effect has been confirmed in other experiments: re-entrainment through advances are usually accompanied by stronger reductions in range than are delays (cf. Figure 13). On theoretical grounds it could be expected that the rate of re-entrainment is correlated with changes in the range of oscillation: a larger reduction is likely to result in a faster shift (Wever, 1979b). This prediction is confirmed by both sets of data used for Figure 10, although in case of the flights the conclusion is less stringent because of difficulties in determining the exact rate of re-entrainment in absolute time (cf. the discussion in Aschoff et al.,1975, p. 69; and in Wever, 1979b).

Difficulties that may arise in determining absolute rates of re-entrainment are less critical in attempts to analyze interindividual differences when the same technique is applied to all data. This approach allows a correlation of the individual (relative) rate of re-entrainment with the range of oscillation measured before the flight. Under this aspect, daily acrophases were determined for each of the subjects whose average curves are displayed in Figure

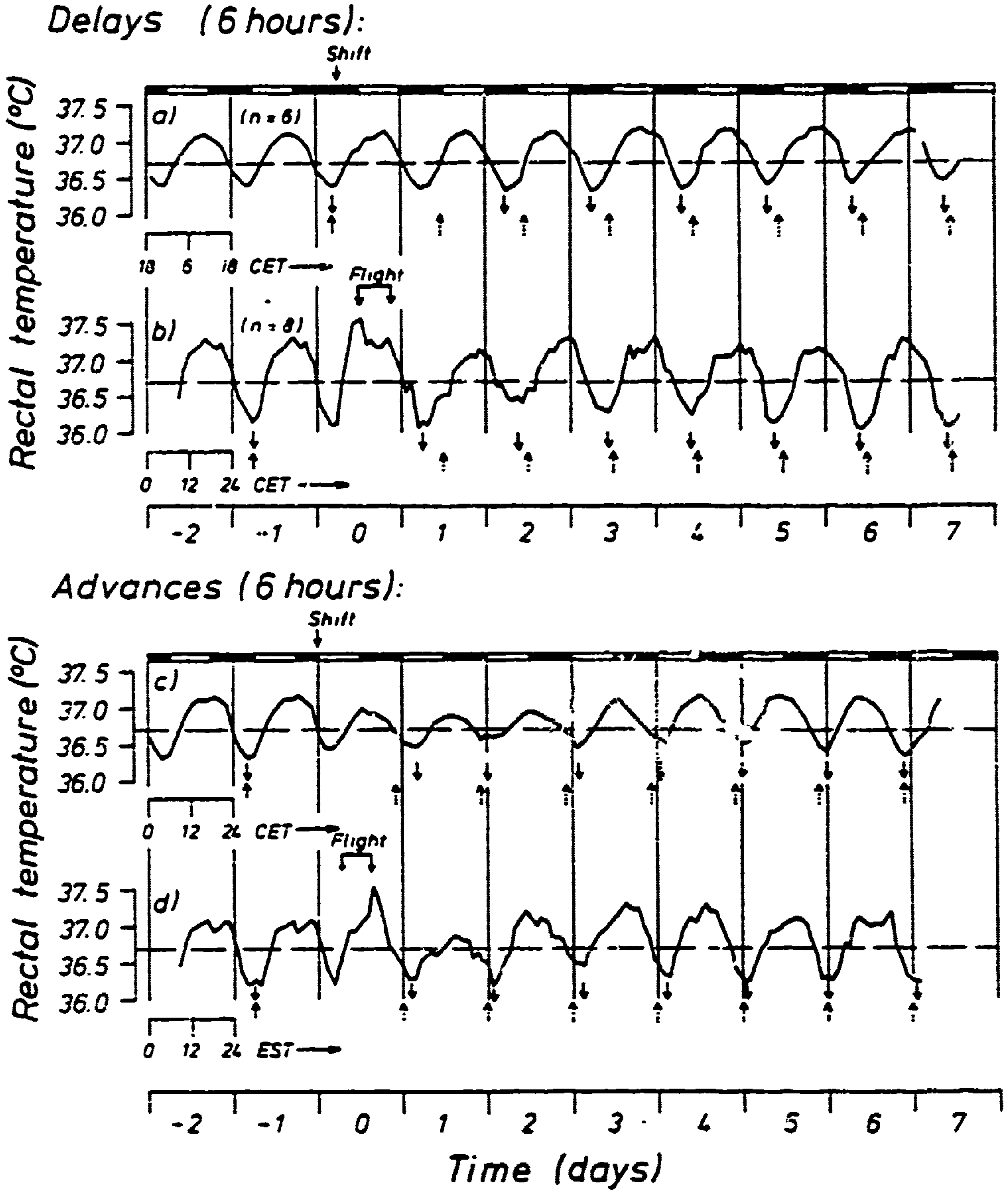

Figure 10. Rhythms of rectal temperature measured before and after a 6-h phase shift of the zeitgeber in an isolation unit (curves a and c) and before and after flights across 6 time zones (curves b and d). White and black bars at the upper margins indicate the light-dark cycle in the isolation unit. Solid arrows are drawn where minima are measured, dotted arrows where the minima are expected to occur after completion of re-entrainment. Data sources: Curves a and c Wever, 1979a (Figure 74). Curves b and d, Sonderfeld, 1977 (Table 10), complemented for the days of flight by personal communication (courtesey Dr. H.M. Wegmann).

10. For curves a and c, this was done by means of a harmonic analysis (i.e., by fitting sine waves). For curves b and d, mean values were computed from the times of peak values (p) and of nadirs (n) as listed by Sonderfeld (1977) using the formula (p + n + 12)/2. The results are given in Figure 11. Both types of experiments reveal a positive correlation between preflight range of rectal temperature and the time needed for 2/3 re-entrainment to occur; in the isolation unit as well as in the flight experiment, the correlation is stronger for advances than for delays. In accordance with these findings, a negative correlation has been seen in shift works between the range of oscillation and the amount of shift after the first day of night work (Reinberg, Vieux, Ghata, Chaumont, & Laporte, 1978).

From the flight data, another interesting result can be extracted that concerns the problem of early and late risers. According to Figure 12 (upper two diagrams) a strong correlation exists between the acrophase determined before the flight, and the duration of 2/3 re-entrainment. Surprisingly, this correlation is positive for the westbound, and negative for the eastbound flight. The lower two diagrams of Figure 12 show that the correlations between acrophase and range of oscillation, both measured before the flights, are consistent with what had to be expected from the data summarized in Figure 11. They do <u>not</u>, however demonstrate a consistent dependence of range of oscillation on phase, because the data from the two diagrams taken together result in a zero correlation. This agrees with the analysis of Wever (1979b) who in a sample of 6 subjects could not find any correlation between range and phase. Nevertheless, the possibility of a systematic relationship between the two variables remains and should be tested on a larger set of data.

The correlation between preflight acrophase and rate of re-entrainment, and the opposite signs of this correlation for the two flight directions shown in Figure 12 does not seem to be accidental; at least it is not unique for these two flight experiments. The same correlations have been derived from data obtained in another sequence of flights across 8 time zones (Mertens, 1973). The results summarized in Figure 13 are based on an analysis similar to that used for the data from the flight across 6 time zones (Figure 10). First of all, there is the same difference in alterations of the range of oscillation: no change after the westbound flight, but a drastic reduction after the eastbound flight. Of greater importance are the correlations shown in the two right diagrams of Figure 13: preflight acrophases and the times needed for 2/3 re-entrainment are again positively correlated after the westbound flight, and negatively after the eastbound flight. It must be emphasized that these preliminary observations on a small number of subjects cannot be accepted without great caution. The positive correlation between duration of re-entrainment and preflight acrophase, derived from the data of the first (westbound) flight might be reliable because the subjects were presumably in a steady state before the flight. More doubtful are the data from the second (eastbound) flight because the circadian systems still could have been in a transitory state when measurements were taken; consequently, the meaning of the preflight acrophases is less clear (cf. the discussion in the following two sections).

On theoretical grounds, and on the basis of animal experimental work, it can be assumed that the acrophase is, at least in part, an indicator of the subject's 'natural' circadian period; the later the acrophase occurs, the

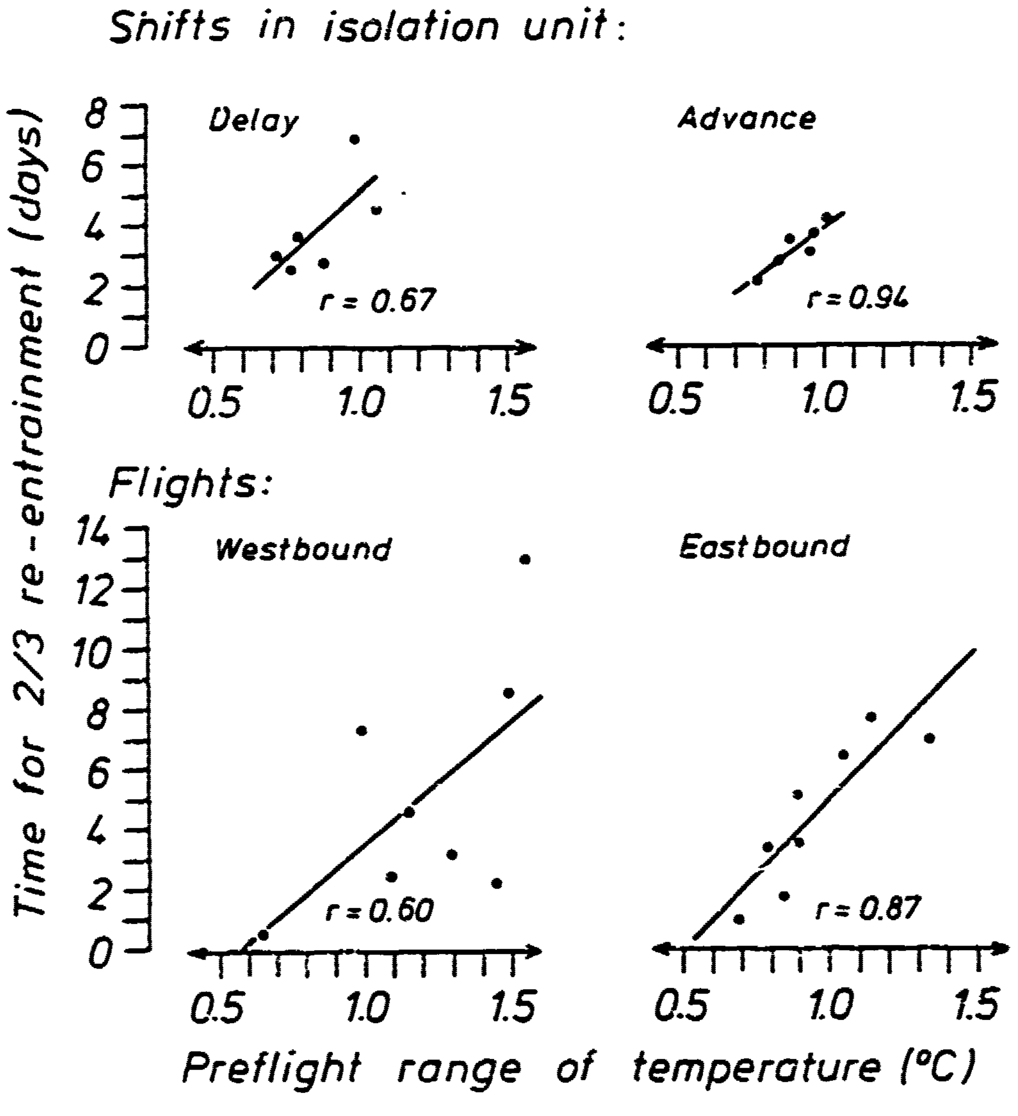

Figure 11. Duration of 2/3 re-entrainment after a 6-h zeitgeber shift in the isolation unit or after flights across 6 time zones, drawn as a function of the range of oscillation measured in the rhythm of rectal temperature before the shift or the flight, respectively. r: Coefficient of correlation. (Data source: Above Wever, 1979b; below Sonderfeld, 1977).

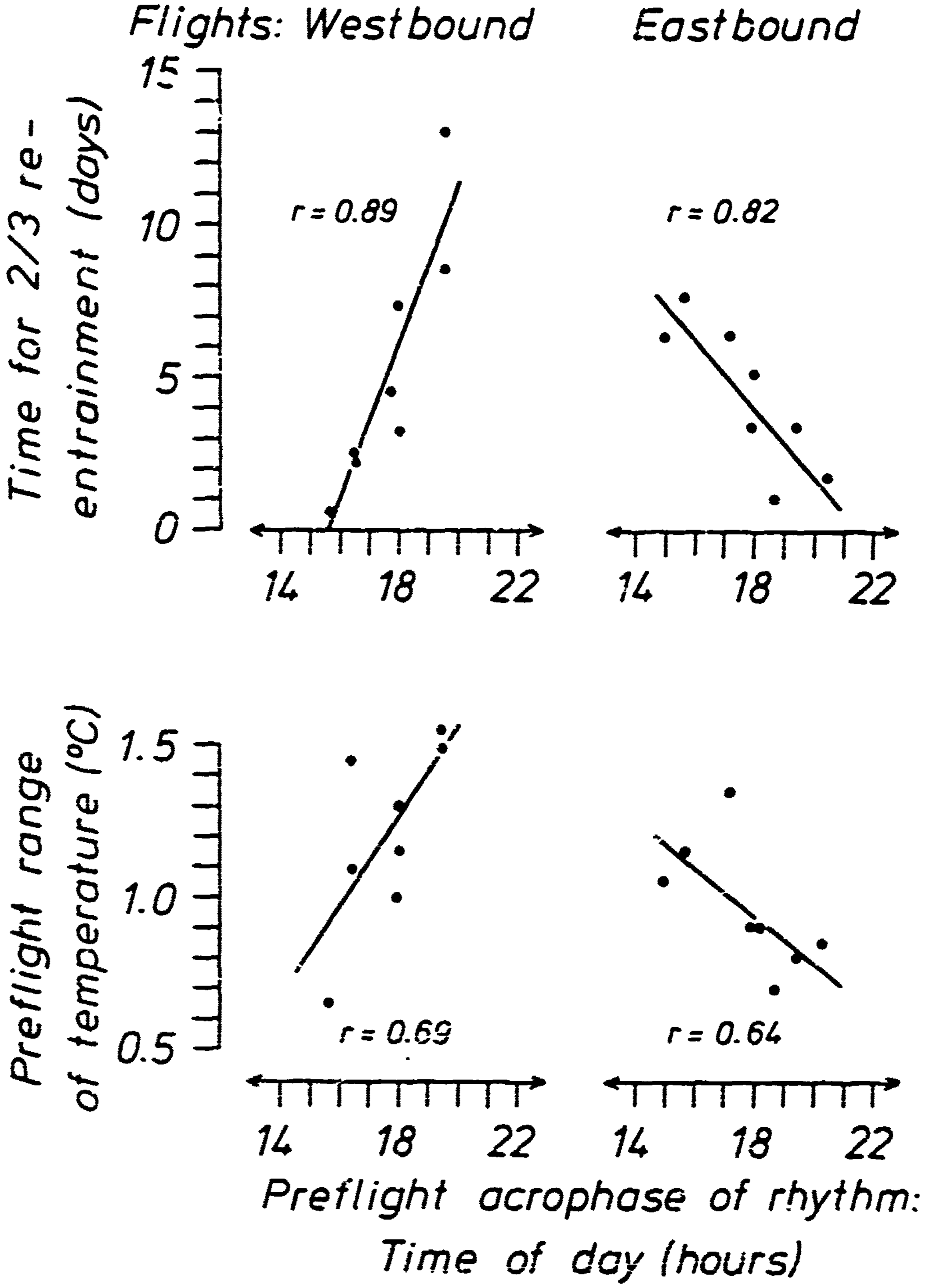

Figure 12. Duration of 2/3 re-entrainment after flights across 6 time zones (above), and range of oscillation of the rhythm of rectal temperature measured before the flights (below), drawn as a function of the individual acrophase of the temperature rhythm determined before the flights. r: coefficient of correlation. (Data from Sonderfeld, 1977).

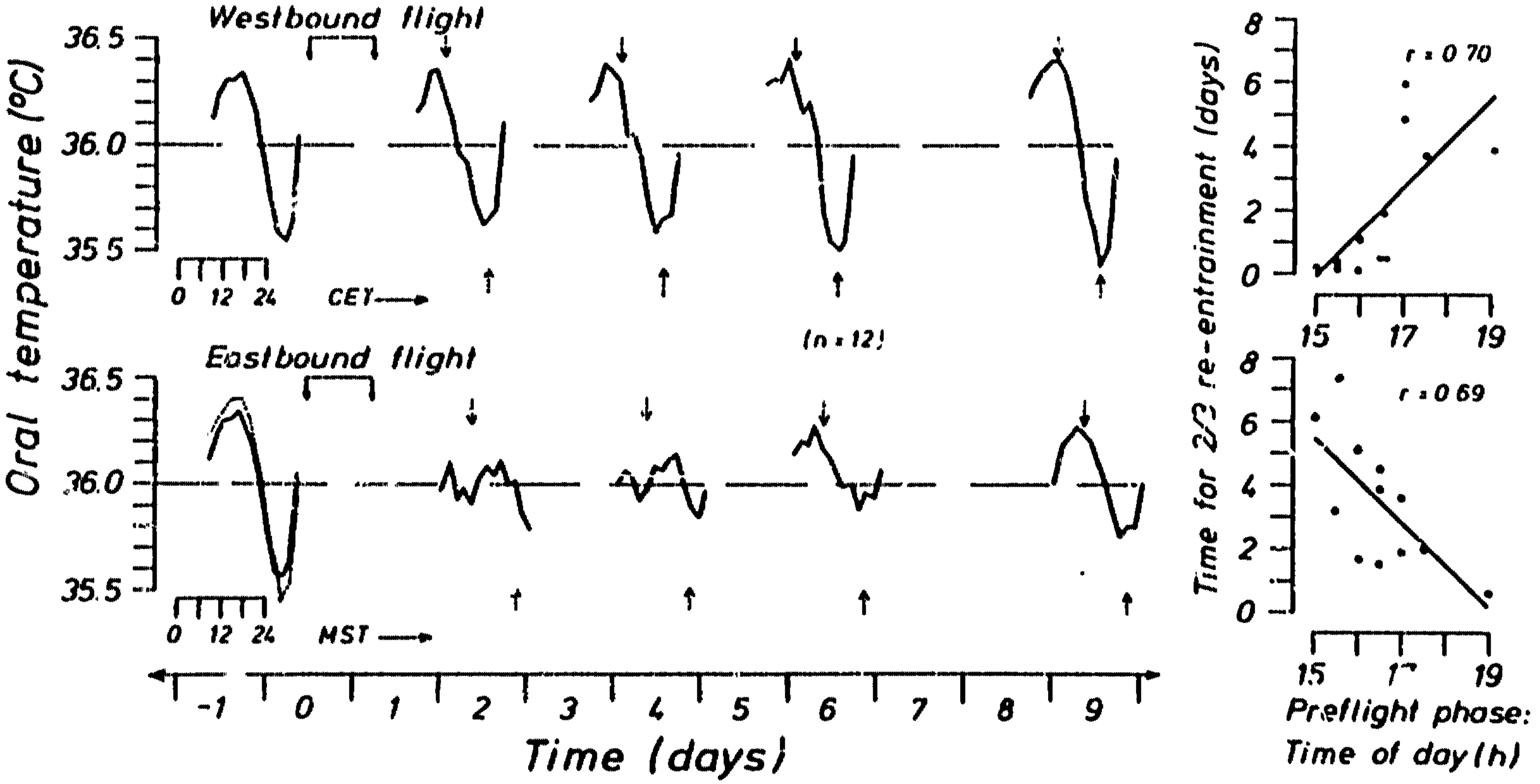

Figure 13. Rhythms of body temperature measured before and after flights across 8 time zones. Dotted arrows: Times expected for maxima and minima after completion of re-entrainment. Right two diagrams: Duration of 2/3 re-entrainment drawn as a function of the individual acrophase of the temperature rhythm determined before the flight. r: Coefficient of correlation. (Data from Mertens, 1973).

longer the expected period (Aschoff, 1965). One may further assume, that a relatively long period facilitates delay shifts, and makes adaptation to advance shifts harder. Hence, faster re-entrainment could be expected after a westbound flight in late risers compared to early risers; the converse should apply to eastbound flights. The correlations shown in Figures 12 and 13 are contrary to these expectations. They also do not agree with observations that 'evening-types' adapt more easily to night work than do 'morning types' (Åkerstedt & Fröberg, 1976; Colquhoun & Folkard, 1978; Östberg, 1973). No solution can be offered at the present time to this problem that certainly is worth attention.

Re-Entrainment by Partition

The results of the shift and flight experiments discussed in the foregoing chapter seem to be more or less unambiguous with regard to the mode by which re-entrainment occurs. With the exception of the measurements made at day 2 and 4 after the eastbound flight across 8 time zones (Figure 13, lower panel), there is always a clear rhythm which is shifted in the direction corresponding to that of the zeitgeber shift or the flight. More complex pictures can be seen in the laboratory after a displacement of the sleep-time by 12 h. The data from two such experiments are redrawn in Figure 14. In both cases, rhythms of urinary excretion have been measured. The rhythm of melatonin excretion (A) has a large range of oscillation, and the steady drift of peaks and troughs toward later hours during the days after sleep displacement is well expressed. The data from experiment B give a less clear picture which cannot be interpreted without a more detailed analysis. For this purpose, acrophases were computed for each cycle from all records; individual data were available for A (Lynch, Jimerson, Czaki, Post, Bunney, & Wurtman, 1978), only the means from 4 subjects for B (Chevrier, 1973; 1974). As can be seen in Figure 15, the melatonin rhythms of all four subjects follow the 12-h shift of sleep-time by delays; re-entrainment is completed within 10 to 12 cycles. Contrary to this uniform pattern, in experiment B only the excretory rhythm of the 17-hydroxycorticosteroids undergoes a delay while the rhythms of potassium and sodium excretion regain their original phase via advances. Such a breakup of the circadian system into components that move in opposite directions has been called 're-entrainment by partition' (Aschoff, 1978a).

As has been shown in animal experiments, a 12-h phase shift of the zeitgeber puts the circadian system in an ambiguous situation which offers a 'choice' between the possibilities to become re-entrained either through advances or through delays (Aschoff et al., 1975). In a way, the displacement of sleep time by 12 h can be considered to provide a similar situation. It is therefore not too surprising to find partial re-entrainment through advances, although intuitively one would expect a preference for delays in the human circadian system. If this is correct, delay transients might be expected after an advance shift of zeitgeber or sleep-time even if it is less than 12 h. In fact, it is under such a situation that re-entrainment by partition was initially observed (Wever, 1970). The results of an experiment carried out in the isolation unit are presented in Figure 16. The left half of it shows the rhythm of wakefulness and sleep (black and white bars), together with the extreme of rectal temperature (triangles). After a 6-h advance shift of the zeitgeber on day 10, the activity cycle was also advanced by eventually 6 h, but the rhythm of temperature delayed by 18 h. In the right half of Figure 16,

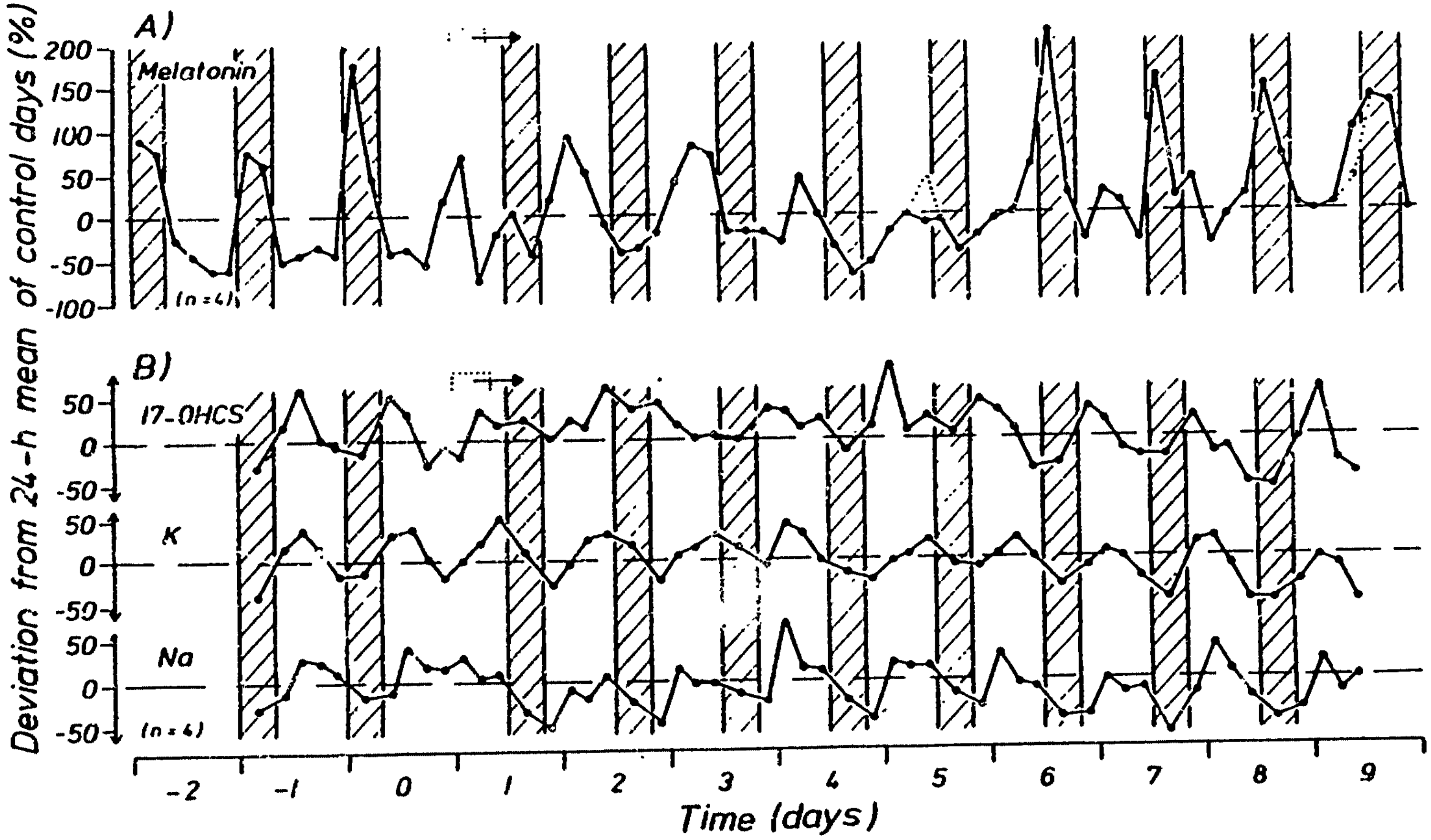

Figure 14. Circadian rhythms of urinary excretion, measured before and after a shift of sleep-time by 6 h. Shaded area: Sleep in darkness. Values in-between dotted lines (in A) averaged after the omission of one exceptionally high or low value, respectively. (Data from A) Lynch et al., 1978, and B) Chevrier, 1973 and 1974).

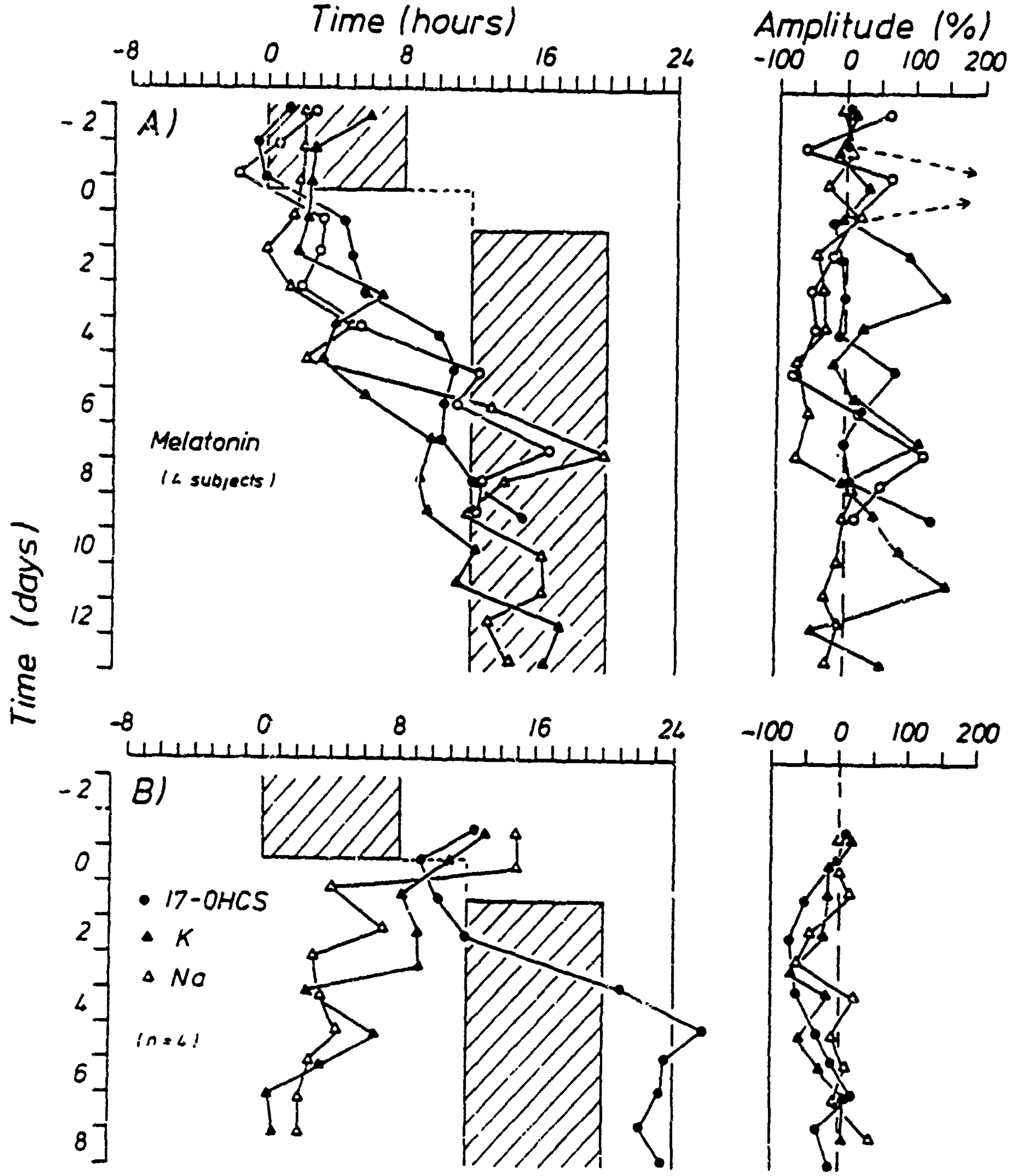

Figure 15. Shift of acrophases of urinary excretory rhythms after a 12-h shift of sleep-time. Shaded area: Sleep in darkness. (Data from: A) Lynch et al., 1978, and B) Chevrier, 1973 and 1974). Right diagram: Deviation of the amplitude of the rhythms from the pre-shift mean.

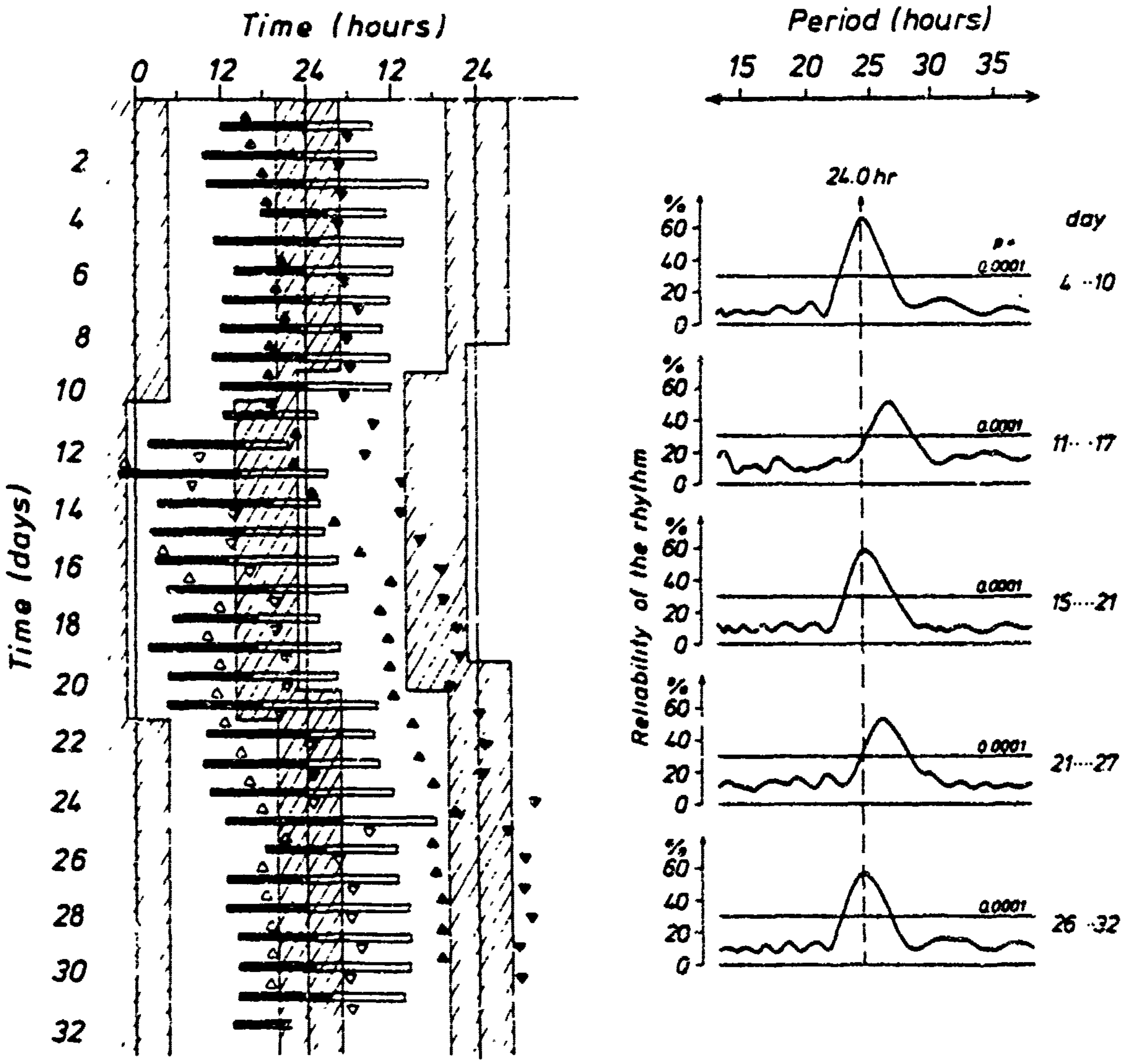

Figure 16. Left: Shift of circadian rhythms in a subject exposed in the isolation unit to a light-dark cycle and to regular gong signals, with reading lamps available. Shaded area: Darkness. Wakefulness and sleep indicated by, black and white bars. Triangles: Maxima and minima of rectal temperature (open triangles: double plot). Right: Period analysis of the temperature data for 7-day intervals, made on the basis of a modified periodogram analysis (Wever, 1979a). The ordinate represents a measure of the reliability of the rhythm (less than 30%: Random fluctuation) (Wever, 1979b).

the period analysis from 7-day sections of the temperature record demonstrates that on days 11 to 17 the period was substantially longer than 24 h (Wever, 1979b).

In the attempt to compare the modalities of phase shifts under a variety of conditions the results from 8 experiments have been put together in Figure 17. In four of the six delay shifts (No. 1 through 4) a more or less uniform pattern of delays was exhibited by the rhythms as indicated by the shift of acrophases. (Note: only minima of temperature are drawn in No. 3; cf. the remarks in the following chapter in connection with Figure 19). Re-entrainment by partition occurred in two of the 12-h delay shifts (Nos. 5 & 6), but its incidence was higher in the advance experiments. After an eastbound flight across 9 time zones, re-entrainment by partition occurred in 50% of the subjects studied (No. 7), and after a zeitgeber advance in the isolation unit by only 6 h, 1 out of 7 subjects still showed this phenomenon. In essence, the observations summarized in Figure 17 seem to indicate that re-entrainment by partition is more likely to occur after advance than after delay shifts, and that the probability for partitioning after advances increases with the extent of zeitgeber shift or with the number of time zones crossed, respectively. These conclusions are corroborated by a publication from Mills, Minors, and Waterhouse (1978b). In 127 subjects, tested in the isolaion unit after 8-h phase shifts, they observed re-entrainment by partition in about 78% of the cases after advance shifts, but only in about 20% after delay shifts.

Applications to Shift Work

It has already been mentioned that a 12-h shift of sleep-time can result in complex patterns that are not easy to explain. This seems especially to be the case when no sufficient efforts have been made to shift all zeitgebers simultaneously with the displacement of sleep, and to carefully exclude other (non-shifted) time cues in the environment, i.e.,in conditions that come close to those of true shift work. The results of an experiment which presumably has been performed under such 'semi-controlled' conditions, have been published by Lanuzza and Marotta (1974). In the laboratory, plasma levels of cortisol, calcium, and magnesium were measured at 3-h intervals in four subjects before and on the 7th day after a 12-h shift of sleep-time. The data from the control day (Figure 18, upper row) show clear circadian patterns, although attention must be drawn to the fact that the range of oscillation in the cation rhythms is in the order of only ± 6 to 8% of the 24-h mean (note the difference in ordinate scales for cortisol and for cations, respectively). On the 7th day after the shift, radically different patterns can be seen (Figure 18, lower panel): in each variable, two peaks of nearly equal magnitude have emerged, while the overall range between peaks and troughs has become small compared to the range of oscillation found prior to the shift. Of the two peaks, one occurs at either the same time of day as the maximum on the control day (cortisol), or about 3 to 6 h later (cations). The second peak seems to have evolved anew at about the time at which a maximum would have been expected after complete re-entrainment. This 'snapshot' out of a dynamic process, taken on the 7th day after the shift, does not contradict the possibility that there had been a steady drift of components of the circadian system, but it also prompts other hypotheses. Could it be that during re-entrainment, one component of the circadian system 'disappears' (or is shifted slowly) while another component 'emerges' at that time of day where it would have been ex-

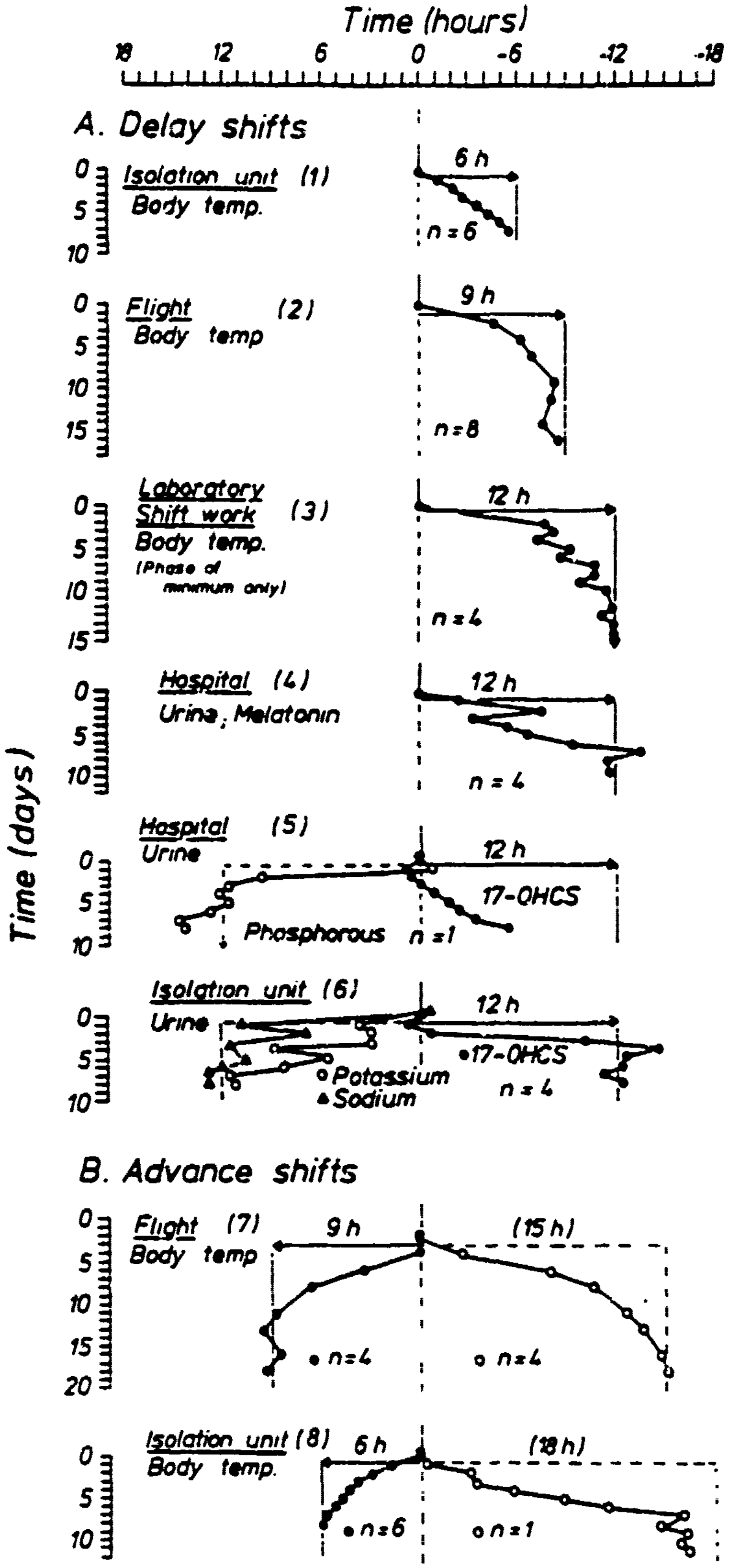

Figure 17. Shift of human circadian rhythms after a shift of the zeitgeber in an isolation unit (1,6,9) a shift of sleep-time in the laboratory (3,4,5), and after flights across several time zones (2,7) at day 0. Zero at the abscissa represents the phase of a rhythm before shift of flight. With the exception of No. 3 all data represent acrophases. Data sources: 1) and 8) Wever, 1979b; 2) and 7) Klein et al., 1977; 3) Knauth and Rutenfranz, 1976; 4) Lynch et al., 1978; 5) Levine, 1976; 6) Chevrier, 1973, 1974).

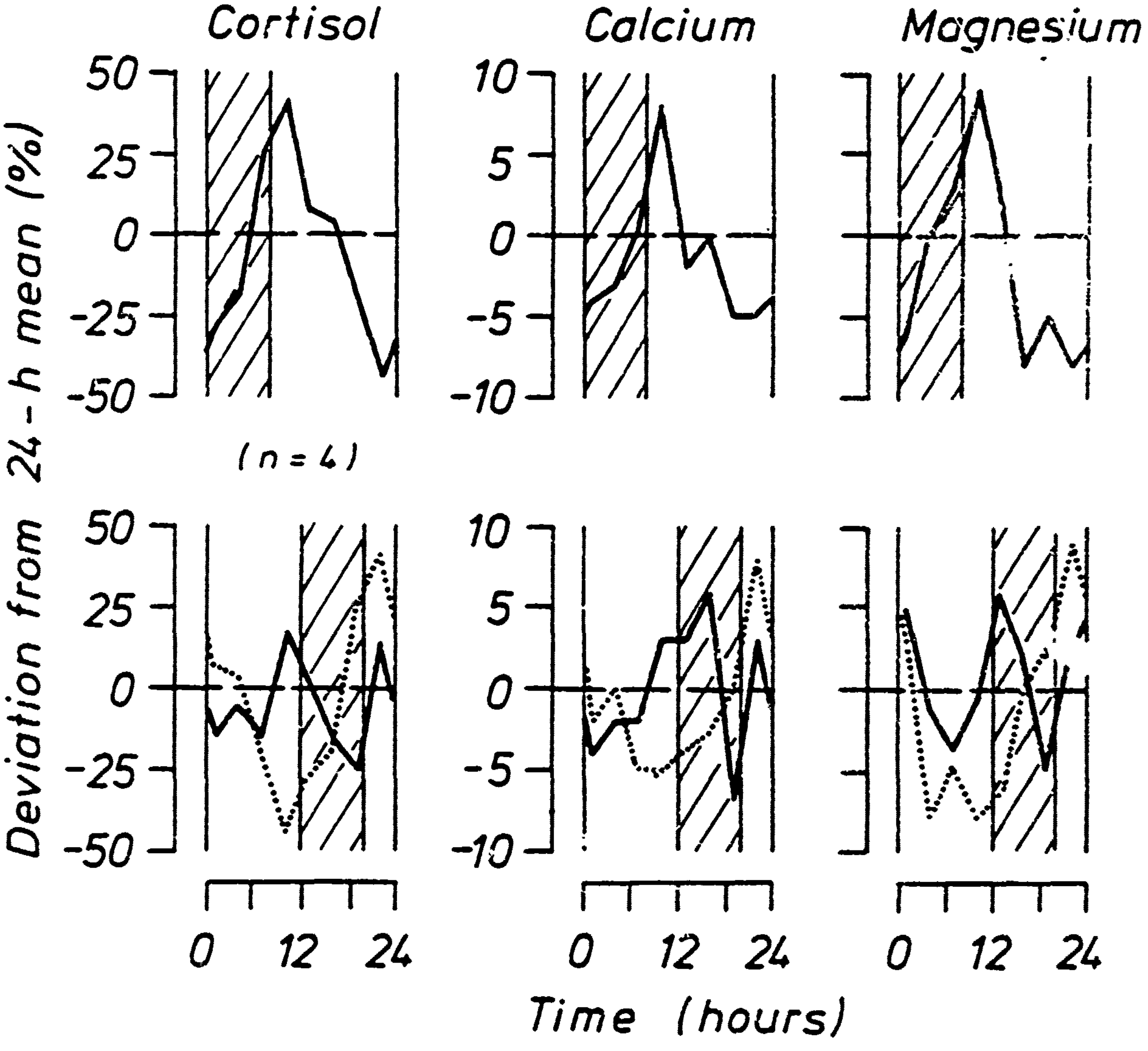

Figure 18. 24-h patterns of three plasma constituents, measured prior to (above) and on the 7th day after a 12-h shift of sleep-time in the laboratory (below). Shaded area: Sleep. Dotted lines: Patterns to be expected after a complete shift. (Data from Lanuzza and Marotta, 1974).

pected after full re-entrainment? A few observations made after transmeridian flights (e.g., Sasaki, Usuku, Kawamura, & Yokobori. 1979; cf. also Figure 13, 2nd and 4th day after the east bound flight) support such ideas which immediately call to mind the concept that the circadian system may consist of two coupled pacemakers (Pittendrigh & Daan, 1976; cf. also the discussion in Mills et al.. 1978b). It seems likely that answers to these questions have to wait until the processes of masking are understood in more detail.

Masking may also be a major factor in 'shaping' rhythms during adaption to true or simulated shift work. To illustrate the problem, Figure 19 presents data collected by Knauth and Rutenfranz (1976) from four subjects who in the laboratory worked first on an 8-h day-shift and thereafter for 21 days on a night shift (displacement of work-time 13 h, of sleep-time about 11 h). According to the curves drawn in Figure 19, rectal temperature has its normal pattern during the day-shift and also during the first day of night-shift. In the following days, the temperatures measured during sleep are progressively depressed, and the minimum slowly drifts from early to late in the sleep-time, as shown in more detail in Figure 17 (No. 3). But if this can be interpreted as a true shift of a rhythm (or a rhythm component?) why is there no shift in the maximum which still occurs at the same time of day as during day-shift on the 21st day of night-shift? The drop in temperature immediately after onset of sleep becomes more pronounced from the 2nd to 21st day of night-shift, probably as a consequence of the elevated temperatures in the hours before sleep, and in accordance with the phenomenon illustrated in Figure 8. But why, then, is there less 'masking' on the first recovery day? Most likely, the curves have to be explained as the result of an interaction between masking and partly shifted components of the circadian system, with the additional possibility that the 'strength' of masking effects changes as the subjects get used to their night work and concurrently with drifts of rhythm components. It is also noteworthy that already on the 2nd recovery day the curve of rectal temperature again approximates that measured during the control days. Does this fast re-adjustement mean that the circadian system (as a whole, i.e., the assembley of pacemakers) was only partly shifted? Further questions: Why does rectal temperature start to decrease about 2 h before the onset of sleep on the 2nd day of night-shift? And why does rectal temperature start to increase in the middle of the 1st recovery day?

Without doubt, real as well as simulated shift work creates a situation in which it is hard to derive the true behavior of the circadian system from the patterns of overt rhythms. Even after prolonged night-work, there is presumably much less shift in pacemakers than suggested by the phase shifts of rhythms. Mills and coworkers (1978b) have emphasized this point of view on the basis of experiments which indicate that such a discrepancy plays its role also in the isolation unit where easier adjustment could be expected. This should be taken as a warning not to infer too much from the drifts of acrophases after transmeridian flights even if they seem to proceed quite steadily (cf. Figures 10, 13 & 17). The following section elucidates these aspects once more.

Selective Entrainment or Masking?

In attempting to analyze shifts of the circadian system, one is confronted with a bunch of complex problems. 1) The system is composed of a multiplicity

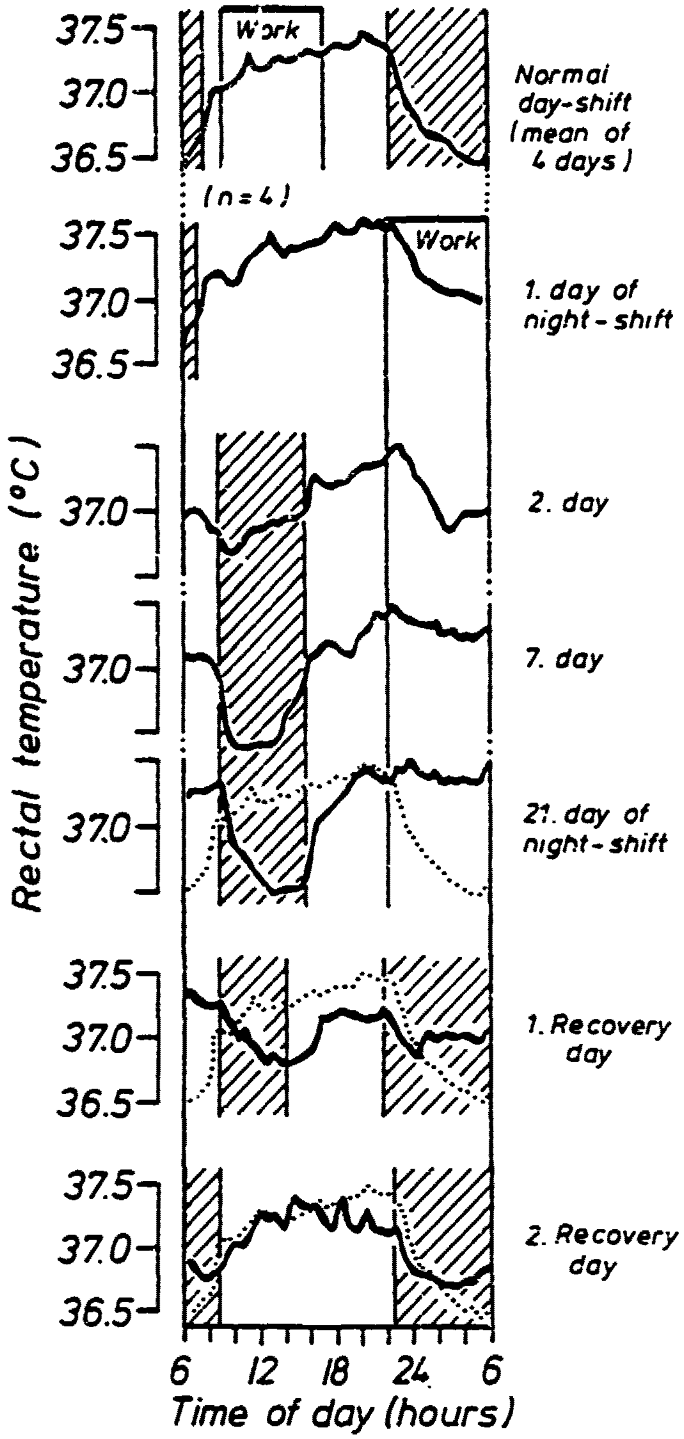

Figure 19. Rhythm of rectal temperature obtained in a semi-natural situation of shift work. Four days of day-shift followed by 21 days of night-shift and two recovery days without work. Shaded area: Sleep in darkness. Dotted lines: Temperature curves from initial control days. (Data from Knauth and Rutenfranz, 1976).

of oscillators, as most convincingly demonstrated by the phenomenon of internal desynchronization in man (Aschoff, Gerecke, & Wever, 1967b) and non-human primates (Sulzman, Fuller, & Moore-Ede, 1977a); 2) These oscillators may be to some extent true pacemakers or at least units capable of self-sustaining oscillations, or they may represent subsystems only capable of forced or damped oscillations, respectively; 3) The coupling forces vary between oscillators, as well as between oscillators and overt rhythms; 4) Patterns of rhythms that indicate entrainment may be confounded by masking effects; 5) Different zeitgebers can probably act on the oscillating units separately and with varying strength. With regard to this, it has already been mentioned that under the influence of a weak zeitgeber, parts of the circadian system may be entrained while others are freerunning (partial entrainment). It is, hence, conceivable that for this reason a shift in zeitgebers results in different rates of reentrainment for various oscillating units. One could further expect that in a situation with conflicting zeitgeber information, the various components of the circadian system react individually and differentially to the zeitgeber stimuli. Observations which support this view have been made in monkeys exposed to two different types of zeitgebers which also differed in their period length: a light-dark cycle with a period of 23 h, and restricted feeding with a period of 24 h (Sulzman, Fuller, Hiles, & Moore-Ede, 1978a). From several rhythms monitored simultaneously, body temperature followed the 23-h, and urinary excretion the 24-h zeitgeber. The possibility that such a kind of 'selective entrainment' occurs also has to be taken into account during shift work. The shift work situation, however, differs from that of the monkey experiment just mentioned in so far as the conflicting zeitgebers usually have the same 24-h period. Hence, it may be more difficult to separate entrainment from masking effects. One last example will suffice to point out these difficulties.

Circadian rhythms usually persist without major alterations in both subjects who are completely starved (cf. the review in Reinberg, 1973), or who receive equal amounts of food at short intervals all over the day (e.g., Yoshimura & Morimoto, 1972; Sagel, Colwell, Loadholt, & Lizarralde, 1973). However, the actual timing of meals can have effects on at least some variables. Goetz and coworkers (1976) and Haus (1976) have shown that, with the exception of cortisol, several plasma constituents change their phase-relationship to the sleep-wake cycle drastically in subjects who switch from having only breakfast to eating only dinner every day (Figure 20). Again, the question arises whether such differences in rhythmic patterns reflect pure masking effects or the behavior of what may be called circadian sub-oscillators. Answers cannot be easily found, as in the case of the question whether meal timing can be a zeitgeber in general. Results which indicate entrainment, have been obtained in squirrel monkeys (Sulzman, Fuller, & Moore-Ede, 1977b), but the experiments of Gibbs (1979) with fixed interval feeding failed to entrain the activity rhythm of blind rats and illustrate at the same time the problematic nature of interpreting those data. The hypothesis that masking rather than entrainment occurs during restricted feeding in rats, is strongly supported by the recent findings of Morimoto, Oishi, Arishue, & Yamamura, (1979) who in appropriate tests followed, after ten days of meal timing, the courses of several rhythms in constant darkness during ad libitum feeding.

Many of the patterns seen during shift work may be a mixture of selective entrainment and masking. The study of masking—presently only a descriptive

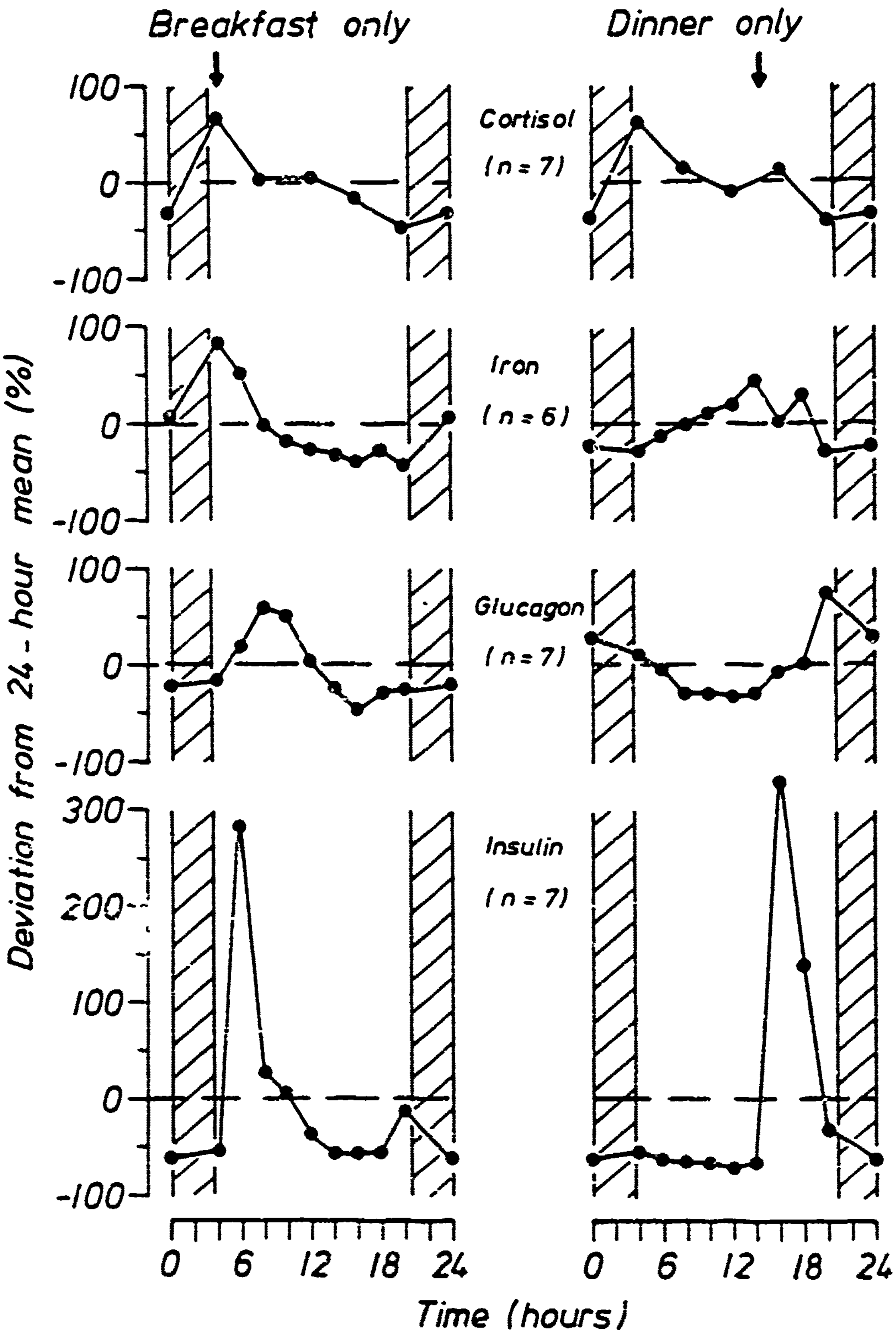

Figure 20. 24-h pattern of four plasma constituents, measured in subjects who for seven days had only one meal per day either as breakfast (left) or as dinner (right). (Data from Gotz et al., 1976, and Haus, 1976).

term for a complex, poorly understood phenomenon—may, hence, prove to be one of the tools to evaluate the feasibility of shift systems. From the catalogue of still open questions a few should be mentioned. We have to know more about the bi-directional coupling between pacemakers, driven oscillators, and overt rhythms. It is via these feedback mechanisms, that masking effects which at first sight seem only to deform the pattern of an overt rhythm may eventually influence the circadian system as a whole. How much of this is done by sleep, by meal timing, by light, and by other factors, respectively? Furthermore, from the well known circadian changes in responsiveness, a phase dependence of masking effects is to be expected. Does this give us tools to facilitate—or to prevent—shifts in the circadian system during shift work? And finally: If selective entrainment does occur—would it be advisable to deliberately synchronize some variables with the hours of work but to leave others at their normal phase? Or is it more important, to preserve as much as possible the natural temporal order of the circadian system? According to our present state of knowledge, the latter approach seems preferable. Taken together with the many obstacles that oppose a perfect adjustment of the circadian system to night-work, this would mean that shifts even of parts should be kept to a minimum—a provision strongly recommended by Mills and coworkers (1978b) and supported by the report that the complaints of night workers and the amount to which their rhythms had been shifted, can be negatively correlated with each other (Reinberg, 1980).

Concluding Remarks

Despite the multiplicity of its constituents, the circadian system often behaves like one unit which is characterized by the durability of its oscillations and its internal temporal order. This order is maintained by mutual coupling between the various components and, in the case of entrainment, by the signals from the zeitgebers. As a consequence, freerunning and entrained systems differ in the character of their internal order (Wever, 1973; Aschoff & Wever, 1976) and in the stability of internal phase-relationships (Sulzman, Fuller, & Moore-Ede, 1978b). The persistance of internally synchronized (freerunning) rhythms under adverse conditions (cf. Figures 4 & 5) and the slow courses of re-entrainment after shifts (Figure 17) indicate the rigidity of the system and its inertia. There are, on the other hand, conditions under which the system due to a loss of coupling between its constituents, is split into components that either can become desynchronized or react differentially to conflicting zeitgebers. In addition to this lability, there is a plasticity, predominantly demonstrated by masking effects on the overt rhythms. In the interplay between all these factors, the rhythm of sleep and wakefulness (of rest and activity) holds a specific place. Although itself part of the system, and, hence, determined by it in some of its characteristics (cf. Figure 9), the sleep-wake cycle exerts masking as well as phase controlling effects similar to those of zeitgebers. The analysis of this bidirectional interaction between the sleep-wake cycle and other components of the circadian system is presently one of the major tasks in this field of research.

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ON VARYING WORK-SLEEP SCHEDULES: THE BIOLOGICAL RHYTHM PERSPECTIVE

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The rhythmic alternation between activity and sleep is based on endogenous mechanisms, but is subject to exogenous influences. The endogenous basis of the alternation is shown by the persistence of circadian rhythms in a constant environment free of time cues. Under these conditions, the freerunning rhythms that can be observed in different variables may either remain in synchrony but out of phase with each other, or become desynchronized, each showing a different frequency. Exogenous factors, when present continuously, may determine the parameters of a freerunning rhythm of this sort; when occurring periodically, they may synchronize it. Exogenous stimuli that affect the endogeneously generated rhythm can be of a physical nature (e.g.,light, temperature), or they can consist of signals with social connotations. The latter are the most effective zeitgebers for the human circadian system.

In assessing characteristics of the activity-sleep cycle, it is helpful to examine endogenous and exogenous influences separately. When exogenous factors are kept constant, the periods of freerunning rhythmic functions, as well as particular aspects of them such as the duration of sleep-time, are exclusively determined by endogenous processes, i.e., they are not due to social conventions, or to time-related changes in motivation. However, in view of the fact that different physiological variables interact with each other and, in addition, may affect the activity-sleep cycle, two states of the circadian system that occur in this situation will be differentiated: (1) a state of internal synchrony in which each rhythm has a consistent frequency and a constant temporal order is maintained, and (2) a state of internal desynchrony in which, due to differences in frequency between different rhythms, temporal disorder results. The effects of exogenous factors will be assessed by considering experiments in which the influence of such factors was studied by exposing subjects to a variety of zeitgebers. The discussion will be mainly restricted to two variables: the rhythm of wakefulness and sleep, and the rhythm of deep body temperature, the latter being representative of physiological rhythmicity in general. The present review is not aimed directly at the practical problems of shiftwork and the like, but rather provides the background for the solution of such problems.

Freerunning, Interally Synchronized Rhythms

When isolated from environmental time cues, human circadian rhythms persist with periods that deviate slightly from 24 hours. In the majority of cases,the rhythms of all variables measured remain synchronized, with a common period close to 25 hours. In the experiment shown in Figure 1, the rhythms of activity and rectal temperature had equal and consistent period values of 25.3 hours throughout 5 weeks of isolation. Apart from the deviation of the period from 24 hours, this figure illustrates another peculiarity of freerunning rhythm. In the steady state, the maxima and minima of rectal temperature occur at much earlier phases of the activity rhythm than they do in the normal 24-hour day. As a consequence, the subject sleeps predominantly during a period of increasing deep body temperature, in contrast to what happens in a normal

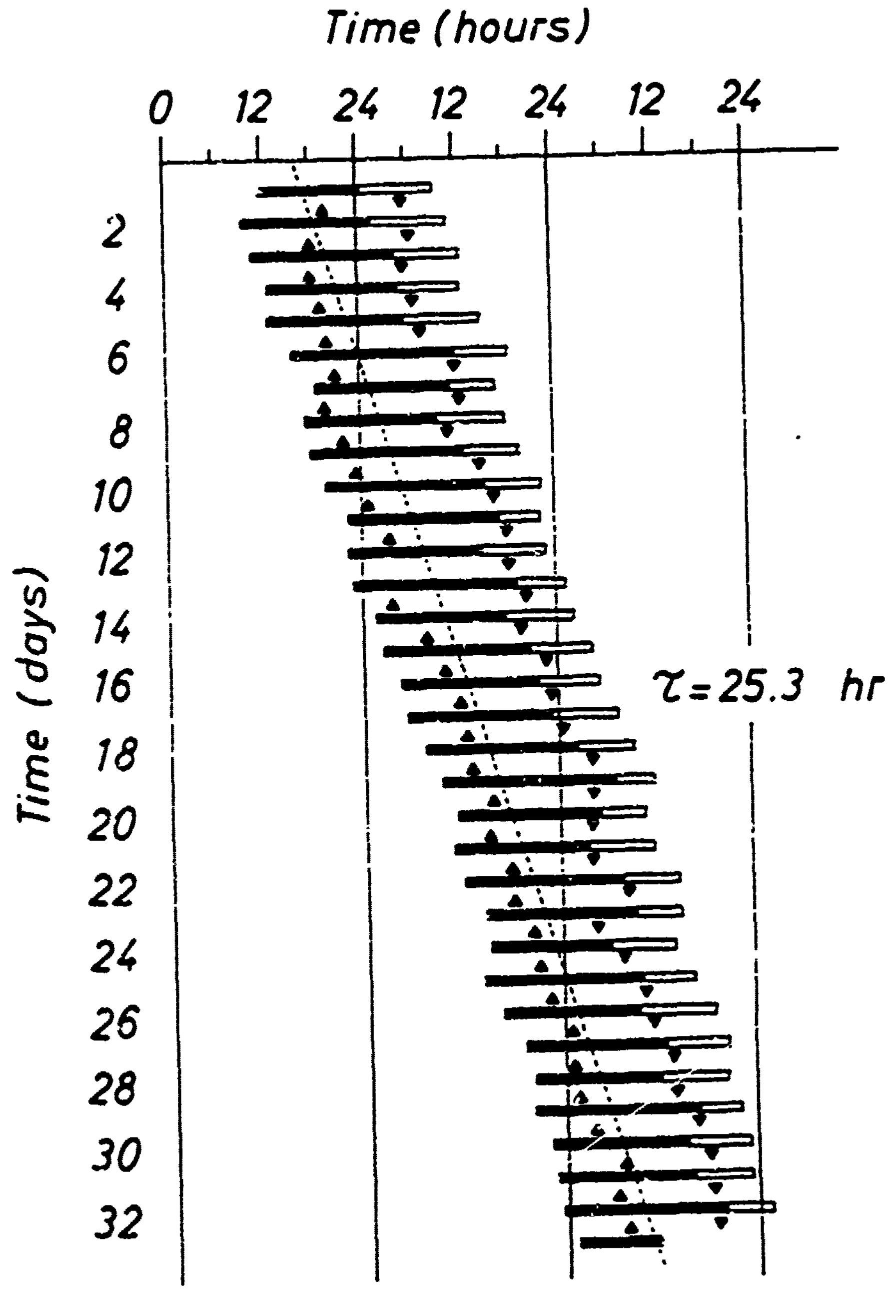

Figure 1. Autonomous rhythms of a subject (A.G., ♂ 26y) living under constant conditions without environmental time cues. The activity rhythm is represented by bars (black: activity; white: rest) and the rhythm of rectal temperature by triangles indicating the temporal positions of maximum (▲) and minimum (▼) values. Abscissa: local time; ordinate: sequence of the subjective days. From Wever (1971).

situation, where temperature decreases during most of a typical night's sleep. The results shown in Figure 1 are representative of more than 100 similar experiments with freerunning, internally synchronized rhythms (Wever, 1979a).

Freerunning, internally synchronized human circadian rhythms can be remarkably stable. This conclusion arises from the observation that the properties of these rhythms are more or less independent of the constraints that are unavoidable in preserving constant conditions in isolation. In this respect, the social deprivation of the subjects might be considered a special burden; in an experiment of the type exemplified in Figure 1, the isolated subject has no direct contacts with other humans for several weeks. To assess the possible influence of this kind of deprivation on the rhythm, groups of subjects have been isolated collectively. As an example, Figure 2 shows the results of an experiment in which two subjects lived together in an isolation unit in constant conditions without environmental time cues. Two conclusions can be drawn: (1) the continuous social contact between the subjects resulted in mutual synchronization of their rhythms, and (2) the joint rhythm had a period close to that of a singly isolated subject (cf. Figure 1). Many similar experiments are required to prove statistically that the periods of freerunning rhythms in collectively isolated groups are slightly but significantly longer than those of singly isolated subjects (Wever, 1975b).

Stimuli of various kinds seem to have little effect on human circadian rhythms. This applies not only to light, which is the most effective external stimulus in nearly all animal experiments, but also to physical workload (cf. Figure 3). The two parts of this figure are taken from two sections of a representative experiment in which a subject lived under constant conditions for a month, but refrained from physical activity as much as possible during the first two weeks and exercised frequently on a bicycle ergometer during the second two weeks. In contrast to the relatively smooth daily temperature curves seen during the first section, those in the second section are chatacterized by large increases in value associated with the ergometer sessions. However, despite these effects of workload, the rhythm parameters, as assessed from separate analyses of the two time series, are essentially identical in both sections. In particular, the period of the freerunning rhythm, and likewise the fraction of sleep within the sleep-wake cycle, are independent of the workload. Eight more experiments of this series, with alternating sections with and without workload, confirm the statistical significance of this result (Wever, 1979b).

The remarkable internal shift between the rhythms of activity and rectal temperature due to the slight lengthening of the period after elimination of the 24-hour zeitgeber (Aschoff, Gerecke, & Wever, 1967a) also has consequences with regard to the structure of sleep (Zulley, 1976; Czeisler, 1978). A section of a 29-day single-subject experiment performed under constant conditions is shown in Figure 4, which presents the polygraphic records of sleep behavior, together with the curves of rectal temperature, on several consecutive days. As can be seen, the minimum of body temperature always occurs immediately after sleep onset, which means that most of the subject's sleep occurs while his body temperature is increasing. The fractions of the different sleep stages are, on average, equal to those observed during normal sleep in a 24-hour day. However, the distribution of REM sleep differs: its latency is shorter, its first phase is always the longest rather than the shortest, and

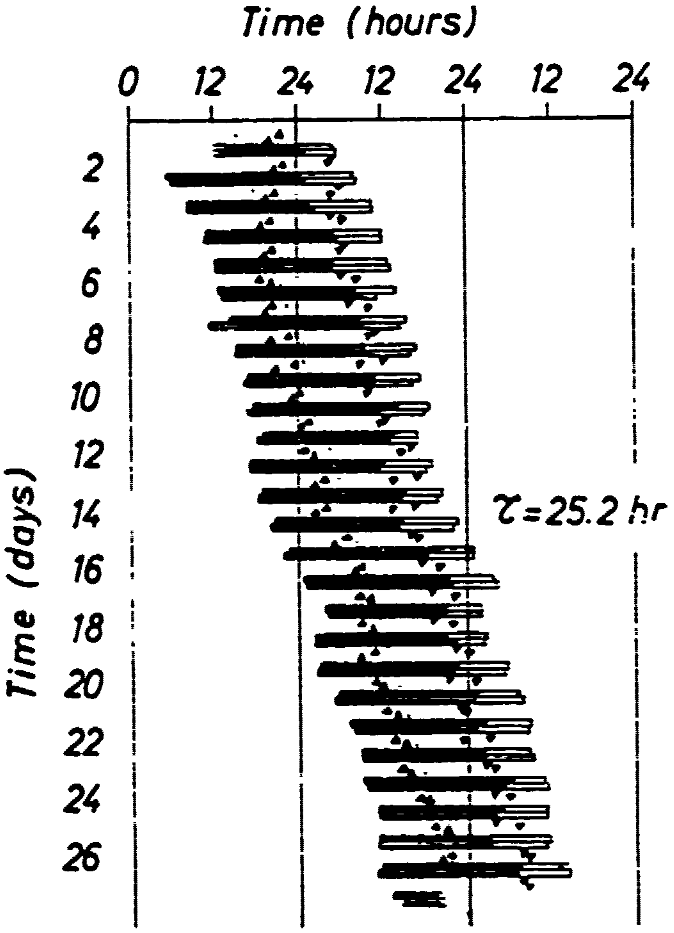

Figure 2. Autonomous rhythms of two subjects (W.S., ♂ 25y, & H.O. ♂ 25y) living together under constant conditions without environmental time cues. The rhythms of activity and rectal temperature are shown as in Figure 1, the records from two subjects being plotted one below the other. From Wever (1978).

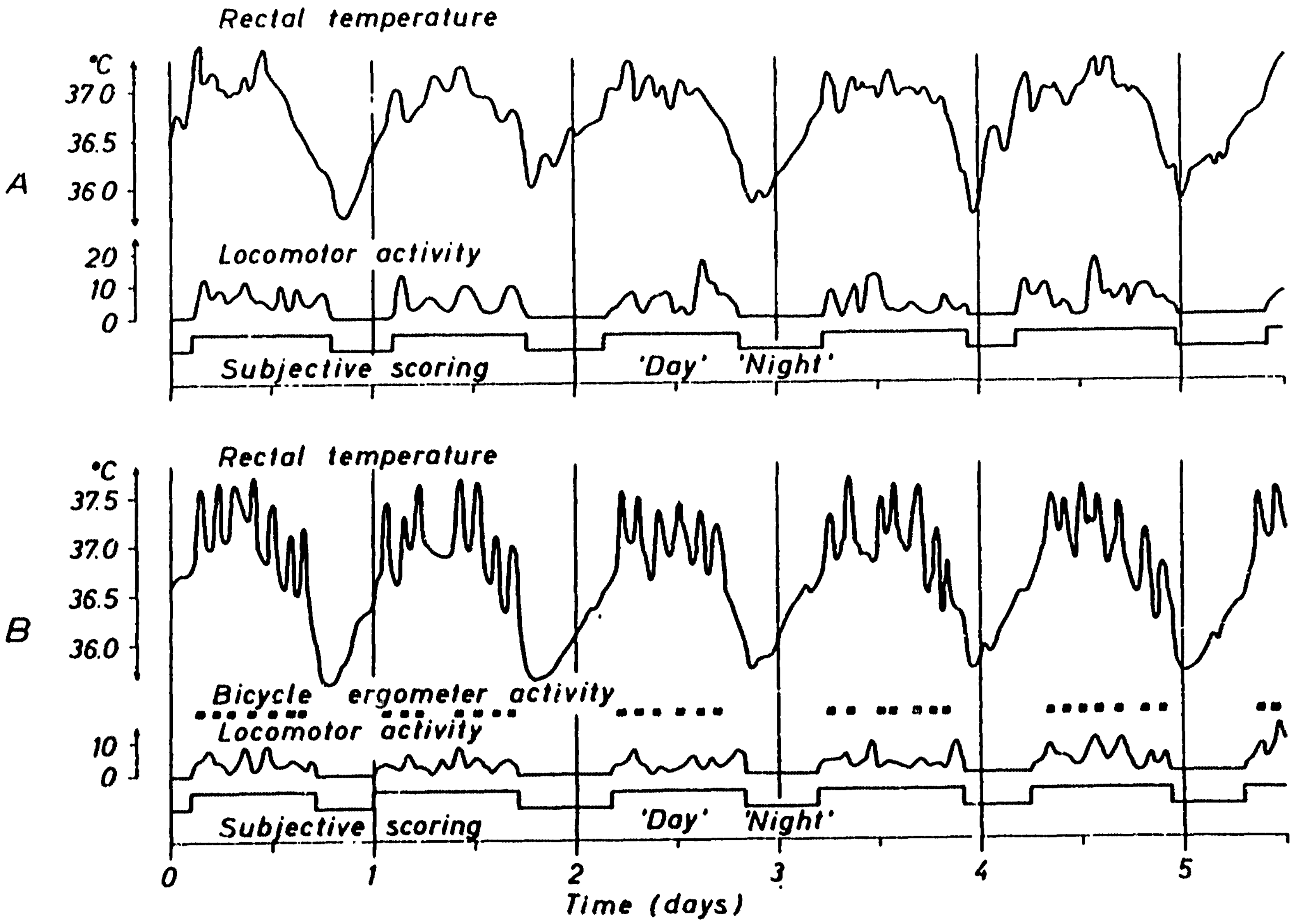

Figure 3. Autonomous rhythms of a subject (T.S., ♂ 25y) living under constant conditions without environmental time cues, and during the second section (B) with a heavy ergometer workload (100 W for about 20 min, 7 times per activity cycle). The records of rectal temperature (measured continuously), locomotor activity (measured from invisible contact plates under the floor), and subjectively scored alternation between 'day' and 'night' are shown, together with the times of the ergometer sessions. For clarity, only short periods (Days 5 to 9 and 19 to 23) of the two week sections are illustrated.

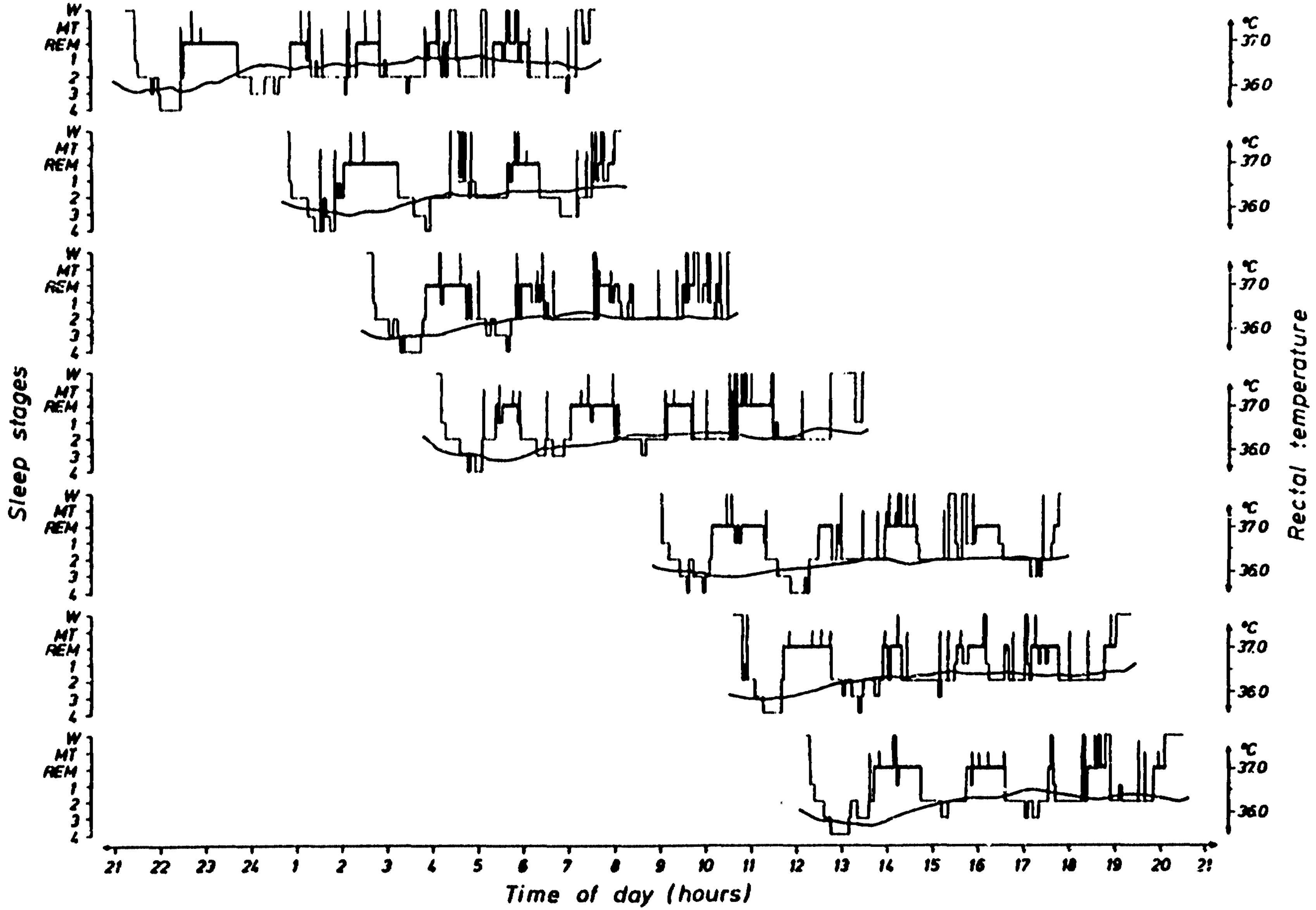

Figure 4. Parts of the autonomous rhythms of a subject (M.C., ♂ 25y) living under constant conditions without environmental time cues. Sleep stages (from polygraphic sleep recordings) and rectal temperature during successive sleeps are shown, as related to local time. For clarity, only days 10 to 16 of the 29-day experiment are illustrated. From Wever (1979c).

its propensity decreases over the sleep rather than increasing as normal (Zulley, 1979).

It can also be seen from Figure 4 that the relationship between the curve of temperature and sleep, and the pattern of sleep itself, are both very consistent, being quite independent of the objective time of day. This, of course, confirms the reliability of the experimental design, which was intended to eliminate any exogenous time reference.

From Figure 4, and from similar results obtained in other experiments, it can be concluded that sleep, when under only endogenous control, takes place at a phase of the temperature rhythm, and with a temporal structure, that both differ from what is observed when the additional influences of exogenous 24-hour signals are present (Wever, 1979c). However, it is not yet clear whether the two changes condition each other, or whether they are independent. Although human circadian rhythms have been shown to be remarkably persistent, they undergo slight cycle-to-cycle variations; in the present context, changes in the sleep/activity ratio, or in the sleep fraction, are relevant. As can be seen in Figure 1, both the duration of activity (activity-time) and of sleep (rest-time) vary slightly from day to day. One way of determining whether the values of th two alternating states are related is by computing serial correlations between them. This can be done by correlating each activity-time either with the preceding or with the following rest-time. Figure 5 shows both these correlations, computed from the data of the experiment shown in Figure 1 (Figure 5, top diagrams), and from two more typical experiments. In all three cases, the serial correlations between activity-time and following rest-time are negative, and statistically significant ($p < .001$). The same holds true for a sample of 38 experiments ($r = -.519 \pm .227$; $p < .001$; Wever, 1979a). On the other hand, the serial correlation between activity-time and preceding rest-time is inconsistent: in the top diagram, this correlation is positive ($p < .05$); in the middle diagram, there is no correlation at all; and in the bottom diagram, there is a negative correlation as strong as that between activity-time and following rest-time ($p < .001$). Again, the typicality of these findings is confirmed by the overall results found in the larger sample of 38 experiments. Although the mean of the correlations in the sample is effectively zero ($r = -.020 \pm .306$; Wever, 1979a), the actual distribution is, in fact, bimodal, with clear clusterings of positive and negative correlations.

The general effect of the serial correlations is to produce a stabilization of the total activity-rest cycle. An activity-time that is longer than average is typically followed by a rest-time that is shorter (and vice versa), and is preceded by a rest-time that, in some subjects, is likewise shorter than average, but, in others, longer; in only a few subjects are the durations of activity-time and preceding rest-time independent of each other.

There are other serial correlations between the day-to-day variations of the total activity-rest cycle. As Figure 6 (left) demonstrates for the data from the experiment shown in Figure 1, there is a significant ($p < .05$) negative serial correlation between the duration of successive activity-rest cycles. This means that an activity-rest cycle that is longer than the average of all the cycles in this experiment is typically followed by a cycle that is shorter, and vice versa. Here, the cycle is defined from the midpoint of one rest-time to the midpoint of the next; however, almost identical correlations are ob-

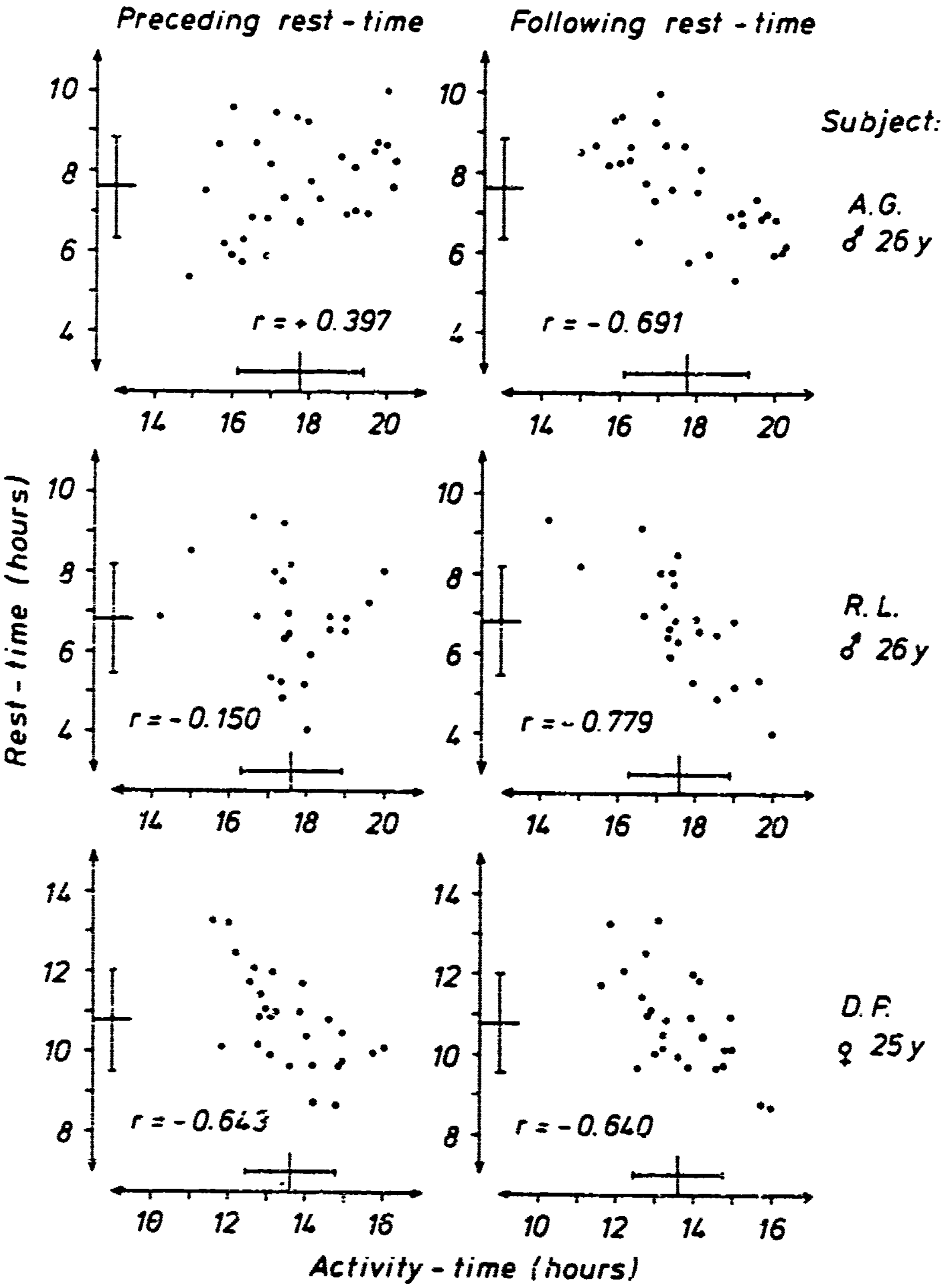

Figure 5. Serial correlations between activity-times and rest-times, computed from 3 experiments performed under constant conditions without environmental time cues. The lines indicate means and standard deviations.

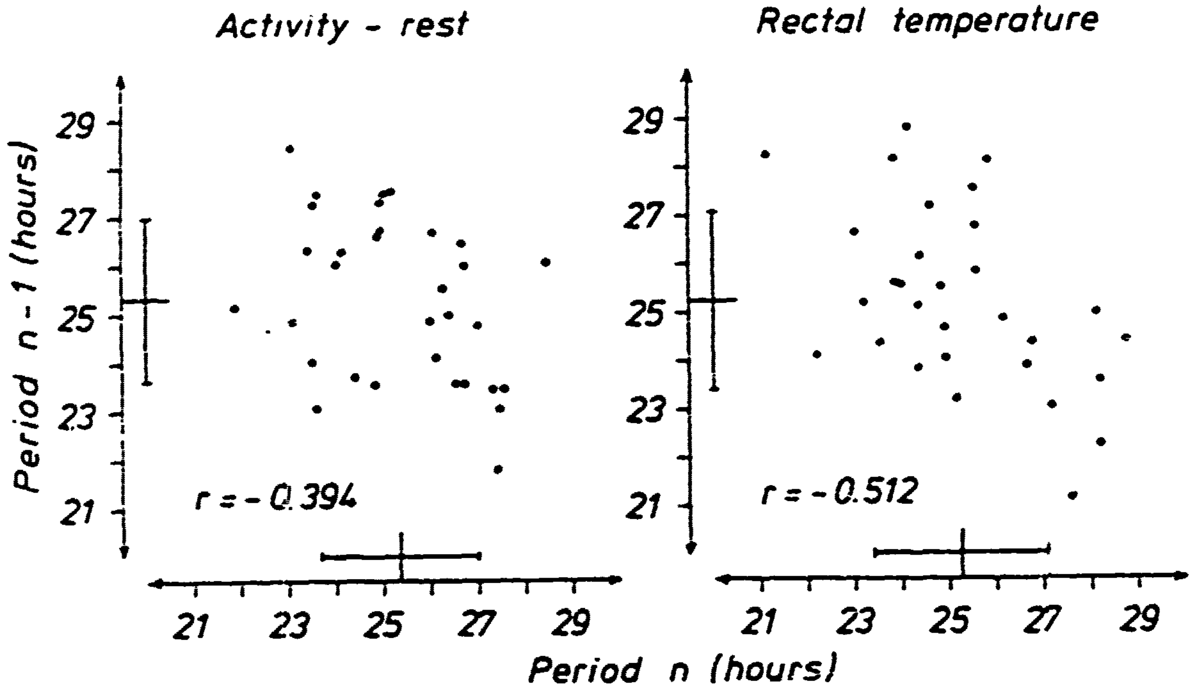

Figure 6. Serial correlation between successive cycles of activity-rest (measured from one midpoint of rest-time to the next) and of rectal temperature (from one minimum to the next), computed from the experiment shown in Figure 1. The lines indicate means and standard deviations.

tained if the cycle is defined in other ways, e.g., from one activity onset to the next. Moreover, there are higher order serial correlations: that between the duration of one cycle and the next but one is also significantly negative, indicating that the deviation of any cycle from the overall average is corrected by an opposite deviation, not only of the immediately following cycle but, also, of the next but one cycle. Again, this latter finding is confirmed by the overall results from the sample of 38 experiments with freerunning, internally synchronized rhythms ($r = -.401 \pm .166$; $p < .001$; Wever, 1979a); because of the obvious consistency in these results, the demonstration of one single example here would appear to be sufficient. Another illustration of the serial correlations within the activity-rest cycles is provided by the observation that the variability of activity onsets around a computed regression function is generally smaller than that of sleep onsets (this is in noteworthy contrast to the subjective feelings of the subjects).

The duration of the cycles of rhythms other than that of activity-rest are also serially correlated. The right-hand diagram of Figure 6 shows the correlation between sucessive period lengths of the temperature rhythm (meaured between minima), calculated from data obtained in the same experiment as were the activity-rest cycles shown in the left-hand diagram (cf. Figure 1). As can be seen, the negative serial correlation within the rectal temperature rhythm is even stronger than that within the activity rhythm. Again, this result is confirmed in the results from the sample of 38 experiments($r = -.461 \pm .118$; $p < .001$; Wever, 1979a). The concurrence of the serial correlations in the two different rhythms is the more remarkable since they are not directly dependent on each other. When, in the data of Figure 6, the activity-rest cycles are correlated with their accompanying temperature rhythm periods, the coefficient does not differ significantly from zero ($r = .353$); the same is true for the mean correlation in the larger sample of 38 experiments. This result means that the different overt rhythms are stabilized independently of each other.

So far, we have discussed spontaneous short-term variations of rhythm parameters; these variations could be considered as 'biological noise'. In addition, however, long-term changes induced by alterations in experimental conditions can occur. The period of a freerunning rhythm is lengthened in subjects in an isolotion unit who are permitted to select their own light-dark cycles (Wever, 1969a), or cycles in ambient temperature (Wever, 1974); or who are in a "self-control" mode because of special conditions, e.g., when they have social contacts within a group (Wever, 1979a). On the other hand, up to the present time, only one physical stimulus is known which affects subjects equally during both activity and sleep, and which modifies human freerunning rhythms in a regular and reproducible manner, and that is a weak electric AC-field (frequency 10 Hz; Wever, 1967, 1969b). When present continuously, this completely imperceptible stimulus shortens the period and, in addition, reduces the sleep fraction and the variabilities of activity and sleep onsets around their computed regressions. Within the rhythm of rectal temperature, it raises the mean value and increases the amplitude; all these effects are statistically significant (Wever, 1971).

Of the various rhythm parameters, the range of the temperature rhythm is most strongly correlated with the fraction of sleep, intra- as well as interindividually. In Figure 7, pairs of these two parameters are plotted from 12

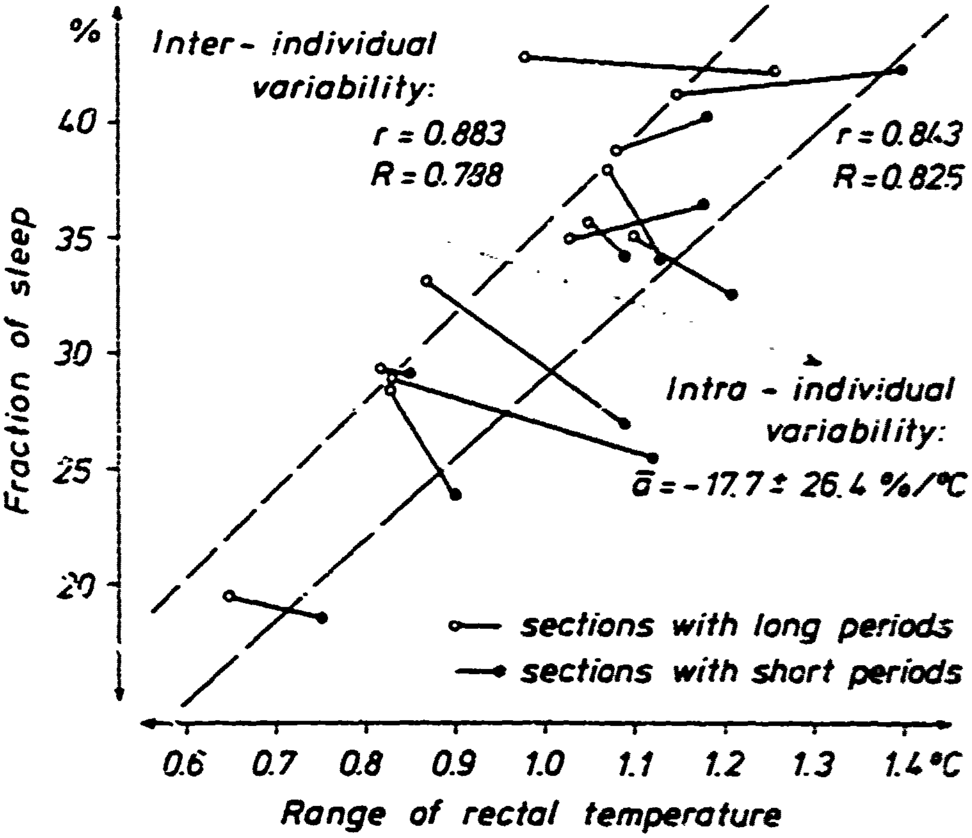

Figure 7. Correlations between range of rectal temperature and fraction of sleep, measured in 12 experiments performed under constant conditions without environmental time cues. In one section of the experiments, the subjects were exposed to a weak electric AC field (10 Hz) which shortened the period. Values from the two sections of each experiment are joined by lines; the mean and standard deviation of the individual regressions constituted by these lines are shown, as are also the inter-individual coefficients of correlation (parametric correlation r, and rank-order correlation R) computed separately for the values obtained in the two different sections of the experiments.

subjects whose freerunning periods were shortened, during one section of an experiment, by exposure to 10-Hz field. For each subject the plotted points from the sections with and without the field, i.e., with short and long periods, respectively, are joined by lines. As can be seen, the fraction of sleep decreases in most subjects when the temperature range increases. Inter-individually, however, the two parameters are correlated positively: the larger the range of the deep body temperature rhythm, the greater is the fraction of sleep. This is true for both experimental conditions. As mentioned earlier, nearly all rhythm parameters are mutually correlated intra-individually with changing conditions; however, in this experiment, there are no other significant inter-individual correlations between any parameters (for instance, the correlation between fraction of sleep and period is r = .110 in the sections with the short periods and r = .258 in the sections with the long periods). The same results are seen when a larger sample of experiments is considered (n = 21; not including the 12 experiments in Figure 7): again, there is a significant correlation, between fraction of sleep and range of rectal temperature (r = .721; p <.001), but there is no other significant correlation, for instance between period and amplitude (r = -.171) or period and or period and fraction of sleep (r = -.425).

It is apparent from Figure 7 that the correlations between fractions of sleep and amplitude of the temperature rhythm have opposite signs when computed from intra- and inter-individual variations. This apparently contradictory result is, however, in agreement with predictions derived from a simple model of selfsustained oscillations, which also predicts the observed interdependencies between changes in many different rhythm parameters (Wever, 1964, 1965, 1966); here, the 'Threshold-level hypothesis' is relevent. According to this hypothesis, the discontinuous alternation between activity and sleep can be attributed to a continuous oscillation (Wever, 1960). As long as this basic oscillation exceeds a threshold, the subject is active, whereas below this threshold, he is asleep; since in humans, activity-time is always longer than sleep-time, the mean level of the basic oscillation must be higher than the threshold. The diagrams in Figure 8 illustrate these relationships. For intra-individual variations (Figure 8, right), the model postulates an increase in the mean level when the amplitude increases; consequently, the 'sleep fraction' becomes shorter. For inter-individual variations (Figure 8, left), there is no need to assume interconnections between amplitude and mean level; consequently, the 'sleep fraction' becomes longer when the amplitude increases. It has to be emphasized that it is not only the observed results from long-term variations that are in agreement with these theoretical postulates, but also those from the short-term variations that were discussed earlier; i.e., the model also predicts serial correlations of the same type as observed experimentally (cf. Figures 5 & 6).

Freerunning, Internally Desynchronized Rhythms

In our total sample of 155 experiments under constant conditions, 53 of the subjects showed internal desynchronization. In all these cases, the overt rhythms of activity and rectal temperature differed in period (Aschoff, Gerecke, & Wever, 1967b); the periods of the rhythms of rectal temperature remained close to 25 hours, whereas activity-sleep cycles with durations between 12 and 65 hours were observed. Remarkably enough, in none of these cases was the subject aware of his unusual behavior.

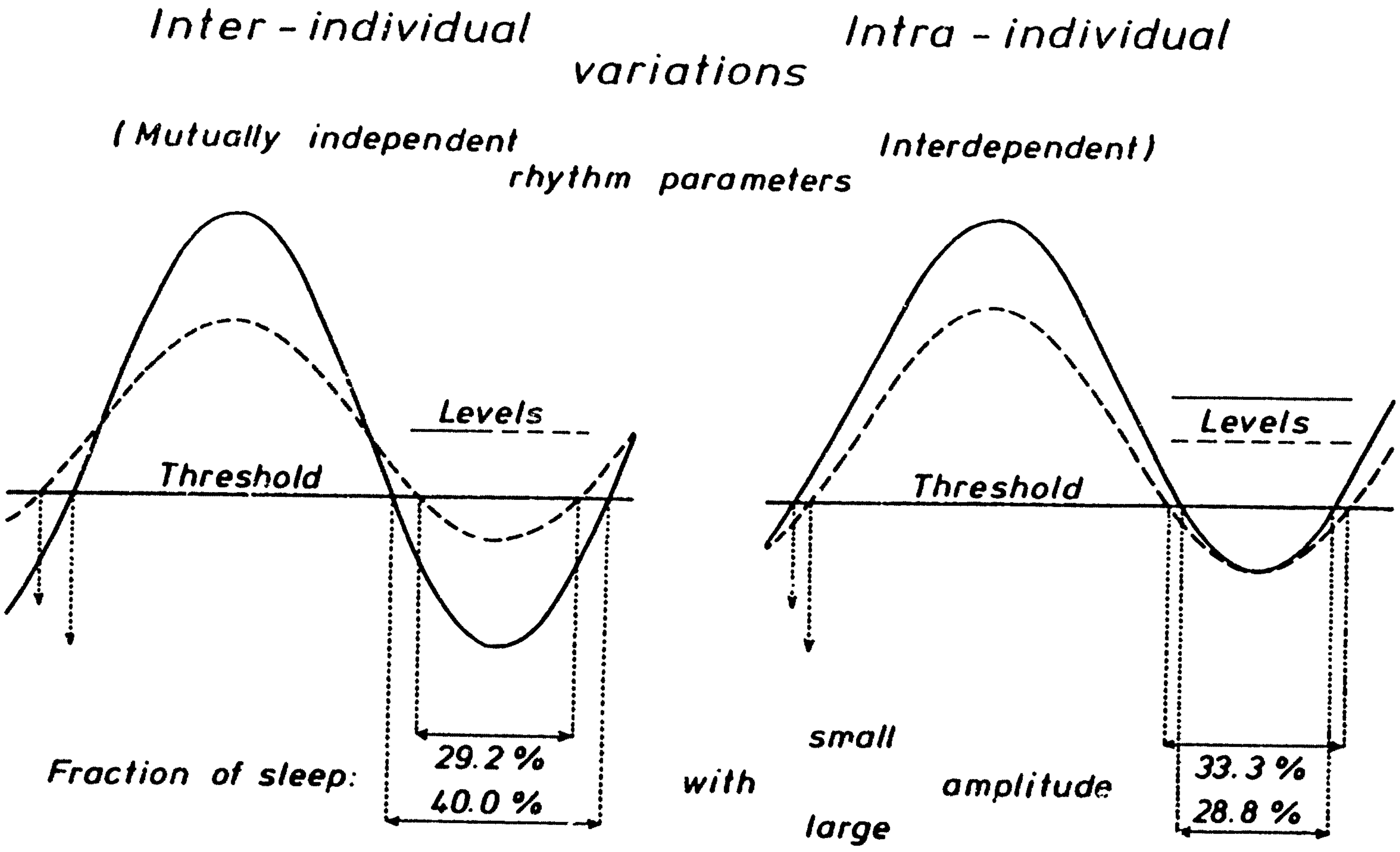

Figure 8. Schematic representations of the relationships between range of oscillation and sleep fraction according to the 'threshold level hypothesis': The oscillation defines 'activity' as long as it is above the threshold, and 'sleep' as long as it is below it. Level and amplitude of the oscillation are correlated intra-individually, but not inter-individually.

In the typical example shown in Figure 9, the activity-sleep cycle has an abnormally long period right from the beginning of the experiment. In other experiments, this lengthening occurred later on; in some cases, the period of the activity rhythm was not lengthened, but in fact drastically shortened. It is characteristic of all these cases of internal desynchronization that the internal phase relationship between different overt rhythms varies from day to day; this means, for instance, that on some days, the subjects sleep when deep body temperature is increasing (as they do with freerunning, internally synchronized rhythms) but on other days when temperature is decreasing (as in the normal 24-hour day). In the particular experiment illustrated in Figure 9, the courses of both rhythms show typical scalloping patterns (left-hand diagram), with repetition periods of about 6 days. The periodogram analyses of the two time series (right-hand diagram) show two peaks in each case. The rectal temperature rhythm has a significant primary period of 25.0 hr, which is obvious in the overt rhythm's course; additionally, there is a secondary, also significant period of 30.2 hr, corresponding to one in the overt activity rhythm. In fact, in the latter, the 30.2 hr period is the primary one, but there is another significant period at 32.5 hr, and a suggestion of one at 25.0 hr,corresponding to the primary period of the overt rectal temperature rhythm (the further peak at 16.25 hr is only due to the fact that this is the first harmonic of 32.5 hr).

The analyses of many other overt rhythms measured in this experiment (e.g., electrolytes in the urine) result in similar peaks. It should be noted that the components of the different rhythms, when the latter are considered separately, keep internal phase relationships which are temporally constant and identical, in contrast to the internal phase relationships between the different overt rhythms themselves, which vary from day to day.

Another example of internally desynchronized rhythms is given in Figure 10, based on data from a subject who had to perform ergometer work during half the duration of the experiment. Each of the two parts presented includes 5 cycles of rectal temperature but only 4 cycles of activity-sleep; the workload had no effect on the period of either rhythm. A few of the activity-times are interrupted by 'naps' which are normally not permissible but could not be avoided by the subject in this experiment. The temporal relationship between the two rhythms changes over time, so that a main sleep occasionally coincides with a temperature maximum; but the naps always coincide with temperature minima. During the section without workload (B), a direct reactive interaction ('masking') between the two variables can be observed: when the subject falls asleep while deep body temperature is high, rather than being at a minimum, the temperature always drops; the magnitude of this 'masking effect', which is nearly independent of the true phase of the rhythm, is roughly a third of the total circadian range. During the section with workload (A), the interactions between the circadian temperature rhythm and the frequent temperature rises due to ergometer sessions are of particular interest. The result is a simple superimposition: the reactive temperature rises can occur even around the temperature minimum without influencing the rhythmicity itself.

From results like those shown in Figures 9 and 10, together with computer simulations, a consistent multi-oscillator model of the human circadian system has been established (Wever, 1975a). It assumes, in essence, two basic oscillators which normally run in synchrony with each other but which can, in spe-

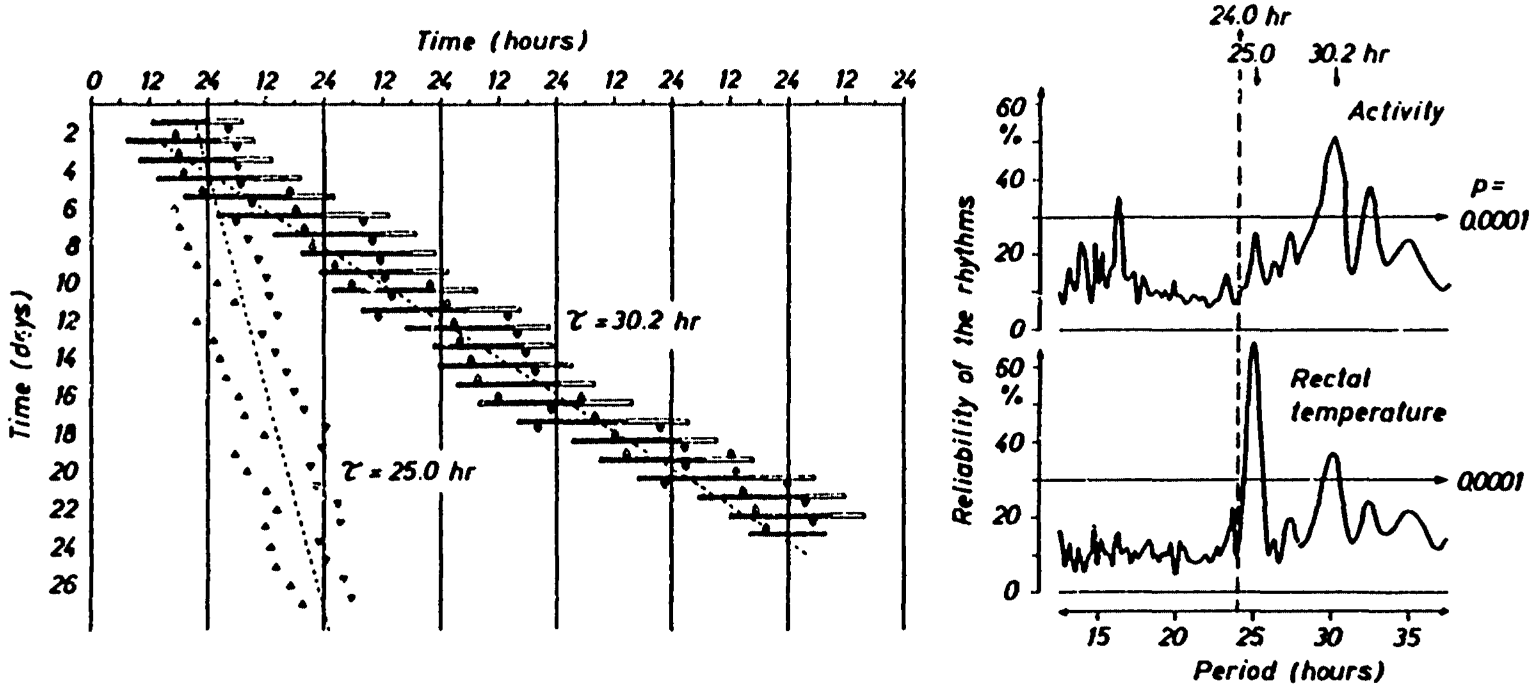

Figure 9. Autonomous rhythms of a subject (A.F., ♂ 24y) living under constant conditions without environmental time cues. Left: rhythms of activity and rectal temperature, graphed as for Figure 1 (the white triangles are the temporally correct placings of the corresponding black triangles). Right: periodograms of the two time series (for details of the analyses, see Wever, 1979a).

cial conditions, have different periods in the steady state. Each of these oscillators contributes to the control of all overt rhythms; or, in other words, every overt rhythm is controlled simultaneously by both basic oscillators, though in proportions varying from rhythm to rhythm. The two basic oscillators are matched in all relevant properties except strength, or degree of persistence: the oscillator that predominantly controls the overt rectal temperature rhythm is about 12 times stronger than the one that predominantly controls the overt activity rhythm. Normally, i.e., in the case of internal synchronization, the overt rhythms behave outwardly as though they are controlled by only one oscillator. In the case of internal desynchronization, every overt rhythm is composed of two or more components with different periods superimposed on each other. As a result, beat phenomena occur, which appear outwardly as a scalloping pattern (cf. Figure 9, left) and as a periodic change in amplitude (cf. Figure 10); the repetition period of the beats is determined by the two contributing rhythm periods. Another consequence of the contribution of two components to every overt rhythm is that the negative serial correlations, which in other time series indicate that the data have an oscillatory origin, are obscured. Actually, these correlations would, in fact, be expected to be present in each of the contributing rhythm components separately and independently; but it is exactly for this reason that they cannot be seen in the composite of these components. Indeed, in the overt rhythms, small positive serial correlations can be expected to show up due to the beats, and, for the same reason, only higher order negative serial correlations.

In the discussions of Figures 9 and 10, it was mentioned that subjects, in a state of internal desynchronization, sometimes sleep with an increasing and sometimes with a decreasing deep body temperature. These variations can be used to test the hypothesis of a direct connection between trends in deep body temperature and sleep structure. Sleep-times with predominantly increasing and with predominantly decreasing temperatures were identified in the data from the experiment shown in Figure 9 and analysed separately. In the upper diagram of Figure 11, the mean duration of REM sleep as a percent of total sleep is shown for the two types of sleep-time, in each third of the sleep (to standardize the evaluation, each sleep-time was divided into three equidistant intervals, independent of its absolute duration). It can be seen that, in those sleep-times where body temperature increases (as it usually does with freerunning, internally synchronized rhythms), REM sleep propensity decreases during the sleep, again in agreement with what is observed with internally synchronized rhythms (cf. Figure 4). In sleep-times where body temperature decreases REM sleep propensity increases, a pattern resembling that seen when rhythms are synchronized to 24 hours. The difference in slope between the two curves shown in the upper part of Figure 11 is statistically significant; as is also the difference in mean absolute duration of the first REM phase in the two types of sleep-time (cf. Zulley, 1979). These differential relationships support the hypothesis of a dependency of the structure of sleep on the rhythm of deep body terperature.

The lower diagram of Figure 11 shows the actual values of rectal temperature recorded during the two types of sleep. It is clear that sleep-times coinciding with decreasing deep body temperature are longer than sleep-times coinciding with increasing deep body terperature. Bearing in mind the correlation between variations in REM sleep propensity and rectal temperature, it fol-

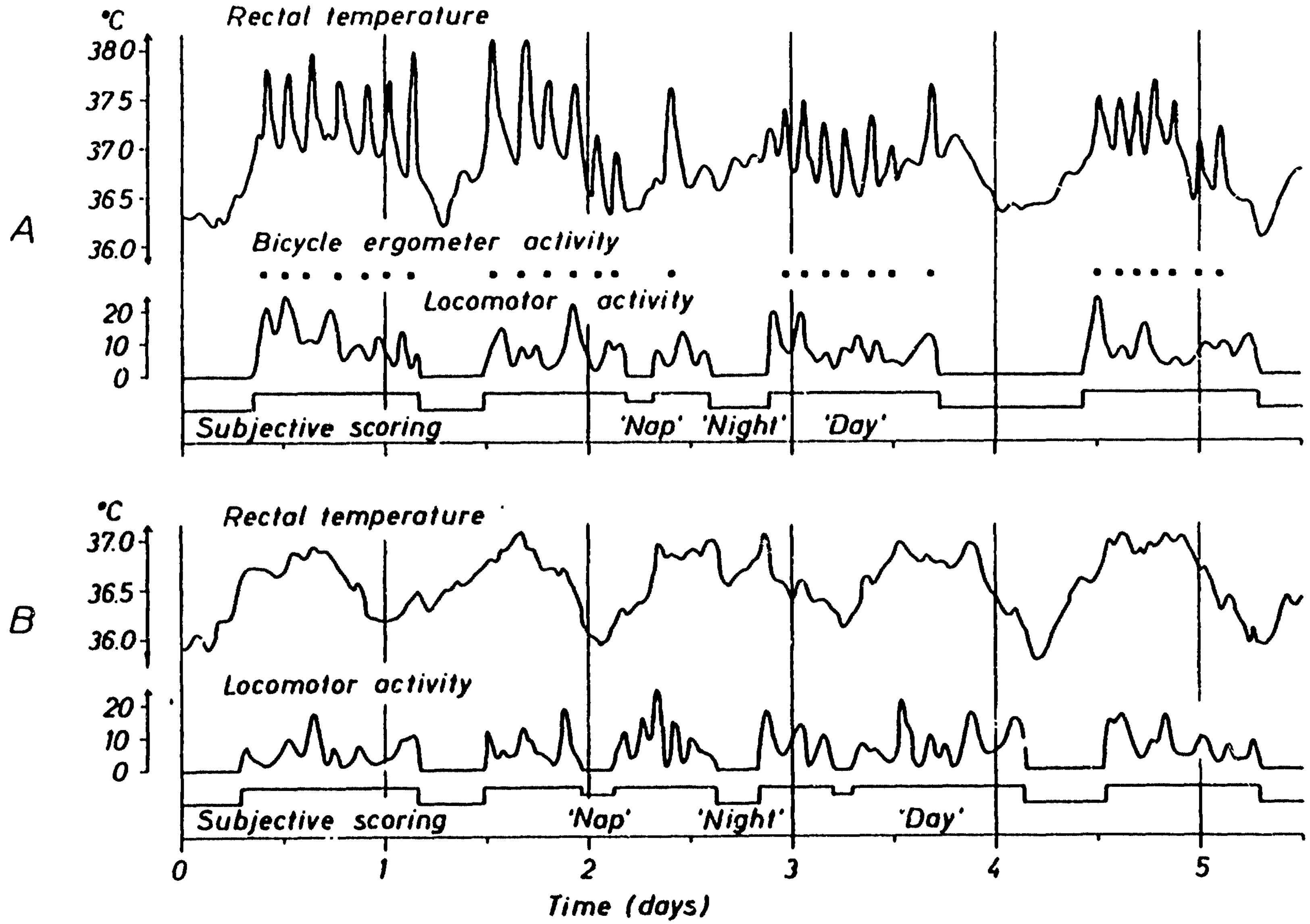

Figure 10. Autonomous rhythms of a subject (P.C., ♂ 24y) living under constant conditions without environmental time cues, and during the first section (A) with a heavy ergometer workload (100 W for about 20 min, 7 times per activity cycle). Rectal temperature, locomotor activity, subjective scorings of 'day' and 'night', and interposed 'naps' are shown in the same manner as in Figure 3. For clarity, only short parts (days 3 to 7 and 22 to 26) of the two-week sections of the experiment are illustrated. From Wever (1979b).

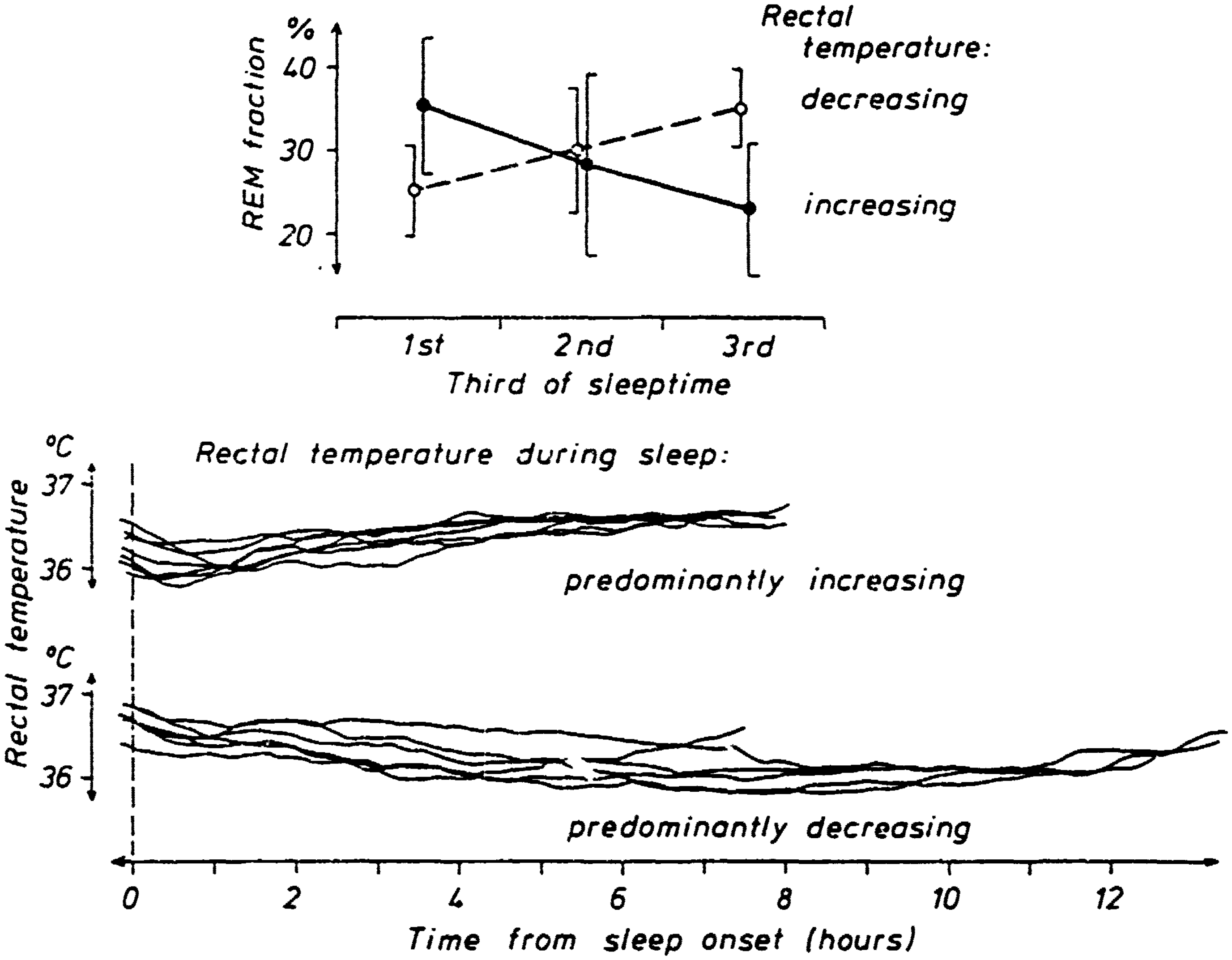

Figure 11. Parameters of sleep, as determined by polygraphic recordings from the subject in the experiment shown in Figure 9. Above: mean fractions of sleep time spent in Stage REM, computed for each third of the sleep-time, and averaged separately for sleeps with (a) predominantly increasing and (b) predominantly decreasing rectal temperature. Brackets indicate SDs. Below: records of rectal temperature during sleeps of type (a) and (b). Data from Zulley (1979).

lows that a correlation exists between structure and duration of sleep: if there is a high fraction of REM at the beginning of sleep and a decrease in REM sleep propensity later on, the sleep will tend to be short; if there is a low REM fraction at the beginning and subsequent increase in REM sleep propensity, the sleep will tend to be long.

The state of internal desynchronization as discussed so far in this paper is mainly characterized by continuously changing internal phase relationships between the overt rhythms of activity and deep body temperature. There is another rhythm state where, although these two rhythms again show different period values, they have a temporally constant internal phase relationship. This happens when one period is an integral fraction of the other. The most frequent type of this state of 'apparent internal desynchronization' is one where there is a 'circa-bi-dian' activity rhythm that is internally synchronized to the rhythm of deep body temperature with a ratio of 2:1, i.e., a state in which two cycles of rectal temperature (period about 25 hr) are coordinated with one alternation between activity and sleep (period about 50 hr). In such a state, the phase relationship between the two rhythms is bivalent but temporally constant. As an example, Figure 12 presents a section of a 29-day experiment performed under constant conditions, showing the polygraphic records of the sleep behavior of the subject, together with the course of his rectal temperature. The presentation corresponds to that shown in Figure 4, apart from the fact that all parts of the cycle are about twice as long, the mean values being: period 49.2 hr, sleep-time 14.3 hr, and activity-time 34.9 hr. The sleep profiles thus appear, as a function of local time, only every other day. It is obvious from Figure 12 that there is a consistent relationship between the trend in deep body temperature, which has a minimum at about the middle of sleep-time, and sleep structure; note that there are 10 REM-phases per sleep-time instead of the typical 5 or thereabouts. The subject did not consciously perceive the long duration of his activity period; possibly due to this unawareness, his behavior was quite normal, although wakefulness of such a long duration would be ordinarily expected to produce symptoms of sleep deprivation.

Internal desynchronization, whether it occurs by a lengthening or by a shortening of the activity-sleep cycle, affects both wakefulness and sleep equivalently. Close examination shows, however, that, during internal desynchronization, the fraction of sleep is smaller than when rhythms are internally synchronized. This conclusion is based on experiments from which the freerunning rhythms remained internally synchronized during one section but became internally desynchronized during another section. In 17 experiments where the activity-sleep cycle lengthened spontaneously during the experiments (from a mean of 25.55 to 34.04 hr), the mean sleep fraction decreased by 3.78% (SD 5.08%), i.e., from a mean of 32.21% to 28.43% (in only two of the experiments did the sleep fraction increase); this mean decrease in the sleep fraction was significant ($p < .01$). This result implies that the lengthening of the activity-sleep cycle during the transition to internal desynchronization concerns the activity fraction more than the sleep fraction. However, it could be argued that undetected naps during the very long lasting apparent wakefulness could give rise to the reduction in the observed sleep-time fraction. Apart from the fact that naps are normally detected, and thus included in the calculations (cf. Figure 10), this argument is refuted by the data of 11 other experiments in which the activity-sleep cycle was shortened from a

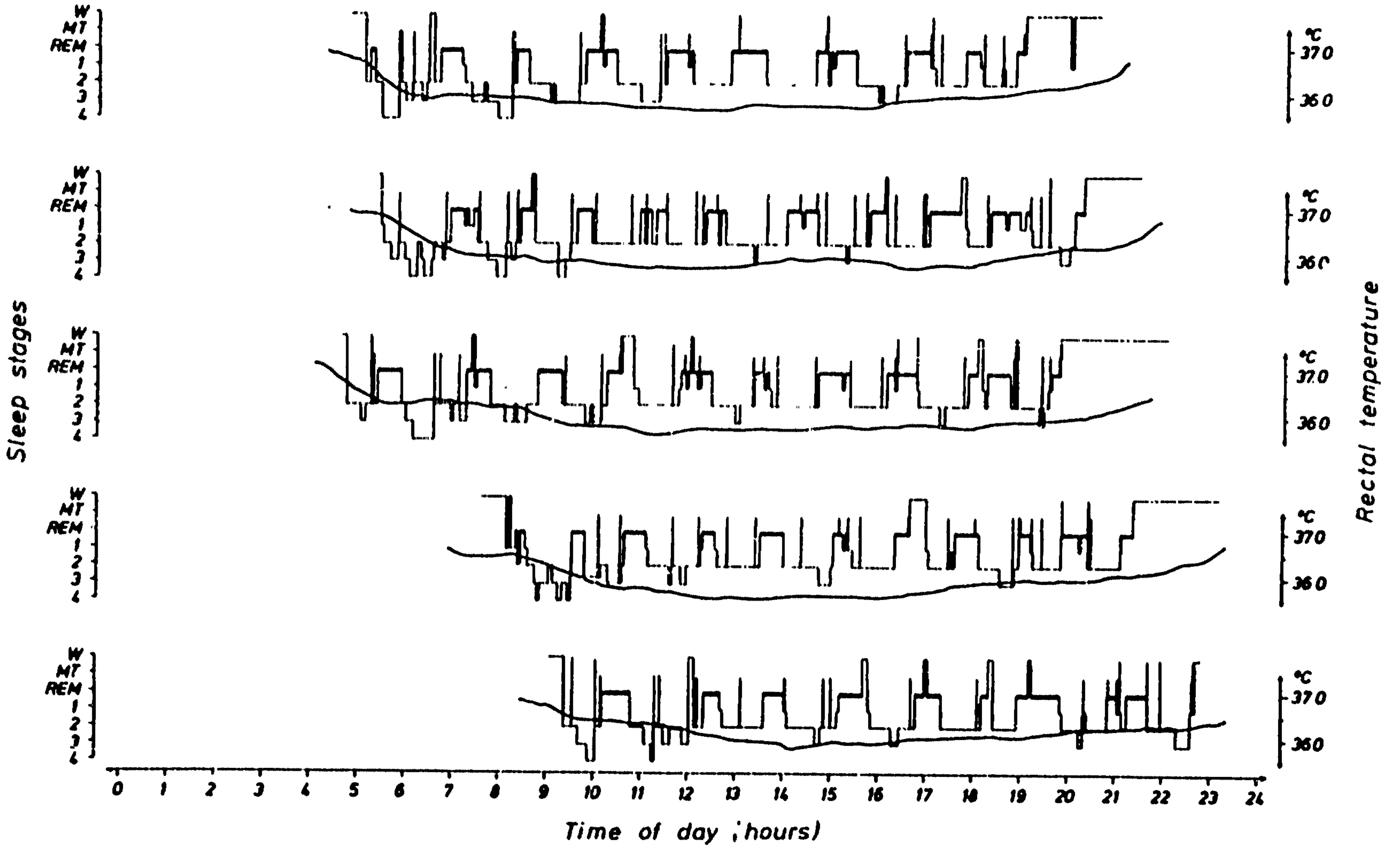

Figure 12. Parts of the autonomous rhythms of a subject (M.K., ♂ 28y) living under constant conditions without environmental time cues. Sleep stages (from polygraphic sleep recordings) and rectal temperature during successive sleeps are shown as related to local time. For clarity, only days 4 to 13 of the 29-day experiment are illustrated. Note: due to the extremely long duration of the sleep-activity cycle, sleep occurs only every second day.

mean of 24.47 to 17.91 hr. Here the fraction of sleep decreased in all experiments; the mean reduction was 4.03% (SD 2.37%), i.e., from 36.27% to 32.24%, and was statistically significant ($p < .001$). Although in this case the sleep-time is affected by the change more than the activity-time, the shortened activity-time affords less time for naps than the "cycle-lengthening" state of internal synchronization.

The general conclusion from the above set of findings is that rhythm disorders reduce the fraction of sleep within the total sleep-wake cycle. It must be emphasized again that, in the experimental conditions pertaining in the studies, the subjects have complete control over when they sleep; though they have no idea about the duration of their sleeps, nor the value of the sleep fraction in any cycle. When, at the beginning of an experiment, a subject thinks he can remember his previous sleep habits, he usually has a tendency to overestimate the duration of his sleep-times in the isolation chamber: most subjects judge their first sleep-time to be longer than normal, whereas, in reality, it is usually shorter. On the other hand, there is a tendency to underestimate the duration of naps, and this is the reason why naps are normally inadmissable. Thus, in some of the experiments where internal desynchronization occurs by a lengthening of the activity period, the sleep-time subjectively scored to be the 'night-sleep' is not lengthened, but is supplemented by a 'nap; such a 'nap' which mostly is subjectively scored as lasting 15 to 30 minutes, actually lasts for up to 15 hours.

From all the foregoing considerations, it must be concluded that the sleep fraction under constant conditions really reflects the need for sleep, and need is obviously reduced under internal desynchronization. So, in other words, the need for sleep is less than normal when the circadian system is in a disintegrated state.

Externally Synchronized Rhythms

In the laboratory, circadian rhythms can be synchronized by means of artificial zeitgebers. The application of periodic stimuli with different modalities and varying properites (e.g., period) is one of the tools to test the effectiveness of zeitgebers. Figure 13 (left) shows the course of an experiment where a subject was exposed to an artificial light-dark cycle (but with reading lamps available) which was changed at intervals,and which was complemented by regular gong signals calling the subject to give a urine sample and to perform certain tests (Wever, 1970). The right diagram of Figure 13 shows the mean rhythms averaged from all but the first two cycles in each of the three sections. From the left-hand diagram, it can be seen that the subject's rhythm is synchronized to all three zeitgeber periods used. [It has been shown in further experiments of the same type that synchronization is only possible within about the limits used here, and the zeitgebers with periods longer than 27 hours or shorter than 23 hours have not the capacity to synchronize human circadian rhythms (see Aschoff, Poeppel, & Wever, 1969).] However, the right-hand diagram shows that some changes occur when the zeitgeber period is shortened: (1) The activity fraction becomes shorter and the sleep fraction longer; i.e., the subject changes from a "short" to a "long" sleeper. (2) The rhythm's phases shift to later points in the cycle, to a greater extent in rectal temperature than in activity; this means that the subject changes from a "morning type" to an "evening type" (Wever, 1969b). [Note that

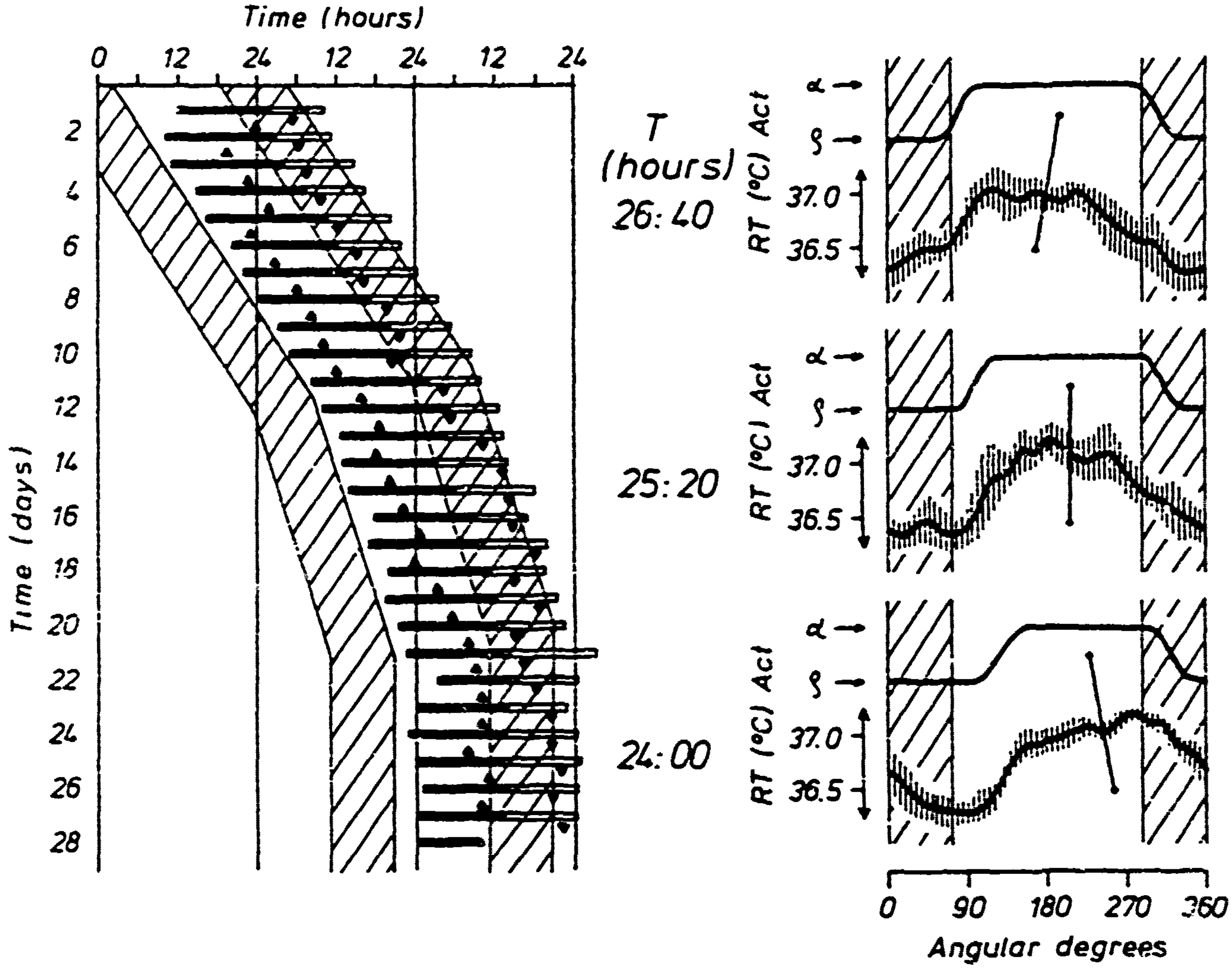

Figure 13. Circadian rhythms of a subject (M.O., ♂ 24y) living without environmental time cues but under the influence of an artificial zeitgeber (light-dark cycle with reading lamps available during the dark-time, and gong-signals at regular intervals calling the subject for urine samples and certain tests), with two alterations of the zeitgeber period. Left: rhythms of activity and rectal temperature, graphed as in Figure 1; hatched areas: dark-time of the zeitgeber. Right: longitudinal representations of the rhythms, averaged separately from the three sections with different zeitgeber periods (omitting the first two cycles of each section). Hatched areas: dark-time of the zeitgeber. Arrowed lines indicate standard deviations computed from the successive cycles within each section; the other lines join the acrophases of the two rhythms.

the subject, although he was aware of his changed behavior, did not realize the reason for it, i.e., the alteration in the duration of his day.] Since the two rhythms are phase shifted by different amounts, the internal phase relationship between the two rhythms changes with the zeitgeber period. This means that the subject sleeps predominantly during a period of increasing deep body temperature when the zeitgeber period is long (first section) but with one of decreasing temperature when it is short (third section); it is known that this can be expected to influence the duration of sleep-time (cf. Figure 11). During the second section, the minimum of deep body temperature would be expected to occur near the midpoint of the sleep-time; however, the average cycle actually shows a split minimum, indicating that this intermediate position of the minimum is not so stable as are positions near the beginning and near the end of sleep-time. This impression is confirmed by inspection of the original data (Figure 13, left), where it can be seen that, during the middle section, the position of the minimum varies between locations near the beginning and near the end of sleep.

The same type of artificial zeitgeber can be used to simulate time-zone shifts accompanying transmeridian flights. In a typical experiment (Figure 14), a subject was exposed to an artificial 24-hour day; on the 8th day, an eastward flight across 6 time-zones was simulated and on the 15th day a 6 time-zone westward flight. The subject did not consciously perceive any change in the experimental conditions; on the contrary, he was convinced that during the whole experiment, he had lived in temporal agreement with the outside environment. When, at the end of the experiment, he observed that he was, in fact, living in accordance with local time, he was reconfirmed in his conviction that nothing special had happened, and was very surprised to learn that, during a substantial part of the experiment, he had been out of phase with local time by 6 hours. As can be seen in the left-hand diagram of Figure 14, the subject's activity rhythm adjusts to the changes in the zeitgeber in about two days, and the rhythm of deep body temperature in a few more days, but more slowly after the delay shift than after the advance shift. The right-hand diagram shows the mean rhythms in each of the three sections (the first two days of each section were again excluded in calculating these averages). The diagrams confirm the general adjustment of the rhythms to the shifted zeitgeber in the second and third sections; even the characteristic individual shape of the rectal temperature rhythm is maintained. Only the phasing of the temperature rhythm suggests that re-entrainment is not totally complete; but this is due to the inclusion in the averaged curves of days where the re-entrainment process is still in progress. The diagrams do not include the data obtained from psychomotor performance tests; however, measurements of computation speed show a clear rhythm which, even during the re-entrainment process, follows the rhythm of deep body temperature. Disregarding the underlying practice effect, there is a clear decrement in performance following the advance shift, but no detectable alteration in level following the delay shift.

The results of the zeitgeber experiments illustrated in Figure 13 (varying period) and in Figure 14 (phase shift) have been confirmed in a sufficient number of additional experiments to be generalized as follows. When the duration of an artificial day is shortened, a subject changes from being a "morning" to being an "evening" type and the rectal temperature rhythm also shifts to a later phase of the sleep-wake cycle; simultaneously, the fraction of sleep increases. When the phase of an artificial day is shifted, different

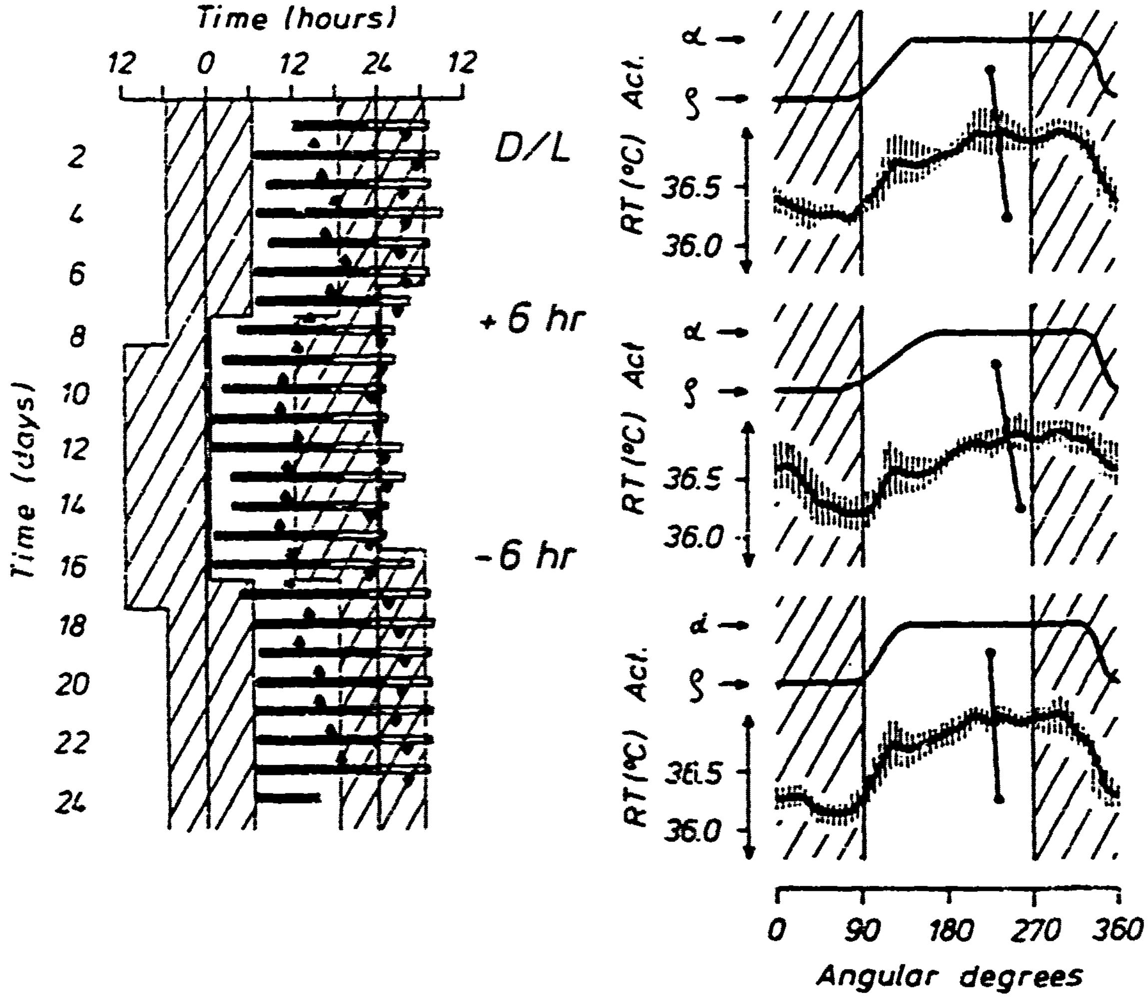

Figure 14. Circadian rhythms of a subject (G.L., ♂ 26y) living without environmental time cues but under the influence of an artificial 24-hour zeitgeber of the same type as in Figure 13, with two phase shifts of the zeitgeber. Left: rhythms of activity and rectal temperature, graphed as in Figure 1; hatched areas; dark-time of the zeitgeber. Right: Longitudinal representations of the rhythms, graphed as in Figure 13.

rhythms re-entrain at different rates, the rhythm of activity always faster than that in physiological functions; after an advance shift, the duration of re-entrainment is shorter than after a delay shift of the same amount, but both the number of subjective complaints and the decrements in psychomotor performance are greater. All these results are in agreement with those from real flight experiments (as long as the different time-shifts are performed under comparable conditions; see Sonderfeld, 1977). The existence of significant inter-individual correlations enables the duration of re-entrainment and the amount of behavioral impairment resulting from a time-shift to be predicted. Both of these predictions are independent of each other: (1) the larger the amplitude of the basic rectal temperature rhythm of a particular subject, the more persistent the rhythm, and the longer will its re-entrainment take after a zeitgeber shift; (2) the earlier the acrophase of the rhythm, the greater the behavioral impairment of the subject after an advance shift (Wever, 1980).

In the freerunning rhythms situation where the subject had no time reference to estimate the duration of his total sleep-wake cycle, or the value of the sleep fraction, there was a clear correlation between the fraction of sleep and the amplitude of the rectal temperature rhythm (cf. Figure 7). It is of interest to determine whether the same correlation exists in the case of externally synchronized rhythms; since here the sleep fraction also depends on the zeitgeber period, only those values obtained in a 24-hour day situation have been considered. There are 15 experiments which include at least one 24-hour section (cf. Figures 13 & 14). In Figure 15, mean sleep fraction in this section is plotted against mean rectal temperature range for these 15 subjects. The resulting positive correlation is weaker than that seen in freerunning rhythms (cf. Figure 7); the parametric and non-parametric coefficients are barely statistically significant. For comparison, Figure 15 (right) shows the regression of fraction of sleep on duration of the artificial day, assessed from experiments of the type shown in Figure 13. As can be seen, there is a strong relationship: the sleep fraction clearly decreases when the zeitgeber period is lengthened ($p < .001$) (it has been shown earlier in this paper that, simultaneously, the sleep shifts to a later phase of the rectal temperature rhythm).

Partially Synchronized Rhythms

The previous discussion of externally synchronized rhythms considered only those experiments in which all overt rhythms followed the zeitgeber synchronously. This is the case if the zeitgeber has a 'normal' strength, and if its periodicity does not deviate too much from 24 hours. However, of greater practical interest, in the present context, is a state of the rhythmic system where some of the overt rhythms follow a zeitgeger while others freerun, or where different overt rhythms follow different competing zeitgebers which deviate from each other in phase or period. This state of 'partial synchronization' is always combined with internal desynchronization, and it is only possible because of the multi-oscillatory set-up of the circadian system.

Since the two oscillators that constitute the human circadian system have different strengths (Wever, 1975a), they also differ in their ranges of entrainment: the weaker oscillator that predominantly controls the activity rhythm has a larger range of entrainment than the stronger oscillator that

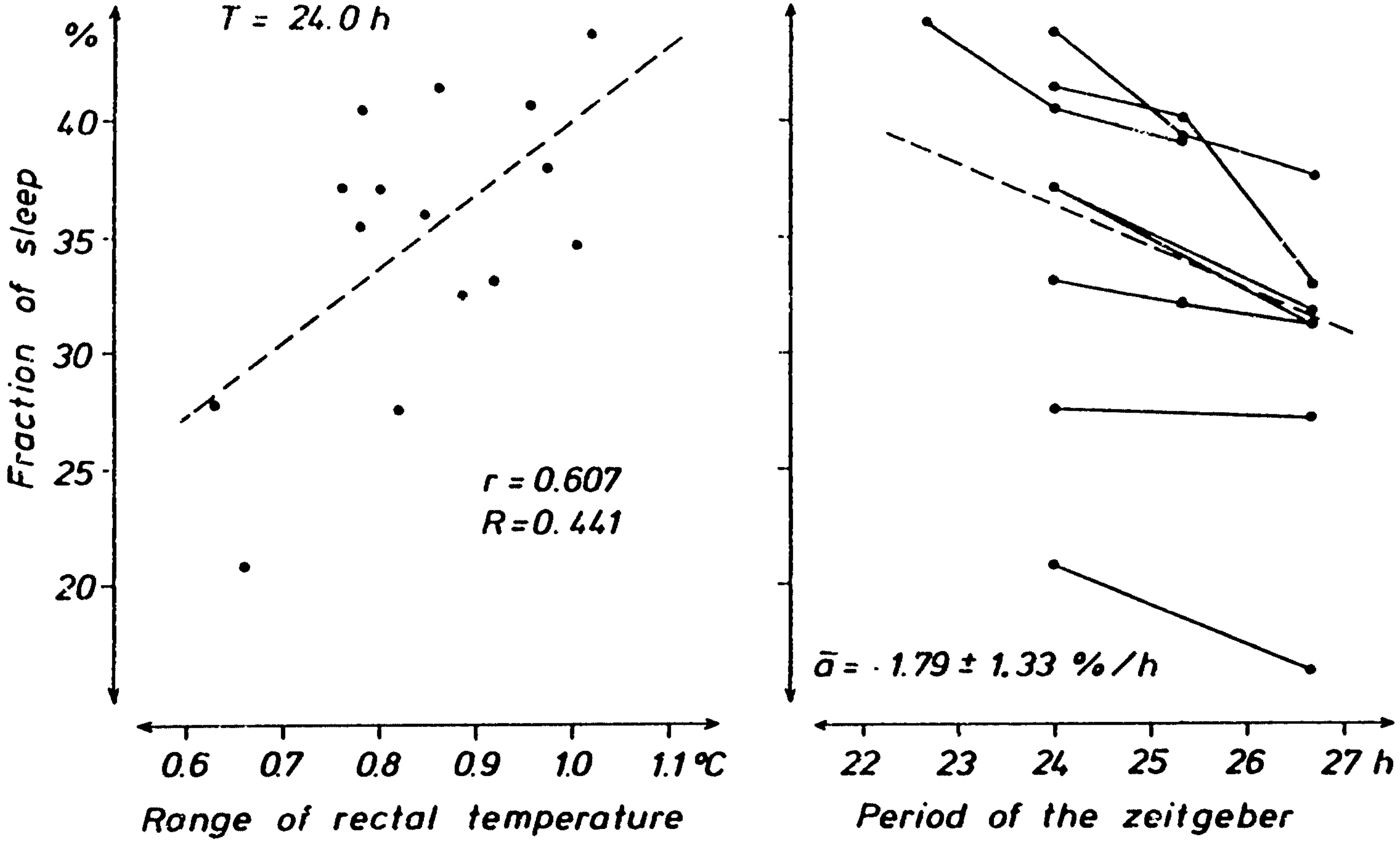

Figure 15. Fraction of sleep, measured in experiments performed without environmental time cues but with an artificial zeitgeber of the same type as in Figure 13; plotted on the left, as a function of the range of the rectal temperature rhythm (from 15 experiments with a 24-hour zeitgeber); and on the right, as a function of the zeitgeber period (from 8 experiments with varying zeitgeber period). In the left graph, r is the parametric and R the non-parametric inter-individual correlation coefficient; in the right graph, the mean and standard deviation of the individual regressions computed from the different sections in individual experiments are shown.

predominantly controls the rhythm of rectal temperature. This means that, under the influence of a zeitgeber with a period that deviates sufficiently from 24 hours, the overt activity rhythm can remain synchronized while the overt rhythm of rectal temperature freeruns. In the experiment shown in Figure 16, the subject was exposed to a strong zeitgeber (with no reading lamps available; Wever, 1975c), the period of which was successively increased from 24 to 28 and eventually to 32 hours. The activity-rest cycle of the subject was synchronized to the zeitgeber during all three sections without conscious perception by the subject of the changes in the duration of his days. The overt rhythm of rectal temperature, however, was synchronized to the zeitgeber only during the first section (24 hours), while it showed the typical freerunning period of 24.8 hours during the two subsequent sections; i.e., during the latter,it was not synchronized either to the zeitgeber or to the activity-rest cycle. Of special interest is the performance rhythm (computation speed): during the first section, this rhythm was synchronized with the zeitgeber and with all other rhythms; during the second section, it was synchronized with the rhythm of deep body temperature but not with the zeitgeber or with the activity-rest cycle; and during the third section, it was synchronized with the zeitgeber and the activity-rest cycle but not with the rhythm of deep body temperature. [It is generally true that the rhythm of performance, like other behavioral rhythms, does not, under varying conditions, consistently follow either the activity rhythm or the rhythm of deep body temperature.]

The findings mentioned above are confirmed by the results of periodogram analyses (Figure 16, right). In the first section, all three time series show one period which coincides with the zeitgeber period. In the two other sections, the activity rhythm again shows only one peak, which is at the appropriate zeitgeber period; and the rectal temperature rhythm shows two significant periods in each section, with the dominant one at 24.8 hours in both sections, and a secondary peak at the appropriate zeitgeber period. The performance rhythm periodogram in the second section is very similar to that of the rectal temperature rhythm; however, during the third section, there is only one significant period which coincides with that of the zeitgeber.

The opposite case, synchronization of the rectal temperature rhythm while the activity rhythm freeruns, has been observed under the influence of a weak zeitgeber. It has been shown in many experiments that a light-dark cycle with reading lamps available, and without any 'gong' signals to the subject, is almost completely ineffective as a zeitgeber (Wever, 1970). Since, under such a weak zeitgeber, rhythms freerun as they do under constant conditions, spontaneous occurrence of internal desynchronization can be expected in at least a part of the experiment (Wever, 1978). Figure 17 shows the courses of three experiments where internal desynchronization occurred after a preliminary period of freerunning internally synchronized rhythms. After the disintegration of the rhythms, the course deviates in each case from that observed under constant conditions, since following its separation from the activity rhythm, the rhythm of deep body temperature runs in synchrony with the zeitgeber. By some additional independent arguments (including e.g., their phase relationships with the zeitgeber), it can be proved that there are not, by chance, any periods of the freerunning temperature rhythms that are very close to 24 hours (Wever, 1979a). This is particularly evident in the third example, where the temperature rhythm loses entrainment by the zeitgeber at the beginning of the last week.

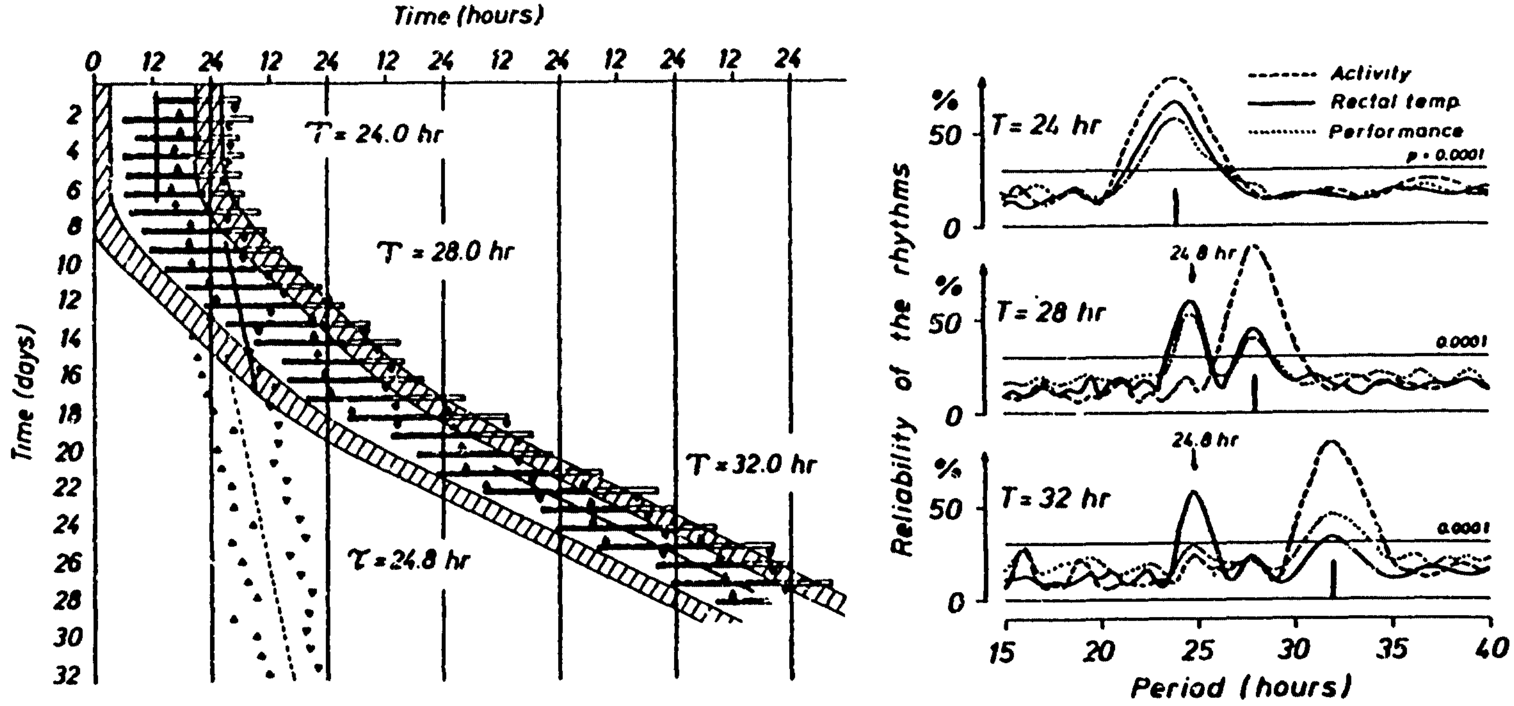

Figure 16. Circadian rhythms of a subject (I.P., ♂ 31y) living without environmental time cues but under the influence of a strong artificial zeitgeber (light-dark cycle without reading lamps available, and gong-signals at regular intervals calling the subject for urine samples and certain tests), with two alterations of the zeitgeber period. Left: rhythms of activity and rectal temperature, graphed as in Figure 1 (for meaning of white and black triangles, see Figure 9); the rhythm of computation speed (Paulitest) is indicated by the solid lines joining successive acrophases within each of the three sections; hatched areas: dark-time of the zeitgeber. Right: periodograms of the three time series, computed separately from the three sections with different zeitgeber periods.

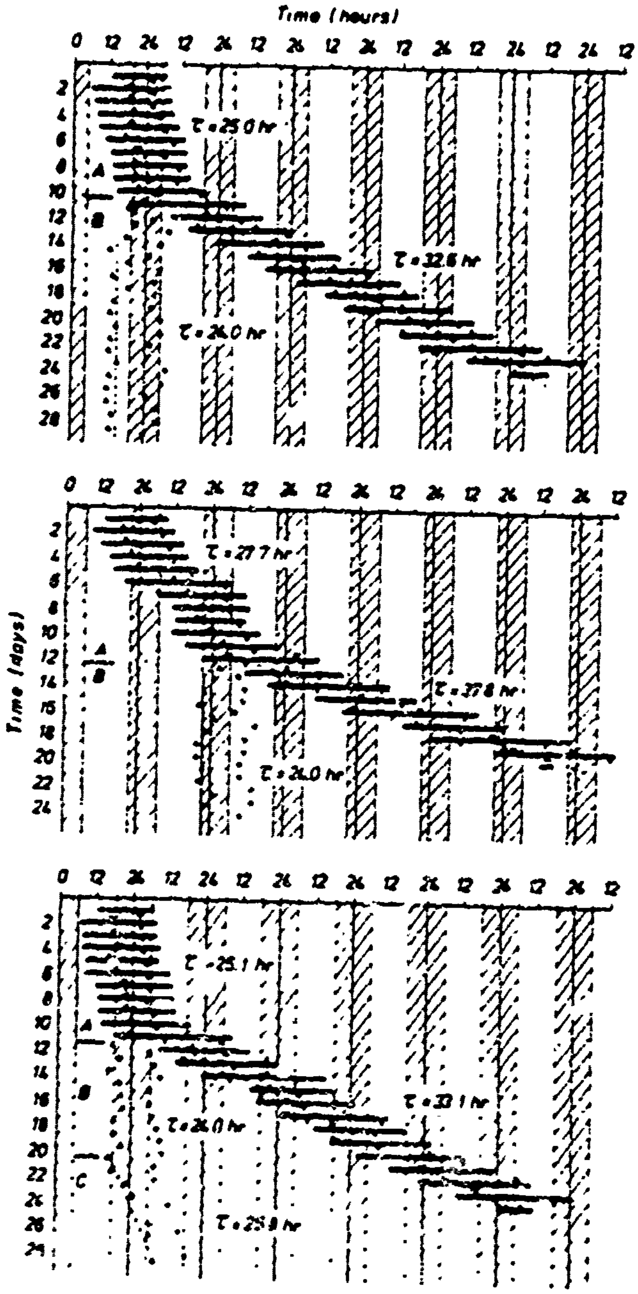

Figure 17. Circadian rhythms of three subjects (G.G., ♂ 25y; R.A., ♂ 27y; H.A., ♂ 25y) living without environmental time cues but under the influence of a weak artificial 24-hour zeitgeber (light-dark cycle with reading lamps available during dark-time); rhythms of activity and rectal temperature are graphed as in Figure 1 (for meaning of white and black triangles, see Figure 9). Hatched areas: dark-time of the zeitgeber. Sections with internally synchronized rhythms are indicated as A; sections after spontaneous occurrence of internal desynchronization as B (and C).

The synchronization found in these experiments is the more remarkable since no subject had consciously perceived the drastic lengthening of his activity-sleep cycle; at the same time, they all considered the light-dark cycle to have been very short and irregular. Nevertheless, the (consciously) imperceptible rhythm of deep body temperature was synchronized to this cycle.

It would, of course, be of particular interest to know whether, during the state of desynchronization, the performance rhythm follows the activity-sleep rhythm or the rhythm of deep body temperature. Unfortunately, the design of these experiments does not allow the measurement of performance rhythms, since in order to ensure the necessary weakness of the zeitgeber, it is not possible to awaken the subject from sleep for tests (as in other zeitgeber experiments); and rhythms cannot be evaluated meaningfully when there are consistent night-gaps in the data (Wever, 1981).

Cases of partial synchronization, as exemplified in Figure 17, have been observed only occasionally. It is only after the spontaneous occurrence of internal desynchronization in subjects who have a predisposition for rhythm disintegration in isolated conditions (Lund, 1974; Wever, 1975c) that a weak zeitgeber can "capture" the rhythm of rectal temperature, while, at the same time, the period of the activity rhythm differs too greatly from that of the zeitgeber to become synchronized (in spite of its larger range of entrainment). On the other hand, cases of partial synchronization of the type illustrated in Figure 16 can be forced in all subjects, including those who have no predisposition for spontaneous rhythm disintegration. In all experiments where the period of the strong zeitgeber is either 22 hours or less, or 28 hours or more, internal desynchronization is forced. The one exception to this occurs when the zeitgeber period is close to 48 hours; here, there is not only a 1:1 synchronization of the activity-sleep cycle, but also a 2:1 synchronization of the physiological rhythms. In most of the experiments that have been conducted with this extremely long zeitgeber period, the subjects have never been consciously aware of the great deviation of their subjective day from 24 hours (this ignorance would even appear to be a necessary condition of the success of such experiments).

The aim of the experiments with only partial external synchronization (and, hence, forced internal desynchronization) is the systematic study of the interactions between disintegrated overt rhythms, and of the effects of such rhythm disintegration on the behavior of the subjects. Preliminary results suggest that there is less need for sleep during sections of experiments with forced internal desynchronization than during sections with intact rhythms (Wever, 1979a), just as is the case with spontaneous internal desynchronization; and that the effects of rhythm disintegration on objectively measurable performance (e.g., computation speed) and on the subject's well-being (as assessed by self-rating scores; Wever, 1981) are advantageous. However, the extent to which these apparently paradoxical but significant results can be applied to practical situations is still an open question.

The capacity of different overt rhythms to become synchronized by external zeitgebers separately and independently of each other suggests the possibility that some zeitgebers are more effective than others for particular rhythms. In conclusion, therefore, two experiments will be described as examples of cases where zeitgebers with different modalities and different periods have been presented simultaneously. The first example is shown in Figure 18, which gives data from a subject who, in an experiment in which the sleep of another subject under constant conditions was being recorded polygraphically, had the job of monitoring the complex recording equipment. Consequently, he had to be awake when the subject was sleeping, and hence, his own activity rhythm was controlled by the subject's freerunning rhythm. On the other hand, he had precise knowledge of the objective time of day, and he also had sufficient contacts with the outside environment. Thus, he was exposed to two competing zeitgebers: (1) the "watchkeeping" schedule imposed by the rhythm of the monitored subject, and (2) local time. As Figure 18 demonstrated, his activity rhythm, as would be expected, deviated from 24 hours, coinciding with the freerunning rhythm of the subject; however, his rhythms of rectal temperature and of other physiological variables were clearly synchronized to local time. This twofold control by two different zeitgebers can be deduced both from the course of the rhythms (Figure 18, left) and from the periodogram analyses (Figure 18, right).

The second example (Figure 19) shows results from an experiment in which four subjects lived together in an artificial 30-hour day (without reading lamps). The strong zeitgeber collectively synchronized the activity-sleep cycles of all the subjects; none of them consciously perceived that this common cycle deviated from 24 hours. On the other hand, the zeitgeber period was too long to synchronize the physiological rhythms which, in consequence, freeran. But instead of showing the inter-individual differences in period that might have been expected due to slight differences in natural frequency, the four temperature rhythms, and also other physiological rhythms, were mutually synchronized. There are good arguments for excluding the possibility that the temperature rhythms of the different subjects had, by chance, exactly equal periods. Thus, it must be assumed that the consciously imperceptible rectal temperature rhythms acted mutually as a zeitgeber; the only feasible way in which this zeitgeber could have acted is by affecting mutual social contacts. Therefore, in this experiment also, each subject must be assumed to have been exposed (although unexpectedly) to two competing zeitgebers: (1) the deliberately introduced 30-hour day, and (2) the rectal temperature rhythm (and other physiological rhythms) of the other subjects. And again, both of these zeitgebers were effective, but with different strengths for the different overt rhythms.

Conclusions

In this brief survey of biological rhythm perspectives, the main emphasis has been on experiments performed under constant conditions, despite an awareness that such conditions are not directly relevant to real life. However, it is only under such conditions, where all time references are excluded, that the influences of social habits, and of consequent variations in motivation, are eliminated, thus ensuring that activity-sleep behavior is determined only by biological necessities. These necessities can indeed be modified by the conditions of modern industrial society, but they cannot be entirely neglected. Thus when, for practical reasons, it is necessary to establish work-rest schedules, it is obviously preferable that these be chosen to fit in, as far as possible, with the known regularities of human circadian rhyhtms.

When freerunning rhythms are internally synchronized, there are certain negative serial correlations between successive cycles and between successive

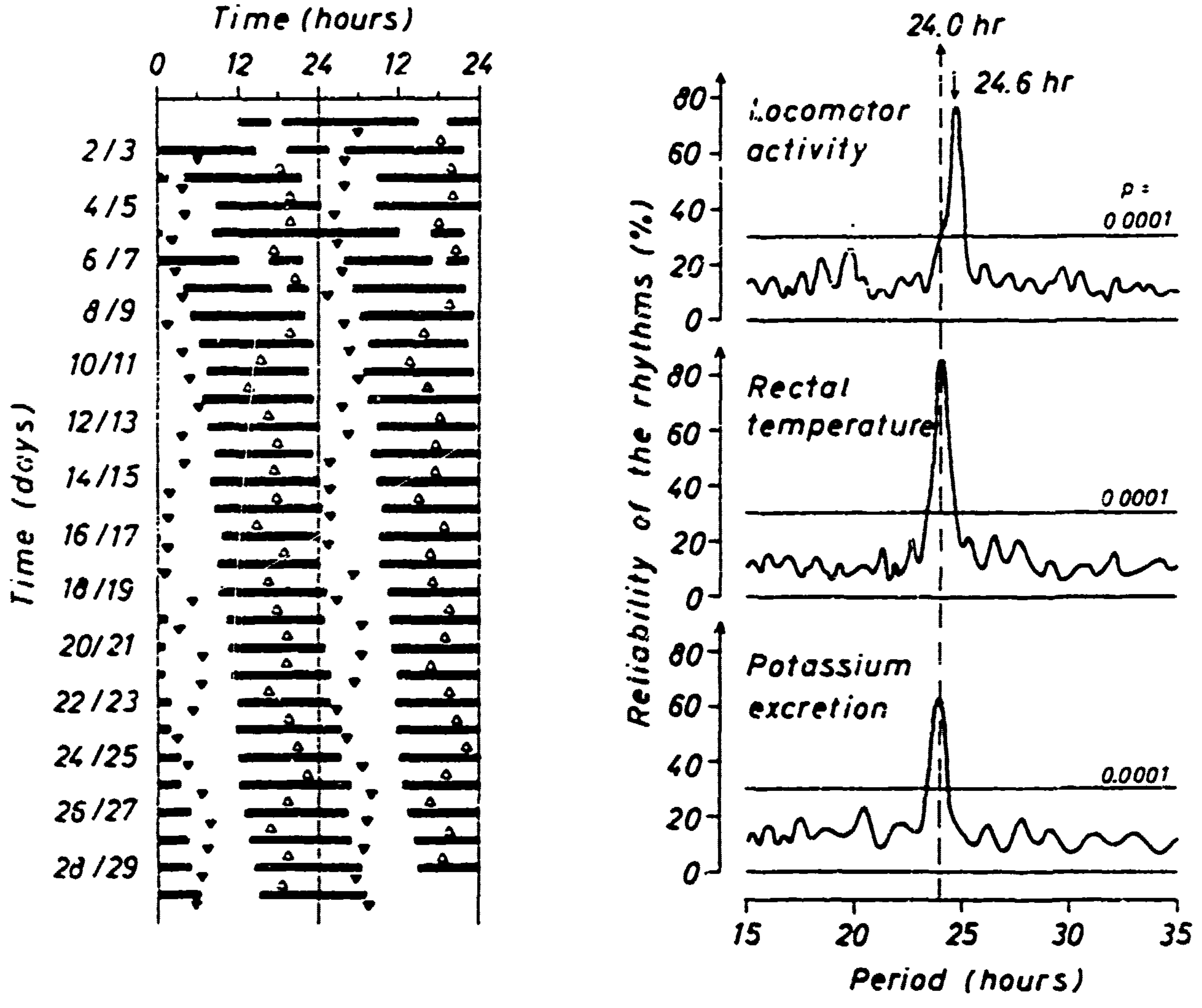

Figure 18. Circadian rhythms of a subject (J.Z., ♂ 29y) who was monitoring the equipment recording polygraphically the sleep of another subject under constant conditions. Left: states of wakefulness (bars) and extreme values of the rectal temperature rhythm (triangles), as functions of local time. Right: periodograms of the time series of activity, rectal temperature, and urinary potassium excretion.

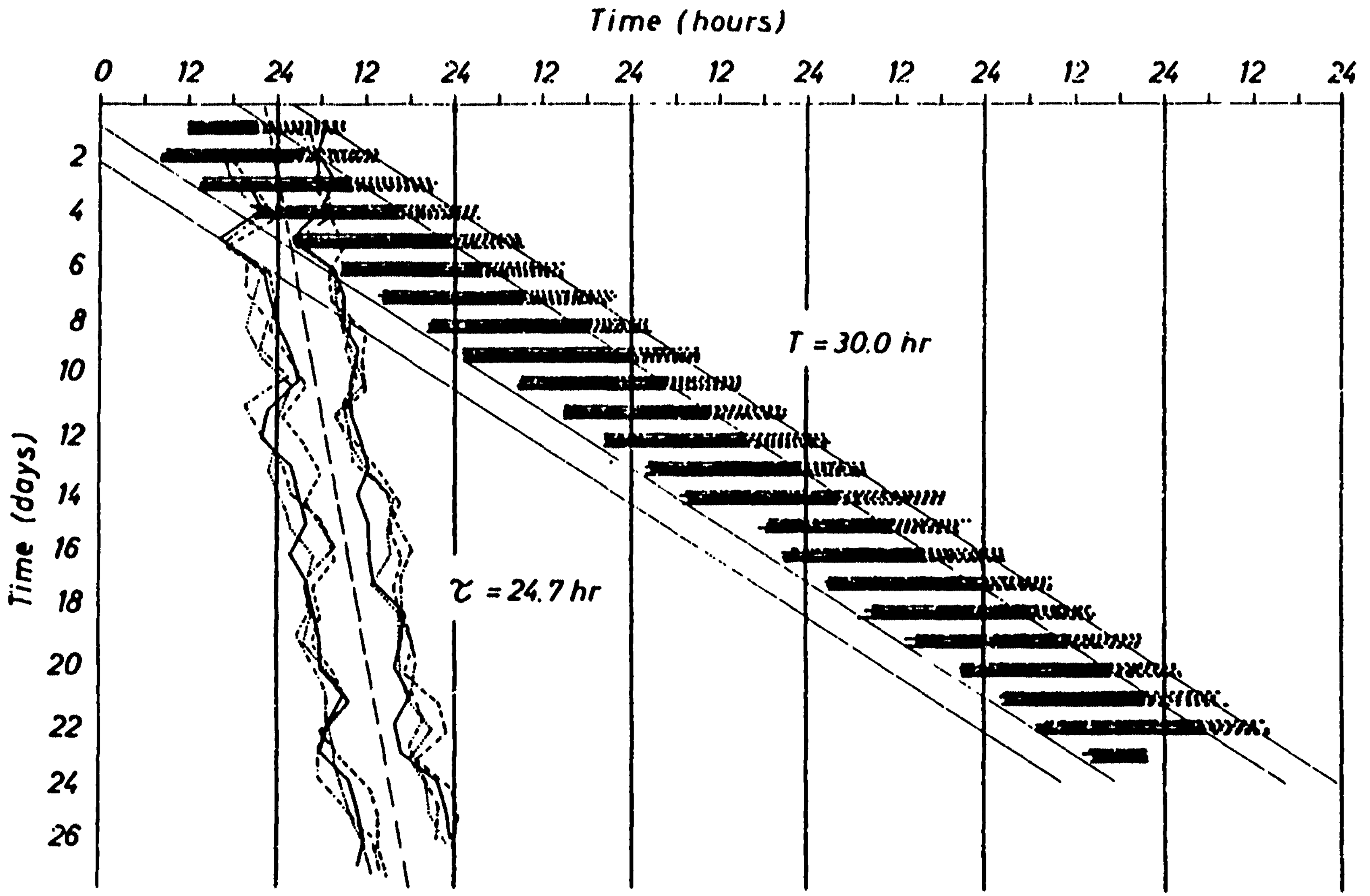

Figure 19. Circadian rhythms of a group of four subjects living together without environmental time cues but under the influence of a strong artificial 30-hour zeitgeber of the same type as in Figure 16. Activity-sleep rhythms indicated by bars (solid: activity; broken: rest). Rhythms of rectal temperature represented by lines joining the temporal positions of successive maxima (left) and minima (right); framed areas: dark-time of the zeitgeber. From Wever (1979a).

elements of each cycle. All these correlations seem to indicate that the system is attempting to achieve stabilization of the cycle at a certain period value; and the negative correlations between activity and sleep seem to demonstrate a preference for stabilization of the full cycle rather than for keeping the durations of the separate sections of activity and sleep constant. Of course, under the influence of a zeitgeber with steady properties, all these negative correlations are self-evident; here they are nothing more than reflections of synchronization. However, the presence of the same correlations under constant conditions demonstrates certain fundamental mechanisms of the circadian system, consideration of which may assist in the solution of practical problems like shiftwork.

Many different investigations show that the amplitude of the rhythm of deep body temperature is one of the most important parameters of the circadian rhythmicity. This means that the amplitude of the rhythm is an index of its degree of resistance to change by external and internal factors: the larger the amplitude, the smaller are the changes in the rhythm induced by a given external stimulus, and the smaller is the tendency towards spontaneous occurrence of internal desynchronization. But, secondly, the amplitude of the rhythm of deep body temperature is also strongly correlated with the need for sleep. This particular correlation is a good example of the mutual interaction between different overt rhythms: the influence of the sleep-wake cycle on physiological rhythms coexists with an even stronger influence of the latter (e.g., the rhythm of deep body temperature) on the former, because of the greater strength of the oscillator that predominantly controls the physiological rhythms. This interaction is directly expressed in the dependence of both the duration and the structure of sleep on the course of rectal temperature during the sleeping period.

The characteristics of the temperature rhythm amplitude mentioned have been determined under constant conditions. They are, however, also applicable to synchronized rhythms; here an advantage of the rectal temperature rhythm is that it is less dependent on socially forced habits than is the activity rhythm. Hence, the amplitude of the rhythm of deep body temperature indicates the need for sleep under natural conditions in the 24-hour day, as it does under constant conditions. Likewise, it is again an index of the degree of resistance of the rhythm to zeitgeber changes; this is expressed, for instance, in the duration of re-entrainment after a particular phase shift of the zeitgeber. The latter characteristic may be of practical interest, since it allows the suitability of a person for time shifts (Wever, 1979b) or shiftwork (Reinberg, Vieux, Ghata, Chaumont, & Laporte, 1978) to be predicted.

In the experiments in the isolation room, disintergration of the rhythmic system, whether it occurs spontaneously or is forced by manipulations of the experimental conditions, reduces the need for sleep, and produced increases in psychomotor performance and in subjective well-being (Wever, 1979a, 1981). However, advantageous effects cannot be generalized outside the laboratory situation; it must rather be assumed that they arise because of the relative lack of external stimuli in the latter. This lack does not, in fact, lead to conscious feelings of lack of well-being in the subjects; but it is assumed that when the number of stimuli to be processed is increased by the addition of the internal stimuli resulting from disintegration of the circadian system, the total input reaches a level which is optimal for inducing a favorable behavioral state.

If the foregoing argument is correct, it follows that in normal life, where the input of external stimuli is considerable, any additional stimuli from the internal system would lead to stress. This conclusion is based on the assumption that the rhythm disintegration which occurs in situation like shiftwork, is, as a stimulus, equivalent to a stimulus emanating from an external source. This hypothesis, the application of which might help to make unavoidable rhythm disorders more tolerable, requires further confirmation; but the results discussed here at least prove that rhythm disintegration need not necessarily lead to loss of well-being.

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CIRCADIAN TEMPERATURE RHYTHM AMPLITUDE AND LONG TERM TOLERANCE OF SHIFTWORKING

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A circadian rhythm may be characterized by its acrophase ϕ (crest time on a 24 h scale, of the best-fitting cosine function to all data), its amplitude $\underline{A}$ (1/2 of the difference between crest and trough) and its mesor M (rhythm adjusted mean) (Halberg & Reinberg, 1967; Halberg, Johnson, Nelson, Runge, & Sothern, 1972).

A phase shift ($\Delta\psi$) of socio-ecological synchronizers (ψs) is followed by an acrophase shift ($\Delta\phi$) of the rhythm which is in the same direction and of the same magnitude as $\Delta\psi$. Practical examples of $\Delta\psi$ for mean are:

(a) transmeridian flights across at least 5 time zones ($\Delta\psi > 5$ h);
(b) shiftwork which involves abrupt changes from day work/night sleep to night work/day sleep or vice versa ($\Delta\psi = 8$ h).

A number of studies (Halberg & Reinberg, 1967, 1977; Reinberg, 1970; Aschoff, Hoffmann, Pohl, & Wever, 1975) have shown that the time needed for a rhythm to adjust from the "old" phase to its "new" one after a $\Delta\psi$ varies:

(a) from variable to variable in the same subject (e.g., the body temperature ϕ typically adjusts faster than the urinary 17-OHCS ϕ);
(b) with direction of $\Delta\psi$ (e.g., after a $\Delta\psi$ equivalent to a flight from Paris to New York (phase delay) ϕs adjust faster than after $\Delta\psi$ equivalent to a flight from New York to Paris (phase advance);
(c) from subject to subject for a given variable.

With Andlauer, Vieux, Ghata and other colleagues, we have used this chronophysiological background (as well as a chronobiological methodology) to try to increase our understanding of individual differences in tolerance of shiftwork (Reinberg, Vieux, Ghata, Chaumont, & Laporte, 1978a, 1978b; Andlauer & Reinberg, 1979).

From clinical evidence, it appears that in a population of healthy human adults, only a limited proportion (the exact value has not yet been ascertained) are able to sustain shiftwork (Akerstedt, 1976; Landier & Vieux, 1976; Andlauer, Carpentier, & Cazamian, 1977). Many people, even after only a few months of shiftwork, suffer from fatigue and sleep disturbances, as well as from other symptoms. Clinical symptoms of intolerance may be seen in some people after several years of shiftwork and/or when they reach 40 or 50 years of age. However, other people are able to do shiftwork for all of their active life span without exhibiting medical problems or complaint. Unfortunately, at the present time, it is not possible to predict whether or not an individual will tolerate shiftwork easily for many years. It is only by on-the-job experience that it is possible to evaluate this capability.

Since the number of persons involved in shiftwork and transmeridian flights is large (almost one million people are employed on shiftwork in France), and since it is of interest, both to the employer and employee to know the likelihood of being able to continue in shiftwork, it is of practical concern to evaluate data from chronobiological studies with the particular aim of identifying possible indices for predicting successful long-term tolerance of shiftwork schedules. The amplitude of the circadian rhythm of body temperature (among other variables) was considered as a candidate for such an index, and was tested in relation to two complementary hypotheses.

The first of these hypotheses (advanced by Aschoff, 1978) is that the circadian amplitude of certain variables, such as oral temperature, is a chronobiological index indicative of the ability to phase shift circadian rhythms. Put as a question, this hypothesis asks: Is a rapid adjustment of ϕ to a phase shift of the ϕs associated with a small circadian amplitude?

The question posed by the second hypothesis (advanced by Andlauer, 1971) is: Is a good clinical tolerance of shiftwork related to a large amplitude of the oral temperature circadian rhythm?

Data gathered from previous studies on oil refinery shiftworkers (Reinberg et al., 1973, 1975, 1976a, 1976b) were complemented and reanalyzed to test whether or not $\underline{A}$s and $\Delta\phi$s (resulting from $\Delta\phi$s) are correlated for variables such as oral temperature, peak expiratory flow, urinary 17-OHCS, etc.(Study 1).

The possible relationship between the circadian amplitude of the oral temperature rhythm and tolerance of shiftwork was merely suggested by inspection of the raw data from 25 subjects. The hypothesis of Andlauer (1971) referred to above was therefore, in fact, a proposal for further studies. These have since been carried out (Andlauer & Reinberg, 1979) and involved shiftworkers from two different industries (Study 2).

The experimental protocol of Study 3 was designed to test both the hypotheses together, i.e., that the cirdadian rhythm amplitude of oral temperature is related either to speed of rhythm adjustment and/or to tolerance of shiftwork. In testing these hypotheses, the problem of their compatibility (and even that of their complementarity) was taken into account (Reinberg, Vieux, Andlauer, Guillet, Laporte, & Nicolai, 1979). From a practical point of view, complementarity would mean that the circadian temperature rhythm in a tolerant subject (resistant to the long-term effects of shiftwork) would have a large amplitude, and would phase adjust slowly to a $\Delta\Phi$. In a non-tolerant subject (with medical complaints that indicated some degree of health loss), the rhythm would have a small amplitude, and would adjust rapidly. At the same time, it had to be borne in mind that someone with an excellent history of tolerance of shiftworking for many years might begin to have problems on reaching his fifties or even his forties. Thus, the subjects' ages and their known tolerance of shiftwork were taken into consideration when forming the groups of Study 3, in which rhythm parameters such as $\underline{A}$, Φ and $\Delta\Phi$ were estimated from individual time series.

Is a Large Amplitude Related to a Slow Phase-Shift in the Circadian Rhythms of Shiftworkers? (Study 1)

Subjects. Twenty-five male shiftworkers in two French oil refineries (Reichstett & Petit-Couronne) who had been on shiftwork (shiftwork duration for from 1-16 years) were used as subjects. At Reichstett there were 20 subjects, ranging in age from 24-48, whose shift length was 7 days (weekly rotation); at Petit-Couronne there were 5 subjects, ranging in age from 21-28, whose shift length was 3-4 days (rapid rotation).

Methods

Self-measurements of oral temperature, grip strength and peak expiratory flow were performed every 4 hours (except during sleep) at the same clock time on Day 1 (among others) of each shift ($\Delta\psi$). Total urine voidings (for determination of urinary 17-OHCS, K^+, Na^+, etc.) were collected simultaneously. The data gathering covered a 6-8 week span.

The single cosinor method (Halberg et al., 1972) was used to quantify the amplitude (A) and the acrophase (ϕ) of the rhythm of each variable for each subject on each shift.

For each variable and each of the 25 subjects, we derived:

(1) the mean amplitude A, computed from all available time series (in so doing, the total variance of this parameter was taken into consideration):

(2) the magnitude (or the speed) of the acrophase shift $\Delta\phi$. $\Delta\phi$ was defined as the difference (in hours) between ϕ on control days (diurnal work and activity/nocturnal sleep) and ϕ on the first night shift day (the 24 h span following the first session of nocturnal work/diurnal rest and sleep). The estimated $\Delta\phi$s correspond to a phase delay ($\Delta\psi$) of approximately 7.5 h.

Correlation coefficients were calculated between A and $\Delta\phi$ for each variable, and also between the $\Delta\phi$s of the different variables.

Results

Figure 1 shows the negative correlation obtained between A and $\Delta\phi$ for oral temperature ($r = -.63$; $p < .01$); the lower the amplitude, the greater the $\Delta\phi$.

Table 1 shows similar significant negative correlations between A and $\Delta\phi$ for peak expiratory flow (PEF) and urinary excretion of 17-OHCS. However, the correlations between A and $\Delta\phi$ were not statistically significant for grip strength, or for urinary excretion of K^+ and Na^+.

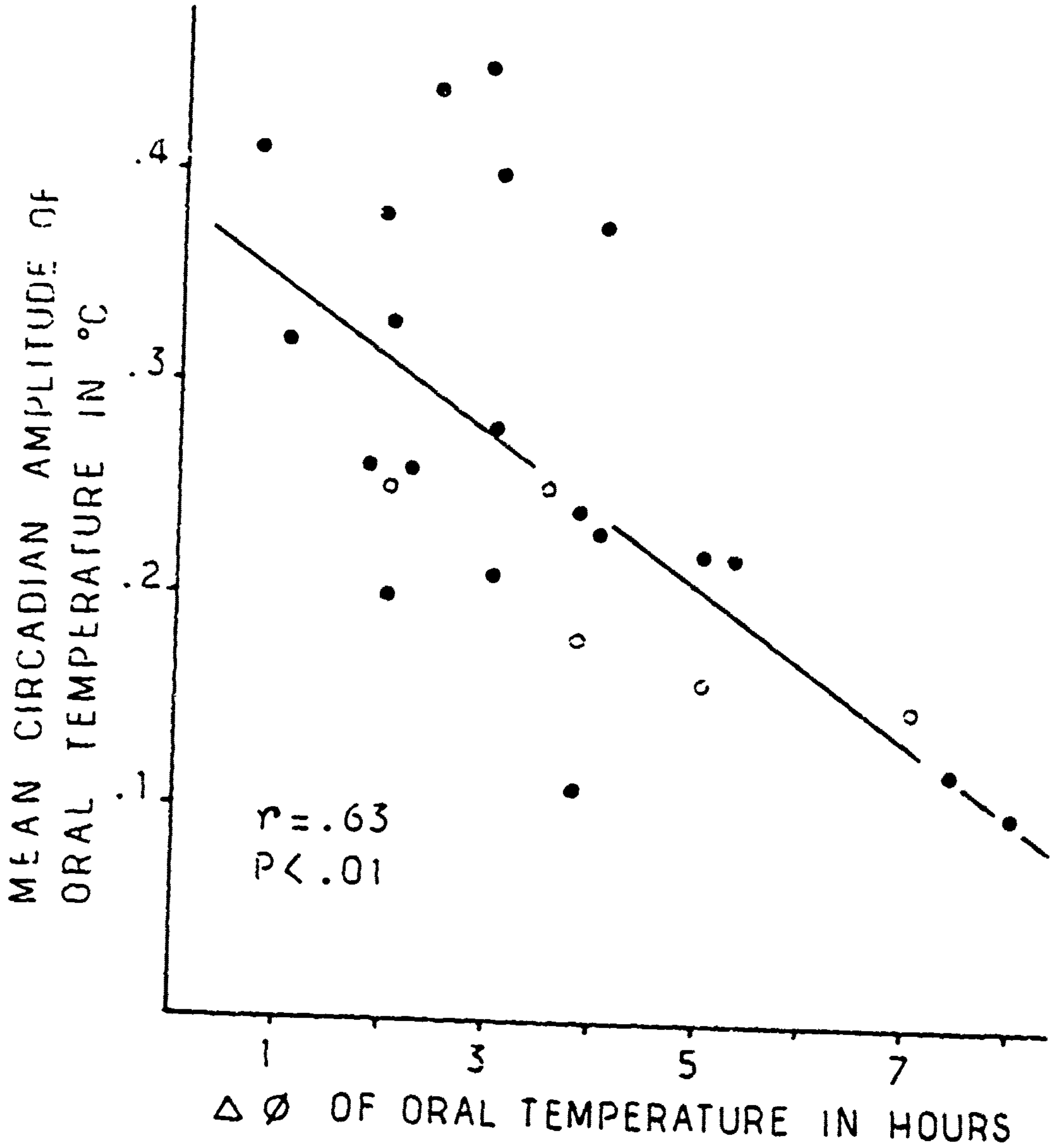


Figure 1. Correlation between individual mean amplitude (A) and acrophase shift (Δφ) of the oral temperature circadian rhythm (Study :): subjects from the Reichstett study (O); subjects from the Petit-Couronne study (O).

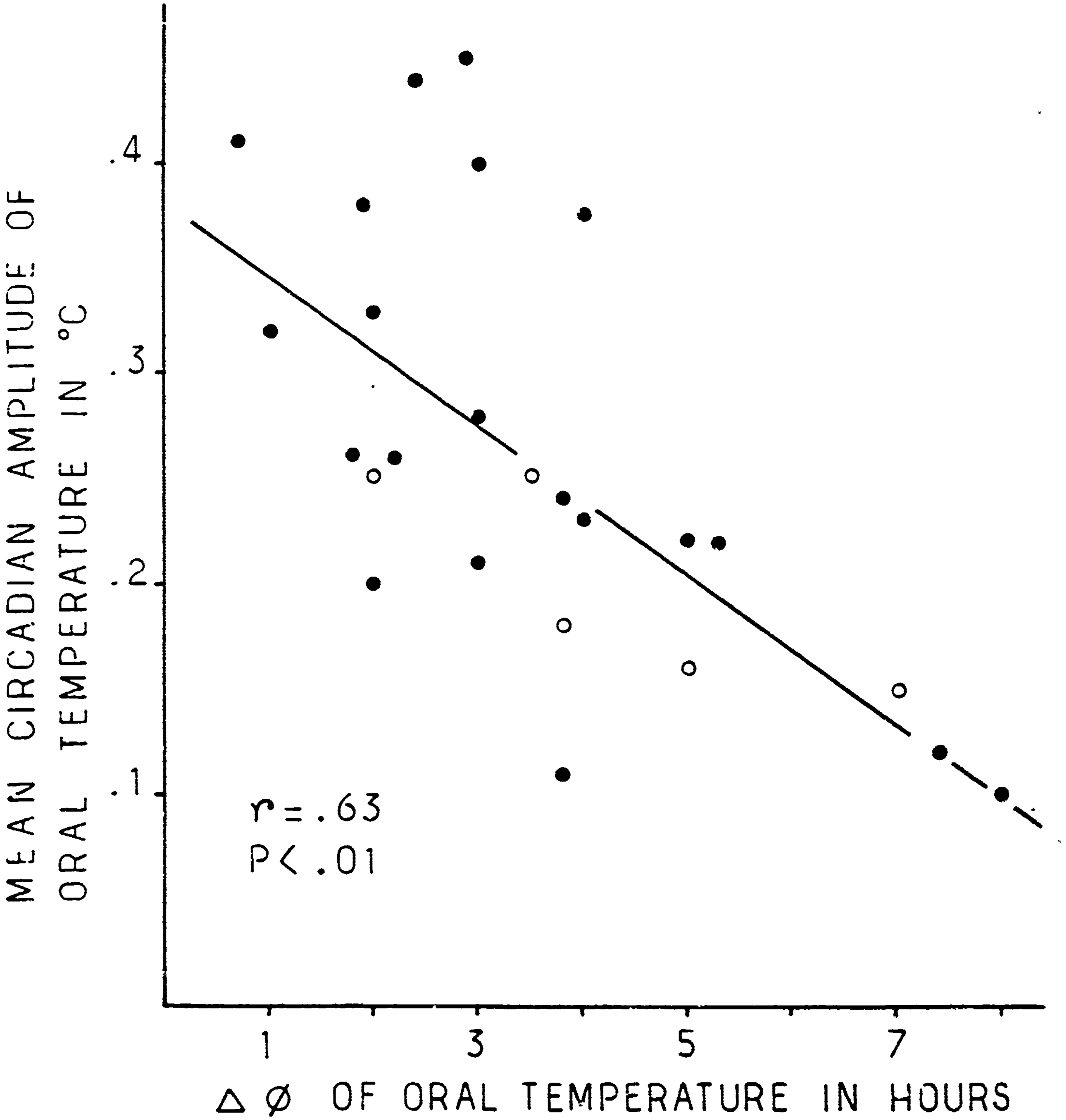


Figure 1. Correlation between individual mean amplitude (A) and acrophase shift (Δφ) of the oral temperature circadian rhythm (Study 1): subjects from the Reichstett study (O); subjects from the Petit-Couronne study (O).

Table 1

Correlation Between the Circadian Rhythm Amplitude A and the Acrophase Shift After the First Night Shift for Six Variables

Variables	r	p
Oral temperature	-0.63	< 0.01
Peak expiratory flow	-0.53	< 0.01
Grip Strength	-0.20	> 0.05
Urinary 17-OHCS	-0.60	< 0.01
Urinary potassium	-0.15	> 0.05
Urinary sodium	-0.18	> 0.05

It was of interest to examine whether or not the amplitudes of different variables were correlated. It appeared that the *A* of oral temperature was correlated with the *A* of PEF ($r = .48$; $p < .05$) but not with the *A* of urinary 17-OHCS ($r = .07$; $p > .05$). A (positive) correlation between subjects' age and circadian rhythm *A* was found only for PEF: the older the subject, the larger the *A* ($r = .57$; $p < .01$).

Is a Large Circadian Rhythm Amplitude in Oral Temperature Related to Good Clinical Tolerance of Shiftwork? (Study 2)

Subjects. Forty-eight shiftworkers volunteered for the study. Twenty-three were employed in a plant of the Steel Industry (SI) near the city of Saint-Etienne; the other 25 were employed in a plant of the Chemical Industry (CI) near the city of Grenoble. Age distribution was quite similar within groups (industry) and subgroups (tolerance of shiftwork). However, a large number of non-tolerant subjects had been employed as shiftworkers for at least 10 years. This unequal distribution was not surprising, since intolerance to shiftwork tends to increase with age (Akerstedt, 1976; Landier & Vieux, 1976). The steel workers had a seven-day shift (weekly rotation). The chemical workers worked a rapidly rotating system with a shift duration of two days.

Criteria for assessing tolerance of shiftwork. Clinical tolerance was assessed conventionally by considering both the existence and the intensity of 3 types of shiftwork-associated problems. These can be classified as *digestive*, *neurological* and *sleep disturbing*. With respect to digestive problems, the common complaints were: dyspepsia, gastritis, colitis, and peptic ulcer. Neurological problems were mainly unusual irritability and persistent fatigue. The latter differed from the physiological fatigue resulting from physical and/or mental effort since it did not disappear after rest. Sleep disturbances included poor subjective quality of sleep, insomnia and frequent awakening. In some individuals, two or three types of problems were sometimes found together.

It must be emphasised that a person who has been shiftworking for many years is well able to recognize changes both in his capacity to carry out work and in his physical vigor following nocturnal sleep when off duty. Thus, it was possible in this study to use a subject's own reports, as well as clinical observations, to judge the degree to which he was tolerating (or not tolerating) his shiftwork schedule.

Methods

Normal large-scaled calibrated clinical thermometers (accurate to 1/20° C) were used for oral temperature measurements. Data were collected over a 4-week span on the last day (i.e., either the second or seventh) of each of the shifts, at 2 h intervals and fixed clock hours.

Both conventional (t-tests of differences between means; Chi Square tests of group distributions, etc.) and cosinor (Halberg et al., 1972) methods were used for statistical analyses.

Results

The differences between the maximum and the minimum (Max-min Diff) were pooled over shifts for group and subgroup analyses. Table 2 indicates a highly statistically significant difference in the Max-min Diff between subjects tolerating and not tolerating shiftwork. This is true for both SI and CI shiftworkers.

Table 2

Mean Difference Between Circadian Maxima and Minima in Oral Temperature (°C) in Shiftworkers Showing Good and Poor Tolerance of Shiftwork

Group (Shift-duration)		Tolerance of Shiftwork Good	Poor	p
Steel Industry [SI]	X	1.42	1.06	
(7 days)	SE	0.13	0.09	<.005
	N	9	14	
Chemical Industry [CI]	X	1.16	0.77	
(2 days)	SE	0.06	0.08	<.005
	N	11	14	
SI + CI	X	1.28	0.92	
Combined	SE	0.08	0.07	<.005
	N	20	28	

Cosinor analysis detected statistically significant circadian rhythms in both tolerant and intolerant subgroups of subjects working in both the steel and chemical industries. The Mesor values of these rhythms were not statistically different in the different groups, or in tolerant and intolerant subjects. The acrophase locations were very similar (around 1600) in all cases.

Statistically significant differences were found only in amplitude: a small circadian A was associated with poor shiftwork tolerance, while good tolerance to shiftwork was associated with a relatively large A (see Table 3).

Table 3

Summary of Single Cosinor Analysis of the Cirdadian Rhythms in Oral Temperature (°C) of Subjects with Good or Poor Tolerance of Shiftwork

Group (Shift Duration)	Tolerance of Shiftwork	Rhythm Detection P(A=0)	Mesor ISE (°C)	Amplitude (°C) (95% limits)	Acrophase (hr min) (95% limits)
Steel Industry	Good (N=9)	<.005	36.66±.17	.49(.41-.56)	16.41(16.07-17.)
[SI] (7 days)	Poor (N=14)	<.005	36.62±.10	.32(.26-.38)	15.34(14.55-16.)
Chemical Industry	Good (N=11)	<.005	36.85±.08	.35(.30-.40)	15.52(15.19-16.)
[CI] (2 days)	Poor (N=14)	<.005	36.86±.06	.25(.21-.29)	16.24(15.44-17.)
[SI + CI]	Good (N=20)	<.005	36.77±.06	.40(.36-.44)	16.21(15.57-16.)
Combined	Poor (N=28)	<.005	36.76±.04	.27(.24-.31)	16.02(15.33-16.)

Individual differences. The Chi Square test was used to examine the association between tolerance of shiftwork and the Max-min Diff in oral temperature rhythm in the different groups. The association was not statistically significant for the SI subjects, but it was for the CI subjects: in this group, of the 11 subjects who tolerated shiftwork, 9 had an average Max-min Diff greater than 0.94° C, while of the 14 subjects who did not tolerate shiftwork, 9 had a Max-min Diff less than 0.94° C (Chi Square = 5.31; p <.025). When the data was pooled across industries, of the 20 subjects who tolerated shiftwork, 16 had a Max-min Diff greater than 1.07° C, while of the 28 subjects who did not tolerate shiftwork, 18 had a Max-min Diff less than 1.07° C (Chi Square = 9.22; p <.005).

Circadian Rhythm Amplitude, Tolerance to Shiftwork, and Age (Study 3)

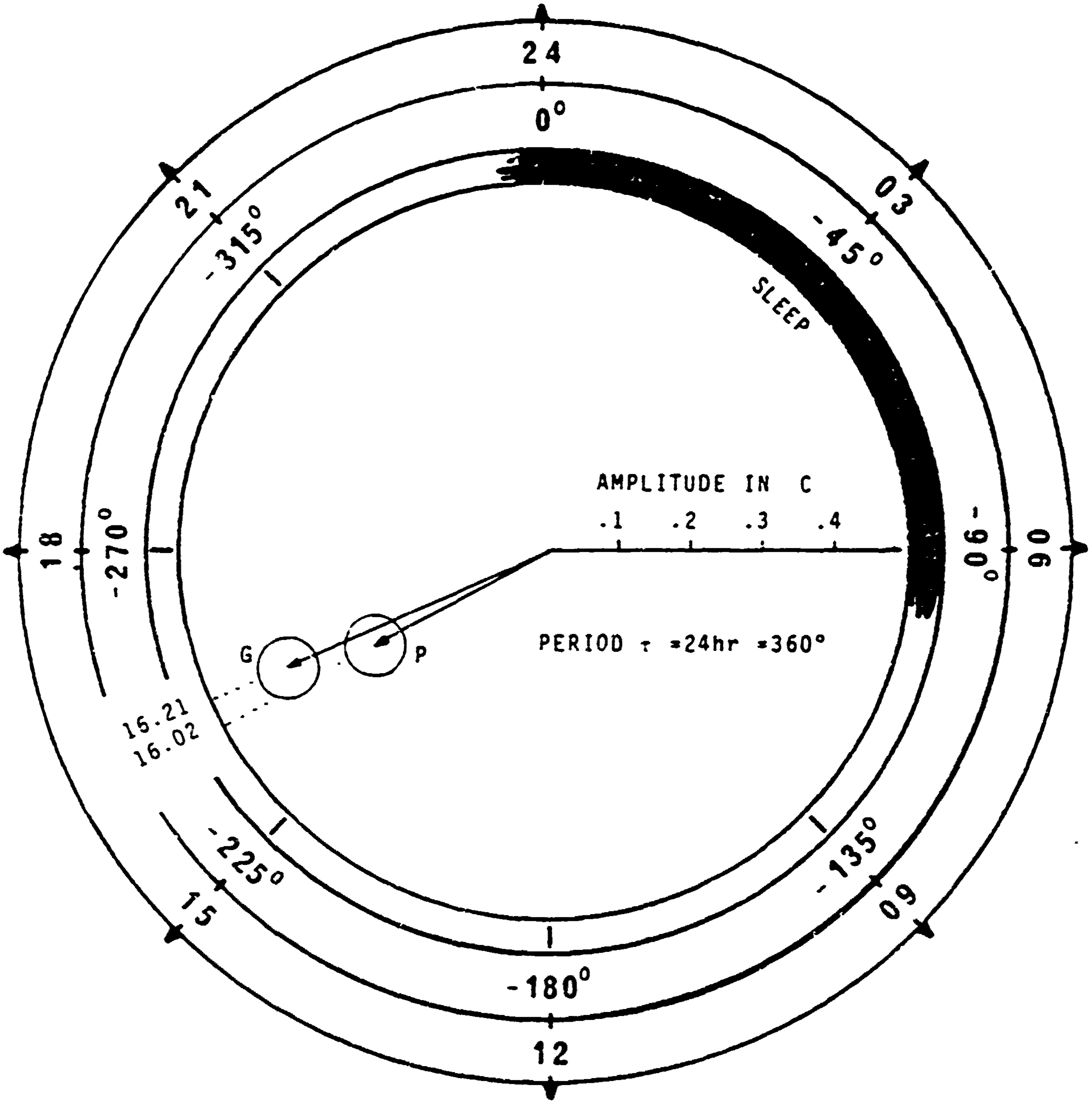
Subjects

Twenty-nine oil refinery operators on a rapidly rotating shift system (3-4 days) volunteered for this study. Four groups of subjects were formed:

Group I: 6 young operators with no previous complaints. Mean age = 25.3 years (range 21 to 35 years). Mean shiftworking duration = 2.3 years (range 1 to 4 years);

Group II: 10 senior operators with no history of shiftwork-related problems. Mean age = 50 years (range 44 to 57 years). Mean shiftworking duration = 25.1 years (range 15 to 32 years);

Group III: 6 senior operators with minor complaints such as feeling tired after the night shift, and poor sleep quality. Mean age = 50.2



ORAL TEMPERATURE CIRCADIAN RHYTHM
COSINOR SUMMARY
GOOD (G) AND POOR (P) TOLERANCE
TO SHIFT WORK

Figure 3. Cosinor plot of oral temperature rhythms of subjects with Good (G) or Poor (P) tolerance of shiftwork (Study 2): Circadian rhythms are detectable in both groups. Acrophases are similar, but amplitudes differ significantly (p <.001), confirming the impression gained from inspection of the curves in Figure 2.

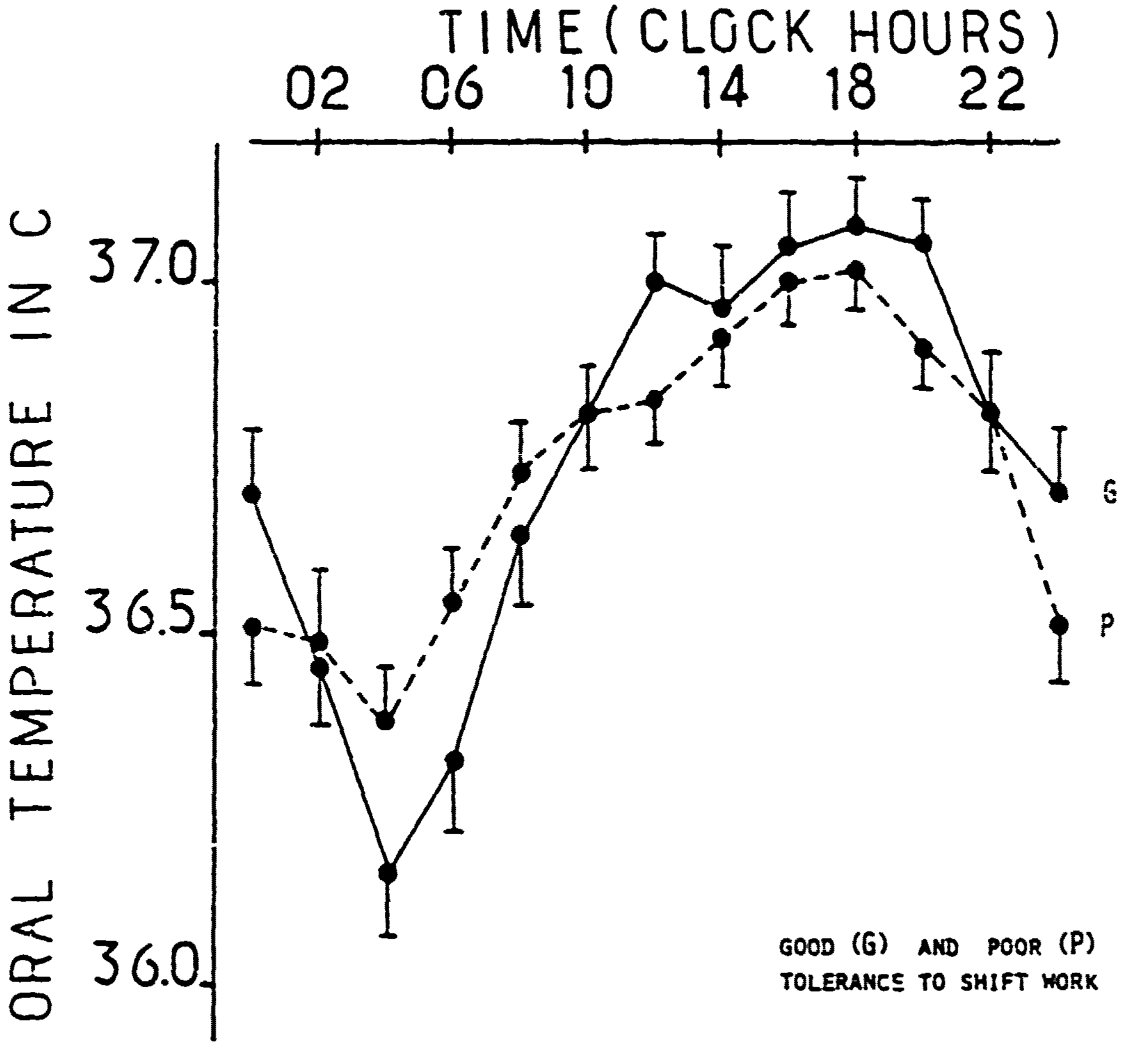


Figure 2. Circadian oral temperature rhythms of subjects with Good (G) or Poor (P) tolerance of shiftwork (Study 2): Means ± 1SE.

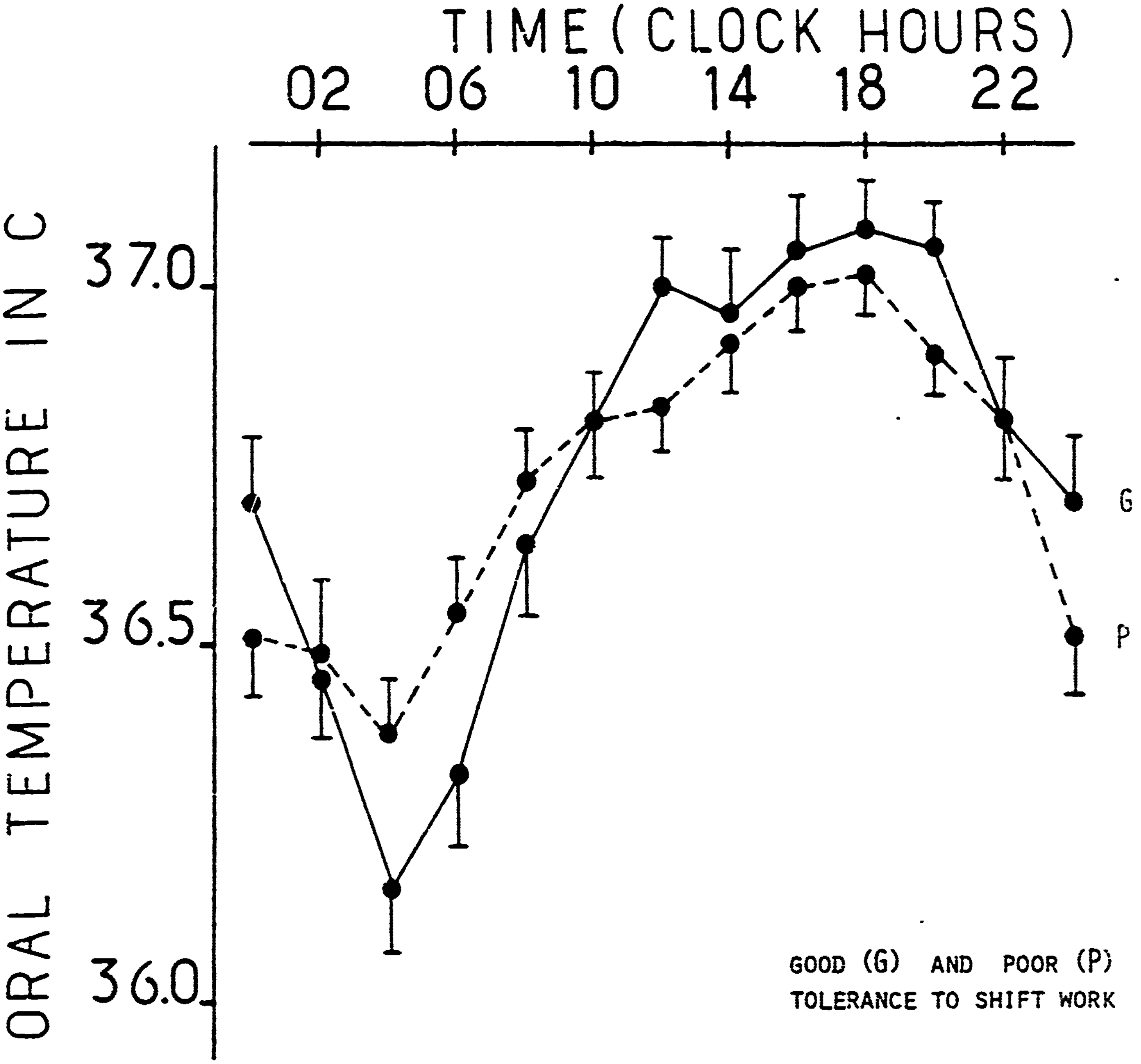


Figure 2. Circadian oral temperature rhythms of subjects with Good (G) or Poor (P) tolerance of shiftwork (Study 2): Means ± 1SE.

ORAL TEMPERATURE CIRCADIAN RHYTHM
COSINOR SUMMARY
GOOD (G) AND POOR (P) TOLERANCE
TO SHIFT WORK

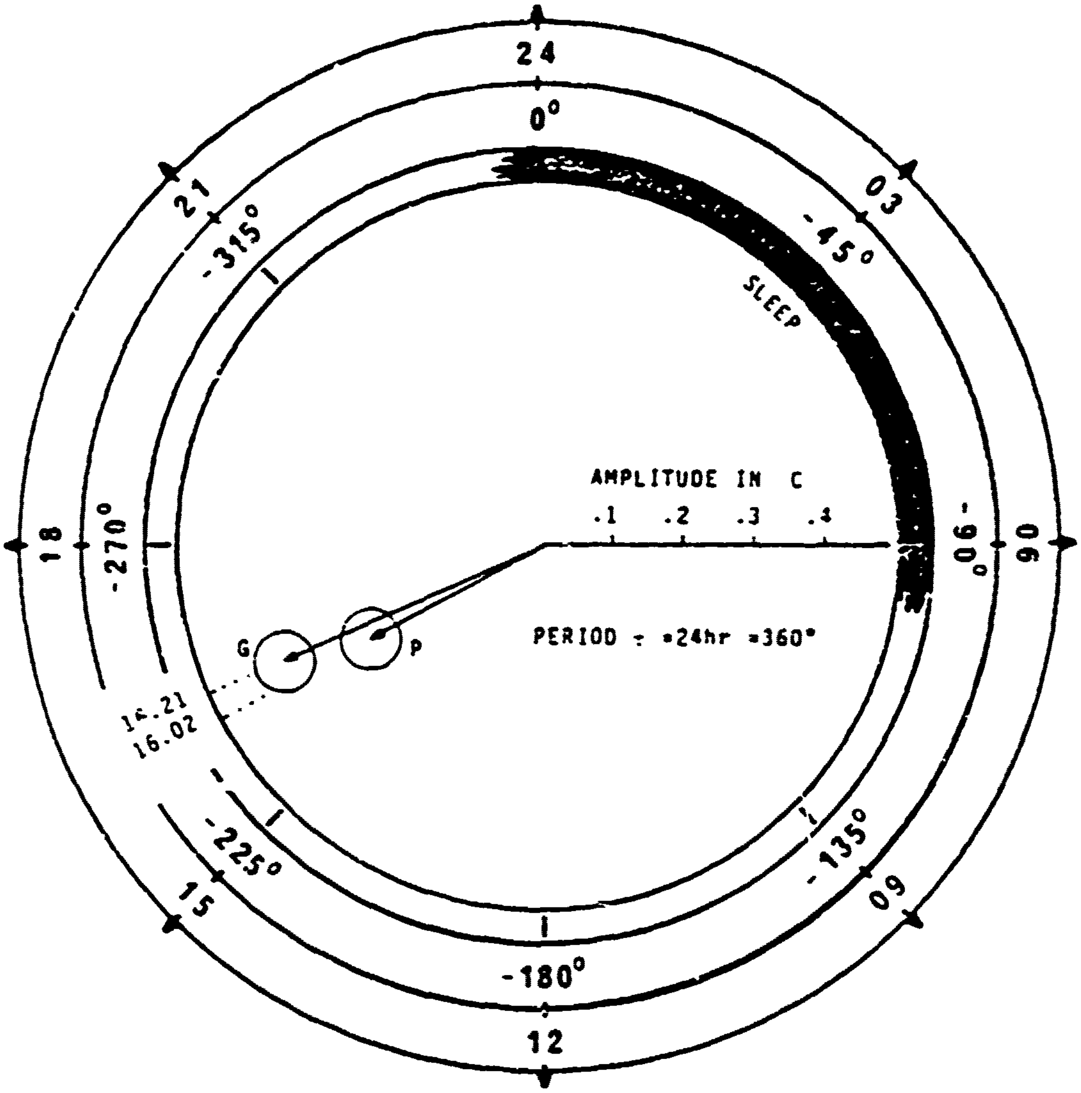


Figure 3. Cosinor plot of oral temperature rhythms of subjects with Good (G) or Poor (P) tolerance of shiftwork (Study 2): Circadian rhythms are detectable in both groups. Acrophases are similar, but amplitudes differ significantly (p <.001), confirming the impression gained from inspection of the curves in Figure 2.

years (range 46 to 56 years). Mean shiftworking duration = 26 years (range 22 to 31 years);

Group IV: 7 senior operators with major complaints such as persistent fatigue, large subjective deterioration in sleep quality, use of sleeping pills. Mean age = 47.4 years (range 30 to 56 years). Mean shiftworking duration = 22.9 years (range 9 to 29 years).

Senior operators' opinions and actions were a major determinant of their allocation to Group II, III, or IV. Those constituting Group III considered themselves capable of continuing shiftwork while those constituting Group IV had, in fact, already requested or agreed to be taken off shiftwork. [The salary of a shiftworker in this refinery was not reduced on resumption of regular day work; thus, there were no financial considerations in this decision.]

Methods

Oral temperature was measured every four hours at fixed clock times (except during sleep). Large clinical mercury thermometers (as in Study 2) were used.

For each of the 29 individuals, a longitudinal time series over 3 weeks (approximately 100 data points) was obtained, from which the oral temperature rhythm was assessed. As for Studies 1 and 2, various statistical methods were used to analyze the data.

Results

Hypothesis I. The relationship between A and $\Delta\phi$ for all the subjects in Study 3 is shown in Figure 4. As in Study 1, there was a significant negative correlation between the two variables, of a magnitude comparable to the one observed in that study. Hypothesis I is, thus, reconfirmed by the results.

Hypothesis II. Max-min Diff gives some idea of the differences in rhythm amplitude between the groups. The Max-min Diff was 0.80°C ± 0.04 (1 SE) for Group I; 0.76 ± 0.03 for Group II; 0.70 ± 0.05 for Group III; and only 0.48 ± 0.04 for Group IV. The difference between Group IV and Groups I and II combined was highly statistically significant ($p < .0005$). The mean rhythms for Group II and IV are shown in Figure 5.

The results obtained from a cosinor analysis are summarized in Figure 6 and Table 4. A statistically significant circadian rhythm was detectable in each of the four groups. The Mesor did not differ between the groups, being around 36.5°C and the acrophase locations were similar. The amplitude value was also similar in Group I, II, and III, but was significantly reduced in Group IV. Thus, the cosinor analysis shows that the only difference between subjects who are tolerant and intolerant of shiftwork is their temperature circadian A.

ORAL TEMPERATURE CIRCADIAN RHYTHM
COSINOR SUMMARY
SENIOR OPERATORS WITH GOOD (G:GROUP II)
AND POOR (P:GROUP IV) TOLERANCE
TO SHIFT WORK

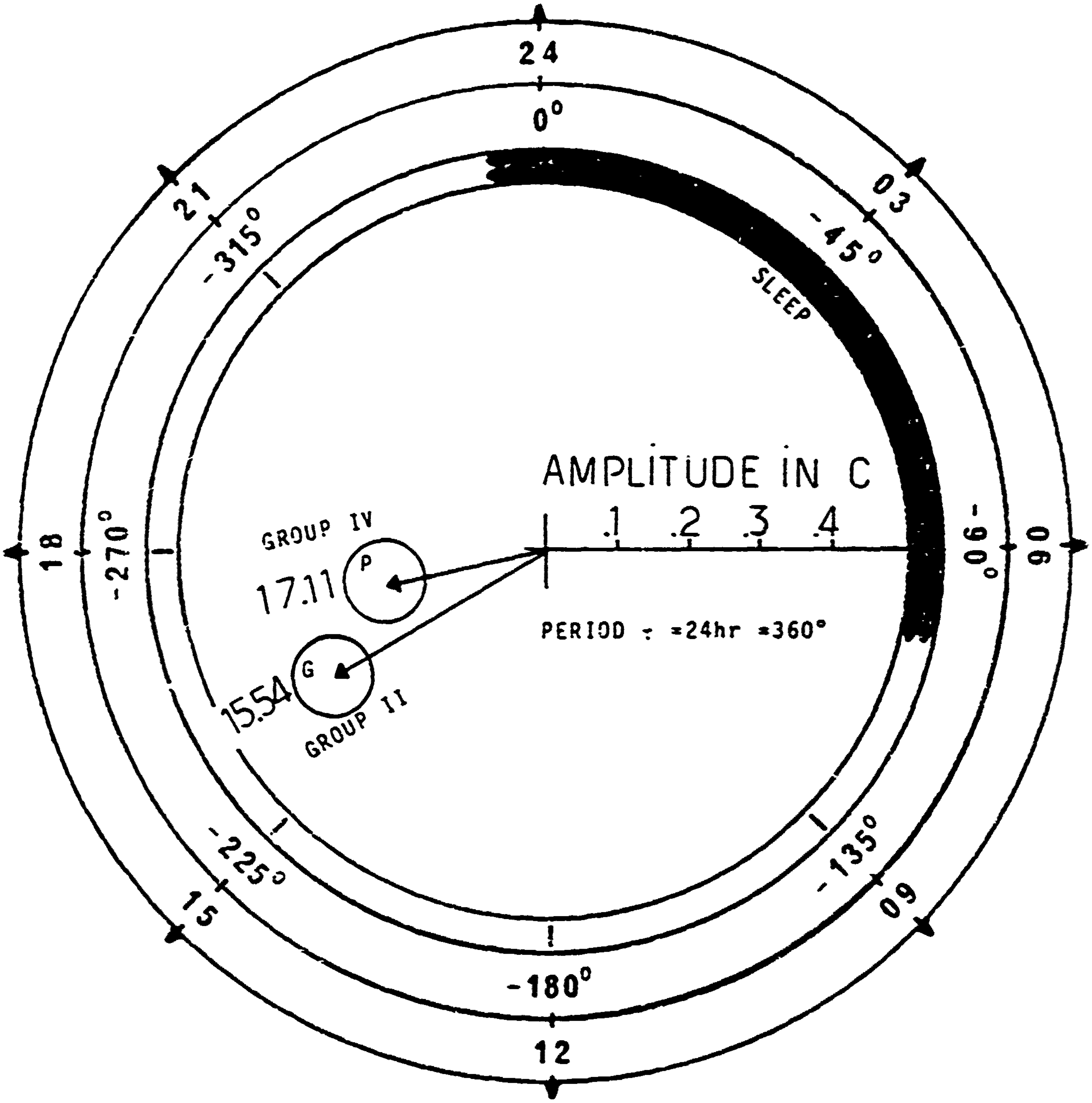


Figure 5. Circadian rhythms of oral temperature (Study 3): Senior operators with Good (G) tolerance of shiftwork (O) [Group II]; Senior operators with Poor (P) tolerance of shiftwork (O) [Group IV].

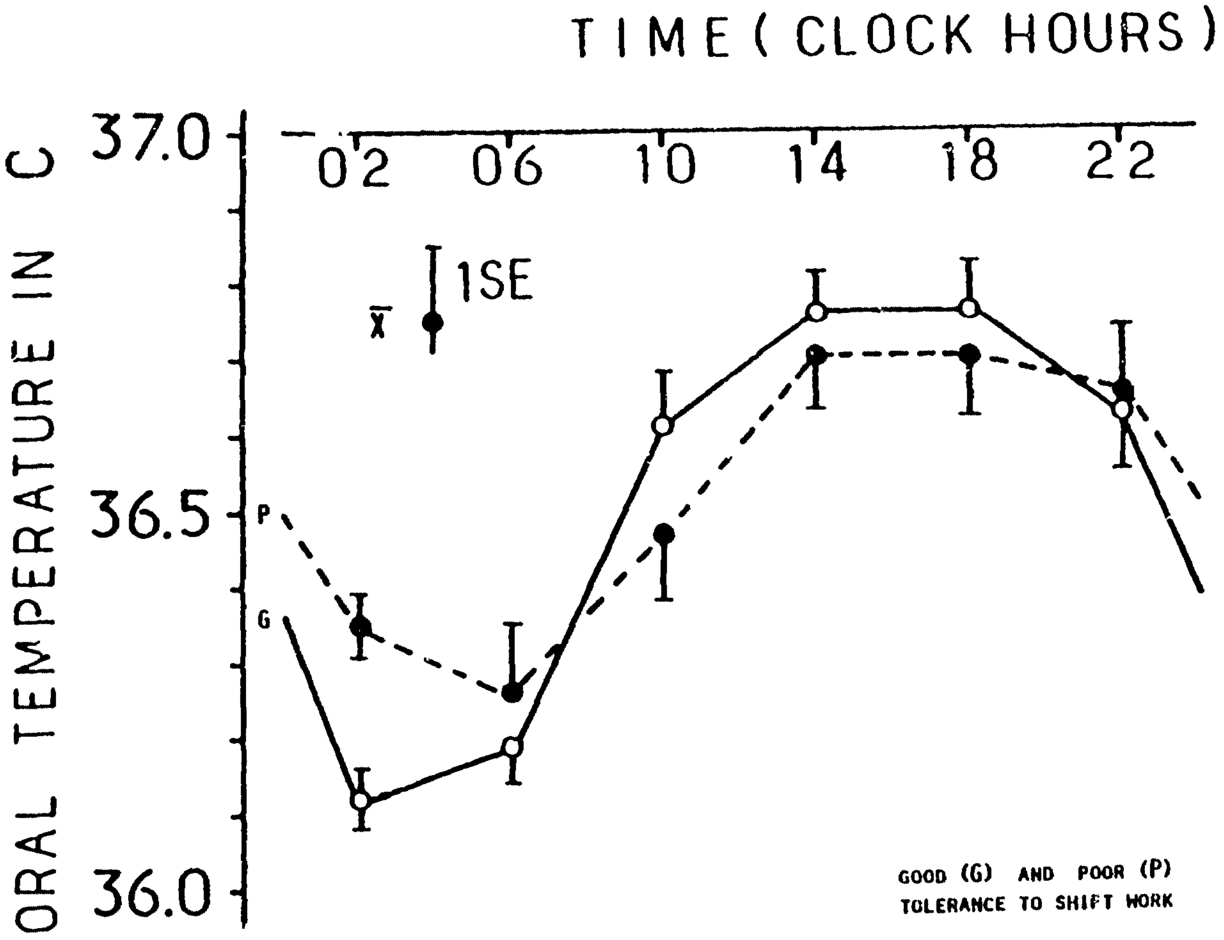


Figure 4. Correlation between individual mean amplitude ($\underline{A}$) and acrophase shift ($\Delta\phi$) of the oral temperature circadian rhythm (Study 3): Pooled data of the four groups.

ORAL TEMPERATURE CIRCADIAN RHYTHM
COSINOR SUMMARY
SENIOR OPERATORS WITH GOOD (G:GROUP II)
AND POOR (P:GROUP IV) TOLERANCE
TO SHIFT WORK

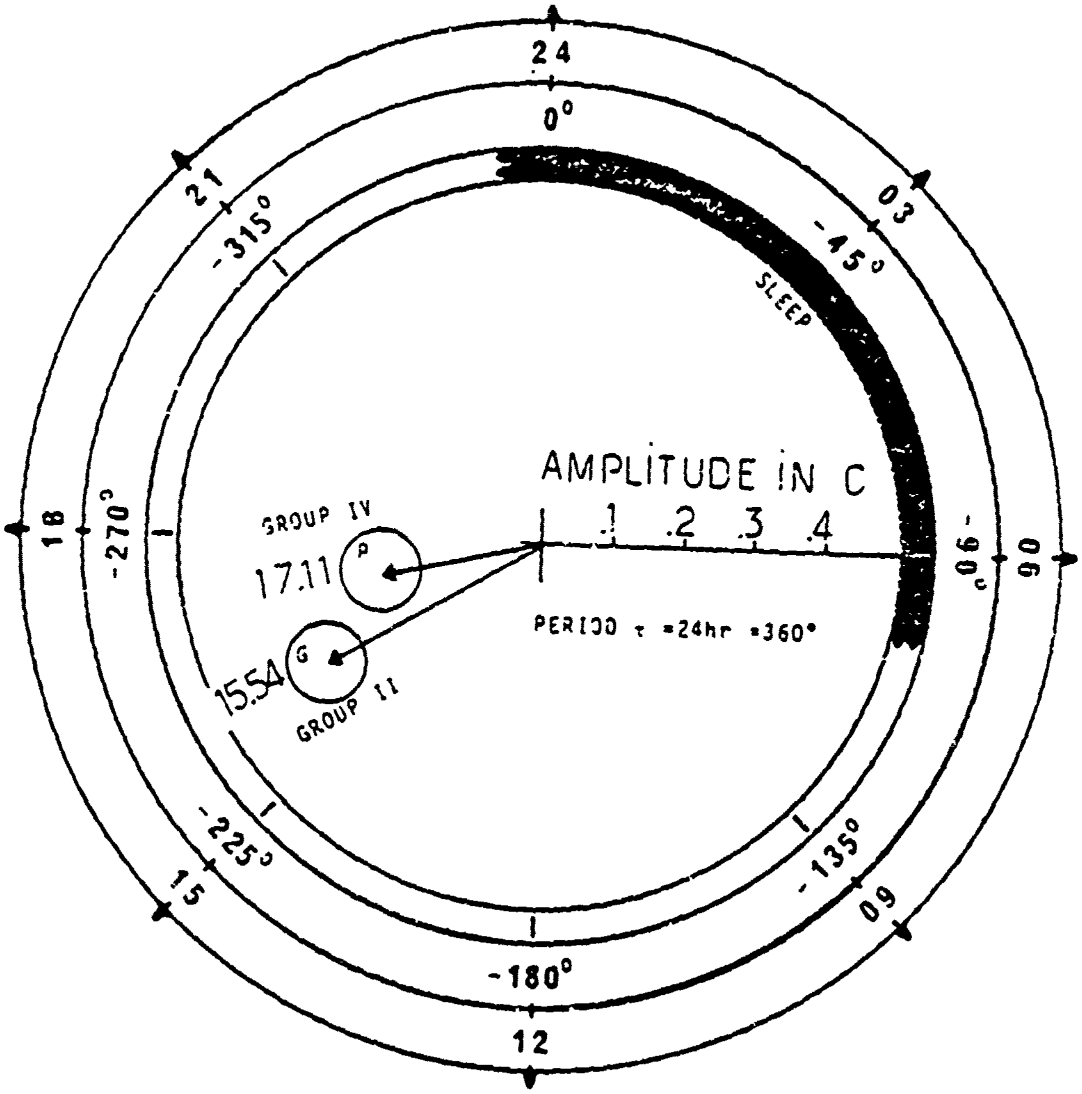


Figure 5. Circadian rhythms of oral temperature (Study 3): Senior operators with Good (G) tolerance of shiftwork (O) [Group II]; Senior operators with Poor (P) tolerance of shiftwork (O) [Group IV].

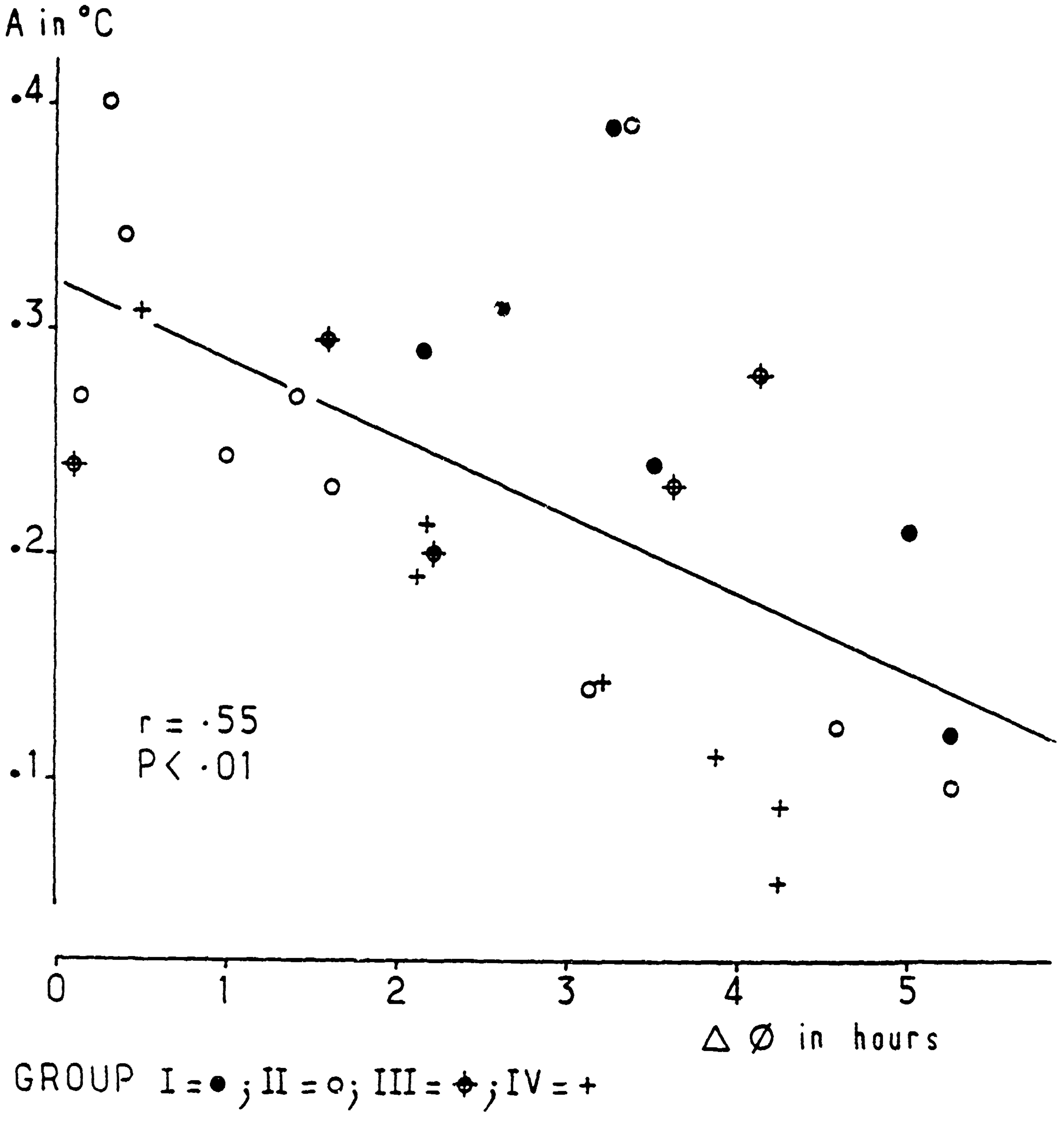


Figure 6. Cosinor plot of oral temperature rhythms of subjects with Good (G) and Poor (P) tolerance of shiftwork (Study 3): Circadian rhythms are detectable in both groups. Acrophases are similar, but amplitudes differ significantly (p <.01), confirming the impression gained from inspection of the curves in Figure 4.

Table 4

Summary of Cosinor Analysis of the Circadian Rhythms in Oral Temperature of Subjects With Good, Adequate or Poor Tolerance of Shiftwork

Group (Mean age in Years)	Tolerance of Shiftwork	Rhythm Detection P(A=0)	Mesor 1SE (°C)	Amplitude (°C) (95% confidence limits)	Acrophase (hr min) (95% confidence limits)
I (25.3)	Good (N=6)	<.005	36.53±.08	.37 (.29-.45)	15.49 (14.38-17.00)
II (50.0)	Good (N=10)	<.005	36.51±.07	.35 (.30-.40)	15.54 (15.21-16.27)
III(50.2)	Adequate (N=6)	<.005	36.53±.11	.30 (.24-.36)	16.57 (15.41-19.05)
IV (47.4)	Poor (N=7)	<.005	36.52±.12	.23 (.17-.29)	17.11 (16.07-18.14)

Results of Animal Experiments

The results obtained by Yunis, Halberg, McMullen, Roitman, and Frenandes, (1973) and Yunis, Fernandes, Nelson, and Halberg, (1974) with animals may have some bearing on the findings of the present studies. Yunis et al. assessed the circadian rectal temperature parameters $\underline{A}$ and ϕ in different strains of mice (mainly CBA and NZB) before, during, and after manipulations of the light-dark (LD) synchronizer, in animals of different ages. From their results, it can be deduced that autoimmune resistant mice of strain CBA adjusted slowly after a $\Delta\psi$ resulting from a LD cycle manipulation, and showed a relatively small decrease in the $\underline{A}$ of the temperature rhythm with age; whereas mice of strain NZB (who develop autoimmune hemolitic anemia, antinuclear antibodies and kidney lesions in their first year of life) adjusted rapidly after the same $\Delta\psi$ of the LD cycle, and showed a relatively large decrease in the circadian $\underline{A}$ with age. In addition, other results obtained by Yunis et al. suggested that both the speed of adjustment $\Delta\psi$ and the amplitude $\underline{A}$ of the temperature rhythm, as well as changes in these parameters with age were of genetic origin.

Comments

The results obtained from the present studies are in good agreement with each other. On the one hand, they show a correlation between $\underline{A}$ and $\Delta\phi$ of the circadian temperature rhythm, the greater the $\underline{A}$, the smaller the $\Delta\phi$. On the other hand, they show that good tolerance of shiftwork is associated with a relatively large $\underline{A}$ of this rhythm. Both of the hypotheses described in the introduction were thus confirmed.

In order to understand the relationship between the temperature circadian $\underline{A}$ and tolerance of shiftwork, the possible role played by age (and/or the number of years of shiftwork) must be taken into account. In these experiments,

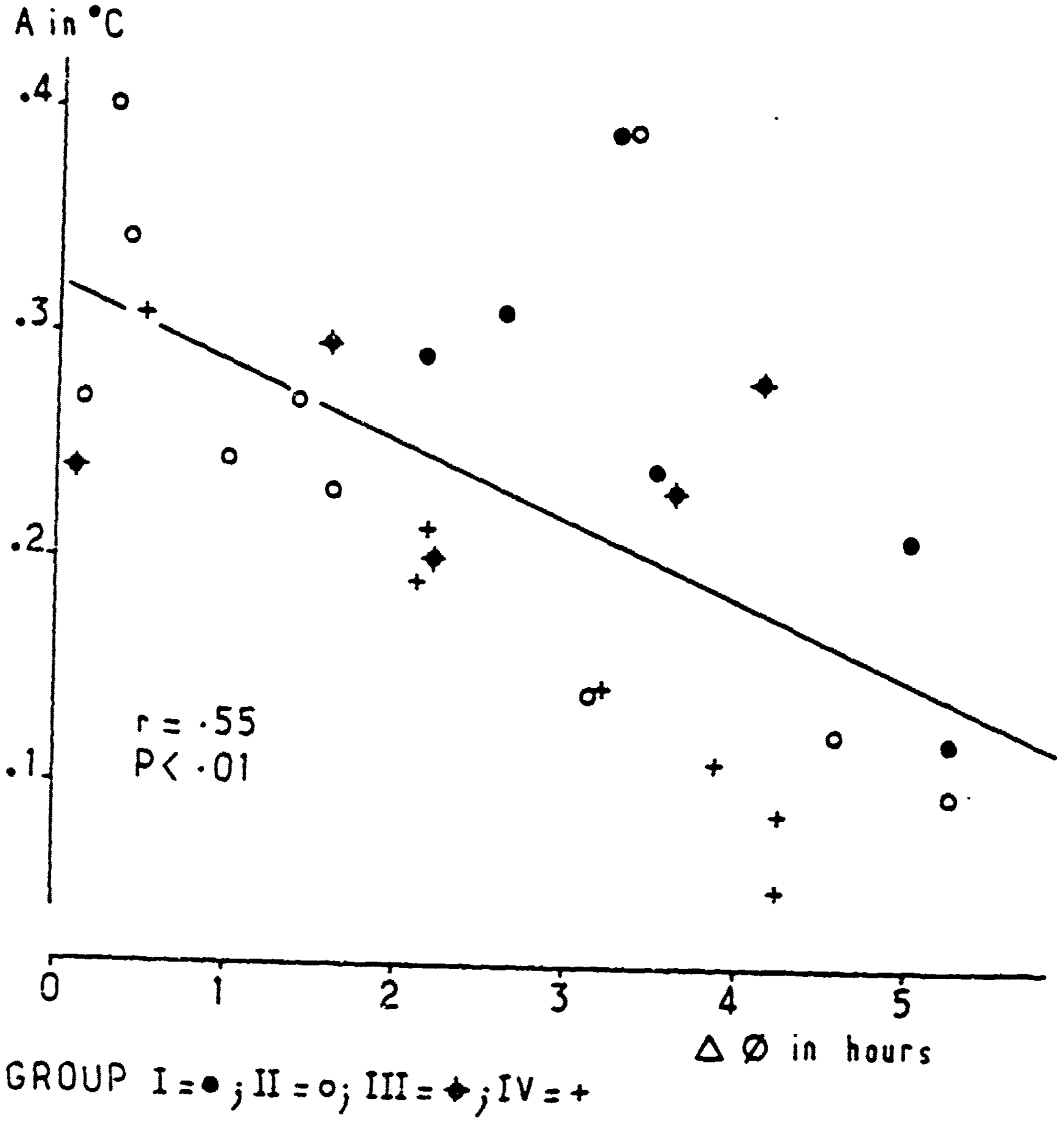


Figure 5. Cosinor plot of oral temperature rhythms of subjects with Good (G) and Poor (P) tolerance of shiftwork (Study 3): Circadian rhythms are detectable in both groups. Acrophases are similar, but amplitudes differ significantly (p <.01), confirming the impression gained from inspection of the curves in Figure 4.

we were dealing with subjects of both different ages and tolerance, and not with the effect of age per se. The animal model of Yunis et al. (1973, 1974) suggests that the age-related reduction of the circadian temperature A could be genetically dependent.

Further experiments will be necessary to test the hypothesis that human subjects with a relatively small A (whether resulting from aging or not) actually become intolerant to shiftwork. The possibility that an observed small A could in fact [illegible] produced by a history of poor tolerance of shiftwork should also be consi[illegible].

Practical Perspectives

If long-term tolerance of shiftwork is associated with a large A and a slow adjustment in the circadian temperature rhythm, shift schedules which do not allow subjects to adjust to a "new" synchronization would seem to be preferable. This means that, for encouraging such tolerance to develop, a rapidly rotating shift system (with shift changes every 2 to 4 days) would be a better choice than the conventional weekly rotating system.

However, it should be kept in mind that in the studies reviewed (Reinberg et al., 1978a,1978b,in press; Andlauer & Reinberg, in press), the shiftworkers did in fact adjust rapidly, as a group. This ability may be related to the age of the subjects, who in both studies were relatively young (means 34.5 and 24.4 years), and it seems that adjustment is faster in younger than in older shiftworkers. In addition, the samples of subjects were less homogeneous than expected with respect to long-term tolerance of shiftwork. We were, in effect, dealing with an already selected group of "tolerant" shiftworkers (tolerance being defined in this case as having had less than 10 years of this type of work, which was true for 23 of the 26 subjects). Intolerance of shiftwork may only be revealed later (as seen in the subjects of Group IV in Study 3). Thus in considering the findings, the ability to adjust rapidly seems, if anything, to be an advantage in a young subject, but of no help in predicting whether or not he will tolerate shiftwork for 20 years or more. Nonetheless, the amplitude of the circadian temperature rhythm appears to be a good candidate for a chronobiological index of long-term tolerance of shiftwork. Obviously, further studies are needed to assess the practical applicability of these findings.

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SLEEP-WAKE, ENDOCRINE AND TEMPERATURE RHYTHMS IN MAN DURING TEMPORAL ISOLATION

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In 1729 de Mairan first reported to the French Royal Academy of Sciences in Paris, that a biological organism (a "sensitive plant") would continue to have a 24 hour rhythm of activity when light-dark entraining stimuli were absent. De Candolle, in 1832 first described a free-running rhythm in the same species of plant with a progressive phase advance of 1.5 to 2 hours per day. Subsequent studies have demonstrated that organisms not entrained by 24 hour "zeitgebers" (time cues), develop daily cycles with periods greater or less than 24 hours (Pittendrigh, 1961). Extensive research in animals utilizing a rest-activity measurement has demonstrated that these "free-running" period lengths are species-specific and genetically influenced. When an animal is maintained in constant conditions the new cycle length can be remarkably constant for months to several years (Daan & Pittendrigh, 1976; Pittendrigh & Daan, 1974; Pittendrigh & Daan, 1976a; Pittendrigh & Daan, 1976b). In 1962, Aschoff and Wever did their studies on three men and three women living for 8 to 19 days in a "deep cellar" in Munich, and first demonstrated that normal man would also maintain a "circadian" activity-rest cycle which would "free-run" with a non-24 hour period when isolated from all time cues. Many subsequent studies have repeatedly confirmed those observations in man (Mills,1966; Mills, 1974; Mills, Minors, & Waterhouse, 1974; Mills, Minors, & Waterhouse, 1976), and have extended the measurements to include body temperature, urinary electrolytes and certain hormonal metabolic products (Aschoff, 1967; Aschoff, 1969; Aschoff, 1970; Aschoff & Wever, 1976; Aschoff & Wever, 1976; Aschoff, Gerecke, & Wever, 1976). In almost all instances of several hundred such studies now performed (Chouvet, Mouret, Coindet, Siffre, & Jouvet, 1974; Jouvet, Mouret, Chouvet, & Siffre, 1974; Siffre, 1965; Siffre, Reinberg, Halberg, Ghata, Perdriel, & Sling, 1966; Webb & Agnew, 1972; Webb & Agnew, 1974a; Webb & Agnew, 1974b) including cave and controlled laboratory environments, the period length of such activity-rest rhythms have been greater than 24 hours, typically occurring at approximately 25 hours. Important conclusions have been arrived at, such as the change of phase angle relationship between body temperature and rest time (Aschoff et al., 1976; Chouvet et al., 1974; Jouvet et al., 1974; Siffre, 1965; Siffre et al., 1966; Webb & Agnew, 1972; Webb & Agnew, 1974a; Webb & Agnew, 1974b; Wever, 1973), the ability of different variables to develop independent cycle lengths during free-running (Aschoff, 1973; Aschoff, Gerecke, & Wever, 1967), and the concept of multiple oscillators normally synchronized with each other but which can become desynchronized under free-running conditions (Wever, 1975; Wever, 1977). The importance of "social" entraining rather than light-dark cues for man has been emphasized (Aschoff, Gerecke, Kureck, Pohl, Reiger, Saint Paul, & Wever, 1971), and in some subjects the ability to develop and sustain very long rest-activity periods (between 30 and 50 hours in length) has been recognized (Mills et al., 1974; Aschoff, 1967; Chouvet et al., 1974; Jouvet et al., 1974; Findley, Mialer, & Brady, 1963).

It has been assumed until recently that the "rest" segment is a sleep period in these studies determined either by "lights out", absence of activity, or "bed-rest" time. Except for the cave studies of Jouvet et al. (1974), and the short "isoloation" studies of Webb et al. (1972; 1974a; 1974b), systematic studies of the temporal complexity of polygraphically defined sleep stages have not been reported. Analysis of the previously reported detailed sequential durations of the "rest" (selected lights out) time indicates that a significant day to day variability is present in almost all subjects, suggesting that interval sleep stage amounts and timing may be related to such variability. The previous assumption that "rest" is sleep cannot be made. These events alter biological rhythm cyclic properties and will influence other correlative measured periodic events such as body temperature and hormonal cycles. All previously reported studies have maintained subjects in time-free environments totally isolated from direct human contacts during the duration of their stay. We considered it important to study subjects in temporal isolation but with human social communication. This has the major advantage of allowing us to make certain biological measurements and psychological observations not possible with the previous constraints. Finally, all previous studies of hormonal cycles in temporal isolation studies have only used urinary measurements of derived metabolic products (Aschoff & Wever, 1962; Aschoff, 1967). In a series of recent studies (Weitzman, Schaumburg, & Fishbein, 1966; Weitzman, Fukushima, Nogeire, Roffwarg, Gallagher, & Hellman, 1971; Weitzman, Boyar, Kapen, & Hellman, 1975; Weitzman, 1976; Hellman, Nakada, Curti, Weitzman, Kream, Roffwarg, Ellman, Fukushima, & Gallagher, 1970), we had developed methods of obtaining frequent plasma samples, and demonstrated that important relationships exist between hormonal blood concentrations, sleep, and sleep stages.

We have carried out detailed and prolonged measurements of sleep-waking function in human subjects for time periods ranging from 25 days to 6 months. We measured polygraphic sleep-stage characteristics, minute by minute body temperatures and frequent (approximately 20 minutes) blood sampling for cortisol and growth hormone in normal adult men living in an environment free of all time cues, under entrained, free-running and re-entrained conditions. The results described are part of a comprehensive multi-variable study of the chronophysiology of man living in a time free environment with a non-scheduled daily pattern of living.

Methods

A special environment was established where the individual subjects lived for many weeks. A three room apartment (study, bedroom, and bathroom) was arranged without windows, the walls sound attenuated and a double door entrance to the temporal isolation facility (TIF). A closed circuit TV system and voice intercom monitored the subject's activities.

Ten male subjects were individually studied. The first group (3 subjects, FR 1, 2, & 3) was studied for 15 calendar days and the second group (6 subjects, FR 4, 5, 6, 7, 9, & 10) for 25 calendar days and a single subject (PR 1) for an extended stay of 105 calendar days. No subject had significant psychopathology, medical illness, nor were any on drugs. Each subject kept a written daily diary of sleep times for at least 2 weeks and maintained a regular scheduled sleep-wake schedule in accord with their usual habits. After entry in the TIF, an entrained condition of 3 or 4 scheduled 24 hour sleep-wake periods preceded the non-scheduled "free-running" portion of the study. The entrained clock times was determined by the subject's recorded habitual lights off-lights on time at home. The subject was told that his sleep time would be scheduled for certain portions of the study but was not advised of the clock times nor the duration. Following the entrained portion, each subject was told that he could choose to go to sleep and awaken at any time he wishes. He was not allowed to "nap". A decision to go to sleep, therefore, represented the sleep period for that biologic "day". Food was available to the subject on demand as breakfast, lunch, dinner, and a "snack". The subject could request any meal type at any time. A set of buttons were available which when pushed were coded on a paper punch tape and indicated the behavior the subject was about to initiate and the elapsed time (to the nearest minute) from the beginning of the study. These behaviors included meal and type, sleep time, awake time, urinating, taking showers, defecating, taking blood samples, and exercising. The paper punch tape structured the entire time series of each study.

The subject was totally isolated from contact with all non-laboratory persons but communicated by intercom and direct discussion with selected laboratory staff. The supervising staff members were scheduled on a random basis as to time of day and duration of work-shift to prevent the subject from obtaining time cues.

The following measurements were made for each subject:

(1) Polygraph-Sleep Recording—The interval between the subject's decision to sleep and light-out with full electrode application for polygraphic recording was less than 15 minutes. All polygraphic records were scored by standard methods (Rechtschaffen & Kales, 1968).

(2) Rectal Temperature—A rectal thermistor probe was maintained by each subject throughout the entire study except for brief daily periods of defecation. The temperature was automatically recorded every minute on the punch paper tape and a print-out.

(3) Plasma Cortisol and Growth Hormones—A catheter with 3 holes at the tip instead of the usual one, was inserted into an arm vein of nine subjects at the start. At approximately 20 minutes, sampling of blood was obtained. This venous catheter was changed at 2-5 day intervals using alternating arm veins without interrupting the sampling. Subject PR 1 did not have blood samples obtained. Plasma cortisol assays were performed using the competitive protein binding technique (Murphy, Engelberg, & Pattee, 1963). The samples were assayed in duplicate using 25ul aliquot for each assay. HGH was assayed in duplicate from each plasma sample by radioimmunoassay using 20ul of plasma for each assay.

(4) Polygraphic Data Scoring—All scored data were transferred to a computer compatible format and analyzed for total sleep, lights out, and all sleep stages for each lights out-sleep period. The pattern of sleep stage sequences was visualized by a special display program. A quantitative determination was made for a set time period of the percent of each sleep stage and waking. The result of that analysis was also displayed utilizing a computer plotting technique.

(5) Special Mathematical Techniques and Computer Algorithms—In addition to the usual statistical method of analysis and computer plotting and display routines, several mathematical techniques were created to assist in the analysis of the data. These include a) estimate of period length using a minimum variance fit, b) wave form eduction and c) averaged time locked response.

Results

Activity-rest Cycle and Sleep Stages

Each of the 10 subjects developed a free-running sleep-wake cycle following the entrained baseline condition. In each case the mean period length was longer than 24 hours (Table 1). The subject population was divided into two types (excluding the tenth subject (PR 1)). In Type A, (6 subjects - FR 1, 2, 5, 6, 7, 9) the period lengths during FR averaged between 24.4 and 26.2 hours, whereas Type B (3 subjects, FR 3, 4, 10) had consistently long periods greater than 37 hours. The lights-out period for the Type B subjects ranged from 8 to 20 hours, with an average of 14 hours. Linear regression analysis through mid-sleep times demonstrated a very stable period length, (r^2.99 for each).

Table 1

Total Sleep Time (Mins) REM % and 3 + 4% of Total Sleep
Time of Subjects During the Three Experimental Conditions

Entrained	FR 1	FR 2	FR 3	FR 4	FR 5	FR 6	FR 7	FR 9	FR 10
TST	435	398	466	448	443	446	390	423	401
REM %	28%	18%	30%	13%	26%	24%	21%	19%	15%
3 + 4%	18%	18%	25%	27%	24%	26%	39%	28%	36%
Free-running									
TST	483	376	830	770	445	448	373	364	584
REM %	25%	22%	28%	15%	26%	25%	25%	17%	15%
3 + 4%	25%	24%	19%	17%	26%	34%	31%	37%	33%
Re-entrained									
TST				454	412	397	366	398	
REM %				15%	26%	25%	24%	14%	
3 + 4%				24%	25%	41%	31%	35%	

Short sleep periods recurred at a regular phase of the circadian cycle with a period slightly longer than 24 hours. The long sleep periods began at a phase angle approximately 180 degrees shifted from that of the short sleep periods.

Variation in sleep lengths were related to the phase of the ongoing circadian oscillation at which the sleep period occurs. When prior wakefulness lasted more than 1440 minutes, there was a clear increase of sleep length with episodes lasting 600 to 1200 minutes.

Subject PR 1, the 10th subject, lived under "free-running" condition for 80 calendar days and demonstrated several important features. He maintained a regular free-running period length of approximately 25 hours for the first 30 activity-rest cycles. He then developed an activity-rest cycle pattern consisting of alternating long cycles (36 hours) with a series of shorter cycles (approximately 25 hours). This alternating pattern persisted until it was interrupted by a special light-dark entrainment protocol on calendar day 84. The sleep time continued on an approximately 25 hour period length in spite of the interruption by very long non-circadian periods. These approximately 25 hour self-selected sleep-wake times were therefore entrained to an internal periodic process, which can be considered an "internal zeitgeber". The long sleep periods (600 minutes) occurred at a phase angle approximately 180 degrees shifted from the short sleep periods but in parallel with the same period-length mid-sleep regression line. Analysis of the relationship between length of sleep period and length of prior wakefulness demonstrated that for only 7 out of 16 waking periods lasting greater than 20 hours, did the subsequent sleep period exceed 12 hours in length. However, as was the case for the other subjects, no long sleep period was preceded by a wake period less than 20 hours in length.

There was a rapid phase delay of lights-out and sleep onset of at least 6 hours within 48 hours of the onset of the free-running condition for 8 of the 9 subjects. The ninth subject (FR 7) delayed his sleep onset by 5 hours on the third biologic day. In addition, all 6 subjects in Group A had a characteristic "scalloped" appearance of the timing of lights-out with a variable cycle of 3-4 days. This could not be explained as a "transient" process related to the onset of FR since it clearly continued throughout the FR condition in four subjects (FR 2, 5, 7, 9).

The lights-out period in general corresponded with the sleep period for each subject and for each night. However, it was found that at times, there was a short delay from lights-out to sleep onset. The two older subjects (ages 50, 51) (FR 9 and FR 10) consistently interrupted their sleep periods by awakening for short periods during the subjective night as well as remain awake in the dark for periods up to one hour after awakening and prior to signaling "lights on". These waking interruptions were also present during the entrained segment as well. These findings emphasize the importance of defining sleep stages polygraphically when measurements of biological ryhthm variables are made.

There was considerable variability in the mean total sleep time (TST) during FR with two subjects averaging 13.8 and 12.8 hours (FR 3,FR 4)(Table 1). In spite of this variability in total sleep time per sleep period during FR, the ratio of sleep time to period length only varied between .24 and.35 across subjects with an average of .29. This compared with .30 during the entrained condition. When the entrained ratio was compared to the FR ratio for each subject, it was noted that two subjects with high entrained ratios (long sleepers)(.31 and .32) increased the value to .35 and .34 respectively, during free-running, whereas four subjects with the lowest entrained ratios (.27, .28, .29, and .29) (short sleepers) all decreased the ratio to .25, .25, .24, and .25, respectively, during FR. The 3 other subjects with intermediary entrained values had little change during FR (Figure 1).

The sleep stage characteristics for all subjects were compared as a function of sequential experimental nights during the three experimental conditions (Entrained, Free-running, and Re-entrained). The values of REM% of TST were remarkably constant throughout and did not differ significantly as a function of experimental conditions (Table 1). The Stages 3+4% of TST did increase to a small extent from the entrained (27.8%) to the FR (29.8%) condition, especially during the last 6 FR sleep periods (Table 1). A small average increment occurred during the five re-entrainment nights (32.2%) for 5 subjects.

An interesting result was obtained when comparisons were made for REM% of TST, by subject and by experimental condition (Table 1). There was considerable variability in REM sleep across subjects (range 15 to 30%), during the entrained period. However, the intra-subject variability was very small as a function of experimental conditions. This was not the case for Stages 3+4 since both the inter- and intra-subject variability was similar in all 3 experimental conditions. These results indicate that each subject maintained an individual control of REM% of sleep time which was independent of the entrained or free-running state. This does not appear to be the case for Stages 3 and 4 sleep.

Three subjects (FR 3, 4, & 10) consistently had long sleep periods associated with long sleep-wake cycle lengths. There were a total of 26 sleep periods lasting 12 hours or longer. These long sleep periods differed from the short sleep periods. The timing of the onset of these long sleep periods occurred at a different phase of the subjects circadian temperature rhythm(130 degrees to 270 degrees, 0 degrees = mid-trough) than the onset of the short sleep periods (270 degrees to 120 degrees). In addition, during the long sleep episodes, sustained Stages 3 and 4 sleep would characteristically occur between 12 and 18 hours after sleep onset. However, the first 4 hours of the long sleep periods did not differ significantly in regard to the characteristic timing and amount of Stages 3 and 4 sleep seen under entrained conditions. Thus, despite normal amounts of 3-4 sleep present at the onset of these long sleep periods, Stage 3-4 would reappear after 12 to 16 hours of sustained sleep (Figure 2). Although occasional awake episodes interrupted these long sleep times, (especially for subject FR 10) they were not sufficiently long to explain the reoccurrence of Stages 3 and 4.

Another characteristic difference between the long and short sleep periods was the timing and amount of REM sleep within the first 3 hours after sleep onset (Table 2, Table 3). All of the sleep periods which had a very small REM latency (20 minutes) were short sleep periods during the FR conditions. The mean REM latency (sleep onset to onset of first REM period) clearly decreased for 9 of the 10 subjects(FR 9 was the exception) comparing entrained to the free-running condition. A partial recovery took place during the re-entrainment conditions. In addition, the mean total minutes of REM sleep in the first 3 hours of sleep increased for 8 of the 9 subjects (subject FR 9 excepted) between entrainment and free-running. However, during re-entrainment

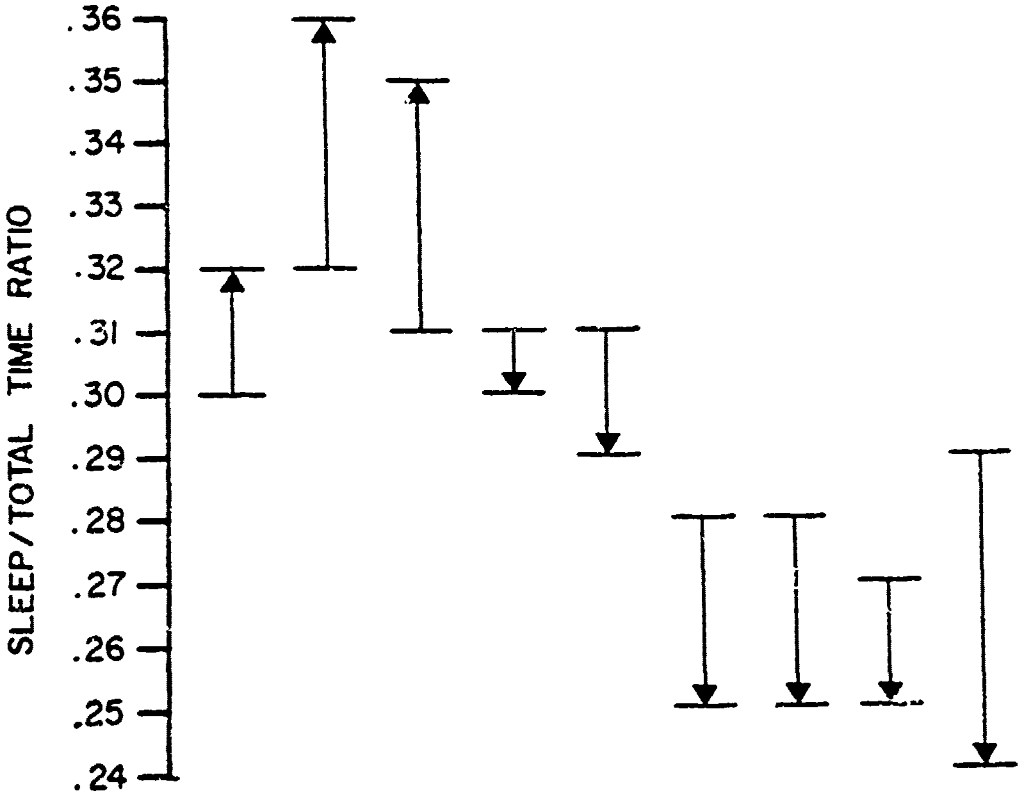

Figure 1. Sleep to total time ratio for each of the 9 subjects. The arrows indicate the change from baseline entrained to the Free-running condition.

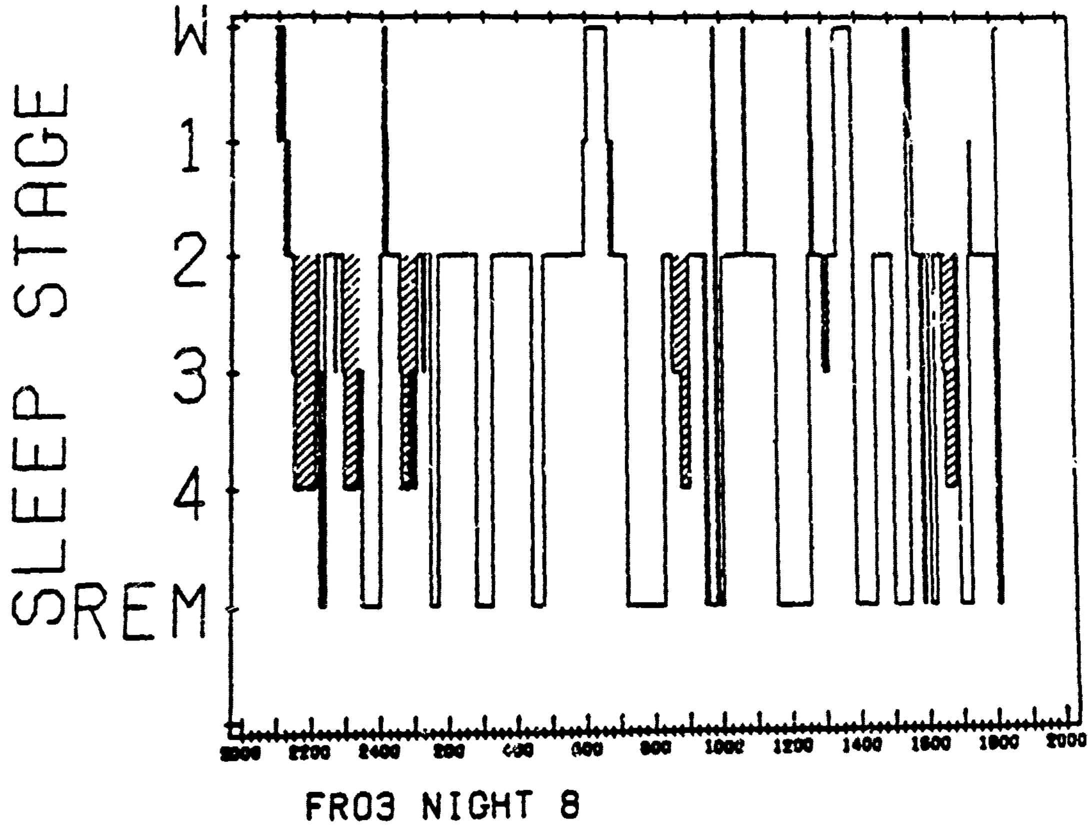

Figure 2. Reappearance of Stages 3 and 4 sleep during a long sleep period (greater than 21 hours) in subject FR 3 on Free-running Sleep period 8.

Table 2

REM Latency (Mins) and REM Time (Mins) During First Three Hours After Sleep Onset of Subjects During Experimental Conditions

Entrained	FR 1	FR 2	FR 3	FR 4	FR 5	FR 6	FR 7	FR 9	FR 10
REM Lat.	78	127	95	94	79	109	72	52	66
REM Mins	15	21	15	7	15	7	13	23	11
Free-running									
REM Lat.	59	70	73	64	57	87	61	56	52
REM Mins	43	37	24	15	36	28	28	23	18
Re-entrained									
REM Lat.				79	72	90	74	64	
REM Mins				14	26	23	34	19	

Table 3

Mean REM Latency and Sleep Period Duration During Free-Running for Four Subjects

	Long Sleep Periods			Short Sleep Periods		
Subject	N	REM Latency	Sleep Duration	N	REM Latency	Sleep Duration
FR 3	4	73.3	1071	3	72.0	591
FR 4	7	67.0	867	2	53.0	637
FR 10	7	65.7	816	5	31.6	406
PR 1	7	57.2	850	6	47.0	491

these values did not return to baseline. The timing and amount of REM sleep during the first 3 hours after sleep onset in PR 1 was determined during the free-running condition when he had the alternating long and short sleep-wake cycles. We determined the mean total sleep duration on sleep periods with short (< 30 minutes) and long (> 30 minutes) REM latency and on sleep periods with REM amounts greater or less than 30 minutes during the first 3 hours following sleep onset (Table 4). We found a statistically significant difference ($p < .025$) with the longer sleep periods associated with less REM sleep and the shorter sleep periods associated with more REM sleep during the first 180 minutes after sleep onset. A similar difference was also found for REM latency but this was not statistically significant ($p < .2$). In addition, all the nights with a short REM latency (< 10 minutes) and the nights with more than 30 minutes of REM sleep in the first 3 hours except one occurred within 90 degrees of the nadir (0 degrees) of the circadian temperature rhythm. In addition, for 12 REM onsets which occurred within 10 minutes of sleep onset, 11 occurred within 60 degrees of a specific phase (mid-trough) of the circadian temperature rhythm.

Table 4

Relationship of Total Sleep Duration to REM Latency and REM Amounts During the First 180 Minutes Following Sleep Onset for 67 Circadian Days of "Free-Running" Sleep-Wake Cycling During Temporal Isolation in Subject PR 1

	REM Latency		REM Amount During First 180 Minutes	
	< 30 Mins	> 30 Mins	< 30 Mins	> 30 Mins
Number of Sleep Periods	27	41	40	28
Mean Amount (Mins ± S.D.)	8.2±6.6	74.2±13.0	20.1±6.0	45.7±10.9
Mean Total Sleep Duration (Mins ± S.D.)	500±128 ←**→	547±138	555±136 ←*→	480±121

* $p < .025$ ("T" Test)
** $p < .20$ ("T" Test) Not Significant

An analysis was made of REM-non-REM sleep cycling during the different experimental conditions. The latency in minutes from sleep onset to first mid-REM period, first mid-REM to second mid-REM, etc., was determined. It was found that except for a shortened latency from sleep onset to the mid-first REM period during free-running there were no differences in cycle lengths as a function of experimental condition. There was a consistent decrease in cycle length for the fourth and fifth cycle for each condition. The sleep cycle length remained stable ($\bar{x}$ 85 minutes) for up to 11 cycles during the long sleep periods (> 10 hours). Thus, there is no evidence that sleep stage cycle length is altered by the increased sleep-wake period length during free-running conditions. In addition, previous reported results (Feinberg, 1974) of a stable but slightly reduced cycle length when sleep is extended, are confirmed by these data for those long sleep periods which extend from 10 to 20 hours.

Body Temperature Rhythm

The mean core (rectal) temperature for all subjects as a group was essentially the same in all three conditions. However, for each subject in Group A there was an increase in the mean temperature during FR whereas there was a decrease for each subject in Group B. During re-entrainment, the mean value of most subjects had returned to that of the entrained section.

During the entrained condition, the rectal temperature curve (values obtained every minute) demonstrated the well described sharp fall (1-2 degrees F) following sleep onset (Aschoff, 1970; Aschoff et al., 1976; Timball, Colin, Boutelier, & Guieu, 1972). A small decrease in temperature typically occurred at approximately 3 hours before sleep onset with a sharp elevation of temperature at the end of the sleep period. During "Free-Running" for all subjects in Group A a change in both phase and shape of the curve occurred (Wever, 1973) (Figure 3). The temperature began to decrease 6 to 8 hours prior to sleep onset. At the time of choosing sleep the body temperature was close to the lowest value of the circadian rhythm. An additional small fall of temperature (0.5 degrees F) took place just after sleep onset during FR. During re-entrainment, the curve was similar to that found in the entrained condition, although it had not fully established the original shape. In two subjects with long sleep periods a wave shape pattern was educed during the FR condition at the same period length as the sleep-wake cycle (39.1 h (FR 3) and 37.6 h (FR 4)) and one at a period length near 25 hours (24.6 h (FR 3) and 24.7 h (FR 4)) (Figure 4). The curves at the long period lengths, resembled those in the entrained conditions (normalized to 360 degrees), both in shape and phase relationship to the average sleep time. These results suggest that the approximately 40 hour component in the temperature rhythm was a "response" to sleep onset in the sleep-wake cycle rather than an independent self-sustained rhythm. In each of these cases (FR 3, 4, 10) as mentioned above there was also an approximately 25 hour component in the circadian temperature rhythm. The amplitude was small (approx. 1 degree F) comparrd to the entrained condition (approx. 2 degress F) and compared to subjects FR with a sleep-wake cycle of approximately 25 hours (1.5 to 2.0 degrees F).

Subject PR 1 had a small drop of overall mean temperature in the entrained compared with the Free-Running Condition (98.42 degrees to 98.17 degrees F). He had a circadian temperature period length of 25.0 hours during the first 30 free-running days which shortened to 24.55 during the next 50 days.

Plasma Cortisol Pattern

We have been successful in obtaining plasma samples at 20 minute intervals for each of 9 subjects during the experimental conditions (FR 1, FR 10; total samples obtained, 15,000).

During the entrained condition all subjects demonstrated the normal episodic pattern of secretion during each 24 hour period. The typical pattern was evident with very low values just prior to and during the first 3 hours of sleep, followed by a series of secretory episodes during the latter half of the night (Figure 5). An intermittent, episodic secretory pattern was present during the waking day (Weitzman et al., 1966; Weitzman et al., 1971). The educed wave form for the entrained condition also demonstrated this circadian

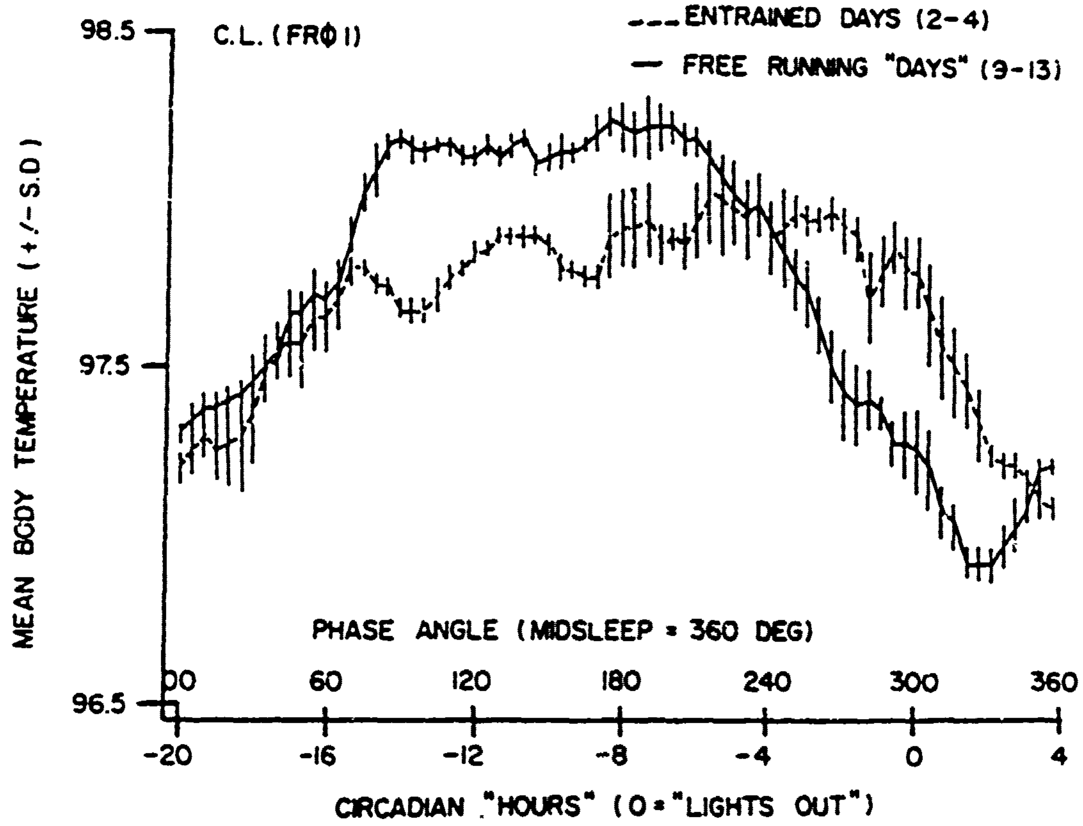

Figure 3. Educed wave form and S.E. of core temperature for subject FR 1 during the entrained and Free-running condition. The mean sleep time during the Free-running condition was 483 minutes (see Table 1). Lights out was at 0 circadian hours and the mid-sleep time was at a phase angle of 360 degrees.

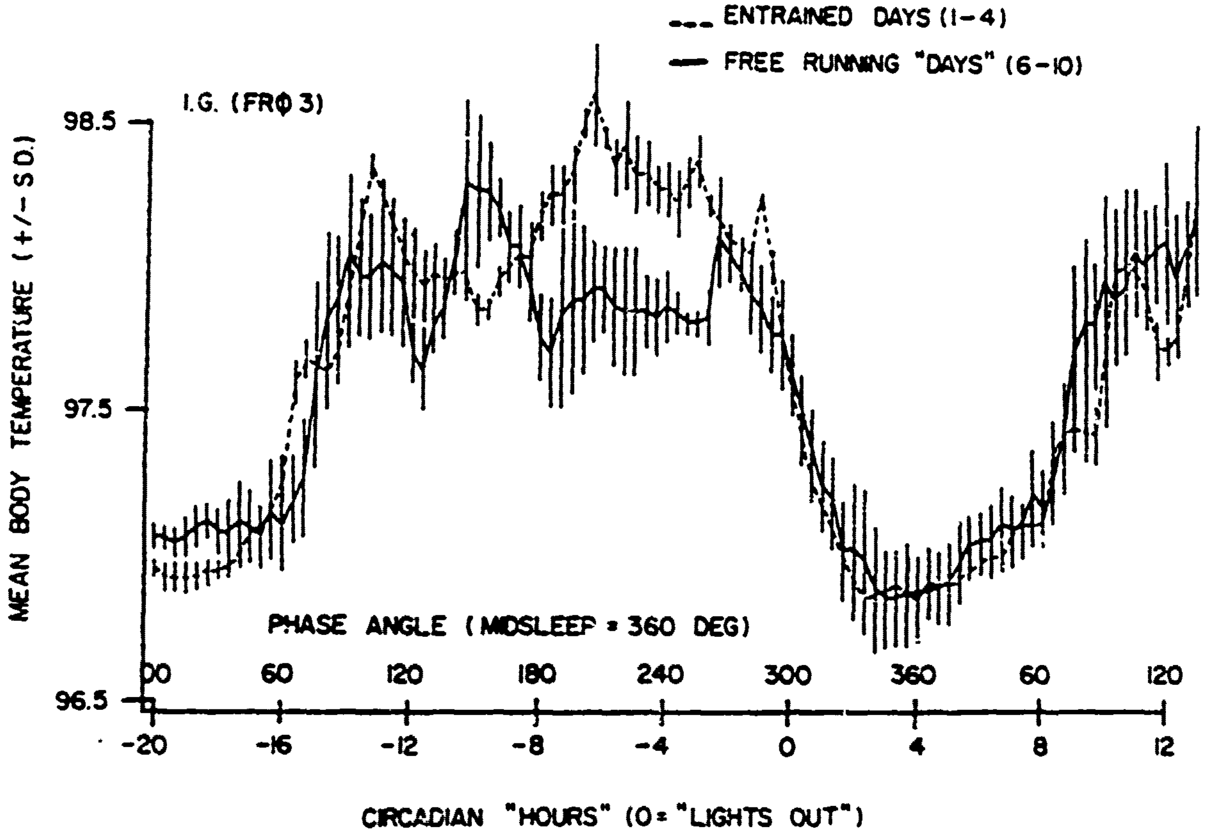

Figure 4. Educed wave form and S.E. of core temperature for subject FR 3 during the entrained and Free-running conditions. The mean sleep time during the Free-running condition was 830 minutes (see Table 1). Lights out was at 0 circadian hours and the mid-sleep time was at a phase angle of 360 degrees.

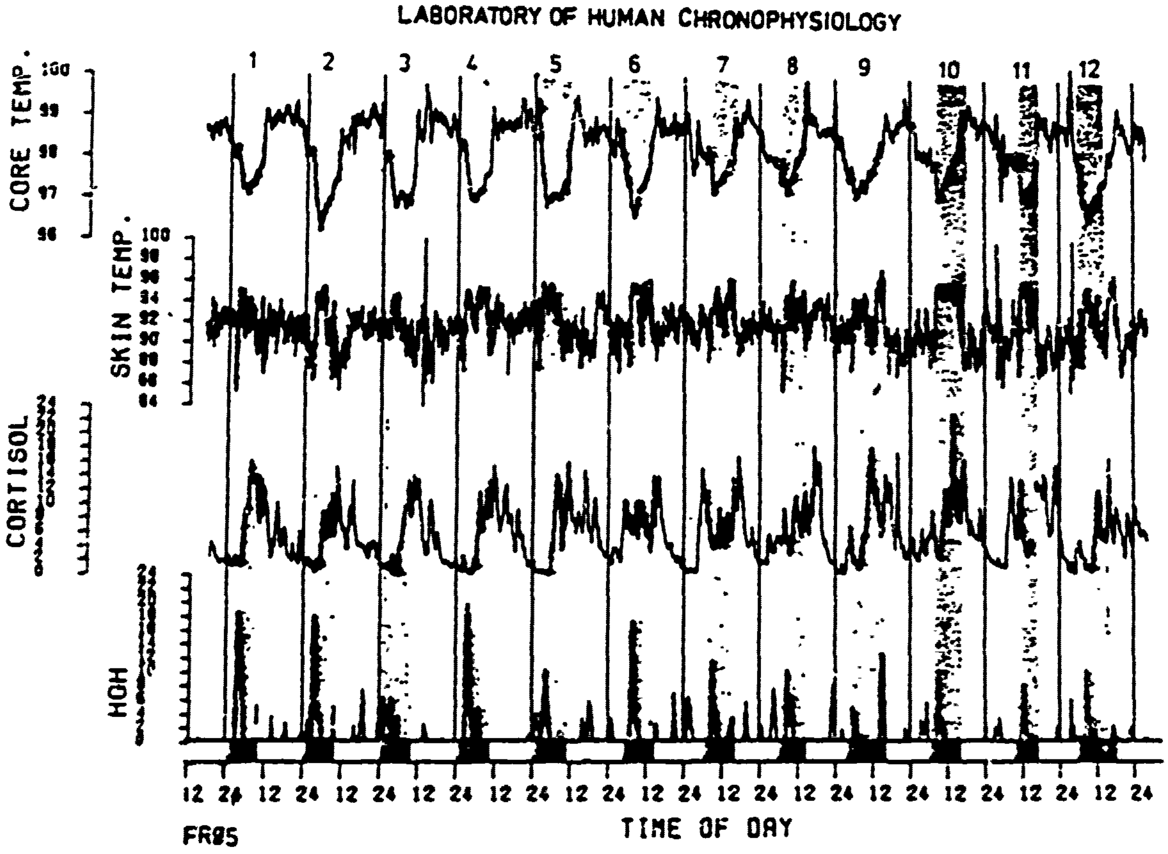

Figure 5. Continuous plot of core and skin temperature (F°), plasma cortisol (ug/100ml) and growth hormone (ng/ml) for subject FR 5 during the entrained (days 1-5) and the Free-running (days 6-12) condition. The shaded areas are the lights out sleep time.

pattern of hormonal activity. During the free-running condition, a clear phase advance and change of wave shape of the circadian cortisol curve was evident for subjects FR 5, FR 6, FR 7 (Figure 6). The nadir of the curve was now occurring 100 to 150 degrees in advance of that during entrainment with respect to sleep onset. In addition, the average rate of rise of cortisol after the low point was much more gradual, nevertheless reaching the highest value at approximately the same time, namely the end of the sleep period.

It is important to emphasize that the process of wave form eduction produces an overall mean curve at a defined period length and therefore will "smooth out" specific point related events. Examination of the cortisol time series itself revealed that on many "free-running" days, especially with a progressive phase delay, cortisol would be secreted just before sleep onset and then would stop being secreted for several hours just after sleep onset.

The duration of this inhibition was 1-3 hours at the beginning of sleep and did not continue throughout sleep. Sleep onset was therefore used as a "zero" point about which a time locked response cortisol curve was obtained in several subjects. All demonstrated a clear pattern of cortisol inhibition following sleep onset. Therefore during the free-running condition a phase advance of cortisol occurred in relation to the sleep period, the overall wave shape was changed and a specific sleep related inhibition of cortisol secretion was apparent. During the re-entrainment condition, a similar pattern was evident since the phase relationship between the cortisol rhythm and sleep had not yet returned to normal. Therefore the subject was going to sleep when the concentration of the hormone was high. Evidence that this sleep related inhibition may well be operative even in subjects habitually living on a 24 hour routine may be deduced from the data obtained during the transition from the entrained to the free-running condition on those nights when a phase delay of sleep onset on a single night exceeded 2-3 hours. On those occasions, the hormone was released just before sleep and then immediately inhibited after sleep onset.

It thus appears that the episodic pattern of cortisol secretion is influenced both by an endogenous rhythmic component, not directly related to the behavioral sleep-wake cycle and a specific sleep (or lights out in bed) related component. Whether other daily behavioral events such as sleep onset, lights on, out of bed, meal time, etc., are also determinants of the episodic pattern will require further detailed analysis of the extensive data we have obtained in these studies.

Growth Hormone Pattern

HGH was found to be secreted in an episodic normal manner in all subjects with the typical pattern of brief episodes of secretion (1-2 hours) followed by long inter-episode intervals (6-12 hours) with no HGH detectable (Weitzman & Hellman, 1974) (Figure 5). The hormonal concentration was less than the overall average (1 ng/ml) 80% of the time. A striking highly consistent relationship between sleep onset and an episode of HGH secretion was found for all three experimental conditions for all subjects (Sassin, Parker, Mace, Gotlin, Johnson, & Rossman, 1969; Weitzman et al., 1975). A clear secretory episode followed sleep onset approximately 90% of the time. Thus far no independent rhythm of HGH could be detected but further analysis for an ultradian, or specific behavioral related event will be searched for.

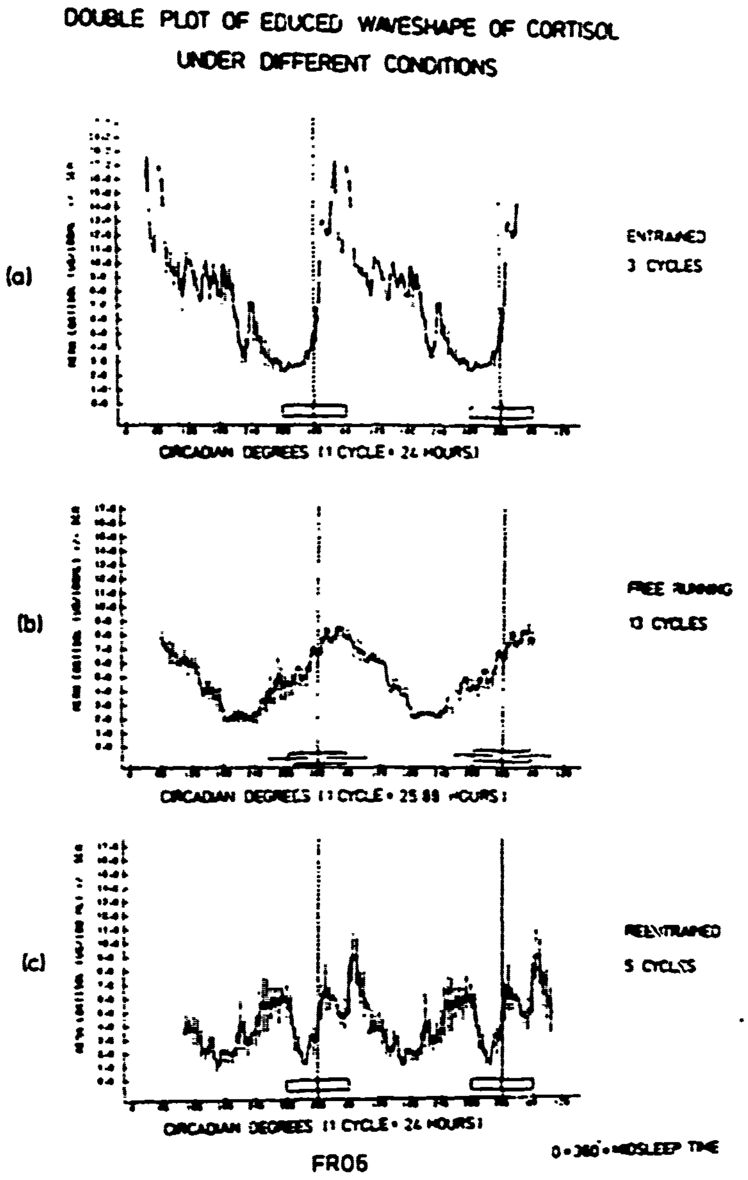

Figure 6. Double plot of educed wave shape of plasma cortisol concentration for subject FR 6 during entrained, Free-running and re-entrained condition. The horizontal bar and vertical dotted line represent lights out sleep time and mid-sleep time respectively.

Summary and Conclusions

We confirm previous studies that biological rhythms of human beings free-run at period lengths greater than 24 hours, typically at approximately 25 hours, but with individual variability. After a variable time of free-running, many normal humans will spontaneously develop "long" biologic days (35 hours) and often these will alternate with "short" days (approx. 25 hours).

During free-running, although the sleep to total time ratio remains remarkably constant (approx. .30), short sleep periods (10 hours) occur at a specific phase angle of an internal circadian rhythm (e.g., body temperature) whereas long sleep periods (12 hours) take place approximately 180 degrees out of phase with the short sleep periods, but maintain the same period length. Sleep stage organization changes during "free-running" such that REM sleep advances to an earlier time during sleep, with a shortened REM latency (occurring at times less than 10 minutes after sleep onset) and increased amounts during the first 3 hours of sleep. The total REM amount and percent for the entire sleep period, however, remains constant. The timing and amount of REM sleep following sleep onset also occurred preferentially at a specific phase of the circadian temperature cycle, strongly supporting the concept that certain sleep processes in the brain are endogenous biological rhythms. The Stage 3-4 sleep distribution remains essentially the same during the three experimental conditions. During the long sleep periods (12 hours), Stages 3 and 4 recur following 14 to 15 hours of sleep indicating that these stages are not dependent on length of prior waking but may be related to length of prior elapsed time.

The core (rectal) temperature develops an approximate 25 hour rhythm in humans during free-running, but the wave-shape changes such that a phase advance (6-8 hours) of the falling phase develops in relation to the onset of sleep. The subject usually then selects sleep when the circadian temperature approaches its lowest value of the day. In addition, at the time of sleep onset (lights out and in bed) there is an additional drop of body temperature. This is especially noted when sleep onset occurs when the immediately preceding core temperature is high (e.g., for the long sleep periods).

Measurements of plasma cortisol throughout each study demonstrated two components of the circadian cortisol curve during free-running. One component had a phase advance (6-8 hours) relative to sleep onset whereas a second component clearly followed sleep onset. This second component appeared to be a sharp inhibition of cortisol secretion during the first 2-3 hours of sleep interrupting a rising phase of the hormonal curve. Growth hormone secretion, on the other hand, was intimately related to the first 2 hours after sleep onset. A sharp episode of hormonal secretion occurred just after sleep onset for almost all sleep periods. No other independent circadian rhythm of GH has been detected thus far.

These and previous reported studies emphasize the lawfulness of biological rhythm functions in man and demonstrate the importance of the methodology using temporal isolation and the analysis of "free-running" rhythms to unravel these chronobiological processes.

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EXPERIMENTAL 12-HOUR SHIFT OF THE SLEEP-WAKE CYCLE IN MAN: EFFECTS ON SLEEP AND PHYSIOLOGIC RHYTHMS

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The 24-hour rhythms of normal man govern the alternation of sleep and wakefulness, body temperature, meals, urinary excretion, and most metabolic functions. These rhythms arise from the interactions of multiple endogenous circadian oscillators in association with environmental synchronizers such as light and dark, sleep and social schedules, meal timing, exercise programs, etc. (Wever, 1975).

Experimental shifts of sleep-wake rhythms are of interest for two major reasons. First, they provide a controlled model for medical events which occur in shift workers, air travelers, and others who undergo sleep-wake rhythm schedule changes in society. Second, the dynamic responses of physiologic rhythms to experimental shifts provide data regarding mechanisms of control of these ryhthms, especially their interrelationships within the human.

Previous studies of rhythm phase shifts have demonstrated important effects. When the sleep period is shifted by 8-12 hours a characteristic sleep disturbance results, characterized by awakening toward the end of the sleep period (i.e., after 5 to 7 hours), a shortened time latency to the first rapid eye movement (REM) sleep period, and increased fragmentation of sleep stage patterns (Bryden & Holdstock, 1973; Chernik & Mendels, 1974; Evans, Christie, Lewis, Daly, & Moore-Robinson, 1972; Globus, Phoebus, & Boyd, 1972; Knauth & Rutenfranz, 1972; Weitzman, Kripke, Goldmacher, MacGregor, & Nogeire, 1970). Sleep-wake cycle shifts of even 2 to 4 hours produce measurable impairment of mood performance (Klein, Bruner, Holtmann, Rehme, Stolze, Steinhoff, & Wegmann, 1970; Klein, Wegmann, Athanassenas, Hohlweck, & Kuklinski, 1976; Klein, Wegmann, & Hunt, 1972; Taub & Berger, 1974; Taub & Berger, 1976). Although a shift of the clocktime in bed produces a rapid shift in the overall sleep-wake rhythm,other body rhythms require several days to weeks to complete the phase change produced by a shift in the timing of sleep. The urine volume and sodium excretion rhythms generally shift their phases within a few days, whereas the body temperature rhythm requires one to 2 weeks and urinary potassium and steroid rhythms require several weeks before achieving a complete shift (Sharp, 1960; Sharp, 1960; Sharp, Slorach, & Vipond, 1961). During the process of phase shifting, certain body rhythms appear to "free run"; the shift is not always achieved by moving in the same direction as the sleep period shift, i.e. by an equivalent advance or delay (Aschoff, Hoffmann, Pohl, & Wever, 1975; Mills, 1976; Mills, Minors, & Waterhouse, 1978; Minors & Waterhouse, 1976).

Most previous studies were done over short time periods, and therefore questions regarding the duration of phase-shift adjustment could not be answered. We have performed two long-term controlled phase shift experiments. The first, a 3-week study, consisted of one week of baseline, followed by two weeks of observation after an acute 12-hour sleep period shift. The results of the sleep recordings of this study have been reported (Weitzman, 1975; Weitzman, Goldmacher, Kripke, MacGregor, Kream, & Hellman. 1968; Weitzman, Kripke, Goldmacher, MacGregor, & Nogeire, 1970). Since phase-shift effects were clearly not complete after the two weeks studied, and because the results suggested that not all functions had achieved a 12-hour phase shift, a subsequent 9-week experiment was performed consisting of three weeks of BASELINE, three weeks after an acute 12-hour sleep period inversion and an additional three weeks after a 12-hour reinversion of sleep to the baseline clock time. We present here the sleep results of this 9-week study as well as the metabolic data from both the 3-week and 9-week studies.

Method

Subjects. The subjects were 10 healthy young men, ages 22 to 28. Each volunteer signed a written informed consent for the experiment and was paid for his participation, Only one subject was studied at a time.

Three-week protocol: Five subjects lived for 3 weeks on a clinical metabolic research unit (Clinical Research Center), and were only rarely allowed to leave on a pass during their waking hours. For the first 7 nights, BASELINE, each subject was confined to bed in a totally darkened and sound-isolated room from 10 pm until 6 am. On the 8th night, the subject was kept awake until 10 am the next day, and for the next 2 weeks, the subject was allowed to sleep in total darkness from 10 am until 6 pm. This was called REVERSAL. Subjects were observed by research nurses and staff, and sleep was not allowed during the 16 hours when the subject were not in bed. During the daytime, subjects were exposed to both natural and artificial light, and at night, when awake, subjects were exposed to bright artificial illumination from both fluorescent and incandescent lamps. During the first week, meals were served at 8 am, Noon, and 6 pm. During the next two weeks, REVERSAL, meals were served exactly 12 hours later. Meals were prepared in a special metabolic kitchen to insure that the subjects were provided a diet which was stable in calories, fluid, sodium, and potassium from day to day, however, subjects were not required to consume the full diet. They were not allowed to eat any other foods. Activities and visitors were ad libitum. The subjects spent most of their time reading, watching television, or talking with staff and other subjects and patients.

Nine-week protocol: Five different subjects lived on a similar but different metabolic research unit (Clinical Research Center) for 9 weeks. For the first 21 nights of BASELINE, the subjects remained in bed in the dark and were allowed to sleep from 11 pm until 7 am. On the 22nd night, each subject was kept awake and was then allowed to sleep in the dark from 11 am until 7 pm the following day and for the subsequent 20 days. This is called the REVERSAL segment. On the 43rd day, each subject was kept awake until 11 pm and was then allowed to sleep until 7 am for that night and for an additional 20 nights. This is called BACKREVERSAL. Meals were carefully regulated as in the 3-week protocol, and activities, television viewing and visitors were allowed ad libitum.

Data Collection

Polygraphic recordings: A half hour before each bedtime, electrodes were applied to the scalp, lateral to each eye, and under the chin to record an electroencephalogram (EEG), horizontal electro-oculogram (EOG), and a chin electromyogram (EMG). The subjects were put in bed and the lights were turned out precisely at the planned bedtimes, and lights were turned on, and subjects were aroused exactly 8 hours later. The EEG, EOG, and EMG were continuously recorded throughout each lights out period and were scored by standard criteria as established by Rechtschaffen and Kales (1968). The duration of any wake or sleep stage "episode" was determined from the number of sequential polygraphic pages (20 seconds) of that stage.

Body temperature: Rectal body temperatures (9 subjects) and oral temperature (1 subject), were obtained just at the time of arising and exactly every 4 hours thereafter until bedtime, i.e., 5 times daily. Subjects were not disturbed during the lights out period for temperature or urine sampling.

Urine: Urine was collected immediately at the time of arising and exactly every 4 hours thereafter until bedtime, i.e., 5 times daily. If the subject awoke and urinated during the lights out period, that specimen was also measured. Volumes were measured and aliquots were frozen for chemical determinations of sodium, potassium, creatinine, and 17-hydroxycorticosteroids (17-OHCS). The rate of excretion per hour of water, sodium, potassoim, creatinine, and 17-OHCS were subsequently computed. These were temporally assigned to the midpoint-times between the times of voidings.

Plasma samples: In the 3-week study an indwelling venous catheter was inserted just prior to every other sleep period and blood samples (4 cc) were obtained every 20 min (approximately 25 samples/sleep period) for cortisol and growth hormone. A blood sample was also obtained by direct venipuncture every 4 hours for the next 16 hours following each catheter study to obtain a 24-hour sample. Cortisol was measured with a competitive protein binding method and growth hormone was measured by radio-immunoassay. Plasma steroid results will not by presented in detail because they were more fragmentary than 17-OHCS results although consistent.

Data analysis: The daily and weekly mean values were computed for the descriptors of sleep stage patterns as well as for the 6 metabolic variables (temperature, urine volume, sodium excretion, potassium excretion, creatinine excretion, and 17-OHCS excretion). These values were paired and were contrasted by a t-test for paired samples (N = 5 subjects for each study). Since occasional "significant" differences may occur randomly when many such comparisons are performed, only those differences which were consistently significant will be reported.

The 24-hour rhythm data of the metabolic variables were statistically evaluated. For each 72 hour of sequential data, a best-fitting 24-hour cosine was estimated utilizing a least-squares technique (Halberg, Johnson, Nelson, Runge, & Sothern, 1972). The confidence of a 24-hour cosine component being present was determined using an F-test. If the confidence was 95% or better, it was inferred that there existed for that variable a 24-hour rhythm which was reasonably approximated by a sinusoidal curve. The results of the F-test therefore served as an approximation of the reliability of the least-squares estimate. The phase of the fitted cosine, defined by the peak value (acrophase), was taken as an estimate of the phase or timing of the 24-hour rhythm of the variable. Acrophases were expressed in negative degrees to indicate a delay of elapsed time after midnight, e.g., - 15 degrees indicated a fitted cosine peak at 0100, - 90 degrees indicated 0600, - 180 degrees indicated 1200, - 270 degrees indicated 1800, etc. "Cosinor" values (Halberg, Yong, & Johnson, 1967) were computed to determine the significance and consistency of the 24-hour rhythms among the subjects for each defined 72-hour interval. In general, when the cosinor was significant (p <.05), it was inferred that there was a significant 24 hour rhythm for the subject group. If the cosinor was not significant, then it was assumed that either a 24 hour rhythm was not present, was not sinusoidal, or was not consistent from subject to subject to achieve significance for the small subject group. This cosinor technique is quite sensitive to changes in the phase and amplitude of a 24-hour rhythm but is relatively insensitive to changes in wave-form or mean values.

A second statistical technique was also used for the 9-week data. The mean 24-hour curve for each variable was computed from the final week of BASELINE, i.e., Week 3. Then, day by day, the squared deviations (variance) of the subsequent daily curves from this mean curve were computed, inverting the curve 180 degrees for the REVERSAL data. At some time during the 3 weeks of REVERSAL, the mean curve was recognized to be inverted, e.g., phase-shifted 12 hours (180 degrees) if the squared deviations returned to BASELINE level. Thus, the variances measured from these mean curves provided a measure of the day-by-day deviations of the 24-hour rhythm from the best BASELINE pattern. This measure was therefore applicable regardless of curve-shape and did not require conformation to a sinusoidal curve. The squared deviations are sensitive to changes in the mean values of the variable as well as to the 24-hour rhythm phase and amplitude. During REVERSAL and BACKREVERSAL, this squared deviation method also indicated the extent to which each variable had fully reversed its pattern.

Results

Sleep stage analysis: During the 9-week BASELINE, the minutes of each of sleep stage from week to week were quite stable (Figure 1). An increase in Stage 2 from Week 1 to Week 2 was the only significant change (p <.02). During REVERSAL, there was a significant decrease in Stage REM (e.g., Week 3 vs. Week 4, p <.02). Although there was some degree of recovery, Stage REM remained below baseline for Weeks 5 and 6. There was a clear rebound during BACKREVERSAL (Week 7 vs. 1,4,5,6,8, and 9, p <.05). Stage 2 was also decreased during REVERSAL, but the differences were only borderline significant. Wakefulness was clearly increased during each of the 3 weeks of REVERSAL (p <.05). The lowest amount of wakefulness was observed for Week 7, but was not significantly less than for Weeks 1-3 or 8-9. The number of minutes of Stages 1,3, and 4 were remarkably constant during the entire study.

Sleep-stage changes and durations: In general, the numbers of changes of sleep stages were fewer, and sleep stages lasted longer at the end of BASELINE, i.e., Week 3 (Figure 2 & 3). However, there was a major increase in changes of stage in Weeks 4 and 5, compared to Week 3, as well as a marked increase for Weeks 7 and 8, compared to Week 6. These changes in fragmentation of sleep

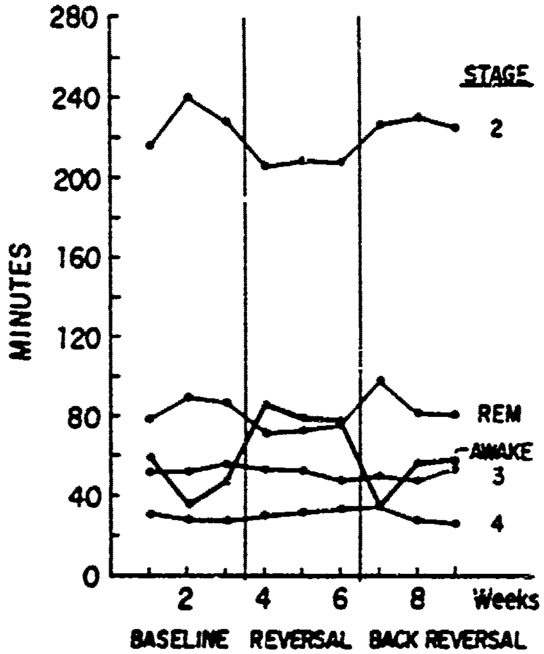

Figure 1. The minutes of each sleep stage (except Stage 1) is shown for each week of the 9-week study.

stages were especially clear for Stage 2 and REM but much less so for Stages 3 and 4 (Figure 2). However, the differences achieved scattered significance for every stage. The decreases in the durations of Stage 2 and REM episodes corresponded to the increased numbers of stage episodes.

Hourly distribution of sleep stages: During BASELINE, the subjects averaged about 30 minutes to fall asleep after lights out but then remained asleep throughout the remainder of the 8 hours in bed (Figure 4). During REVERSAL, the sleep latency was reduced, especially for Week 4, but awakenings were much more prominent during lights-out hours 5 to 8. At that time, early awakenings repeatedly occurred and interrupted the sleep periods. These early awakenings influenced all stages but especially Stage REM (Figure 5). In the first 2 weeks after REVERSAL, Stage REM was clearly markedly increased during the 2nd and 3rd hours and decreased by one-third during the last hour of the lights-out period. During the 3rd week of REVERSAL, this changed pattern had partially recovered. The response to sleep inversion was partially recapitulated during BACKREVERSAL for the first week (Week 7), but the BASELINE pattern unequivocally was re-established during Weeks 8 and 9. Thus there was a clear relationship between early "morning" awakenings and a reduction in REM sleep during the later 3rd of the night in the first 2 weeks of REVERSAL. Therefore, sleep inversion produced a phase shift of REM to an earlier part of the sleep period and a concomitant shift of waking to a later part.

Body temperature: The 24-hour body temperature curves demonstrated great stability and consistency from day to day and from subject to subject throughout the BASELINE periods (Table 1). The individual least-squares cosine fits and the group cosinor analyses were highly significant throughout the 1-week and 3-week BASELINE. A complex pattern of change occurred after acute inversion of the sleep-wake rhythm. The monophasic curve shape of BASELINE was converted into a biphasic curve with two peaks (Figure 6). A fall in temperature occurred 8 hours after awakening and temperature then rose again at 12 and 16 hours after awakening. This was clearly the case for the first 2 weeks of REVERSAL. During the third week of REVERSAL, a monophasic temperature curve was re-established with peak values occurring during the wake time. However, statistical analysis demonstrated that exact 180 degree inversion of the temperature rhythm was not fully established even after 21 days of an inverted sleep-wake cycle. During REVERSAL, the cosinor significant (Table 1) for the temperature rhythms was less consistent. In addition, applying the squared deviation method (see Methods) the reversed rhythm fit imperfectly the baseline curve shape. Considering the cosine fitting results, for the 3-week subjects, the reversal appeared to occur by a cosine phase delay which only achieved about 130 degrees after 2 weeks (Figure 7). For the 9-week subjects, the inversion of the temperature curve better resembled a cosine phase advance, but this advance only achieved 164 degrees after 21 days, (i.e.,a shift from 5 pm to 6 am). It should be emphasized that the temperature rhythm shift did not occur like the progressively moving hands of the clock, forward or backward. Rather the shift occurred by progressive elevation of a new peak and fall of the old temperature peak. This is readily seen in Figure 6. The decrease in amplitude (range) of the circadian body temperature rhythm, the fall of mean waking temprature (.15 degrees F), and the decreased significance of cosinor fits during REVERSAL reflect this pattern of change.

In contrast, re-establishment of the BASELINE temperature curve shape occurred very rapidly during BACKREVERSAL. Both the cosinor method and the

TABLE 1
NINE WEEK COSINOR RESULTS

	DAYS	TEMPER-ATURE			URINE VOLUME			URINE NA+			URINE K+			URINE CREATININE			URINE 17-OHCS		
		Φ	C (°F)	P	Φ	C (CC/HR)	P	Φ	C (MEQ/HR)	P	Φ	C (MEQ/HR)	P	Φ	C (MG/HR)	P	Φ	C (MG/HR)	P
BASELINE	1-3	-255°	.56	.01	-273°	18	.03	-275°	3.1	.06	-246°	1.3	.03	-296°	9	NS	-218°	.06	NS
	4-6	-257°	.72	.01	-266°	16	NS	-275°	1.9	NS	-229°	1.4	.004	-275°	7	NS	-202°	.07	NS
	7-9	-265°	.70	.005	-244°	13	.04	-255°	2.0	NS	-192°	1.2	.04	-220°	0	NS	-192°	.06	.10
	10-12	-263°	.76	.005	-258°	14	NS	-250°	2.3	NS	-193°	1.1	.08	-224°	6	NS	-193°	.09	NS
	13-15	-249°	.77	.005	-252°	18	.03	-259°	2.7	.08	-216°	1.0	.03	-245°	2	NS	-216°	.06	.07
	16-18	-250°	.85	.003	-263°	17	NS	-248°	2.4	NS	-206°	1.2	.07	-301°	4	NS	-183°	.08	NS
	19-21	-257°	.82	.006	-237°	23	NS	-247°	2.3	.02	-199°	1.8	.02	-277°	7	NS	-207°	.11	.03
REVERSAL	22-24	-242°	.11	NS	-154°	19	.02	-162°	.9	NS	-171°	.52	NS	-349°	2	NS	-176°	.04	NS
	25-27	-105°	.12	NS	-141°	6	NS	-198°	1.2	NS	-163°	.9	NS	-196°	10	NS	-205°	.04	.08
	28-30	- 83°	.29	NS	- 74°	14	NS	- 82°	.8	NS	- 98°	.55	.03	- 26°	4	NS	- 42°	.04	NS
	31-33	-142°	.24	.10	-101°	19	NS	- 96°	1.4	NS	- 99°	.6	.04	-131°	2	NS	- 46°	.03	NS
	34-36	- 95°	.37	.03	- 89°	19	NS	- 91°	2.0	NS	- 77°	.9	NS	-101°	30	NS	- 39°	.06	.05
	37-39	- 94°	.47	NS	- 89°	21	.08	- 89°	2.3	NS	- 93°	.8	.10	-139°	6	.03	- 27°	.07	NS
	40-42	- 91°	.73	.003	- 77°	23	.10	- 82°	2.3	.03	- 80°	.9	.05	-182°	5	NS	- 28°	.07	NS
BACK REVERSAL	43-45	-218°	.42	.003	-322°	9	NS	-320°	.3	NS	- 30°	.2	NS	-311°	10	NS	- 55°	.07	.03
	46-48	-231°	.64	.003	-252°	12	NS	-234°	1.9	.02	-210°	.5	NS	-307°	17	NS	-169°	.02	NS
	49-51	-249°	.78	.002	-267°	15	NS	-261°	2.7	.07	-221°	.8	NS	-288°	18	NS	-158°	.06	NS
	52-54	-258°	1.06	.001	-243°	18	NS	-240°	2.2	.006	-193°	1.0	.06	-239°	9	NS	-166°	.11	NS
	55-57	-261°	.72	.04	-256°	19	NS	-246°	2.3	.07	-220°	.9	.05	-312°	13	NS	-203°	.06	NS
	58-60	-254°	.78	.003	-248°	18	NS	-246°	2.1	.09	-204°	.8	.03	-313°	12	NS	-188°	.08	.03
	61-63	-251°	.96	.03	-232°	6	NS	-211°	1.6	NS	-174°	.8	.08	-211°	5	NS	-174°	.13	NS

Φ = ACROPHASE IN NEGATIVE DEGREES FROM MIDNIGHT

C = CIRCADIAN AMPLITUDE

P = PROBABILITY OF NULL HYPOTHESIS, IE., NO 24 HR. RHYTHM. NS = NOT SIGNIFICANT, $P > .10$.

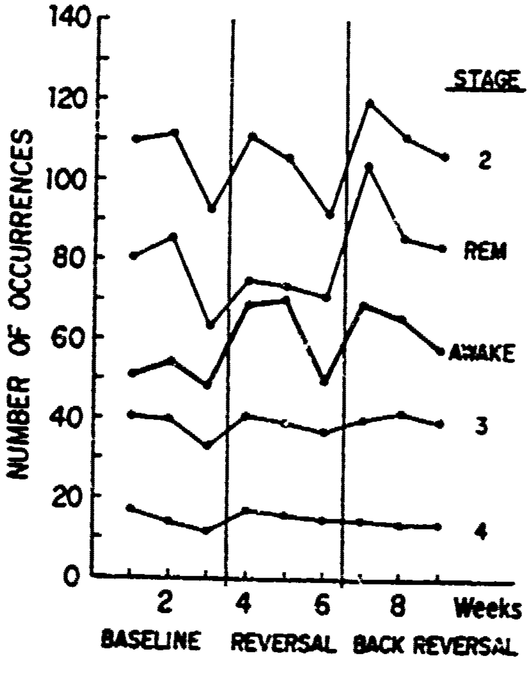

Figure 2. The number of episodes of each sleep stage is shown for each week of the 9-week study.

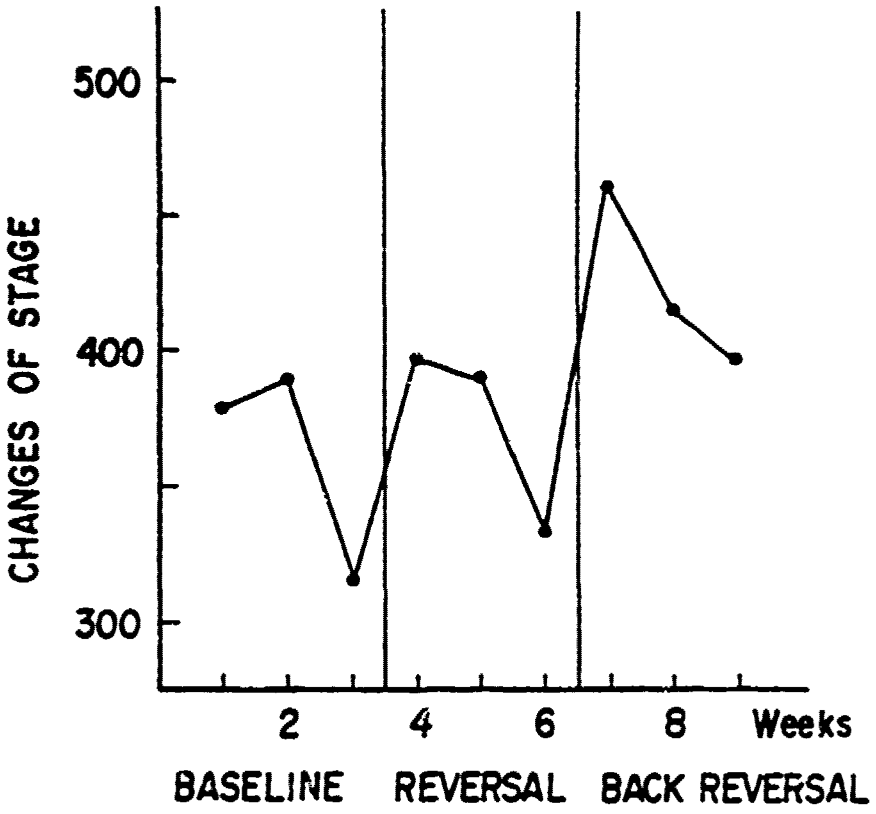

Figure 3. The number of changes of sleep stage per week is shown for the 9-week study.

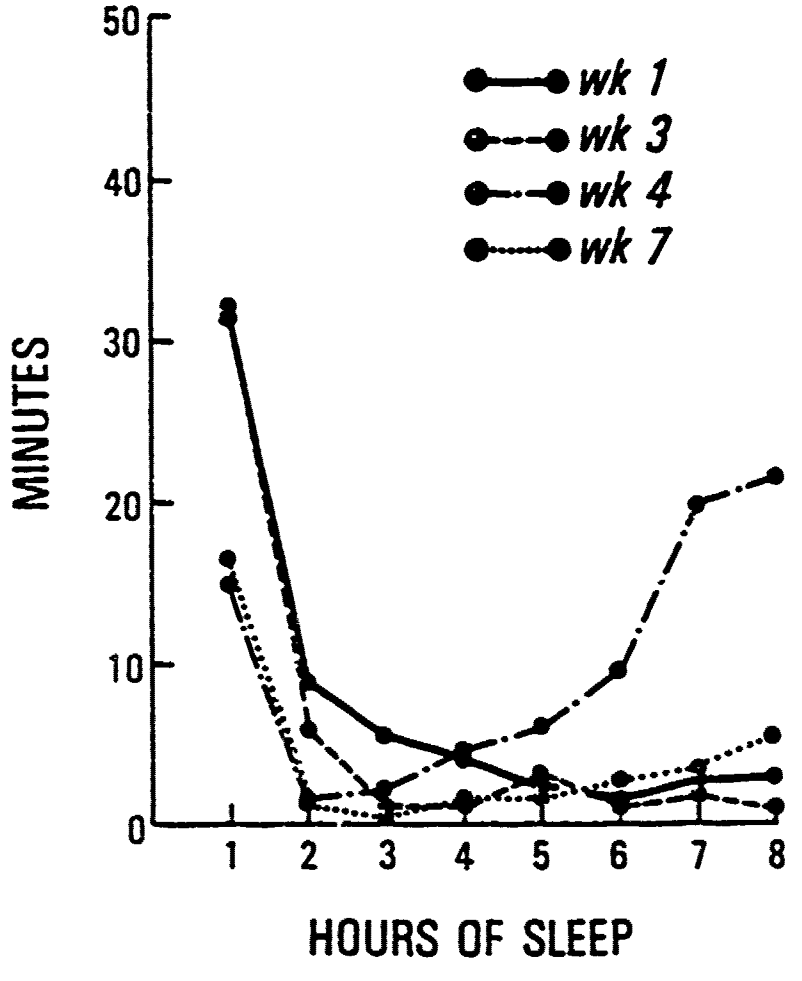

Figure 4. The minutes of Stage Awake per hour of sleep.

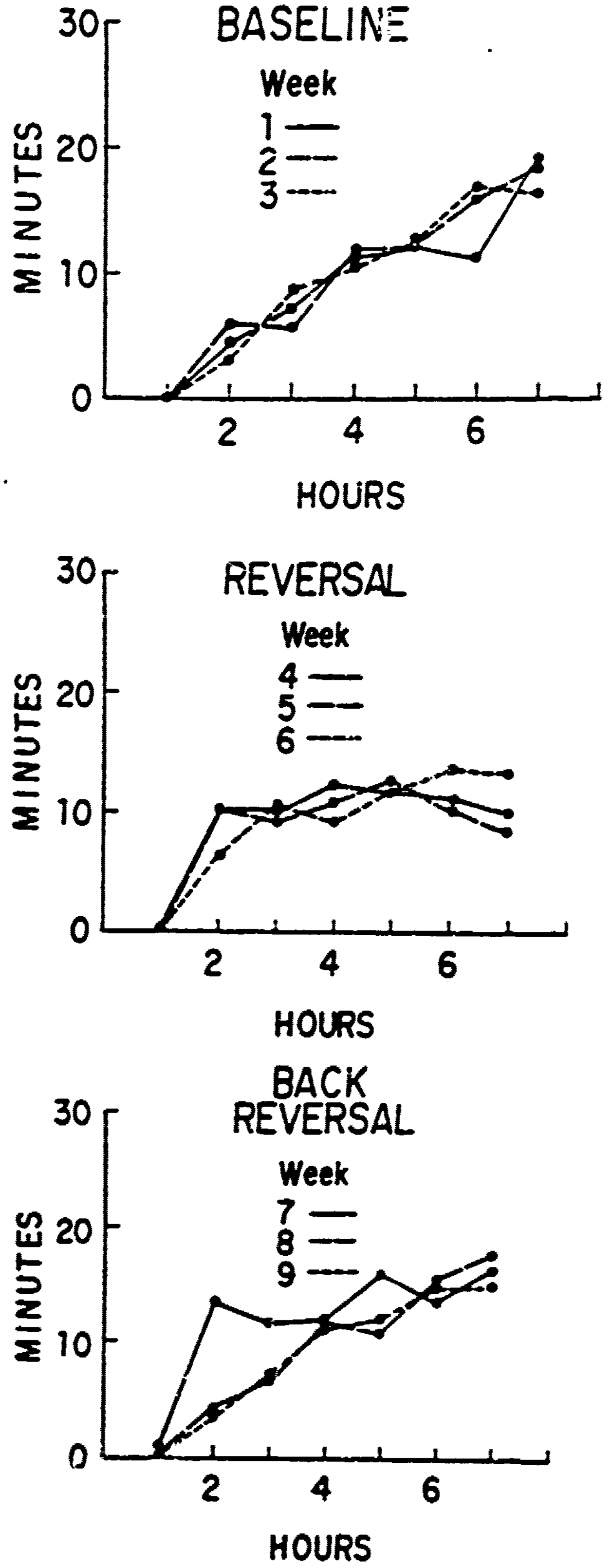

Figure 5. The minutes of Stage REM in each hour of sleep: A) BASELINE, B) REVERSAL, C) BACKREVERSAL.

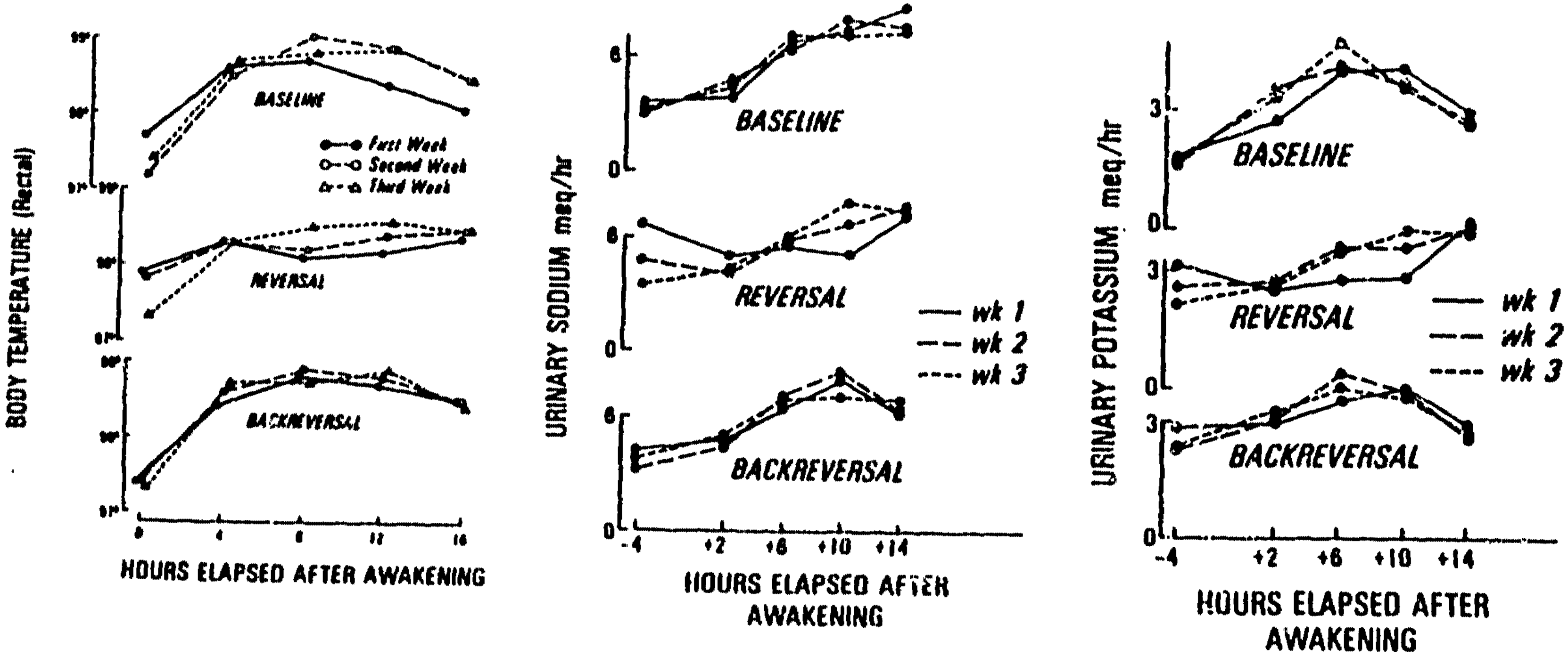

Figure 6. Circadian waveforms are shown for A) rectal temperature, B) urinary sodium, and C) urinary potassium, averaged for 5 subjects week by week.

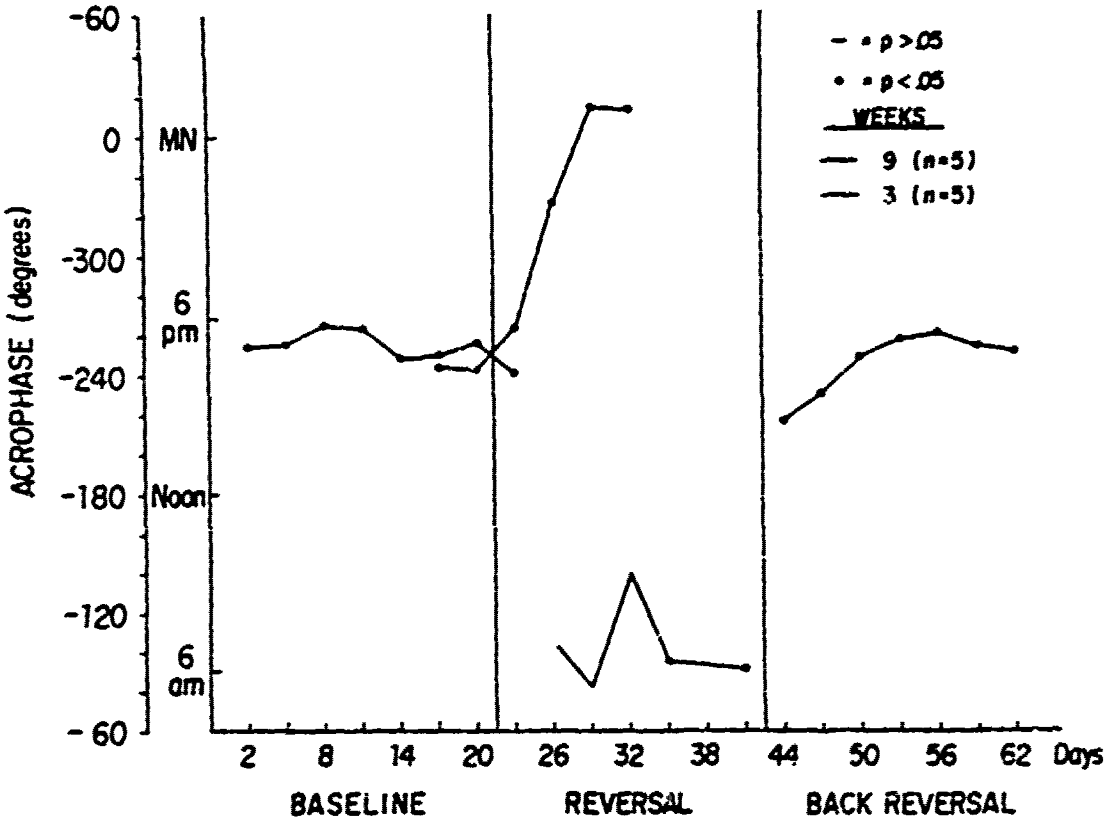

Figure 7. Temperature cosinor phases are shown for both the 3-week and 9-week studies. Each point represents a 72-hour interval, and where the cosinor was significant, a large dot is shown. Consecutive phase estimates were not connected by lines when the discontinuity between consecutive phase estimates was greater than 90 .

curve-fitting technique indicated that the rhythm restoration was complete within 7 to 9 24-hour periods.

Urine volume: During BASELINE the acrophases of the urine volume rhythms were consistent although the cosinor analyses did not always achieve significance in the 9 week study (Table 1, Figure 8). After REVERSAL for both studies, a rapid advance of the acrophase of the rhythm took place. This progressed to about -130 degrees or 0840 am (a 110 degree phase shift) during the 3-week study and to approximately -80 degrees of 0520 am (a 170 degree phase shift) by the end of 3 weeks in the longer study. During BACKREVERSAL, the urine volume rhythm clearly returned to the BASELINE phase angle within 4 to 6 days,but least-squares analysis indicated a lack of consistent rhythms in 2 of the subjects as well as for the group as a whole during BACKREVERSAL. The squared deviation results also indicated that the adjustment was less rapid and complete during REVERSAL than during BACKREVERSAL.

The daily total urine volume was increased for each of the 3-week subjects and for 3 of the five 9-weeks subjects after REVERSAL. Total urine volume was also increased for 3 subjects during Week 7 after BACKREVERSAL. Detailed analyses indicated that these increases in urine volume occurred primarily during sleep when urine output was not markedly decreased as it was during BASELINE.

Urinary sodium excretion: During BASELINE cosinor values were significant for the 3-week subject group and for all 10 subjects measured together. The acrophases were consistent for the 9-week subjects as well but not statistically significant (Figure 9). During REVERSAL, there was a rapid phase advance of approximately 100 degrees during the first 6 days and by the end of 12 days, the 9-week subjects had undergone a 165 degree phase inversion. However, the cosinors did not become significant until the 19th to 21st day. By contrast, during BACKREVERSAL the rhythm was fully shifted within 4 to 6 days. Squared-deviation analyses were consistent with this picture. There were no week-to-week changes in the amount of sodium excreted. The results of analyzing the sodium concentrations and the meq/hour rates were essintially similar.

Urinary potassium excretion: The BASELINE potassium cosinor values were significant and stable for both studies (Figure 10). During REVERSAL, a progressive slow advance was noted. This had only progressed approximately -140 degrees after 3 weeks. However, during BACKREVERSAL, the return of the acrophase was largely complete within 4 to 6 days. The squared deviation analysis also supported this result. The total amount of excreted potassium was significantly higher during the 3rd and 7th weeks of the 9 week study than during other weeks. Since urine volume was also elevated during this time, the potassium concentration was not increased.

Urinary creatinine excretion: Creatinine cosinor values and least-squares cosine fits for individual subjects indicated that 24-hour creatinine excretion rhythms were unreliable for both the 3-week and 9-week subjects. The phase changes found after REVERSAL and BACKREVERSAL approximated the urine volume pattern but these findings lacked significance and reliability. There were not changes in the mean creatinine excretion from week to week.

Urinary 17-Hydroxycorticosteroids: During BASELINE, the urinary 17-OHCS rhythms were stable and generally significant (Figure 11). Following acute RE-

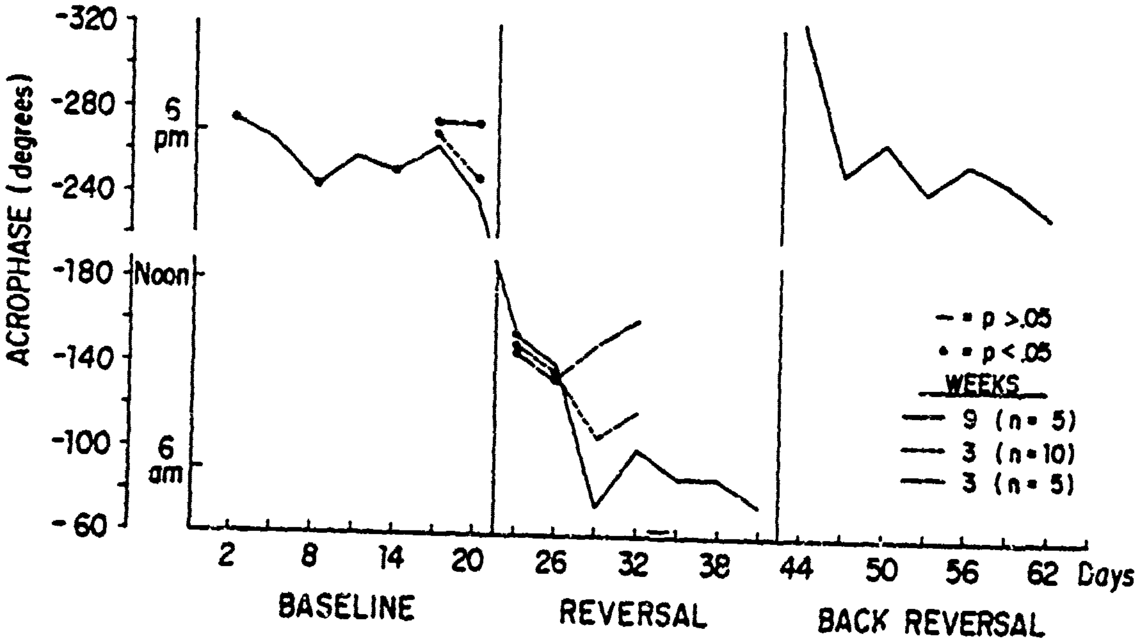

Figure 8. Urine volume cosinor phases are shown as in Figure 7 for the 3-week and 9-week studies, and combined results for both studies are also plotted.

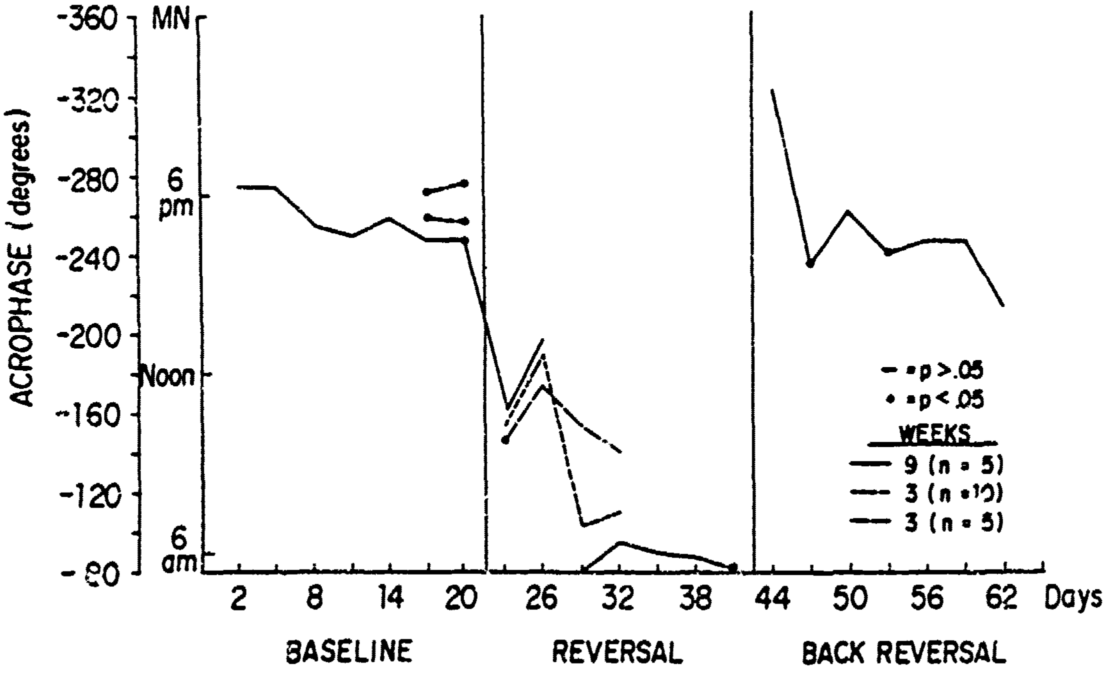

Figure 9. Urinary sodium excretion cosinors are plotted as in Figure 8.

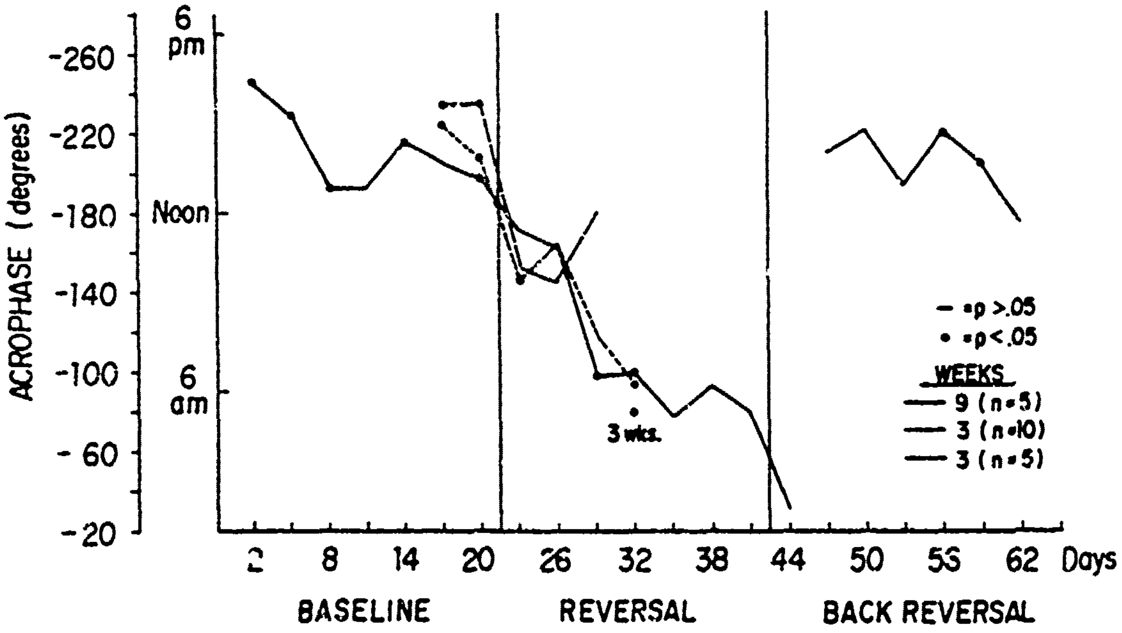

Figure 10. Urinary potassium excretion cosinors are plotted as in Figure 8.

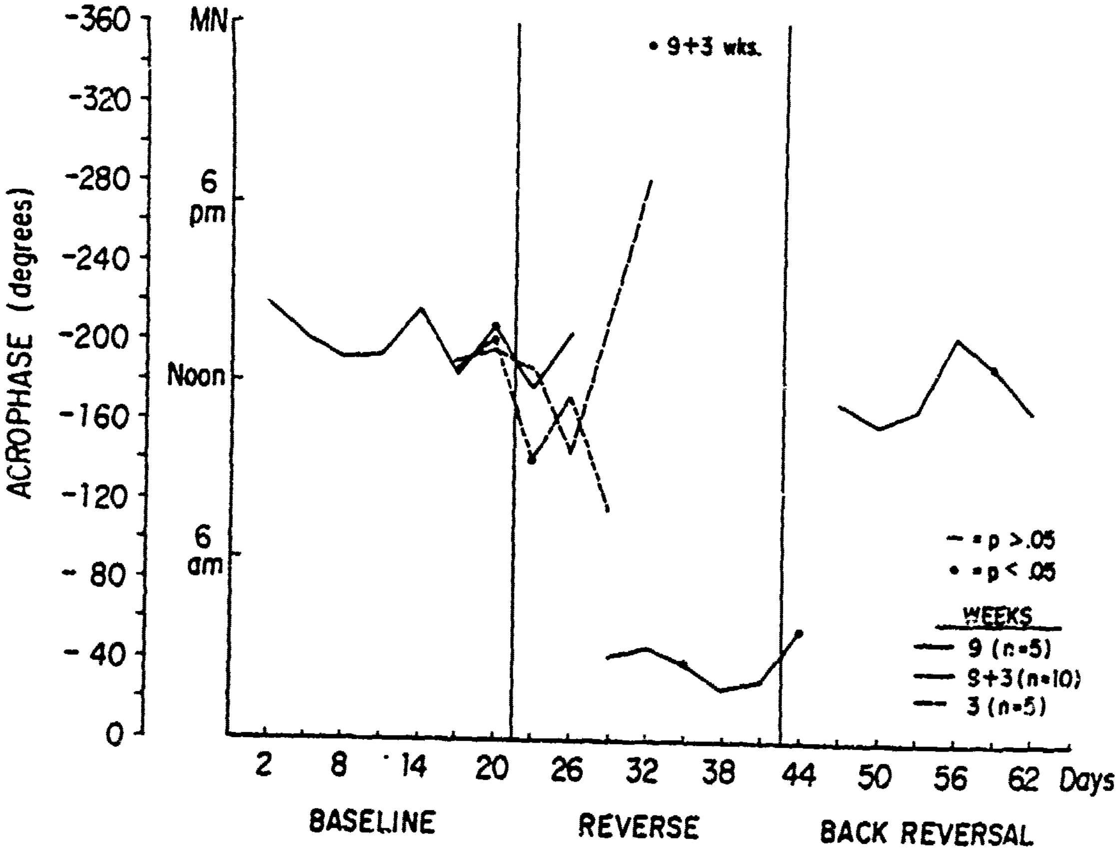

Figure 11. Urinary 17-OHCS excretion cosinors are plotted as in Figure 8.

VERSAL, there was no major change in phase for 4 to 6 days. During the 2nd week of REVERSAL there developed considerable variability among the subjects (some advancing and some delaying). A clear rhythm was not detectable for the group, and rhythm discontinuities occurred in several individual subjects. However, by the 13th to 15th day during REVERSAL among the 9-week subjects, the circadian rhythm had been re-established and a consistent and stable phase shift of about 160 degrees could be identified. In both the 3 week and 9 week studies, a biphasic 24 hour curve was present for urinary 17-OHCS during the reversal process, indicating that the process of shift was not primarily by advance or delay of a single "peak". A rapid re-inversion took place within the 1st week during BACKREVERSAL.

Although no statistically significant changes were identified in weekly steroid excretion amounts for both study groups as a whole, four of the five 3-week subjects had 20 to 50% decreases in 24 hour urinary 17-OHCS at some point between 2-8 days after REVERSAL. This decrease was independently confirmed by plasma cortisol measurement. No clear decrease in 17-OHCS were seen after REVERSAL among the 9-week subjects. However, transient 27 to 70% decreases in 24 hour urinary 17-OHCS excretions did occur in four of the five subjects from 1 to 7 days after BACKREVERSAL. These lasted only 2 to 3 days. In two of these cases, plasma cortisol confirmation was available. The daily steroid excretion was variable and the observed decreases were not consistent for the group as a whole.

Discussion

The 9-week study fully confirmed the previously reported results of the effect of sleep-wake reversal on sleep stages in the 3-week subjects (Weitzman, 1975; Weitzman, Kripke, Goldmacher, MacGregor, & Nogeire, 1970). It is now clear that a twelve-hour inversion of the sleep-wake period under controlled conditions, produces a shortened sleep latency, shortened Stage REM latency, and a increased amount of Stage REM sleep during the first 2 hours of sleep. Early awakenings occur during the 5th to 8th hour of sleep, and all stages of sleep are reduced during the final hours of the sleep periods. In addition an acute sleep reversal produces a transient increase in the number of occurrences of each sleep stage by increasing the number of changes or shifts of stage and by shortening the durations of episodes of each sleep stage. These increased numbers of changes of stage persist approximately for 2 weeks after reversal. However, early awakening and decreases in total Stage REM and Stage 2 sleep persist throughout the 3 weeks of REVERSAL. Although the REVERSAL condition was not a period of sleep deprivation per se, a deficit in sleep and a deficit in Stage REM did develop and immediately after BACKREVERSAL, a rebound increase resulted. The BACKREVERSAL period demonstrated a clear increase in changes of sleep stage which also persisted for 2 weeks. A shortened REM latency and mild but definite morning awakening were also present during the first week, but sleep quantity was [illegible] reduced in BACKREVERSAL. Thus, the fragmentation of sleep stage patterns and the altered hourly distribution of sleep stages within the sleep periods is presumably due to the process of sleep-wake phase shift. The "insomnia" present during the REVERSAL condition also is clearly the result of the acute phase inversion, but other factors may be present as well. Since the 8-hour available sleep periods were the same during the BASELINE and REVERSAL conditions and since the sleep environment was equally dark and quiet, no direct environmental disturbances can be implicated in depriving subjects of sleep during the REVERSAL condition. It is probable that certain 24 hours oscillators were not shifted even after 3 weeks of the REVERSAL condition. Concomitant lowered waking body temperatures and increased urine volume during REVERSAL support this supposition. The REVERSAL sleep disturbance is of special interest because early "morning" awakening, fragmented sleep, and reduced REM latency are characteristic of primary depression (Kupfer, 1976; Kupfer, Foster, Coble, McPartland, & Ulrich, 1978) and to some extent narcolepsy (Montplaisir, 1976), two illnesses which may be related (Roth & Nevsimalova, 1975). This phase shift result may serve as an experimental model for these and other sleep disorders.

The 24-hour rhythms of urine volume and urinary potassium were also not fully established even after 3 weeks of REVERSAL compared to BASELINE. In addition, the non-sleep parameters (temperature, urine volume, creatinine, sodium, potassium, and 17-OHCS) were shifted only 140-165 degrees after 3 weeks of REVERSAL; none shifted a full 180 degrees. Although the sleep-wake rhythm was inverted more than the metabolic rhythms, the persistence of mild early-awakening even in the third week of REVERSAL suggested that this rhythm was phase-advanced during the REVERSAL condition in reference to the lights out period. The non-sleep parameters therefore were delayed in reference to the polygraphic stages.

We have considered several alternative explanations for the failure of complete phase inversion of several of the variables studied. One possibility is that one or more endogenous circadian oscillatory pacemakers are so resistant to the phase change ("inertia") that 3 weeks is an insufficient amount of time to produce a 180 degree shift. Since there are data that a more rapid phase shift occurs among air travelers (Klein, Wegmann, Athanassenas, Hohlweck, & Kuklinski, 1976; Klein, Wegmann, & Hunt, 1972) or in other controlled experimental isolation studies (Aschoff, Hoffmann, Pohl, & Wever, 1975), this argues against an "inertial" explanation. Another possibility is that environmental synchronizers over which we had little control exerted substantial effects on the phase of the rhythms. For example, the subjects received visitors and would watch television during the evening hours whether they were sleeping during the day or at night. These waking alerting activities might alter sleep rhythms by delay during day-wake schedules. During REVERSAL,these activities occurred shortly after the subjects awakened and might lead to an advance of components of sleep rhythms. The general difference in levels of stimulation, activity and ambient illumination which the subjects experienced during REVERSAL as compared with BASELINE could also affect the rhythms. Studies in animals have demonstrated a negative correlation between the strength of the synchronizing stimuli and the length of time needed for reentrainment (Aschoff, Hoffmann, Pohl, & Wever, 1975; Erkert, 1976; Hoffmann, 1969). In addition, it has been reported that a complete resynchronization of rhythms took 50% longer for trans-meridian air flight passengers who were kept in relatively isolated hotel rooms, compared with passengers who left the hotel rooms and participated in outdoor activities during the adjustment period (Klein & Wegmann, 1974).

Night shift workers experience similar environmental lighting conditions as well as social synchronizers like those experienced by our subjects. The inability of night shift workers to reverse their social milieu and to experience daylight at night - no matter how carefully and thoroughly sleep patterns are reversed (bedrooms darkened and sound-proofed and meals reversed) - could lead to disturbances similar to those experienced by our experimental subjects. Not only were our subjects unable to achieve a complete 180 degree reversal of their 24 hour rhythms after 3 weeks of scrupulously maintained sleep period and meal timing reversal, but they experienced a persistent decrease in total sleep and Stage REM durations. Actual night workers experience similar sleep problems (Bryden & Holdstock, 1973), which suggests that the ubiquitous sleep problems of night workers may not be resolved by even the most optimal sleep and meal arrangements and stability of day-sleep patterns even after several weeks. Further studies are needed in man to determine the length of time required to fully re-establish prior relationships of circadian rhythms to the new sleep period after an acute phase shift, under conditions where social synchronizers and other environmental stimuli such as light are not fully shifted. These non-equivalent conditions between the day time and the night time are clearly experienced by the shift worker. It is conceivable that rhythm shifts under these conditions might never be complete.

The rapid physiological shift response to BACKREVERSAL supports the concept that the subjects had not fully adapted even after 3 weeks of the REVERSAL condition. Although the disruption of sleep patterns as indicated by the number of stage changes and the number of Stage 2 and REM episodes was greater for the 1st week after BACKREVERSAL as compared to the 1st week after REVERSAL, the amount of early "morning" awakening during the same periods was less, especially during the last 2 weeks of BACKREVERSAL. Thus, the sleep data suggested that after the end of the REVERSAL period, a combination of a transient phase-shift response plus a rapid rebound-recovery response occurred.

The non-sleep rhythms during BACKREVERSAL returned to the BASELINE pattern with extreme rapidity compared to the adjustments required for the equivalent first REVERSAL. Several explanations should be considered. First, it is possible that environmental factors such as natural light and social synchronizers may have facilitated the BACKREVERSAL process. It is also possible that a more rapid shift during BACKREVERSAL occurred because the REVERSAL shifts had only been incompletely achieved. Indeed, non-sleep variables had only achieved a 140 to 165 degree shift. It is certainly conceivable that an unmeasured endogenous rhythm functioning with strong "inertia" may have been maintained in close conformity to the BASELINE timing during the REVERSAL segment.

Although an attempt was made to reduce many influences of the real world in these studies,the results indicate that very complex and variable responses occur to a phase shift even in experimental settings. Clearly, different body rhythms undergo phase-reversals at very different rates and in different directions. For example, for the 3-week subjects, temperature ostensibly reversed by delay whereas potassium reversed by an advance. Disparities between advance and delay were also noted among each group of subjects for certain variables; moreover, the cosinor analysis revealed substantial disparities between the 3-week and 9-week studies in the transient responses to the REVERSAL phase shift. It should be emphasized however, that the concept of shifting by advancing or delaying the phase of a rhythm is a misleading interpretation arising from an analytical model restricted to sine function model. Indeed it was very clear that temperature and urinary 17-OHCS shifted by a two component mode. A progressive increase in body temperature during the new waking period occurred along with a progressive decrease of body temperature during the new sleep period. Indeed the rates of these waveform changes appeared to be dissociated, with the fall of the old peak occurring more rapidly than the rise of the new temperature peak. A similar process was apparent for 17-OHCS. A similar process also occurred for urinary sodium, potassium and creatinine since clear decreases in rhythm amplitude and alterations of wave form were observed, although biphasic patterns were not always present for each subject. Aschoff et al. (1975) and Mills et al. (1978) have also concluded that phase-shifts occur through changes in several wave-form components, and dissimilar responses appear in different variables. Thus, depending on the conditions and the individual subject's response, a variety of patterns of internal phase coupling and uncoupling among rhythms may result from a major phase shift.

The factors controlling circadian rhythm phase shifts deserve further study, considering the increasing frequency that man undergoes shift work and rapid jet travel across many time zones. In addition, the occurrence of a persistent insomnia, early "morning" awakening, shortened REM latency, and the failure of certain metabolic rhythms to re-establish a BASELINE phase-angle in relation to the sleep rhythm during a 3-week REVERSAL resembles the sleep disorder associated with depression and narcolepsy. Extremely small alterations of the phase angle between light-dark and activity cycles in hamsters produce remarkable endocrine alterations (Elliott, 1976). Altered internal phase angle relations among body rhythms may also contribute to the seasonal responses of numerous lower species (Pittendrigh, 1974). These results from animals suggest that social synchronizers, lighting, or other factors which might produce subtle perturbations of circadian rhythm organization could have a role in the etiology of affective diseases as well as sleep disorders.

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ENDOCRINE RHYTHMS ACROSS REVERSAL SLEEP-WAKE CYCLES

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That the endogenous sleep-wake cycle has long been the object of man's innate curiosity is reflected in his earliest myths, and that such cyclicity is involved in some way with his well-being seems to be the consensus of this evidence of the collective unconscious. However, it is only in the past decade that we have come to recognize that hormones basic to growth, nurture, development, maturation, reproduction and energy metabolism have patterns of daily variation which are influenced by the human sleep-wake cycle (Parker, Rossman, Kripke, Hershman, Gibson, Davis, Wilson, & Pekary, in press). Since human hormones such as growth hormone (hGH), prolactin (hPRL), luteinizing hormone, testosterone, and thyrotropin (hTSH) drive these physiologically and phylogenetically essential processes, the a priori assumption that such periodic fluxes in these hormonal concentrations subserve these processes is logically inescapable. Indeed, rather impressive evidence that such is the case is seen in the temporal relation of sleep-related rises in the gonadotropin, luteinizing hormone, and as a result, in male hormone, testosterone, to the initiation and evolution of subtended masculine puberty (Judd, Parker, Siler, & Yen, 1974; Parker, Judd, Rossman, & Yen, 1975; Judd, Parker, & Yen, 1977; Boyar, Rosenfeld, Kapen, Finkelstein, Roffwarg, Weitzman, & Hellman, 1974) and the peaking of average daily growth hormone maxima in sleep during puberty (Parker & Rossman, 1973; Parker & Rossman, 1974; Parker, Rossman, Kripke, Gibson, & Wilson, 1979) to the subtended rapid increase in stature that occurs at that time. These latter strike us as significant physiologic and endocrinologic "performance." There is little question that hormones have important and often rather direct effects upon behavior. However, for clarity, simplicity, brevity and limitation of interpretative scope at this time, here we ask you to forego your own preferred views of performance and behavior and allow flux in plasma concentrations of these potent hormones across the day to represent the observed daily performance or behavior itself. Restated, the presumption that daily endogenous fluxes in hormonal concentration have some influence upon how that hormone exerts its effect(s) upon subsequent behavior does not strike us as an unreasonable thesis that requires an unwarranted leap of faith. After all, relation of externally applied stimuli to subsequent complex and externally observed behaviors requires a similar but much larger leap of faith in cause-effect assignment.

Here we will show the effects of phase reversal of the sleep-wake cycle upon the endogenous daily patterns of release of man's growth hormone, prolactin, thyrotropin, and cortisol. This latter is a reflection of its pituitary tropin, ACTH (Gallagher, Yoshida, Roffwarg, Fukushima, Weitzman, & Hellman, 1973; Krieger, Allen, Rizzo, & Krieger, 1971).

Basal State Conditions

Our observations were made in 8 healthy young adult males between the ages of 19 and 28. Our sampling technique consists of the drawing of 2 ml volumes of blood at 30 minute intervals from an indwelling antecutibal venous catheter across 24-72 hour sampling periods. All hormones are measured by sensitive, specific and stable radioimmunoassays in the same plasma sample (Parker et al., in press; Pekary, Hershman, & Parlow, 1975). Such intracaths were painlessly emplaced, carefully secured and dressed, and maintained patent by a heparin-lock system. A small bore 10 foot extension line (void volume 1.8 ml) allowed sampling from outside the bedroom. Sleep was polygraphically recorded and scored by standardized techniques (Rechtschaffen & Kales, 1968). The room was not entered nor the subject's sleep disturbed by intrasleep sampling. Wakefulness was carefully supervised by us and consisted of sedentary wakeful activity, regular equispaced feedings and minimization insofar as possible of intercurrent stresses. Subjects were not permitted to lie in bed or nap during wakeful segments and were exposed to usual social and environmental cues during wakefulness. Awareness of cues to 24 hour clock time was maintained by radio and TV programming, clocks, watches and visiting schedules. Basal sleep schedules ran from 2300 to 0700 hours and were maintained by all subjects at home prior to study, during an accommodation day and during subsequent days under these basal state conditions. Six of 8 subjects also had additional 24-36 hour long segments of basal state data available.

Sleep-Wake Reversal

Reversal of the sleep phase was achieved by delaying bedtime from 2300 hours until 1100 hours on the first day of reversal and then holding the bedtime sleep segment fixed in this 1100-1900 hour interval thereafter. In all wakeful segments across both basal and reversal studies, all subjects were exposed to the available natural light phase of the LD (Light Dark) cycle. On all basal and reversal study days the artificial illuminative schedule conformed to the respective wake phase. Four subjects were studied in an accute SW (Sleep Wake) reversal protocol which consisted of a 72 hour sampling period of serial 24 hour long (1900-1900) basal (B), first (R_1) and second (R_2) reversal segments. They were fed the same meal three times per day at 0730, 1230 and 1730 basally. This 10 hour feeding segment was phase-reversed to 1930, 0030 and 0730 during sleep-wake reversal. This group slept in full darkness in a bedroom from which natural light was excluded during the 1100-1900 sleep segment in the R_{1-2} reversal period. The natural LD cycle was 14:10 (2 subjects: July; sunset 1956 PST) and 11:13 (2 subjects: February; sunset 1738 PST).

The other 4 subjects who continued their sleep-wake reversal schedule for 15 days were sampled in a basal 24 hour segment from 1900 to 1900 and then during three 60 hour long periods across the sleep-wake reversal: "R_{3-5}" was from 1900 of R_2 to 1100 hours of R_5; "R_{8-10}" was from 1900 hour of R_7 until 1100 hours of R_{10}; "R_{13-15}" was from 1900 hours of R_{12} until 1100 hours of R_{15}. The "long" reversal's subjects were fed the same meal every 2 hours beginning at 0800 until 1800 basally so that the 24 hour ration of calories was taken as 6 equal feedings in wakefulness. During sleep-wake reversal, this 10 hour long feeding segment was phase reversed to run from 2000 until 0600. During the 15 day long reversal period, natural light was <u>not</u> excluded from the sleeping quarters during their 1100-1900 bedtime sleep segment. This study was carried out in September when the LD cycle was 12:12 and sunset at 1900 PST. Thus, the differences between the acute and long reversal studies were in subjects, feeding schedule and the availability of natural light in daytime sleep segments during the sleep reversal periods.

Data Calculation and Display

a) Raw hormonal data: The mean hormonal concentration for each 24 hour Basal, 48 hour R_{1-2} or 60 hour long R_{3-5}, R_{8-10} and R_{13-15} segment for each hormone in each subject was calculated and every one of his hormonal concentrations at 30 minute intervals expressed as a percent of this mean. This represents an attempt to "normalize" variation between subjects. Then the subjects' percent concentration data were pooled at 30 minute clocktime intervals across that segment for that hormone to arrive at the group's mean percent concentration plot across clocktime of that basal or reversal segment. This permits hormonal events that are synchronized both across 24 hour clocktime and between subjects to stand out. These are shown as Figure 1, 5, 7 and 11 for GH, PRL, cortisol and TSH, respectively, in an actigraphic representation. An individual's cortisol and TSH results in this format are seen as Figure 9, 10, 13 and 14, respectively.

b) Cosine fits were done according to the technique of Halberg (Halberg, Johnson, Nelson, Runge, & Sothern, 1972) to full 24 hour (1900-1900) segments of the data such as Base, R_1, R_2, R_3, R_4, etc., but not to segments with less than 24 hours of data such as R_5 (16 hours from 1900 to 1100 or R_5). The acrophase results are shown in Figure 3 for the individuals' daily acrophases across the reversal.

c) Rayleigh testing for evidence of significant directionality of such groups of acrophases (B, R_{1-2}, R_{3-4}, R_{8-9}, R_{13-14}) as developed by Batschelet (1965) were also done, and the circular mean o and 95% confidence arcs of the resultant mean acrophases also estimated for each segment of the studies. These appear as Figure 4.

d) The autocorrelation function (Parker et al., in press; Parker et al., 1979) of each 48-60 hour long reversal segment (R_{1-2}, R_{3-5}, R_{8-10}, R_{13-15}) was calculated for each subject at 30 minute lags and the group's mean plot of the autocorrelation function then obtained at each such point across the reversal for each hormone.

e) The variance spectra (Parker et al., in press; Parker et al., 1979) of each individual's reversal segments were also calculated at 1 c/d resolution and from these, the group's mean variance spectra calculated across R_{1-2}, R_{3-4}, R_{8-9} and R_{13-14} segments of the reversal for each hormone (Parker et al., 1979). The mean autocorrelation function and variance spectra results for each hormone are shown in Figure 2, 6, 8 and 12. Since the specific basal segments of the present acute and long reversal studies are too short to permit the autocorrelation function to reach events 24 hours apart they are not shown. We have published normative data from other subjects studied under identical basal conditions (Parker et al., in press).

Growth Hormone

Somatotropin or hGH was the first hormone to be shown to have a relationship between its daily 24 hour maxima and daily sleep (Quabbe, Schilling, & Helge, 1966; Parker, Mace, Gotlin, & Rossman, 1968; Takahashi, Kipnis, & Daughaday, 1968; Honda, Takahashi, Takahashi, Azumi, Irie, Sakuma, Tsushima, & Shizume, 1969; Parker, Sassin, Mace, Gotlin, & Rossman, 1969; Sassin, Parker, Mace, Gotlin, Johnson, & Rossman, 1969). In Figure 1's actigraphic format can be seen this relationship over the most prolonged period of sleep-wake reversal yet shown. This group mean plot faithfully represents each individual's plots. The basal daily peak early in nocturnal sleep is seen to shift immediately and completely into early daytime sleep on R_1 and then to hold in this position over the rest of the 15 days of sleep-wake reversal. Scanning down the midnight line in the early segments of sleep-wake reversal (R_{1-5}) offers little evidence of a residual peak that might have been circadianally synchronized. However both basal and reversal hGH patterns show multiple peaks in wakefulness whether fed 3 meals/day (R_{1-2}) or every 2 hours (R_{3-15}) in wakefulness. However, the second major synchronized peak of the day during reversal also tends to occur in late sleep. This will later be seen to influence the acrophasal loci of fitted 24 hour-long cosines, as does the nonsinusoidal waveform (principally the duration) of the early sleep maxima.

This immediate reversal of daily hGH maxima with reversal of the sleep phase demonstrates what endocrinologists have been calling sleep-related, sleep-enhanced, sleep-augmented, sleep-stimulated, sleep-dependent or sleep-entrained hGH release. This has been rather loosely referred to as the "circadian rhythm" in hGH variation though we have used the term nychtohemeral (night>day) rhythmicity for basal state data. Perhaps most appropriate of all nominatives is "sleep-wake rhythmicity of hGH." In rhythmic terminology, this hGH rhythm may be seen as that resulting from a rather pure masking effect (Aschoff, 1979; Aschoff, 1960; Aschoff, Hoffman, Pohl, & Wever, 1975) of sleep that is stimulatory.

In Figure 2 are seen the group mean autocorrelation functions and variance spectra for hGH across the reversal segments. The principal difference in the autocorrelation function across the reversal is not that of the constant persistence of 48 lag (e.g., 24 hour) maxima (which also exists in basal state means) but in the midrange of the functions of R_{1-2} compared to R_{3-15}. We suspect this to be due to the difference in feeding schedules of the acute and long reversal protocols such that a masking effect of feeding that is inhibitory has been increased in frequency between the 2 sleep-wake reversal conditions. A persistent circadian component should have shown itself as a 24 lag peak in the reversal's autocorrelation functions. Mean basal variance spectra peak at 2-3 c/d. Across the reversal, the spectra are advanced slightly toward faster frequencies initially (R_{1-4}) and then resume their basal configuration (R_{8-15}). These faster frequencies are based both in the need of the Fourier technique to fit the waveform of the sleep peak and in the real releasing activity in wakefulness and the real appearance of second hGH peaks in sleep during reversal. Thus, despite the easily visualized 24 hour periodicity in raw GH data, the variance spectra correctly attributes larger components of the variance to frequencies > 1 c/d in both basal and reversal states. Thus GH's variation is multifrequential in both conditions.

In Figure 3 is seen the actigraphic display of daily hGH acrophases (ϕ) of 24 hour-long cosines fitted to 24 hour-long (1900-1900) segments across the course of reversal. The immediate delay and then fixation of the acrophasal loci for hGH is readily seen, as in the tautness of their distribution at each point in the reversal. In Figure 4 are plotted the group daily mean ϕ and their 95% confidence arcs for each segment across the reversal. Here it can be seen that the mean R_{1-2} acrophase shift is a delay and is significantly

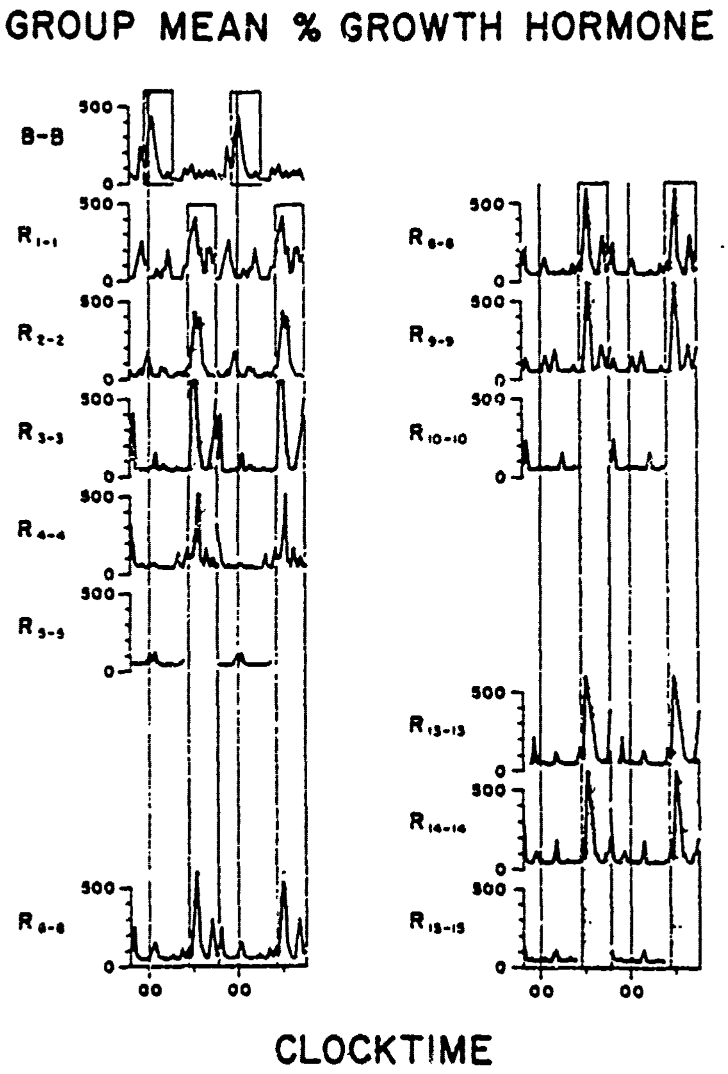

Figure 1. Actigraph of group mean % hGH concentrations across 15 days of sleep-wake reversal. Each hormonal data point at 30 minute intervals was first expressed as % of that subject's 24 (basal, B), 48 (R_{1-2}) or 60 hour (R_{3-5}, R_{8-10}, R_{13-15}) mean for that hormone, and the resultant % of sequential mean data was then pooled for daily averaging at 30 minute intervals from 1900 to 1859. The ±SE bars have been omitted. Eight subjects furnished 14 basal days of data and 4 subject's daily patterns were represented in every daily reversal mean. The gray bars on 8 hour bedtime sleep segments (23-07 basally and 11-19 in reversal) and the vertical black lines are midnight (0000) lines in the doubly plotted (B-B, R_{1-1}, etc.) format. this allows events synchronized across time and between subjects to stand out and their movement across 24 hour time seen.

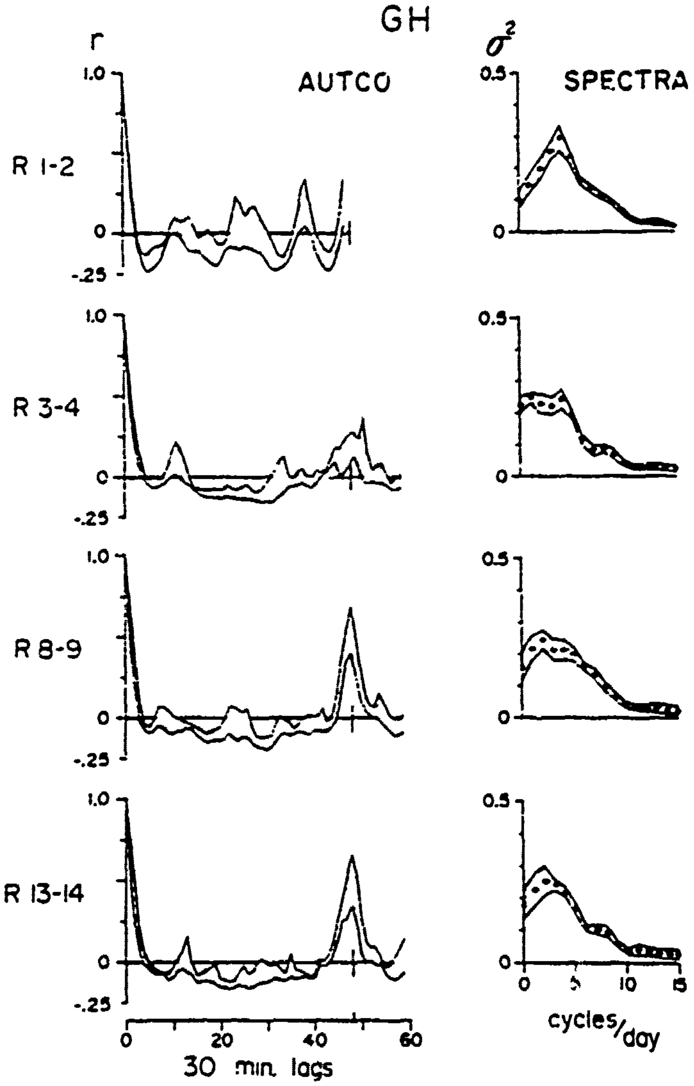

Figure 2. hGH: Group mean autocorrelation (Autco) functions and variance spectra across sleep-wake reversal segments. Autocorrelation functions at 30 minute lags were collected across the 48 hour (R_{1-2} and the 60 hour R_{3-5}, R_{8-10} and R_{13-15}) segments for each hormone in each individual. Then the group's averages were calculated at each lag for each reversal segment. The gray zip line plot shown is the mean ±SE zone. The variance spectra at 1 c/d resolution were similarly correlated, averaged and plotted.

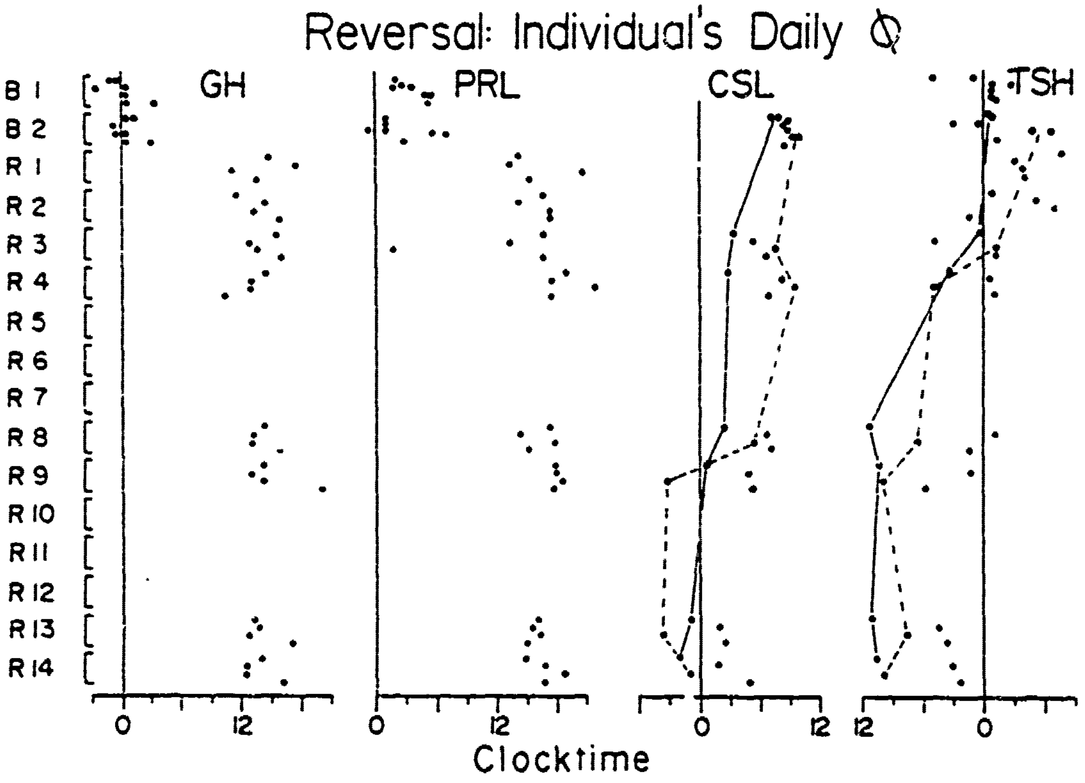

Figure 3. Eight individuals' daily 24 hour cosinor acrophases across sleep-wake reversal: Growth hormone, prolactin, cortisol and thyrotropin. Results have been converted into clock-time from 1900 to 1900 hours of the fitted segment. Basal sleep = 23-07, reversal sleep = 11-19. The solid and dotted lines connecting the open circles represent the phase shifts of subject 300 and 315, respectively.

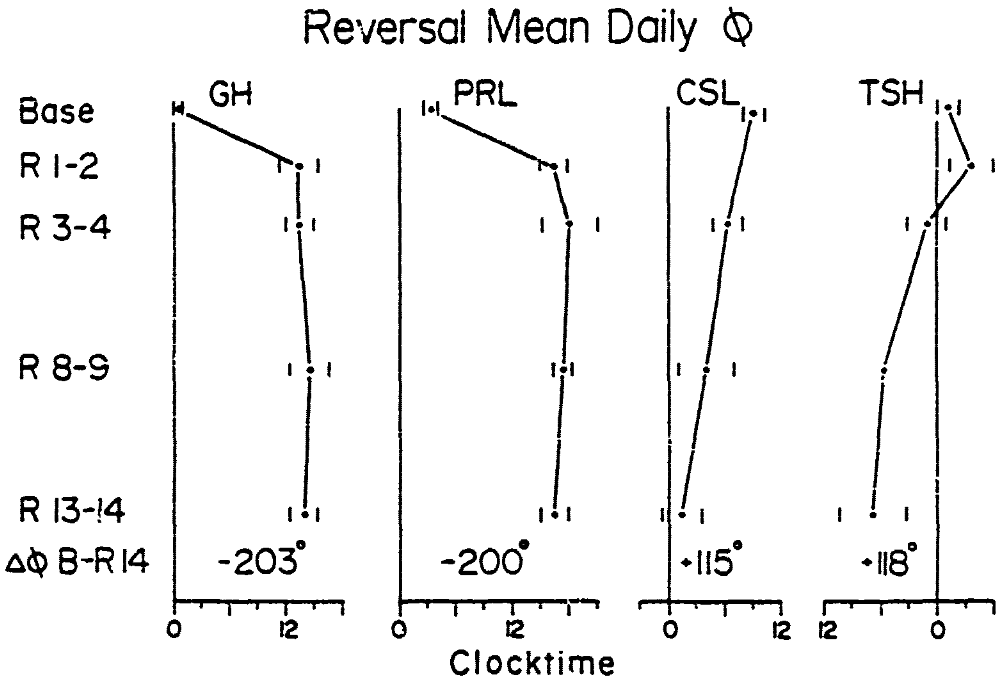

Figure 4. Groups mean daily acrophases 95% confidence arc for hGH, PRL, cortisol and TSH across sleep-wake reversal segments. Cosinor o's from Figure 3 had their circular mean, 95% confidence arc calculated for Basal, R_{1-2}, R_{3-4}, R_{8-9} and R_{13-14} segments. Rayleigh testing for significant directionality of each mean was also done. The $\Delta\phi$ B-R_{14} is the difference between the basal and R_{13-14} means.

different from the basal mean, while subsequent mean R_{3-4}, R_{8-9} and R_{13-14} acrophases are significantly similar to R_{1-2}. We interpret the phase-shift beyond 180° in the ultimate phase delay from basal condition here to be attributable to the displacement of acrophase away from reversals' raw data display of early sleep maxima in hGH that was induced by the addition of second major episodes of hGH release later in daytime sleep during reversal.

Prolactin

PRL, the human lactational hormone, was the second hormone shown to have a relation of daily maxima to sleep (Parker et al., in press; Sassin, Frantz, Weitzman, & Kapen, 1972; Parker, Rossman, & Vanderlaan, 1973; Sassin, Frantz, Kapen, & Weitzman, 1973). The onsets and offsets of maximal release appear to us to be more closely related to sleep itself under basal state conditions than to clocktime itself. However, some who have not objectively monitored sleep have suggested that the onset and offset of the nocturnal peak in PRL extends beyond the confines of basal bedtimes and interpreted this as indicative of sleep-unrelated circadianess in its variation (Vekemans & Robyn, 1975; Nokin, Vekemans, L'Hermite, & Robyn, 1972; Copinschi, DeLaet, Brian, Leclercq, L'Hermite, Robyn, Virasoro, & Van Cauter, 1978). Therefore, examination of prolactin's response to phase reversal of the sleep-wake cycle is of interest in clarifying the determinants of its daily pattern of variation.

Seen in actigraphic format in Figure 5 is the group mean percent PRL data across the reversal, which as for GH, faithfully represents individuals' data plots and shows events synchronized across time and between subjects. Daily maxima in relation to sleep consistently characterize both basal and reversal conditions, where the onset of rise and segments > 100% are clearly restricted to sleep, and declines follow the end of the sleep interval regularly. This all reinforces our point of the strength of the sleep-enhanced (or masking effect of sleep that is stimulatory) contribution to PRL's patterns of daily variations in young men. The immediate shift of the PRL maxima with the sleep phase on R_1 and its subsequent fixation thereafter to the sleep phase across the reversal both resemble the pattern of shift that hGH had undergone. Scanning down the 19-00 interval early in the reversal for evidence of a residual peak in PRL release that could represent an unmasked (from sleep) and synchronized circadian component, one infrequently encounters release that rises above the 100% line (R_{4-5}) nor in individuals' plots did one see much temporal synchrony here. Throughout the latter half of reversal one sees even less evidence of a nocturnal peak in wake that has remained synchronized by the natural LD to which exposure had been maintained. Thus if a non sleep-related circadian component to PRL variation exists, it must be of low amplitude and thereby relatively easily obscured.

The group mean autocorrelation functions and variance spectra across the reversal are seen in Figure 6. The autocorrelation maintains the same 48 hour lag maxima (e.g., 24 hours apart) that characterizes basal state across the entire reversal. The only appreciable change is the appearance of a lessened nadir in negative autocorrelation in the mid-range of R_{3-4} and R_{8-9}. This latter causes the shift in peak of the variance spectra away from the 1 c/d peak of B, R_{1-2} and R_{13-14} to 2 c/d in the R_{3-4} and R_{8-9} spectra. One surmises from Figure 5 that the suggestion of bimodality in the PRL patterns of R_4 and R_8 and their lessened amplitudes in sleep are the sounce of this minor change

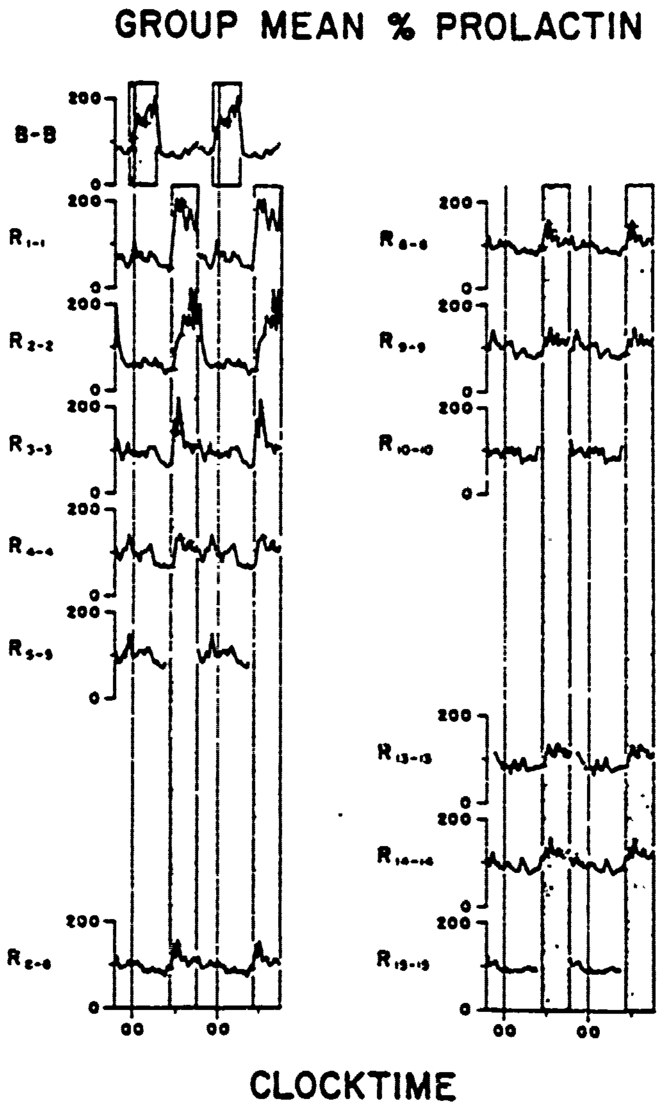

Figure 5. Actigraph of group mean % PRL concentrations across 15 days of sleep-wake reversal. Details as per Figure 1.

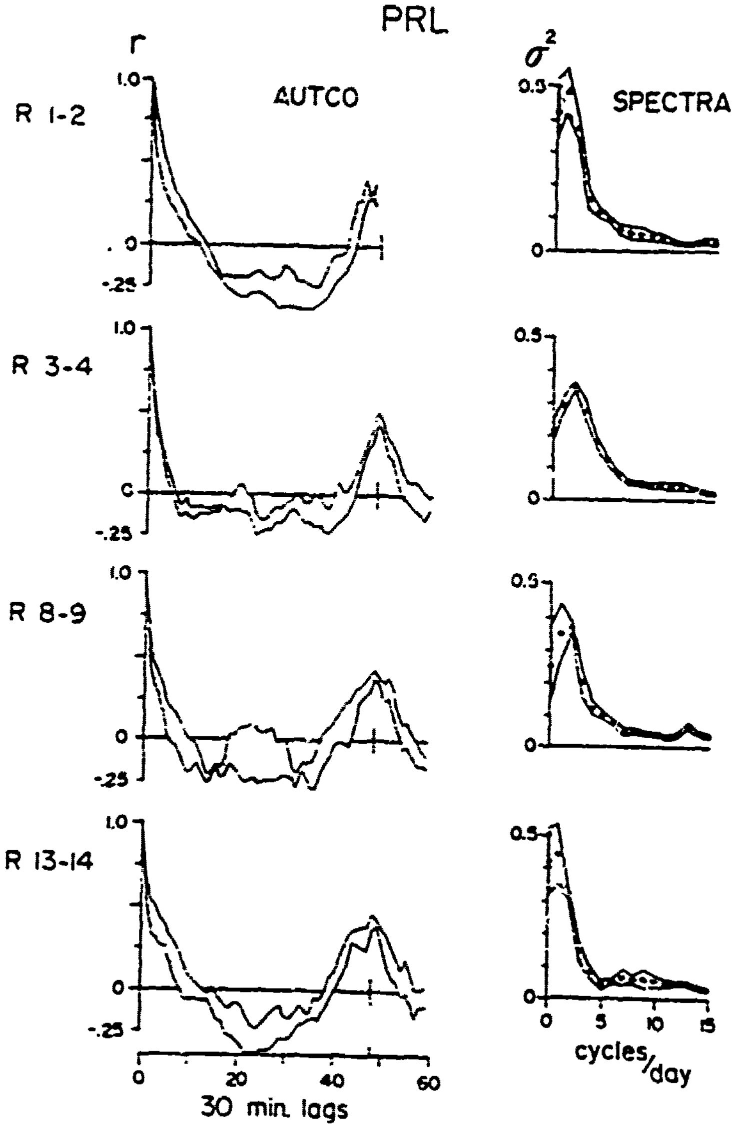

Figure 6. PRL: Group mean autocorrelation (Autco) functions and variance spectra across sleep-wake reversal segments. Details as per Figure 2.

in the autocorrelation and variance spectra. However this may be seen as weak evidence of a residual circadian component that exists in addition to the sleep-related component in the 24 hour PRL variation patterns. Again, one would like to see them persist across the entire reversal or to gradually be lost from R_{1-2} onward to be convincing evidence of circadianess.

The acrophases of the individuals' 24 hour cosine fits to PRL are seen in Figure 3 and are akin to those for hGH. An immediate delay and then fixation across the reversal as well as a nice tautness of distribution are evident. Thus the cosine fits cannot identify any circadian persistence of acrophases in the 23-0700 interval during reversal.

The group mean acrophases for PRL and their 95% confidence arcs across the reversal are seen in Figure 4. All exhibited significant directionality in Rayleigh testing as had those for hGH. The mean ϕ for all reversal segments were significantly different from the mean basal ϕ but were without significant differences within the reversal segments. The confidence arc of the ultimate shift achieved by R_{13-14} of -200° encompassed an 180° delay from the mean PRL ϕ of basal sleep-wake state.

Thus it seems to us that PRL variation exhibits a 24 hour rhythm attributable to a masking effect of sleep itself that is stimulatory and that the evidence of any additional circadian component is somewhat weak. If the latter exists, it is of a low amplitude and easily obscured.

Cortisol

The daily pattern of plasma cortisol variation was the first recognized hormonal circadian rhythm (Tyler, Migeon, Florentin, & Samuels, 1954; Migeon, Tyler, Mahoney, Angel, Castle, Bliss, & Samuels, 1956) and remains today the classical endocrinolgic prototype of such rhythms. Though the light-dark (LD) cycle appears well established as the principal environmental synchronizing cue in the laboratory animal, the demonstration of the importance of the LD cycle in maintaining synchrony of cortisol's endogenous circadian oscillator in man is unclear (Krieger, 1979). For example, blinded humans usually exhibit 24 hour rhythm rather than a free-running one (Weitzman, Perlow, Sassin, Fukushima, Buralk, & Hellman, 1972); when sighted humans are kept in constant darkness but exposed to 24 hour-periodic social cues, again periodicity and phase are maintained (Aschoff, Fatronska, Gisdke, Doerr, Stamm, & Wisser, 1971 1971). However, man usually conforms his sleep-wake cycle to the available LD cycle. Thus transmeridian flights include a shift of all available environmental and social cues as well as that of the elected sleep-wake cycle. Weitzman, Goldmacher, Kripke, MacGregor, Kream, and Hellman (1968) have shown that after laboratory reversal of the sleep-wake cycle for between 1-3 weeks, the phase of the plasma cortisol rhythm becomes reversed. There was considerable disruption of the 24 hour cortisol patterns during the sleep-wake reversal period until its phase-reversal was achieved. Krieger has shown that reversal of the sleep-wake cycle in constant light results in phase reversal of the cortisol rhythm (Krieger et al., 1969). Thus it is clear that there are important sleep-wake effects upon the phasing of man's endogenous cortisol rhythm. In men living on a 1 hour: 2 hour sleep:wake and dark:light schedule, Weitzman, Nogeire, Perlow, Fukushima, Sassin, MacGregor, Gallagher, and Hellman (1974) have seen not only a 3 hour periodicity imposed upon cortisol but also saw a persistent 24 hour circadian pattern to underlie this. From the foregoing, we suspect that both the sleep-wake cycle and environmental synchronizers play some role in the phasing of the cortisol rhythm. Because of this and because we were curious to know what was happening to the cortisol patterns before full phase reversal was finally achieved, we elected to examine cortisol patterns over the course of our 15 day reversal study.

In Figure 7 are shown the group mean plots of daily 24 hour cortisol patterns across the reversal in an actigraphic format. The average basal pattern is seen to be basically an unimodal nonsinusoidal waveform. Glancing down the daily mean actigraph one sees lesser amplitude bimodal release on R_{3-5}, less clearly organized or synchronized patterns that are bimodal (or more) on R_{8-10} and resumption of a basically unimodal pattern on R_{13-15} whose waveform is still different from basal in that it is basically sinusoidal but slightly bifid. If one follows the basal circadian peak near 0700 down the actigraph one sees it to largely hold its position until about R_{10}, whereafter it appears to slightly advance. Then running the eye down the 1700-00 interval (e.g., late-sleep and post-sleep segments during reversal) one sees increasing amplitude and duration of mean cortisol release here and finally a melding of this with the previously described "basal circadian" peak that has advanced. This suggests that more than just advance (or delay) of a single circadian oscillator for cortisol may be involved in the ultimate achievement of the expected phase-reversal.

In Figure 8, the midranges of the group mean autocorrelation functions for cortisol across the reversal segments also indicate the presence of bimodal components on R_{3-5} and R_{8-10} that have largely "dropped out" by the R_{13-15} remelding. The 48 lag maxima indicates persistence of a predominant 24 hour correlation across all the reversal segments. Peaks in the variance spectra also shift to 2 c/d on R_{3-4} and R_{8-9} before resuming the basal 1 c/d peak on R_{13-14}. This synchronizing of bimodal peaks in Figure 7 and of midrange peaks in autocorrelation in Figure 8 caution against regarding these trends as simply those of noisy transients during reversal.

Turning to the group mean results of cosine fitting, in Figure 4 we see that significant directionality by Rayleigh testing is achieved by each group of acrophases (B, R_{3-4}, R_{8-9}, R_{13-14}) and that a significant advance away from the basal distribution is achieved by R_{8-9}, despite the latter's having the broadest 95% confidence range and therefore probably the greatest disparity in patterns of shift. The group's mean acrophases show a slow gradual advance across the reversal to achieve about an 8 hour advance by the 14th day of sleep-wake reversal. However, since we have shown you hormonal and autocorrelative patterns that are bimodal, one needs to be cautious in interpreting 24 hour cosine fits since the cosine is a test of unimodal fit. Bimodal peaks close together are fit relatively well by a cosine, whereas those 12 hours apart are not as well descirbed. However, this did not prove to be a problem with individuals' 24 hour cosine fits to cortisol as only one of 31 basal and reversal days (315: R_8) was not significantly fitted. A glance at the mean cortisol concentration actigraphic in Figure 7 indicates that the group mean acrophases of Figure 4 are in the main following cortisol's "basal circadian peak" component as it advances.

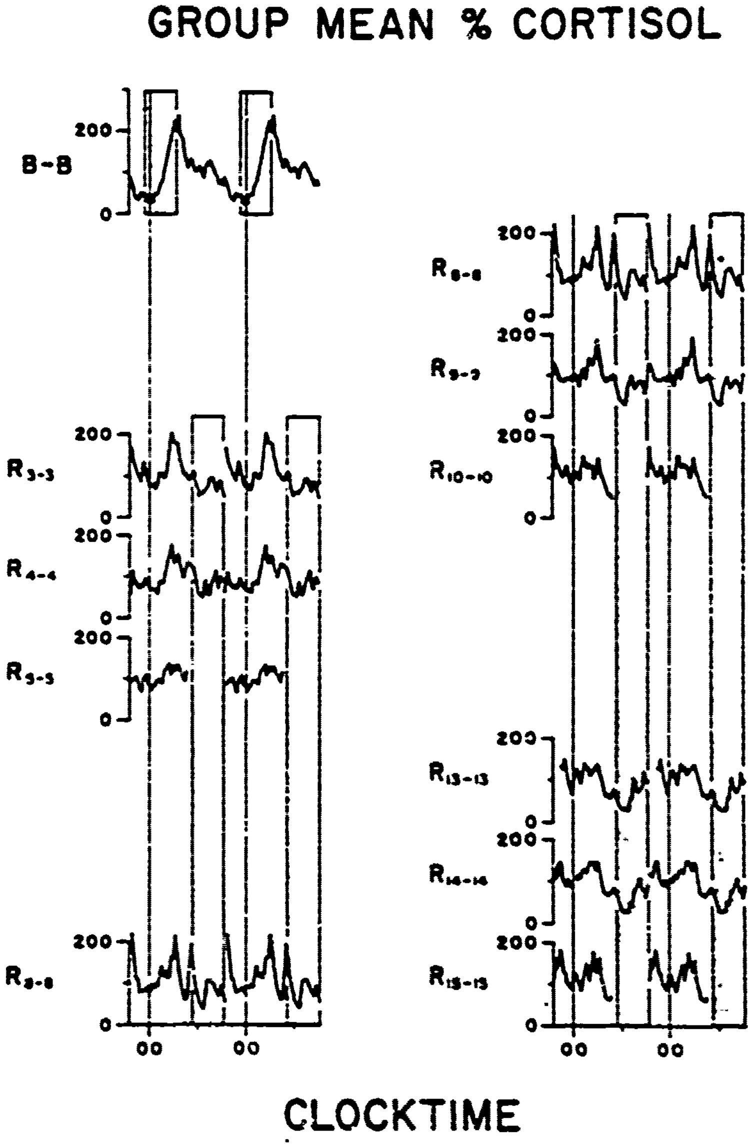

Figure 7. Actigraph of group mean % cortisol concentrations across 15 days of sleep-wake reversal. Details are as per Figure 1 except that the basal groups' plot is from 7 days of 4 subjects who have had no R_{1-2} cortisol data.

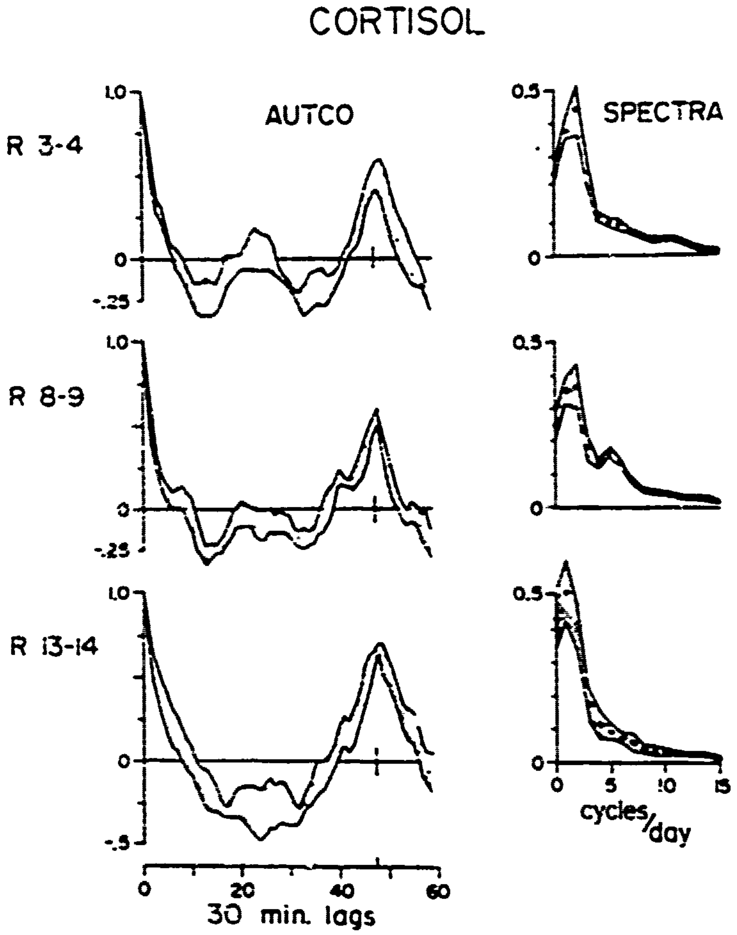

Figure 8. Cortisol: Group mean autocorrelation (Autco) functions and variance spectra across sleep-wake reversal segments. Details as per Figure 2.

The individuals' daily acrophases across the course of reversal (Figure 3) reveal that the pattern of shift in cortisol maxima occurred in at least 3 ways; (1) two (305, 311 - black dots on Figure 3) largely held their basal circadian acrophase position through R_{8-9} and then advanced only minimally by R_{13-14} so that a total advance of about only 90° was achieved. The cortisol actigraph for one of these subjects (305) is shown in Figure 9. Here a bimodal basal pattern (which was also seen in his autocorrelation functions) is largely maintained across the reversal so that the larger "basal circadian" component has advanced its peak only 4-5 hours while the second lesser basal afternoon-wake component was delayed initially and then persisted as the late- and post-sleep component without ever gaining in amplitude or duration and not melding with advancing basal circadian component by R_{15}. Thus a fully reversed pattern was not achieved by R_{15}. The second subject (311) largely held a unimodal pattern throughout (also seen in his autocorrelation function) in which his major basal circadian component held with only slight advances while he failed to organize a consistent late- and post-sleep component. Thus these 2 had not reversed their patterns and had advanced only slightly by Day 15.

Of the 2 who reversed their patterns more fully, each exhibited a different pattern. (2) one, 300, shown actigraphically in Figure 10, exhibited basically a unimodal pattern (also seen in his autocorrelation functions) across the reversal in which the basal circadian maximum steadily advanced to complete the phase shift by R_{13-14}. His acrophases are the open circles connected by a solid line on Figure 3 and accurately replicate these cortisol concentration data results. (3) the other subject who phase-reversed his cortisol pattern completely is represented by the open circles connected by a dotted line on Figure 3. Here he held his basal acrophase position through R_8 and then by R_9 had undergone a rapid 180° phase advance (or delay) which he subsequently held. His Day 8 acrophase was insignificant so that this may have occurred more gradually on non-data days R_{6-7}. However the basal circadian component in his percent cortisol plot (not shown) appeared to be delaying toward sleep on R_{3-4-5} and also diminishing in amplitude, while a late- and post-sleep component was also evident as early as R_3. This lent the R_{3-5} and R_{8-10} cortisol data a bimodal pattern (the latter confirmed by his autocorrelation functions) in which the circadian component (0700) either lost amplitude and dropped out by Day 9 or it was delayed into and masked by early sleep inhibition (Parker et al., in press; Aschoff, 1979; Aschoff, 1960; Aschoff et al., 1975). In either case the late- and post-sleep maximum became the only identifiable acrophase for the cosinor on R_9. After this point the late- and post-sleep component remained as the major unimodal daily component on R_{13-15} (again seen in the autocorrelation function). Thus his reversal was accomplished dramatically and early in the reversal and came about probably by either a true phase delay or a "false" advance that came from identification of a second already existing peak as the new acrophase when the old maximum simply faded out. Clearly it would have been nice to have both D_{5-7} data and unmasked R_{8-9} data here.

To summarize for cortisol, we are convinced there are important events transpiring during the reversal period from which insights about the oscillator(s) involved can be gained, and that this is not just a period of noisy transients. We also strongly suspect that there may be 2 components melded in the basal unimodal circadian pattern, one clearly circadian and the other sleep-related (e.g., a masking and/or a phasing effect) that may become vis-

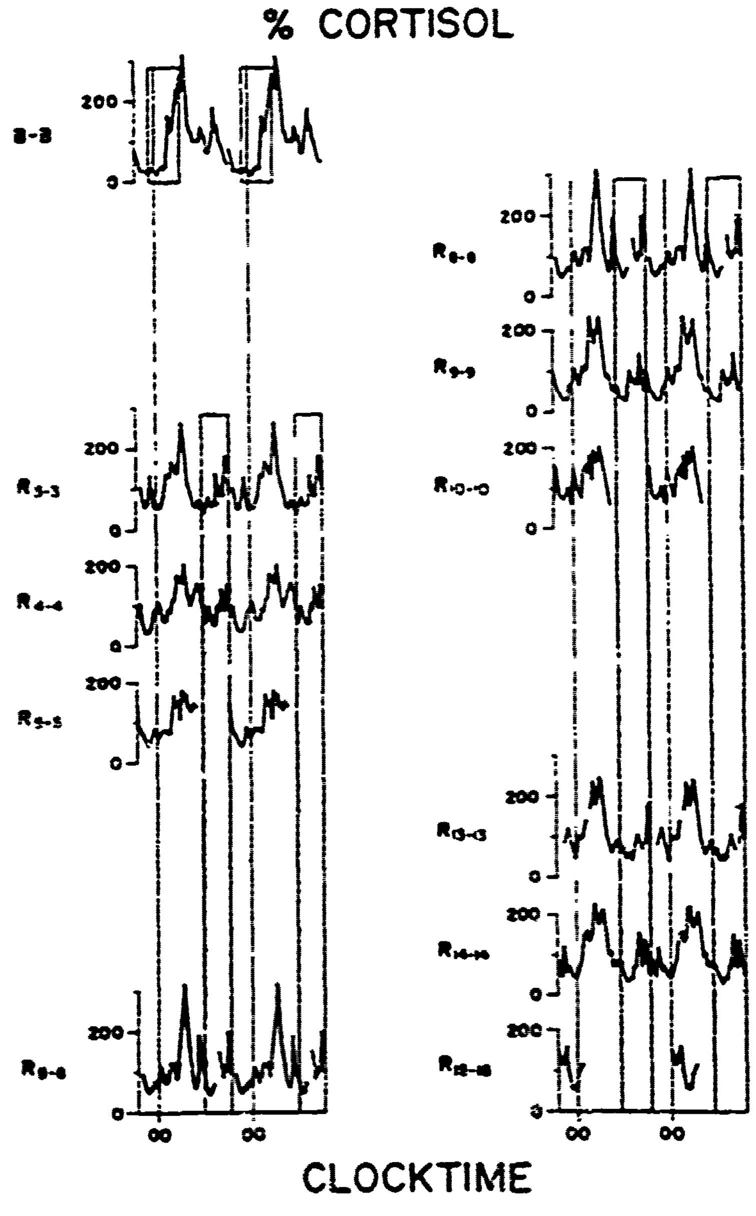

Figure 9. Subject 305's cortisol actigraph across 15 days of sleep-wake reversal. Actigraph details may be found in Figure 1. He has failed to phase-reverse his bimodal daily pattern of maxima by day 15, advancing it only 4-5 hours.

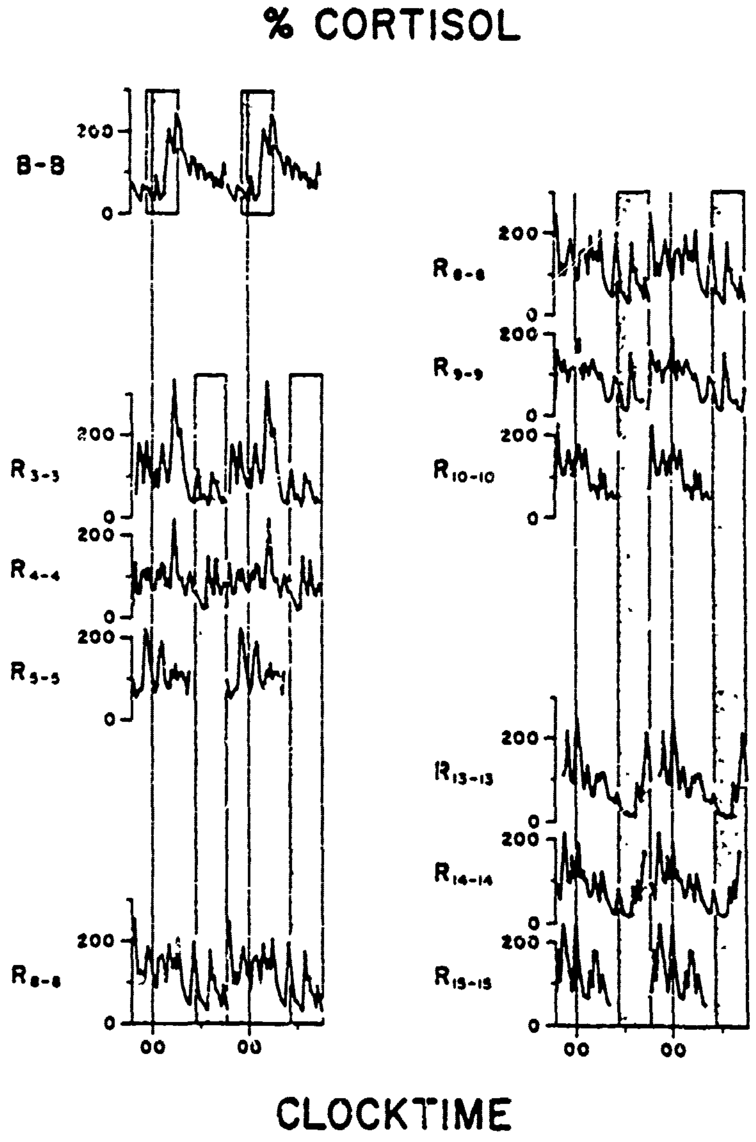

Figure 10. Subject 300's cortisol actigraph across 15 days of sleep-wake reversal. Actigraph details as per Figure 1. He has phase-reversed his unimodal cortisol pattern of maxima by a series of phase-advances across the reversal.

ible during reversal. The circadian component also appears to more commonly phase advance in reversal.

Thyrotropin

The daily maxima are seen to rhythmically recur each evening and to precede the onset of the sleep interval (Parker, Pekary, & Hershman, 1976; Azukizawa, Pekary, Hershman, & Parker, 1976; Weeke, 1973; Weeke, Hansen, & Lundaek, 1975; Alford, Baker, Burger, deKrester, Hudson, Johns, Masterson, Patel, & Rennie, 1973). The rise to peak begins in the early evening and then declines occur across sleep. These results stand in contrast to previous reports in which the sleep phase was not carefully fixed or objectively measured and in which the loci of the maxima were found to vary across the entire night or to not be consistently observed (Webster. Guansing, & Paice, 1972; Nicoloff, Fisher, & Appleman, 1970; Vanhaelst, Van Cauter, Degaute, & Goldstein, 1972; Van Cauter, Leclercq, Vanhaelst, & Goldstein, 1974; Van Cauter, Goldstein, Vanhaelst, & Leclercq, 1975). This contrast indicates sleep to be almost as important a determinant of the locus of maxima of this TSH rhythm as it was for hGH and PRL above (Parker et al., 1976). That sleep exerts an immediate inhibitory effect upon such TSH peaks was shown by advances and delays in sleep during this early evening period from 2000-0000 (Parker et al., 1976). Thus sleep exerts an inhibitory masking effect upon rhythmical daily TSH variation in plasma. In addition, in the absence of this masking effect of nocturnal sleep, the basal daily output of TSH is virtually doubled, an event that should be physiologically significant (Parker et al., in press; Parker et al., 1976). We were also intrigued by the suppressed secretion of TSH that followed on the day after such unmasking when it was accomplished by a 12 hour delay in sleep. At that time (Parker et al., 1976) we were unable to distinguish whether the source of reduced daily TSH release was due to a negative feedback effect of the prior day's huge TSH release or due to a dampening of a circadian rhythm by a phase effect of the reversed sleep-wake cycle. Thus, here we have examined TSH release across more prolonged sleep-wake reversal to gain insight into its apparent circadian rhythmicity and its modulation by sleep-wake cycles.

In Figure 11 are shown the group mean percent TSH concentration data in actigraphic format across the reversal. The basal pattern shows the usual evening pre-sleep peak in TSH whose maximum lies in close relation to sleep onset, and whose waveform is that of a sharp nonsinusoidal peak. On R_1 is seen the effect of acutely unmasking this basal rhythm from inhibitory sleep in darkness. Note that on R_{1-1} the ordinate is 1/2 scale to accommodate the huge release of TSH seen on this night. R_2 shows the suppressed 24 hour pattern of TSH that follows sleep in the 11-19 hour interval. We now know that such suppression also occurs on the third day of serial 6 hour delays in sleep onset, when the previous day's sleep has also been in the 11-2000 hour interval. In this case however, the TSH patterns on the 2 previous days where sleep had occurred in the 05-14 and 11-20 hour segment respectively, were both days in which maximal prolonged TSH secretion had occured (unpublished data). Thus this R_2 pattern of TSH suppression is not the result of negative feedback that we have previously proposed as one alternative explanation (Parker et al., 1976) but is clearly a dampening effect upon phase of the the reversal conditions. R_3 begins the data of our longer sleep-wake study protocol in which subjects now slept in natural light. This is recent preliminary data not yet

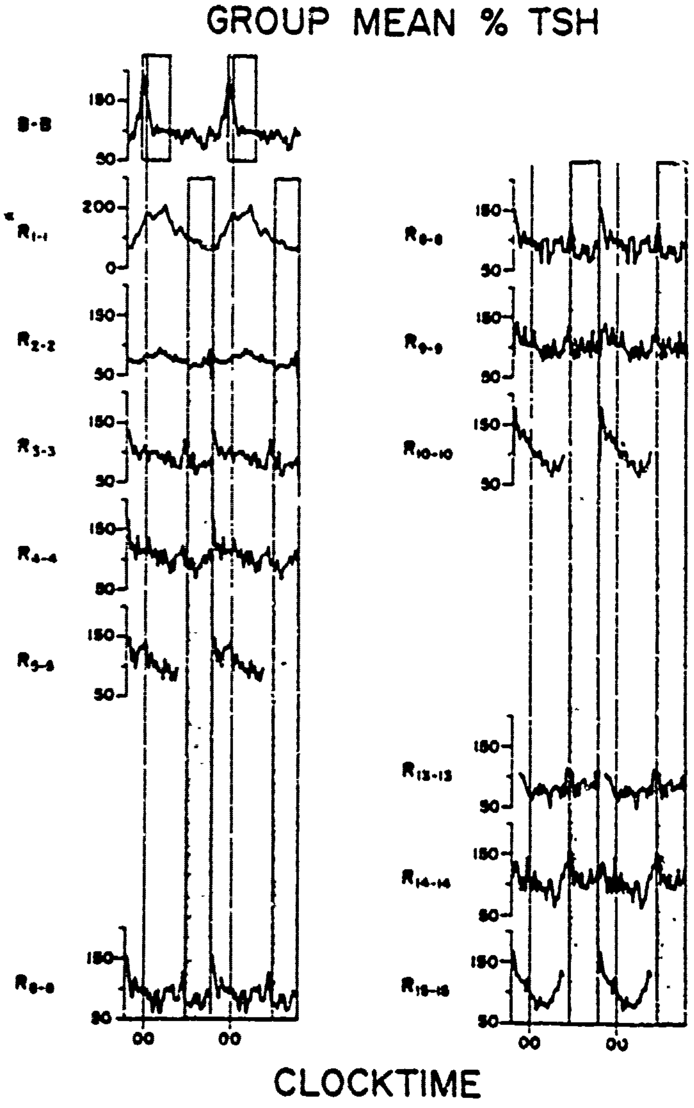

Figure 11. Actigraph of group mean % TSH concentrations across 15 days of sleep-wake reversal. Details as per Figure 1. Note the half-scale ordinate for huge TSH release on R_1.

replicated in a second radioimmunoassay. Here the daily maximum occurs at 1900 hours at the end of sleep - e.g., has advanced from its basal locus at 2300 and has advanced or delayed from its unmasked locus about 04-0600 of R_{1-2}. In addition a small pre-sleep peak in TSH is seen on R_{3-4}. R_{8-10} shows this same pre- and post-sleep pattern though the nadir following the post-sleep peak seems to be advancing. By R_{13-15} the post-sleep component is reduced in amplitude and the pre-sleep component enhanced, so that the phase-reversal of the basal (masked) pattern appears fully established. However, the majority of the advance appears to have been accomplished by a large initial phase advance (or delay) between R_2 and R_3. Here one would have to propose that R_1 sleep or some other phasing event phase delayed the R_2 TSH peak into R_2 sleep where it was masked and subsequently reemerged on R_3. Another alternative is competing synchronizers or uncoupled oscillators responsible for the pre- and post-sleep peak patterns that persist across the study.

In Figure 12 is seen the group mean autocorrelation functions and variance spectra across the reversal for TSH. This shows that the 48 lag (24 hours) peak in positive autocorrelation, which is also seen basally, persists across the reversal except in R_{1-2}. This latter is to be expected from the nature of R_{1-2} TSH release, where the large peak on R_1 is literally not repeated on R_2. In effect, a long delay (> 24 hours or 48 lags) between maxima occurs in the raw data to produce this autocorrelative effect. This is also indicated by the R_{1-2} variance spectra maximum at 0.5 c/d or less.

The group mean TSH acrophases for each segment of the basal and reversal segments and their 95% confidence arcs are shown in Figure 4. Here one sees the initial delay in R_{1-2} attributable largely to unmasking from sleep. Thereafter there is a steady advance of mean φ across the reversal. If one assesses the degree of advance from its unmasked locus on R_{1-2} then virtually full 180° phase delay is achieved by R_{8-9}, but if assessed from its basal masked locus to final reversal masked locus, it is only about 8 hours. Note that the R_{8-9} group of TSH acrophases is the only one for all hormones in Figure 4 to fail to achieve significant directionality by Rayleigh testing. This indicates a wide dispersal of acrophases here and speaks to the likelihood that the mode of such shifts is also disparate at this point. A look at the individuals' 24 hour cosinor acrophases in Figure 3 confirms this. Two subjects indeed phase-reversed by a rapid phase advance on R_4 and R_8, and were the same 2 subjects who had fully shifted their cortisol acrophases. The other 2, who had also slowly and incompletely reversed their cortisol acrophases via advances, again did the same for TSH. However, TSH and cortisol were probably not phase-linked as their advances in Figure 3 and Figure 4 were not parallel nor did their group mean cross-correlation functions reveal a fixed-lag peak in cross-correlation to be commonly held across all reversal segments.

Turning to the hormonal actigraphic data of the individuals, one can see in Figure 13 that subject 305 did not reverse completely. Both he and his cohort (311) had basically unimodal patterns across the reversal (and confirmed by their autocorrelation functions) in which the daily peak was a post-sleep one from R_{3-4} on. Neither developed a pre-sleep peak during the reversal (except for 305 on R_3 in Figure 13). Thus both appeared to advance a circadian mechanism a little and then hold. Figure 14 shows an actigraphic example of one subject (300) who did phase-reverse. Both subjects who fully reversed had pre-sleep and post-sleep peaks from R_3 onward and such bimodality was also

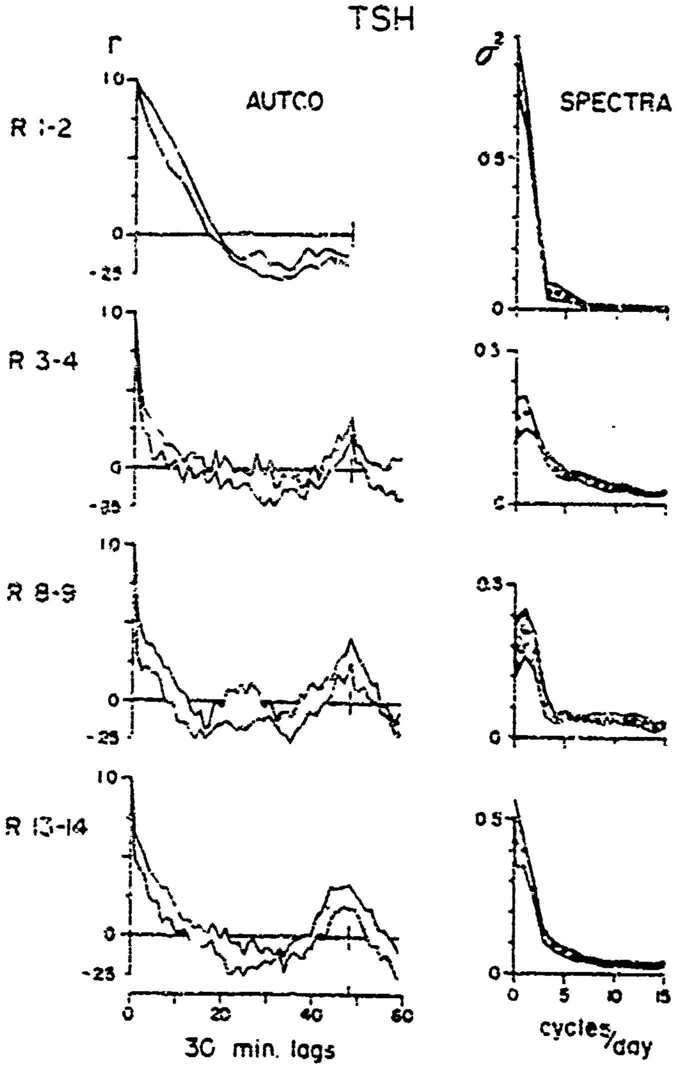

Figure 12. TSH: Group mean autocorrelation (Autco) functions and variance spectra across sleep-wake reversal segments. Details as per Figure 2.

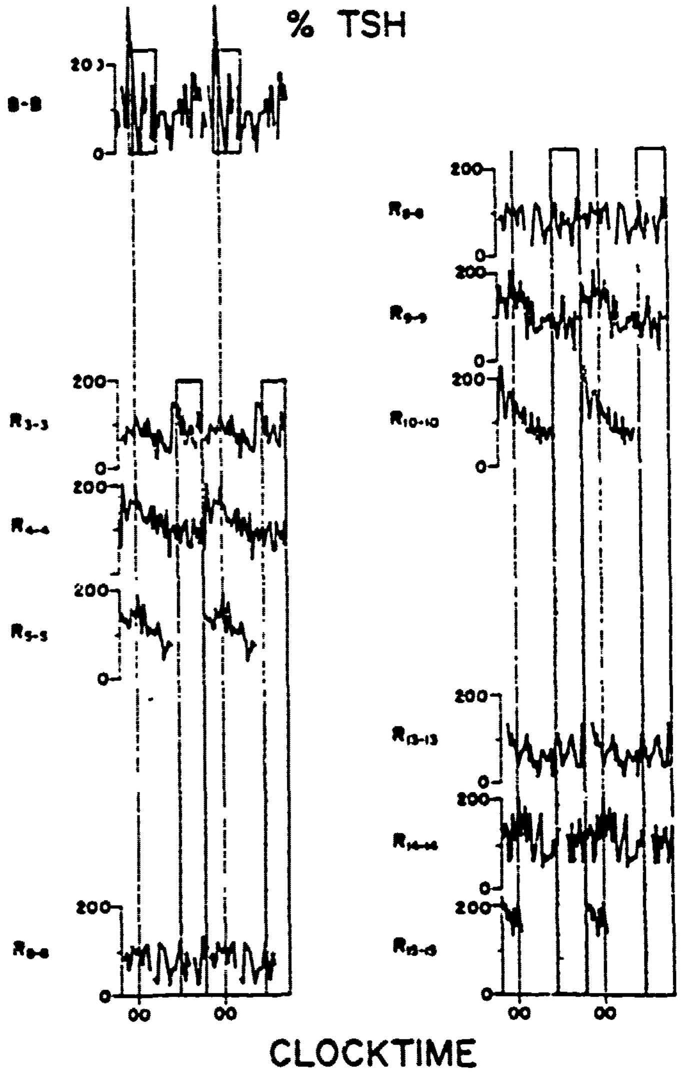

Figure 13. Subject 305's TSH actigraph across 15 days of sleep-wake reversal. Actigraph details as per Figure 1. He fails to fully phase reverse his daily unimodal TSH pattern of maxima, advancing the maxima to 6 hours early in the reversal and then virtually holding in this post-sleep (locus) thereafter.

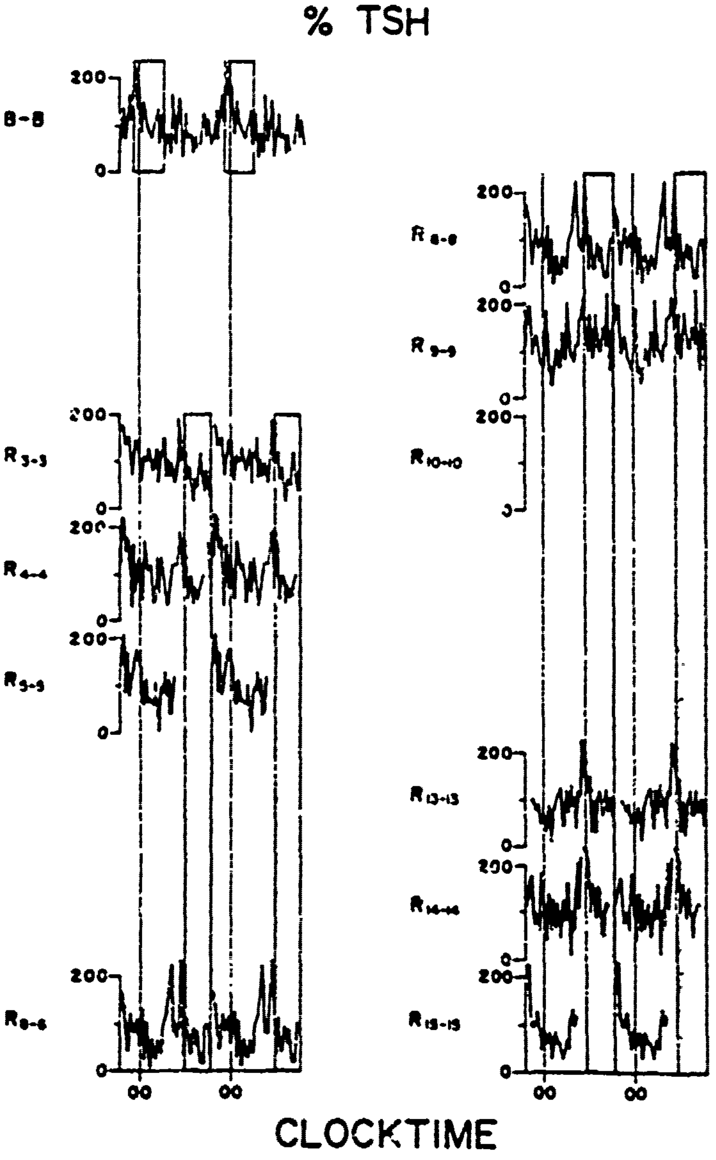

Figure 14. Subject 300's TSH actigraph across 15 days of sleep-wake reversal. Actigraph details as per Figure 1. his daily bimodal pattern of maxima is largely phase reversed by R_3, though a further series of small advances seem to be required to adjust the amplitudes of the pre- post-sleep of R_{3-5}, pre- post-sleep of R_{8-10} to the final pre > post-sleep of R_{13-15} through the sleep-masking effect.

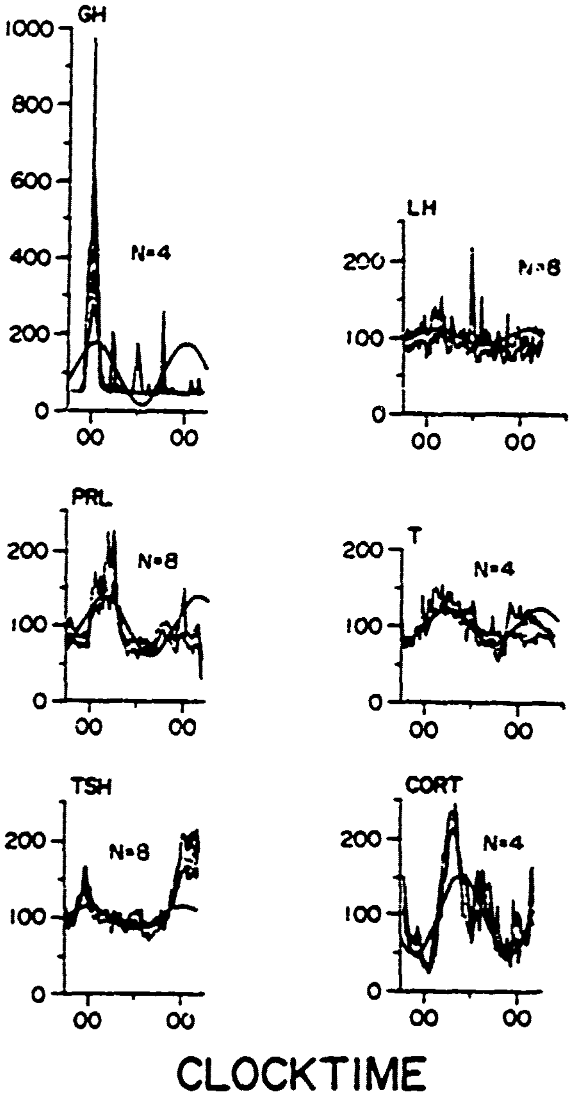

Figure 15. Immediate effect of missed sleep upon overt phasing of hormonal nychtohemeral rhythmicities. The hormonal time series across the first 24 hours of each study for that hormone was fitted with a 24 hour cosine. From these amplitudes (%.C) and acrophases (ϕ), the group mean %C, ϕ, and cosine were derived. This group mean cosine (thick, black, smooth curve) of the fit to the first 24 hours was superimposed on the % mean hormonal plot for the first 24 hours (thin black line) in order to visualize goodness of fit. The mean cosine was then projected across a remainder segment on the second night that is devoid of sleep.

seen in their autocorrelation functions. However by R_{13-15} the post-sleep peak and autocorrelation bimodality were fading in 300 and gone in 315, while in both subjects the pre-sleep component had increased in amplitude. This suggests that a circadian mechanism had been phase advanced first into the end of sleep and then had emerged on its "front" side. Sleep unmasking studies are crucial to this formulation and have not yet been done. A rather complex explanation is that there are 2 competing phasers or dissociated oscillators whose effects have been pulled apart in reversal. In any case it's clear that there are circadian, sleep masking and sleep phasing effects occurring here in regard to TSH.

Masking Effects of Sleep

Shown in Figure 15 are pooled data on studies in which basal 23-0700 hours sleep on the first night of study was not followed by sleep at this time on the second night. Superimposed is the group mean cosine derived from first 24 hour fits which is then projected across the second unslept nocturnal segment. For GH, there is no second night peak in the absence of sleep and no cosine fit. For PRL, the only evidence of a circadian residual does not reach the 100% line and the fit deteriorates after 2300 on the unslept night. This further exemplifies our notion of their "circadian" rhythms being almost entirely rhythms of stimulatory masking effects themselves. Cortisol remains immunely circadian in its peaks. However, evidence of its early-sleep inhibitory masking effect is present on the first night and absent on the unslept second. TSH shows its very dramatic unmasking from sleep-related inhibition on the second night. Testosterone and perhaps even young adult male LH also exhibit sleep-stimulatory masking.

This makes it terribly clear that one can't really talk about circadian hormonal acrophases without doing the necessary acute sleep deprivation segments to show where the real acrophase is. From what we have shown here, we are reasonably certain that when this is done, the additional phasing effects of sleeping and waking upon circadian hormonal oscillators may finally become clear to us all.

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ULTRADIAN RHYTHMS IN PERCEPTUAL MOTOR TASKS

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Research of rhythms in human performance has mostly focused on circadian rhythms (CR), and for obvious reasons a) there is a large volume of data on circadian rhythms in biological processes, b) there are distinct and measurable circadian environmental "time givers" that can potentially modify behavior, and c) the nature of human engineering problems presented by air traval growth and shift work is related to circadian rhythms. Experimental designs directed towards the investigation of CR tend to obscure short term variations in performance by employing sampling rates too slow to detect rapid variations, and by averaging data across subjects, a procedure which hides time related variability.

The term ultradian rhythms (UR) was introduced by Halberg (1967) to describe rhythms with frequencies greater than 1/day. In recent years most of the research on UR have been focused on rhythms within the frequency range of 10 to 20 cycles/day, which corresponds to the frequency range of the sleep REM-NONREM cycles. Theses latter cycles, easily measured during sleep, were suggested by Kleitman (1963) to be a part of a more general biorhythm that is manifested in wakefulness as recurrent fluctuations in arousal.

Research accumulated in recent years has borne out Kleitman's hypothesis by demonstrating UR in several indices of arousal such as electroencephalographic activity (Kripke, 1972), and pupillary activity (Lavie, in press), in waking humans with periodicities remarkably similar to the sleep cycles. The integration of these waking rhythms within a 24-hour rhythm, which includes also the REM-NONREM cycles, as proposed by Kleitman, has yet to be demonstrated.

Regardless of the relationships between the waking rhythms and the sleep cycles, investigation of their source and controlling mechanisms has both theoretical and practical importance. It is therefore rather surprising that only two studies investigated so far comparable UR in human performance. Globus, Drury, Phoebus and Boyd (1972) reported on equivocal evidence for 100 min rhythms in performance of visual detections, and Orr, Hoffman and Hegge (1974) extracted similar rhythmicity from vigilance data by the complex demodulation technique. In both studies the relative magnitude of these oscillations was not reported. The question of the rhythm magnitude is rather important since it may well be that UR indeed exist, but because they account only for a small portion of the total variability they have no practical value.

In the present paper we report the results of two experiments investigating UR in two perceptual motor tasks: linear positioning and tracking. Orthogonal variance spectra was utilized to determine whether significant ultradian rhythms occurred in the data, and subsequently least squares spectra was used to pinpoint the exact periodicity and to estimate its contribution to the total variability.

Experimental Tasks and Procedures

Linear Positioning

Subjects. Sixteen male students, ages 24 to 31 years, participated in the experiment, and were paid for their participation. Subjects were randomly assigned to two experimantal groups, hereafter referred to as Group 1 and Group 2.

Apparatus and procedure. The apparatus employed in the present experiment generally replicated the one used by Adams, Gopher and Lintern (1977). It consisted of a 100 cm metal rod, on which a lever was mounted on ball bearings for smooth movement. The lever could move from left to right and had a button on top. Subjects pressed down the button while moving the lever and released it when movement was completed. Releasing the button locked the lever in place. Visible only to the experimenter was a scale reading which allowed measurement of errors to the nearest mm. Apparatus was placed on a table; subjects were seated in front at a distance of their convenience. To eliminate visual feedback, subjects wore opaque goggles. Proprioceptive feedback was a augmented by attaching a 500 g weight to the lever string. In addition, a variable frequency auditory oscillator was attached to the lever and provided auditory feedback information. The frequency of the auditory tone was smoothly varied over a range of 500 Hz to 3000 Hz for a displacement of 30 cm of the lever. Movement time (MT) to the nearest msec was recorded by an electronic timer.

Subjects were instructed to press the button and move the lever in one quick continuous movement to a distance of 30 cm, then release the button. The experimenter returned the lever to the starting point, this procedure eliminated interference from return movement. Both proprioceptive cues (weight) and auditory information (tone) were introduced by the experimenter, and subjects were allowed to practice several movements before putting on the opaque goggles. Then goggles were put on and a 50-trial practice session with knowledge of results was provided (experimenter indicated direction and size (mm) of deviation from required movement after each trial).

During the experimental session Group 1 was tested every 10 min on the linear positioning task while Group 2 was given the task every 20 min. The 10 and 20 min sampling intervals were selected to investigate the possible influence of sampling frequency on the ultradian rhythmicity. In each testing period subjects were given 10 trials, the first 5 trials with knowledge of results (KR); knowledge of results was withdrawn in the last 5 trials (NKR). Subjects were tested for 10 hrs from 0800 to 1800. The first two hours were considered as training and adaptation and were not analyzed.

Between tests, subjects were permitted to read, listen to music, leave the experimental room, converse with each other or with the experimenter. Smoking was not allowed.

Error Measures--

Two error measures were obtained for each 10-trial testing period: Absolute error means in the last 4 KR and 4 NKR trials (labeled EKR and ENKR respectively). Then two 60-point time series were constructed from these variables for each subject in Group 1, and two 30-point time series were constructed for each subject in Group 2. Similarly, two time series were constructed for each subject from MT in the two conditions (MTKR and MTNKR).

Tracking

Subjects. Nine male subjects, ages 24 to 28 years, participated in the experiment, and were paid for their participation.

Apparatus and procedure. A target and a control signal were presented on a CRT display (effective screen size was 12x12 cm). The target was driven in the horizontal and vertical dimension by two independent, random, band limited forcing functions. The control symbol was operated by a two dimensional, spring centered hand controller (for a detailed description see Gopher, Navon, & Chillag, 1977). Experiment was controlled by PDP 11/45 mini-computer.

Subjects performed two dimensional tracking and tracking difficulty in each dimension could be changed manually, or adapted continuously by changing the parameters of the forcing functions.

Each subject was tested every 10 min for 1.5 min, for 12 continuous hours. The first two hours were considered as practice session and the adaptive procedure was used to drive subjects to their maximum ability on two dimensional tracking. In the last 10 hours, tracking parameters were the values obtained by the subject at the end of the practice session. Experiments were conducted in a small, semi-soundproof room, furnished with a comfortable chair, table, a CRT screen and the hand controller. Subjects remained isolated throughout the experiment. All communications with the experimenter were carried out via an intercom system.

Error Measures--

Root Mean Square (RMS) tracking error in 15 second trial segments was measured and averaged for 1.5 minute, then 60 point time series were constructed for each subject from the RMS scores of the horizontal and vertical dimension for the last 10 hours. Only the results of performance along the horizontal dimension will be reported in the present paper. The rationale for separating performance along the two axes was elaborated by Gopher, Navon, and Chillag (1977).

Statistical analysis. Data were analyzed by two methods. Variance spectra were calculated from autocorrelation functions (Jenkins & Watts, 1968). Spectra were smoothed, normalized and averaged across all subjects, separately in each of the experimental groups. Spectra peaks were searched, and when found, their statistical significance was determined by t tests. (One way t test was used whenever the ultradian peak occurred at the expected frequency of 14.4 c/d, corresponding to periodicity of approximately 100 min/cycle.) Subsequently, nonorthogonal least squares spectral analysis was used according to the method described by Lubin, Nute, Naitoh and Martin (1973). Least squares spectra estimates were calculated for periodicities within the range of 40 min to 160 min, in one minute increments.

Since previous results indicated that ultradian rhythms may be nonstationary (Lavie, 1977; Orr, Hoffman, & Hegge, 1974), whenever 10 hours of data, sampled at a rate of 6/hour, were available, time series were halved and the first and second halves were analyzed separately by orthogonal variance spectra.

Results

Linear Positioning

Table 1 presents the means, standard deviations and coefficients of variation (CV) for EKR and ENKR of both groups. The mean error pooled across subjects in each group was lower in the KR than NKR condition, but this difference was statistically significant only for Group 2 ($t = 3.22$, $df = 7$, $p < .05$). In both groups CVs reflected high within subject variability, ranging from 41.6% to 53.8% in Group 1 and from 51.5% to 93.7% in Group 2. Figure 1 displays performance data of 4 subjects, two from each group; successive error peaks can be easily eyeballed.

Table 1

Error in Positioning (in mm) SDs and CVs for Group 1 and 2

Subject	Group 1						Group 2					
	ENKR			EKR			ENKR			EKR		
	$\bar{x}$ (mm)	Sd	CV (%)	$\bar{x}$ (mm)	Sd	CV (%)	$\bar{x}$ (mm)	Sd	CV (%)	$\bar{x}$ (mm)	Sd	CV (%)
1	14	6	42.8	14	7	50	12.0	8.2	68.1	9.7	6.4	65.9
2	13.5	5.8	42.9	12	5	41.6	9.9	8.2	82.8	6.2	4.9	79.0
3	13.9	6.4	46.01	15	7	46.6	12.0	9.7	80.8	8.1	7.3	90.1
4	11.6	5.2	44.8	12	5	41.6	20.0	12.6	63	10.2	7.8	76.4
5	14.2	6.5	45.7	13	6	46.1	18.9	10.2	53.9	8.0	7.5	93.7
6	17.4	7.6	43.6	14	6	42.8	20.5	13.0	63.4	19.6	10.1	51.5
7	13	7	53.8	11	5	45.4	10.1	7.8	77.2	6.1	5.3	86.8
8	13	6.4	49.2	14.1	6.7	47.5	7.0	4.6	65.7	7.1	5.1	71.8
$\bar{x}$	13.8		46.1	13.1		45.2	13.8		69.3	9.3		76.9
Sd	1.6		3.7	1.3		2.9	5.2		10	4.3		13.8

Average 20 frequency spectra of Group 1 and average 5 frequency spectra of Group 2 peaked at different frequencies for EKR and ENKR (Figures 2 & 3). In both groups average spectra for ENKR peaked at the expected frequency of 14.4 cycles/day; average variance at both peaks was significantly different from the average variance at the adjacent frequencies and the average variance at the rest of the spectral frequencies, with at least $p < .05$. Average spectra for EKR, however, peaked at much faster frequencies, between 50.4 and 57.6

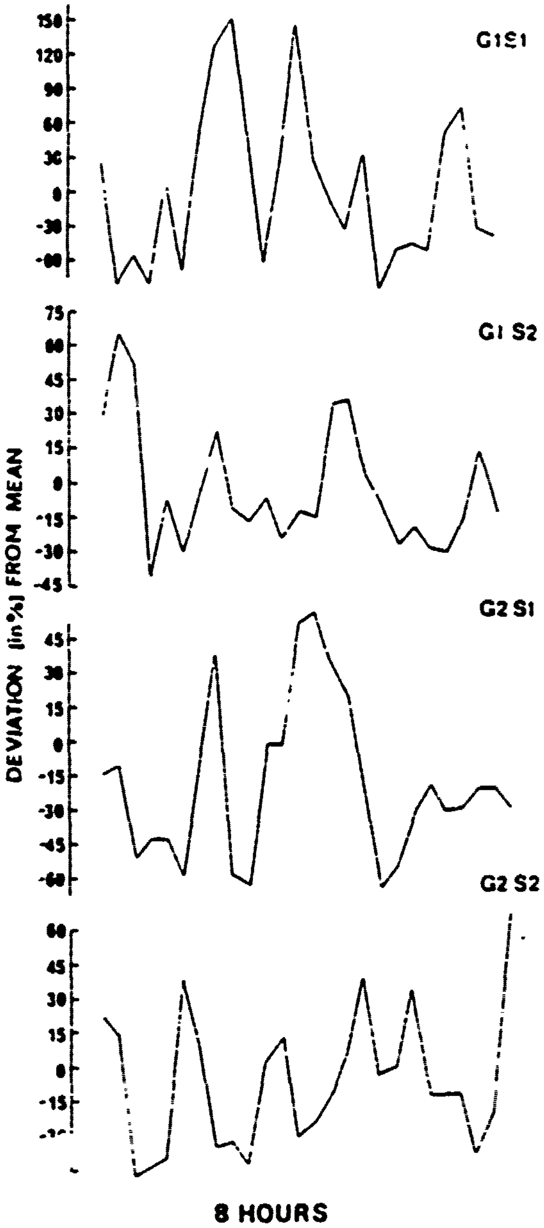

Figure 1. Ultradian rhythms in error in positioning (NKR) in 2 subjects of Group 1 (20 min values) and in 2 subjects of Group 2.

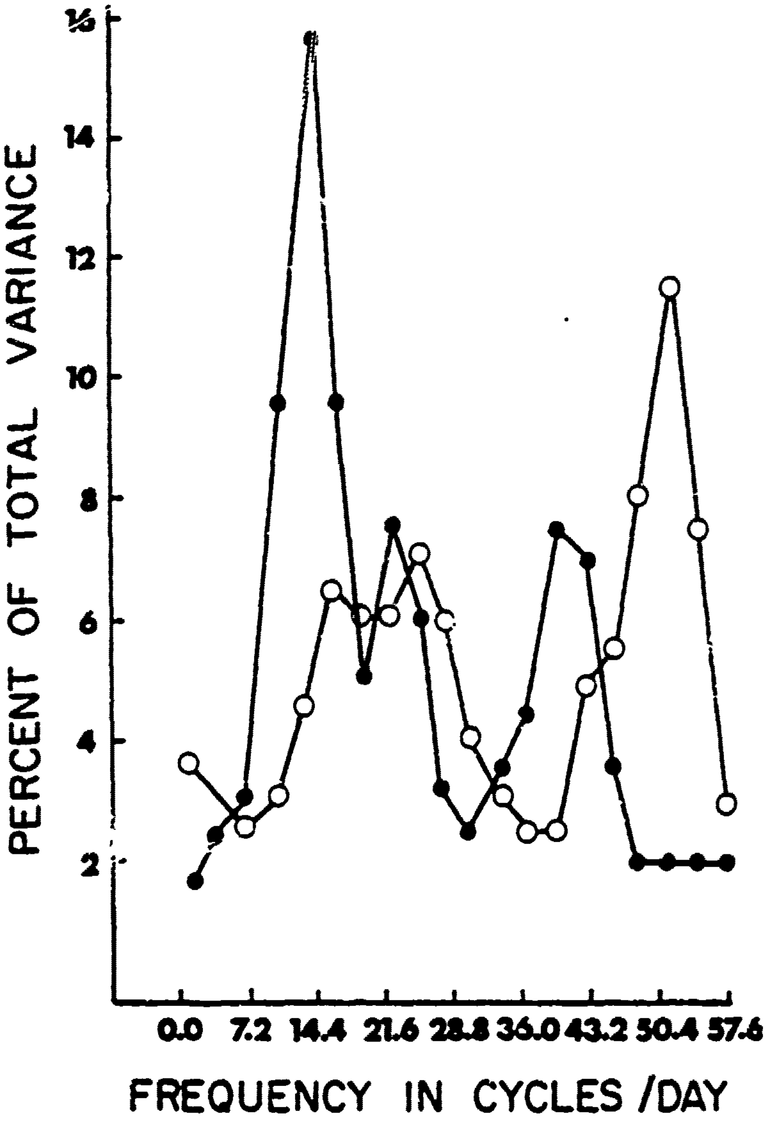

Figure 2. Average 20 frequency spectra for EKR (empty circles) and ENKR (filled circles) of Group 1. Note the prominent peak at 14.4 c/d for ENKR.

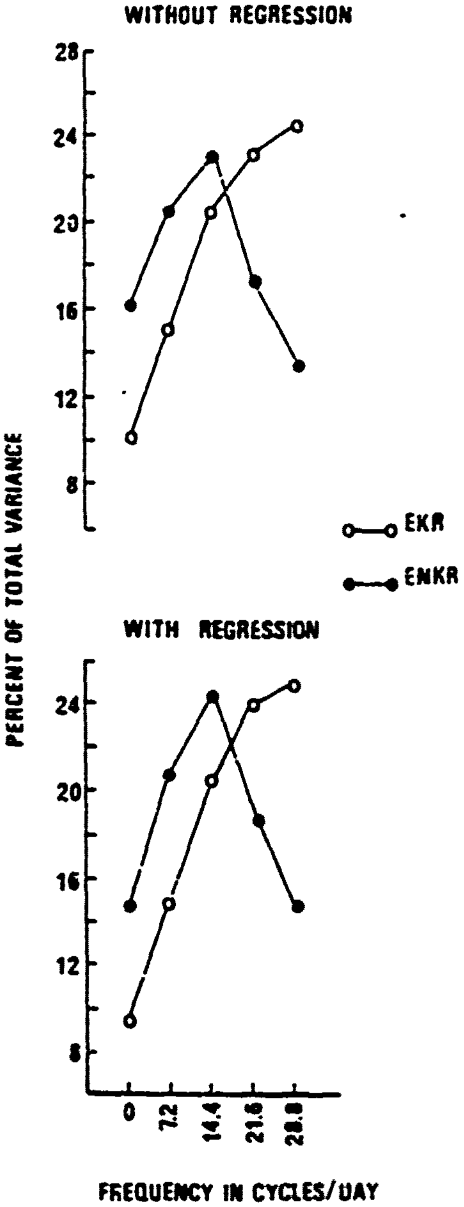

Figure 3. Average 5 frequency spectra for EKF and ENKR of Group 2. Since detrending could overestimate the variance at the ultradian frequency. spectral analysis was calculated before and after the subtraction of the linear trends. Note the similarity to the average 20 frequency spectra of Group 1 in Figure 2.

c/d for Group 1 and at 28.8 c/d for Group 2. Spectra analysis of MTKR and MTNKR revealed no comparable UR. Most of the spectral variance was concentrated at the zero frequency indicating linear and circadian trends.

Analysis in halves was done on ENKR and EKR data of Group 1 only, since Group 2 did not have sufficient data points for such an analysis. Average 10 frequency spectra are presented in Figure 4. For the first half of the experiment ENKR and EKR spectra peaked at 14.4 c/d, with additional peak at 64.8 c/d for EKR. In the second half, ENKR still peaked at 14.4 c/d, but EKR peaked only at 64.8 c/d.

Table 2 summarizes the results of the least squares spectra of ENKR for both groups. In Group 1, 5 of the 8 subjects (62.5%) had primary peak within the range of 40 to 160 min, 4 of these were between 90 to 110 min. The average r^2 value of these periodicities was 0.17±0.03. Similarly, 6 of the 8 subjects of Group 2 (75%) had the primary peak within the range of 70 to 127 min. Two additional subjects who had primary peaks at 40 min and 148 min, had secondary peaks at 130 min and 90 min, respectively. The average r^2 value for this group was 0.24±0.11, in 3 subjects, however, primary peaks accounted for 30% or more of the total variance (r^2 =0.3, 0.39, 0.43). None of the MTKR and MTNKR time series had primary periodicities within the investigated range. In summary, least squares spectral analysis revealed that 10 of the 16 subjects

Table 2

Primary Periodicities in ENKR data of Group 1 and 2

	Subject	Primary Period in min	r^2
Group 1 (10')	1	100	0.18
	2	149	0.11
	3	103	0.17
	4	106	0.17
	5	97	0.22
	6	-	-
	7	-	-
	8	-	-
Group 2 (20')	1	115	0.39
	2	120	0.13
	3	127	0.43
	4	79	0.15
	5	70	0.24
	6	70	0.13
	7	148*	0.30
	8	40**	0.22

* Secondary peak at 90 min (r^2=0.24)
** Secondary peak at 130 min (r^2=0.14)

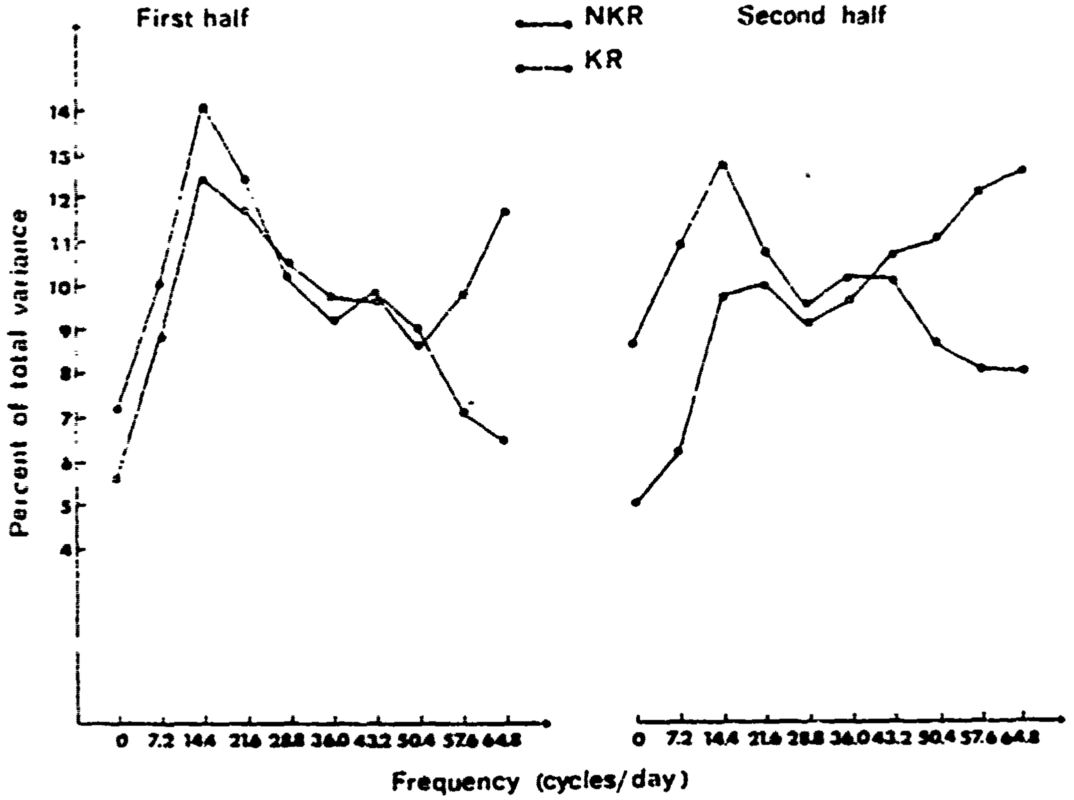

Figure 4. Average 10 frequency spectra for EKR and ENKR for the first and second halves of the experimental sessions of Group 1.

(62.5%) had primary periodicities between 70 min and 130 min, with two additional subjects having secondary peaks within this range. These results are in good agreement with the results of the orthogonal variance spectral analysis.

Tracking

Report on tracking performance is preliminary and limited to the results of horizontal tracking only. Although originally it was intended to analyze and compare performance on both tracking dimensions, an artifact was revealed late in the experiment in the generation of the forcing function on the vertical axis. We delay the report of these data until this artifact is removed. We nevertheless decided to report the data on horizontal tracking performance because of the similarity of the general pattern of results to those obtained in the linear positioning task.

Table 3 presents the average RMS scores for horizontal tracking in the two dimensional tracking conditions, standard deviations and CVs for the 9 subjects. Between subjects variability was remarkably low, overall mean was 0.162±0.01, and within subject variability was considerably lower than for the linear positioning, average CV was 11.8±1.48%. Data of 3 subjects, smoothed by 3 point moving average window are displayed in Figure 5. During the first 5 hours these subjects showed some rhythmic variations that can easily be eyeballed. Rhythmicity was lost, however, in the second part of the experiment. Average 10 frequency spectra for the results of the entire experiment (Figure 6, upper panel) peaked at 14.4 c/d and 64.8 c/d but ultradian spectral peak was not statistically significant. Least squares spectral analysis revealed that only two subjects had a primary ultradian periodicity within the total range of 40 min 160 min (99 min, $r^2 = 0.12$ and 87 min, $r^2 = 0.18$).

Table 3

Average Tracking Error (in RMS units) SDs and CVs for 9 Subjects

Subject	$\bar{x}$	Sd	CV (%)
1	0.160	0.019	12
2	0.150	0.021	14
3	0.200	0.024	12
4	0.156	0.017	11
5	0.179	0.023	13
6	0.164	0.018	11
7	0.154	0.02	13
8	0.150	0.016	11
9	0.148	0.014	9
$\bar{x}$	0.162		11.77
Sd	0.01		1.48

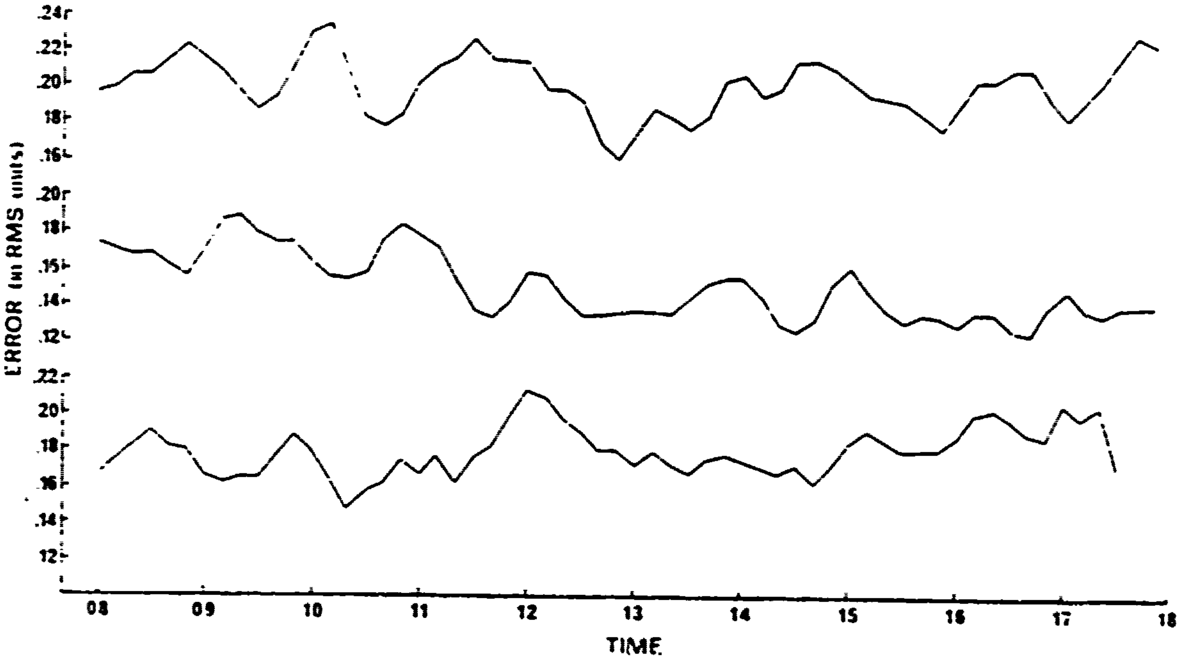

Figure 5. Tracking errors of 3 subjects (smoothed by 3 point moving average window).

Figure 6 (lower panel) presents separate 10 frequency average variance spectra for the first and second halves of the experiment. Ultradian peak at 14.4 c/d is now evident during the first half of the experiment, five subjects (55%) now had ultradian peak at 14.4 c/d, compared with two subjects having an ultradian peak before. The average peak at 14.4 c/d, however, only bordered statistical significance (p <.1). This peak disappears, however, in the average spectra of the second half. The difference between variance at the ultradian frequencies of the two halves was statistically significant (t = 3.0, df = 8, p <.05, two tailed).

Discussion

The present results demonstrate the existence of approximately 100 min UR in both linear positioning and tracking tasks. The presence and magnitude of these rhythms were more pronounced in the linear positioning task. Although it is not necessary to assume separate physiological mechanisms, it appears that the prevalence and magnitude of the oscillations depend both on the nature of the tasks involved as well as on within task variables. First, linear positioning that depends on the acquisition of a stable inner trace for a required movement (Adams, 1971) was more susceptible to ultradian variations than the tracking task which demands analog perceptual judgments and seems most heavily loaded on the response side (Navon & Gopher, in press). Secondly, while movement accuracy on the linear positioning task revealed organized rhythmicity, movement time did not reveal such rhythms. It therefore appears that further investigation of tasks characteristics that may be related to ultradian oscillations is fruitful and theoretically important.

As indicated by the difference between experimental conditions with and without immediate knowledge of results (KR and NKR conditions), feedback may be a potential suppressor of UR, or alternatively, ultradian oscillations may reflect variations in spontaneous activity. An interesting outcome is the observed differences in rhythmicity between the two halves of the experimental session. While the first and second halves were similar in the NKR condition within the linear positioning task, movement accuracy in the KR conditions and tracking performance in the tracking task revealed rhythmic oscillations only in the first half of each session. Practice effect is unlikely to account for the disappearance of the rhythm, since linear trends were not revealed, and error levels did not differ in the two halves. One possible interpretation for these results is that since both experiments were conducted at the same phase of the circadian sleep-wake cycle, "time of day" effect cannot be ruled out. It may be that both frequency and amplitude of the UR are affected by circadian variations, as suggested earlier (Lavie, 1977).

Regarding the prevalence and magnitude of the UR phenomena, 62% of the subjects in the linear positioning task showed primary UR periodicity, while only 55% of the subjects showed such periodicity during the first half of the tracking experiment. The general magnitude of oscillations was also much tempered in the tracking task. In the linear positioning task UR accounted for as much as 30% of error variance for some of the subjects with 40% of the subjects exceeding the 20% level. Individual differences and task variables seem to jointly determine the magnitude of UR variability.

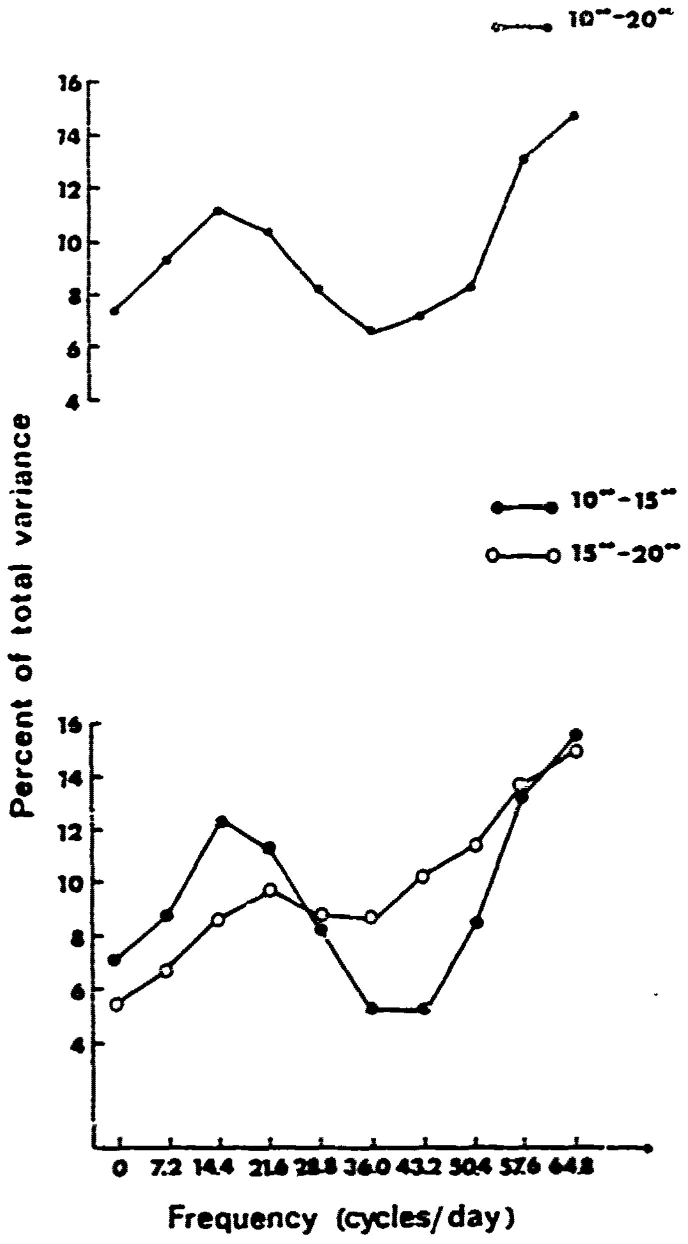

Figure 6. Average 10 frequency spectrum for tracking error of the entire experiment (upper panel), and for the first and second halves of the experimental period (lower panel).

It is uncertain yet whether the fast variations in linear positioning detected by the spectral analysis in the KR condition and in tracking reflect a true rhythmicity, or perhaps were caused by random fluctuations around a mean level of performance. Systematically varying sampling rate can help resolve this problem.

Practical implications ought to follow but are difficult to specify at this time. In light of the present results, particularly those of large magnitude rhythmicity in positioning error in the NKR condition, we believe that some tasks may be modulated to a large extent by ultradian variations. Surely further experimental effort is required to characterize the type of tasks that are susceptible to ultradian variations, the environmental conditions that favor such rhythmicity and the interaction of UR with circadian variations. A special effort should be devoted to the discovery of a reliable and convenient marker of the underlying ultradian oscillator. On-line monitoring of such a marker would provide the operator or an adaptive machine with some indication of instantaneous efficiency, and periods of expected low performance levels might be anticipated. The early demonstration of significant UR with similar periodicities in electroencephalographic and pupillary activities (Kripke, 1972; Lavie, in press) promise that the establishment of a physiological marker within experimental reach.

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METHODOLOGICAL ISSUES AND PROBLEMS IN SHIFT WORK RESEARCH

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Let us assume we have complete freedom for designing a field study on shiftwork research. How would we start it? One obvious way would be to take a representative sample of people who are beginning to work and divide it randomly into groups who work in different kinds of shiftwork and control groups who perform similar work, but not on shifts. We then would have to keep all environmental factors constant and follow the groups up prospectively by taking measurements of all relevant social, psychological, physiological, and medical variables. Finally, we would have to evaluate the data by complex statistical analyses in multifactorial designs (different kinds of work schedules, different kinds of shiftwork, time factors, etc.).

This model illustrates the range of methodological constraints that exist in shiftwork research. We will try to discuss some of these constraints and some of the ways in which we tried to overcome them in our studies.

Issues and Problems of Generalizability and Comparability of Shiftwork Research in Different Countries

One precondition for generalizations derived from shiftwork research, and for comparability of results between countries, would be a sound statistical documentation of the amount of shiftwork and of the trend of development of shiftwork in different countries. The first problem in this area is the definition of shiftwork. What kinds of shiftwork should be included? Some statistics include nightwork, Sunday work, and "work at unusual times". How many types of shift systems should be differentiated? Some statistics distinguish between 2 shifts, 3 shifts, and 4 or more shifts, and subdivide the shift systems with 3 or more shifts into continuous and non-continuous shifts. What types of work should be included? Some statistics include social services, as well as industry, but obviously, it is harder to get accurate data about shiftwork in the former. We should try to get international standardization of such statistics. Some proposals are made by Rutenfranz, Colquhoun, Knauth, and Ghata (1977b) to this end.

There is also the question of the trend of growth in shiftwork. Many people state that shiftwork is expanding, but clear-cut data for such statements are rare. It would be useful to have a statistical basis at least to estimate this trend. One example is given in Figure 1, derived from a report by de Jong (1979), who used the Reports of the Netherlands Ministry of Social Affairs as his source. From this figure, it appears that, in the Netherlands, the incidence of shiftwork increased from about 7% in 1909 to about 20% in 1970. More statistical data of a similar kind should be obtained in different countries. In Austria, we sent out a questionnaire through the labor unions and found that 21.4% of the respondents worked on shifts (for men, the figure was 23.8% and for women 16.1%). In industry alone (where we got the most reliable data), 27.2% worked on shifts and for about half of these, this included night work (Brössler, Kundi, & Taratula, 1979).

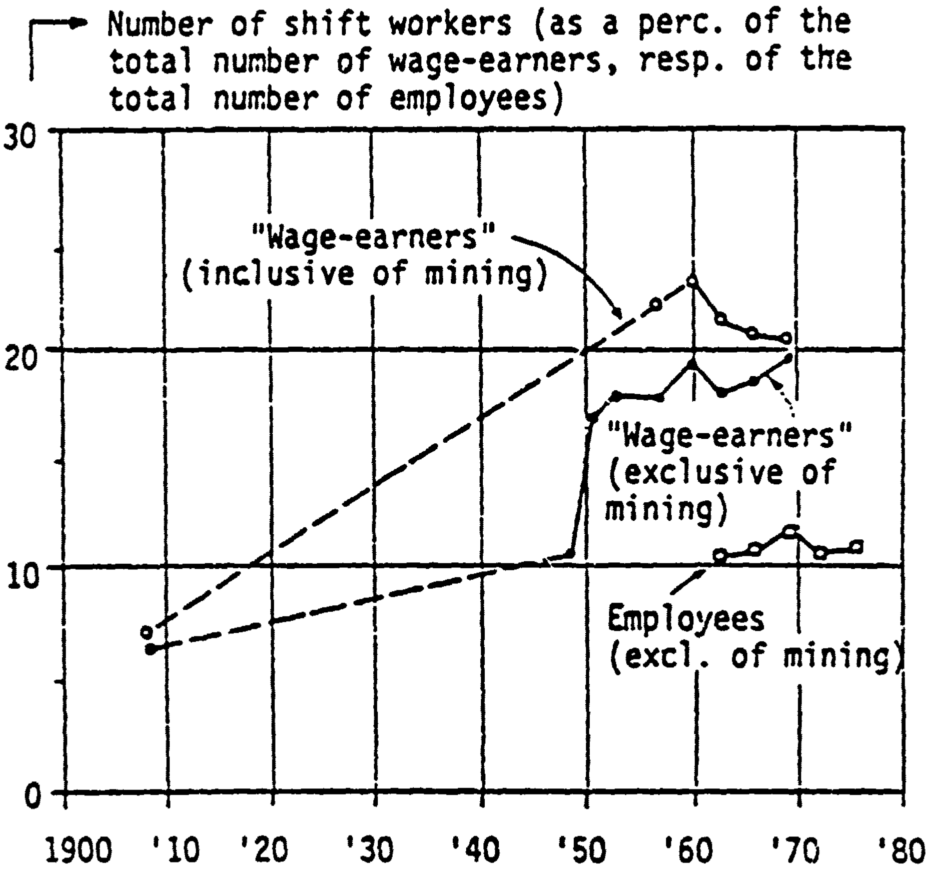

Figure 1. Changes in numbers of shiftworkers in industry (a) as a percentage of the total number of wage-earners, and (b) of the total number of employees (inclusive of wage-earners). Sources: Reports of Ministry of Social Affairs surveys, and relevant publications in Sociale Maandstatistiek (De Haan, Zeist, resp. Centraal Bureau voor de Statistiek). From: J.F. de Jong, Annex 5 in Haider and Koller (1979).

The comparability of shiftwork studies in different countries may be confounded by legislative, ethnic, cultural, or political differences. For instance, because of differing conditions, studies performed in some eastern countries often may not be acceptable to workers and managements in western countries, and vice versa. As an example of differences in legislation, it may be mentioned that in countries like Sweden, Netherlands, and some eastern countries, women are allowed to perform night work, whereas in Austria, France and Germany, this is forbidden. But even in these latter countries, women work in 2-shift systems, and in the services area, they often have to work at night. To be able to make general statements about shiftwork effects on women we would need more information on sex-dependent aspects, derived from comparable studies of male and female workers in the same job conditions.

Of course, these are many other factors which limit the generalizability of results from shiftwork research. Among these are age-dependent aspects, individual differences, motivational variables, differences due to task and job demands and so on. We will deal with some of these factors in the following sections.

Issues and Problems of Research Designs

In contrast to the "ideal" experiment described in the introduction, our research designs have to deal with highly selected populations. We will discuss some of the constraints resulting from these problems first for field, and then for laboratory studies.

Field Studies

Since, in most countries, we do not have detailed statistical data on shiftworkers, it is clearly impossible to draw "representative samples" of shiftworkers and control groups. But even if we had the statistical basis for it, such a procedure would be very difficult indeed. Most studies, therefore, have taken the workers in a particular factory as their "population" Such groups of workers are already selected at entry for different social, economic and personal reasons. Workers who think of themselves as being able to endure shiftwork will be overrepresented among the applicants. The initial medical examination will exaggerate this, since only those people whom the physician thinks will be able to endure shiftwork will be accepted for it. Moreover, as has been pointed out (Reid, 1957), each population of workers is a "survivor population", since those people who have changed work, or have retired early or have died have been "lost". This loss may be especially marked in shiftworkers who, for instance, may change their work for health conservation reasons.

The selection factors described above may be one reason why some studies (especially the earlier ones) have not found any differences in health between shift- and dayworkers (e.g., Wade, 1955). One way to partially control for the selection bias is to include a study of the "drop-outs" as an extra group. We have done this in our studies and have found some differences in health in this group (Koller, Kundi, & Cervinka, 1978; Kundi, Koller, Cervinka,& Haider, 1979; see also Andersen, 1960; Taylor, Pocock, & Sergean, 1972; Rutenfranz & Colquhoun, 1978). But it must be acknowledged that some studies with separated groups of drop-outs did not find differences between shift- and dayworkers with respect to mortality and absenteeism rates (Thiis-Evensen, 1958; Taylor & Pocock, 1972). The inconsistency in these results may, apart from selection factors, arise from the use of different kinds of "health" or "sickness" score. This will be brought up later under the problem of measurement and data collection.

Laboratory Studies

In laboratory studies, we are mostly dealing with small groups of young and healthy subjects. This may render it rather difficult to generalize the results to the "real problems" of shiftworkers. There are many issues connected with this question of real problems and their relation to laboratory studies on shiftwork. For instance, reentrainment of physiological functions may be quite different under laboratory and field conditions. Motivation also may be different, since laboratory studies hardly have "real consequences". Again, in sleep studies, there are discrepancies between field and laboratory situations because, in the latter, the subjects can take compensatory sleep after the experiment whereas shiftworkers cannot. One might question, therefore, whether laboratory studies are useful in shiftwork research at all. This question was discussed at length in our European Seminar on "Performance time functions" (Haider & Koller, 1979), in which it was agreed that there are many ways of bridging field and laboratory studies. Some of them will be mentioned here.

How to Bridge Laboratory and Field Studies

One conclusion of the European Seminar was that field and laboratory studies do not constitute a clearly distinguishable dichotomy, and it seems better to think of any study as lying on a continuum, representing the amount of intervention and control that is exercisable. Therefore, both kinds of studies should be run in parallel, the laboratory studies affording more opportunity to control variables in testing specific hypotheses.

Field studies may be used to derive some of the hypotheses which could then be tested in the laboratory. Sleep studies may first be performed in the homes of the workers. Experimental studies would then follow in which the subjects would be awakened on a schedule similar to the one observed in real life. Further experimental shiftwork studies could examine the effects of combining shiftwork with other stressors like heat and noise. One experimental study (Rutenfranz & Knauth, 1972) suggested that sleep disturbances due to changed biorhythms and to noise may be additive, and one field study (Koller et al., 1978) showed that "drop-outs", even after years of daywork, still had more sleep disturbances due to noise than permanent dayworkers.

Field studies may also be used to confirm the results of laboratory findings under field conditions. An example of this methodological procedure is provided by the studies of Colquhoun, Paine, and Fort (1978), testing circadian rhythms of body temperature in a series of experimental studies under various types of watchkeeping systems, and then under field conditions during a prolonged submarine voyage.

Issues and Problems of Measurement and Data Collection

Since, as in other fields, the mere act of observation and measurement may influence the variables we want to measure, it is desirable in shiftwork research to use procedures available which are as unobtrusive as possible. Fortunately, recent technical developments have enabled some originally laboratory-bound measurement procedures to be adapted to the field situation. These are already available for many physiological measures, and such procedures will no doubt be developed in the future for performance measurements also.

Physiological Measurements and the Issue of Activation

Each physiological measure has its own methodological difficulties which cannot be discussed here in any detail. In shiftwork research, long-term recording over days or even weeks presents many technical problems.

For continuous heart rate recording, Rutenfranz, Seliger, Andersen, Ilmarinen, Floring, Rutenfranz, and Klimmer (1977a) give some criteria against which measurement systems can be evaluated. These criteria are:

1. Weight and size should be socially acceptable;
2. Uninterrupted use (>8h or, better, >24h) should be possible;
3. No constraints on subject mobility or on occupational and leisure activities (except swimming);
4. Sequential recording of mean rate over short time intervals (mins);
5. Data recovery unbound to "real" time;
6. No specific computing system necessary for data analysis.

Rutenfranz et al. (1977a) argue that telemetric systems do not fully guarantee points 2 and 3, and that the "cardiac interbeat interval distribution" technique does not fulfill criterion 4. On the other hand, these techniques may be better in fulfilling point 1 than the cardiocorder-techniques which actually fulfill all 6 criteria. There are now different cardiocorder systems available (like Mnemoport "Helligre", Medilog "Oxford", Meditype "Siemens", etc.) which may also be judged against criteria like the possibility of analyzing the form of the ECG, how precisely one needs the heart rate to be recorded, and so on.

Since body temperature is one of the parameters most frequently examined in shiftwork research,one should also evaluate the increasing number of available transportable systems for continuous measurement of this variable. The Thermolog system, for instance, uses a solid state memory instead of tape recording for long-term monitoring of both body temperature and activity. Some newer developments aim at picking up deep body temperature from the skin surface (see Fox, Solman, Isaacs, Fry, & McDonald, 1973). It is important to evaluate the reliability and validity of such methods for shiftwork research.

Besides heart rate and body temperature, the other measures most often used in shiftwork research are respiratory rate, EEG, and certain hormone levels (e.g., adrenalin and melatonin). The state of the organism defined by some of these variables is, in many cases, characterized as its level of "acttivation". But we must be quite clear that "activation" is not a single dimension defined absolutely by the covariation and functional relationships of the above named physiological parameters. In neuro- and psychophysiology, we prefer to think of a "hierarchical system of activation" (Haider, 1969, 1970), as shown in Figure 2.

In this hierarchical system, we first assume some basic, general activation or arousal mechanisms, normally involved in regulating wakefulness and sleep. Then we have "tonic" activation with long latencies and durations, slowly changing the state of the organism between low and high arousal; reticular and limbic activation mechanisms mediate these changes. Next there are "phasic" activation or arousal mechanisms with shorter latencies and durations; the truncothalamic and mediothalamic-frontocortical systems may be involved in these mechanisms. Finally, we have to consider highly differentiated and selective activation processes, related to selective perceptual, cognitive, and motor acts without gross changes in arousal level; specific thalamocortical and striatocortical feedback mechanisms may be responsible for these processes.

Empirically, the generality of activation may be defined operationally by the number of variables differentiating different levels. The greater the number of indicators that vary as the level changes, the more general is the activation. This is shown for some physiological variables in Figure 3.

Models like this may perhaps be helpful in solving problems such as the choice of physiological variables in shiftwork research. For instance, the question arises as to what kind of information you may expect from each variable. If you want information about basic changes of general activation (for instance in circadian rhythms over long times), then the variables at the right hand of Figure 3 seem to be the most appropriate, i.e., body temperature and hormone levels will probably give good results for this purpose. If, on the other hand, you want information about shorter cycles (phasic activiation changes), then pulse rate and EEG will be appropriate; the EEG has proved its special usefulness for changes in sleep rhythms, sleep cycles, and so on: from the study of slow (DC) changes, we know that these vary with sleep-wakefulness cycles (Caspers, 1961, 1963) as well as with more specific phasic changes like expectancy and motor readiness. [As an aside here, it would be interesting to see what changes occur in these slow brain potentials during the adaptation of different circadian rhythms to an altered regime.] Since in a hierarchical system each level influences the other levels to a certain degree, it would be interesting to discuss the question of desynchronization in the light of such a system, in which each variable has to be conceptualized as a separate but related organismic function.

Performance Measurements

In field studies, performance criteria are, in many cases, relatively easy to collect. There are, for instance, data on work output, occurrences of errors, frequencies of accidents and so on. But, with certain exceptions, it has not yet been shown that such data are very informative for shiftwork comparisons. Most results are masked by stronger relationships, and dependencies on factors like motivation, working strategies, contact with the research team, amount of intervention, etc. Since most workers are able to maintain a given output level within certain limits, it is probably more informative to look at what "costs" an individual incurs in maintaining a certain performance level than just to measure performance alone. One should also look at the relationship between performance and expectations of work demands.

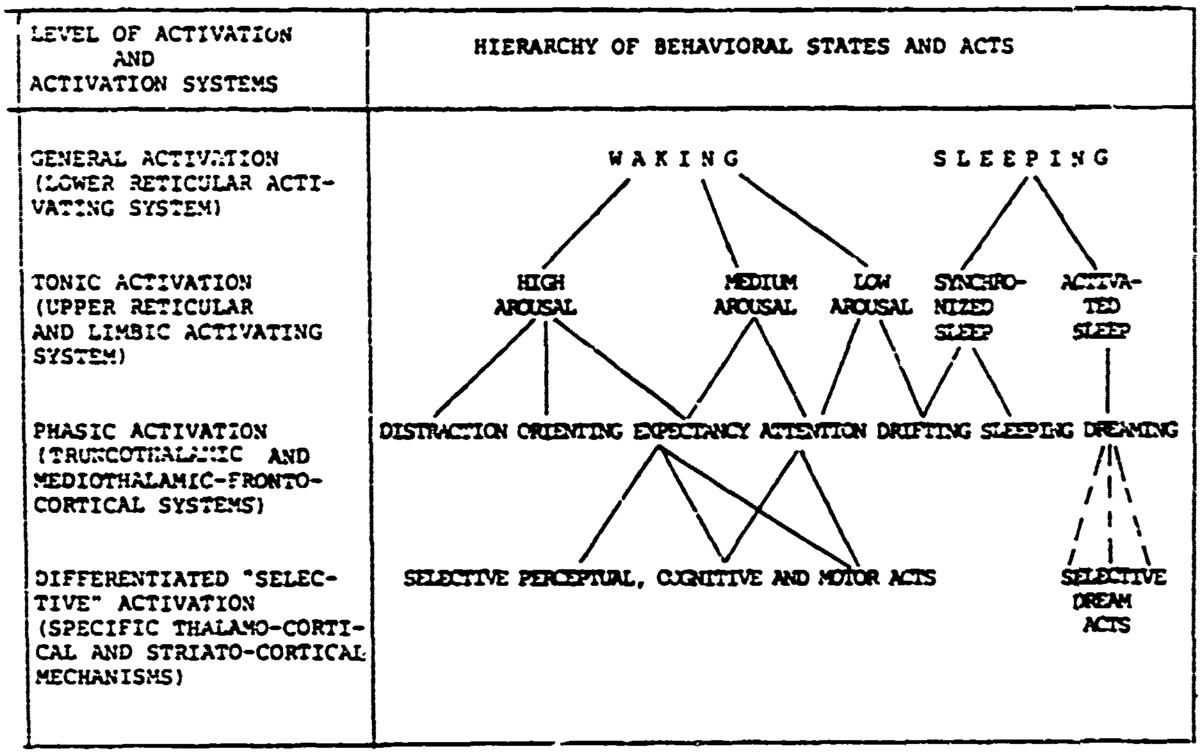

Figure 2. A hierarchical model of activation and behavior.

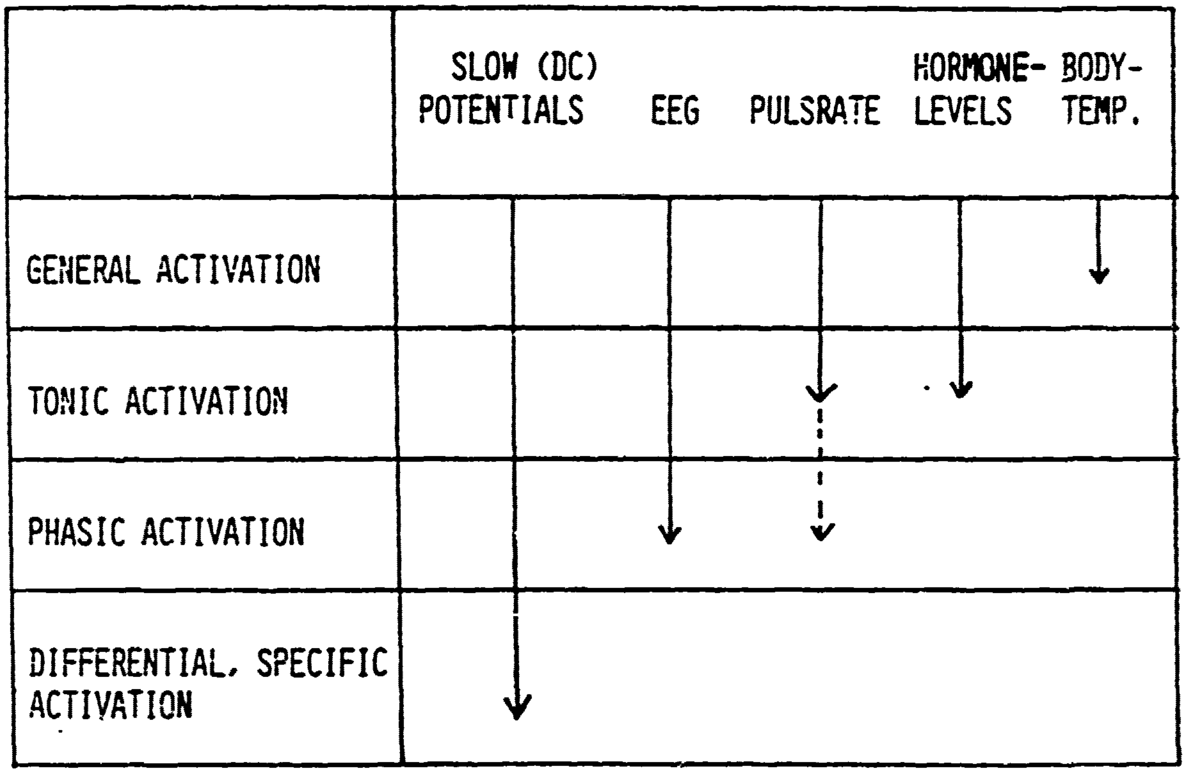

Figure 3. Different levels of activation an their relation to physiological variables.

Many performance tasks have been shown to exhibit circadian variation (see for instance Colquhoun et al., 1975; Rutenfranz and Colquhoun, 1978), but others have not. One of the methodological difficulties here may be that most tasks are developed for specific investigations, and that no satisfactory categorization of performance tasks exists. One of the proposals in the "European Seminar" (Haider & Koller, 1979) was, therefore, to try to develop some kind of "taxonomy" for performance by relation both to different tasks as well as to different situations, and to try to establish "phase maps" of mental performance, sensorimotor performance, and other performance data and to examine their relation to phase maps of biological rhythms. A further suggestion was that more attention should be paid to individual differences and subgroups in performance, to determine if they are consistent, and also if they are predictable. In this connection, one should try to find out why the results of circadian rhythm performance studies are only valid for some people in some situations for some tasks.

Many performance (and other) measures have circadian rhythms which differ in period, amplitude or phase. It has been shown, for instance, that speed and accuracy measures may represent different diurnal components of performance (Englund, 1979), and that immediate memory decreases over the normal waking day, whereas delayed retention is superior for material presented in the afternoon or evening (Folkard, 1979). In view of these complexities, special methodologies will be needed to analyze basic changes in overall behavior, as well as in phase shifting, adaptation, and reentrainment; the currently favored cosinor approach may not be sufficient for these purposes. A promising new technique, based on likelihood ratios, has been devised by Monk (1977).

For further development in the field of performance measurement, we will have to tackle a lot of important unsolved problems. One of these is the identification of performance measures which can be used both in the laboratory and in the field. Another one is the development of reliable techniques to measure an individual's level of motivation, as well as the degree of effort he applies in performing a task.

Questionnaires and Subjective Indices

Personality differences, assessed by specially devised questionnaires, have been shown to be important in shiftwork research. Blake (1967), for instance, observed differences in the temperature rhythm of introverts and extraverts. Colquhoun and Folkard (1978) showed that these differences were more marked in neurotic subjects and that "neurotic extraverts" exhibited the greatest degree of adjustment of their temperature rhythm to night shift. In other research (Horne & Östberg, 1976; Torsvall & Åkerstedt, 1979) questionnaires to determine diurnal types have been devised. The reliability of such instruments is quite good. For instance, Torsvall and Åkerstedt (1979), found a correlation of 0.79 between two administrations in a one-year interval. Some authors (Östberg & Svensson, 1975; Breithaupt, Hildebrandt, Dohre, Josch, Sieber, & Werner, 1978) have shown that "morning types" react more adversely to night work than "evening types".

Each typology has, of course, many methodological problems. One problem is that definite "types", defined as extreme at one or the other end of the scale, are rather rare. Another problem is that, at the moment, the correlation between different circadian-type questionnaires seems to be rather low.

Finally, there is lack of agreement about the correspondance between different typologies. Hauke, Kittler, and Moog (1979), for instance, were not able to confirm the suggestion of Colquhoun and Folkard (1978) that "evening types" may correspond to "neurotic extraverts".

The reason for introducing such concepts as Introversion-Extraversion and Morning-Evening types into shiftwork research is, of course, to find out if there are attributes of the worker which make him more or less adaptable to shiftwork. However, little or nothing is known about the stability of attributes over time; this introduces a further methodological problem into research on the prediction of adaptation to shiftwork, which has been considered by Tasto, Colligan, Skjei, and Polly (1978).

Many questionnaires and subjective indices are available from which a researcher can choose those which seem to be most relevant for his study. Of course, the "ideal research design" which we mentioned in the introduction would require measuring instruments for all the variables relevant to shiftwork. But this is obviously utopian. In our study, we based our questionnaires and interview forms partly on validated and tested procedures (Mott, Mann, McLoughlin, & Warwick, 1965; Neuberger, 1976; Östberg, 1973; Rutenfranz, Knauth, Hildebrandt, & Rohmert, 1974) and partly on techniques developed by authors (Koller et al., 1978). The headings for the different groups of questions asked are listed in Table 1.

Table 1

Headings of Question Groups

Questionnaire Items

1. Personal and Family Data
2. Details of housing, with special respect to sleeping conditions
3. Job History
4. Attitudes towards various elements of shift systems
5. Opinion of different working conditions
6. Stress-producing factors at work place
7. Family Life
8. Leisure time activities

Interview Items

a. Attitudes towards materialistic and idealistic values
b. Morning-evening-type assessment
c. Biorhythmic functions assessment
d. Sleep-quality assessment
e. Health state: subjective assessment, psychosomatic disorders, disorders of several functional systems
f. Eating and smoking habits, alcohol and coffee intake

We cannot avoid having to rely on subjective scales, especially in the case of "measurement" of attitudes. One problem in using such scales is how to estimate standard indices, like reliability. It may well be that "one-item scales" turn out to be superior to collections of specially chosen items because, in these cases, homogeneity of the item set is a necessary condition for the sum score to be meaningful and homogeneity is very difficult in most scales used in shiftwork research.

A further basic problem in using questionnaires and subjective scales is that the score obtained from them may represent, to some extent, stereotyped responses; thus we cannot be sure that they correspond to real feelings, even subjective ones. Shiftworkers' answers to questions about their life and work are influenced by many personal, situational, and social factors (Nachreiner, 1975). One of these is the fact that most field studies cannot be performed "blind".

The mere fact that shiftworkers know that one of the aims of the research is to study their work problems may bias their answers in one or the other direction. Thus, in some cases, they may tend to describe their situation as very strenuous and therefore particularly meriting compensation, financial or otherwise. But in others, they may try to avoid a kind of "cognitive dissonance" by describing a situation in which they stay on anyway as not too strenuous. Some results of our pilot study on "retired shiftworkers" support the latter hypothesis because these people's attitudes towards shiftwork are worse than active shiftworkers.

No general solutions for these problems exist as yet. It would seem that in this field, we will have to rely largely on "trial and error" to identify, and then to exclude scales which do not differentiate between different groups of shiftworkers, or between shiftworkers and dayworkers, etc.

Measurements of Health State and Wellbeing

To define health and wellbeing operationally is not an easy task. Some criteria, like "Absenteeism" are apparently obvious, and data can be collected relatively easily; but it is difficult to determine the extent to which personal attitudes and social and legislative influences are involved. In Austria, for instance, we have a very high proportion of 3-day absences, since for longer periods a medical certificate is needed. So it is small wonder that absenteeism data have not given clear-cut results in shiftwork research.

Another possibility is to use mortality and morbidity statistics in epidemiological surveys. Unfortunately, in most cases, we have no sound epidemiological methods available to perform well-controlled studies; furthermore, the results will depend very much on the way that the original data were collected, which varies widely between countries. In a number of countries (excluding England, Wales, Canada, Holland) there are, except for the initial medical check, no obligatory medical screenings for ordinary shiftworkers, so that no current register of "nonoccupational" diseases exists. Another point is that workers are not obligated to give complete details about their health state to the occupational health doctor. So medical examinations carried out by different industrial physicians may differ widely. Further, such data refer only to those complaints and symptoms reported during working hours, and to first-aid cases. For all the groups in our study, we used medical histories. of diseases and disorders of different functional systems which were obtained and evaluated by the same physician.

Many of the procedures used to operationally define state of health, presence of disease, and wellbeing need further evaluation and, if possible, a certain degree of international standardization. One proposal would be to base scoring systems on the International Classification of Diseases.

Issues and Problems of Data Analysis and Modelling

Progress in science may be viewed as proceeding in stages of increasing knowledge from primitive models based on only relatively few facts to complex models that incorporate much detailed and well-established information. Wold (1973) makes a distinction between descriptive and explanatory knowledge and indicates two lines of evolution from low information to high information models. One line by-passes higher degrees of explanation, using the results from controlled, replicable experiments, and also nonexperimental evidence and various facts to derive explanatory information expressed in the form of descriptive information, for instance by factor analysis or canonical correlations and then again uses experimental and nonexperimental data and known facts, to build a complex model. The final models emerging from both lines of evolution will contain much information of both an explanatory and of a descriptive nature. They are complex structures that have considerable explanatory power and also provide much descriptive knowledge via their many parameters. In the following sections, we will discuss some ways of constructing such complex models for the mechanisms of shiftwork effects and for their dynamic, sequential development.

The Complex Interaction Structure of Shiftwork Effects

As examples of complex model building for shiftwork effects on health and wellbeing, we will discuss the Swedish model of Åkerstedt, Fröberg, Levi, Torsvall, and Zamore (1977) and that of our own group (Kundi et al., 1979). The model which the Swedish group uses to illustrate the mechanisms behind the consequences of shiftwork is shown in Figure 4.

The starting points for the discussion are the circadian rhythms of physiological and psychological functions as reviewed by Colquhoun (1971,1972) and Fröberg (1975). The normal daily rhythm of an individual alters in response to his particular working hours. If the new daily rhythm changes in a way which adjusts it to night work, it then comes into conflict with the daily rhythms of family and society, and this may lead to difficulties in fulfilling social roles. But if the new physiological and psychological rhythms do not become sufficiently adapted to nighttime activity and daytime sleeping, conflicts result with working-hour requirements. These eventually cause different types and degrees of complaints, such as tiredness, difficulty in sleeping, digestive problems, etc., which together lead to a gradual development of poor attitudes to shiftwork, absenteeism, and possibly actual illness.

The results from certain controlled experiments and field studies provide an explanation of some of the ways in which shiftwork can, in the long run, result in reduced wellbeing and increased health complaints. For instance, the demonstration that during a working period of 72 hours, circadian rhythms in adrenalin and melatonin secretion, body temperature, self-rated fatigue, and performance capacity are clearly evident (Fröberg, Karlsson, Levi, & Lidberg, 1975), with high activation in the middle of the day and low

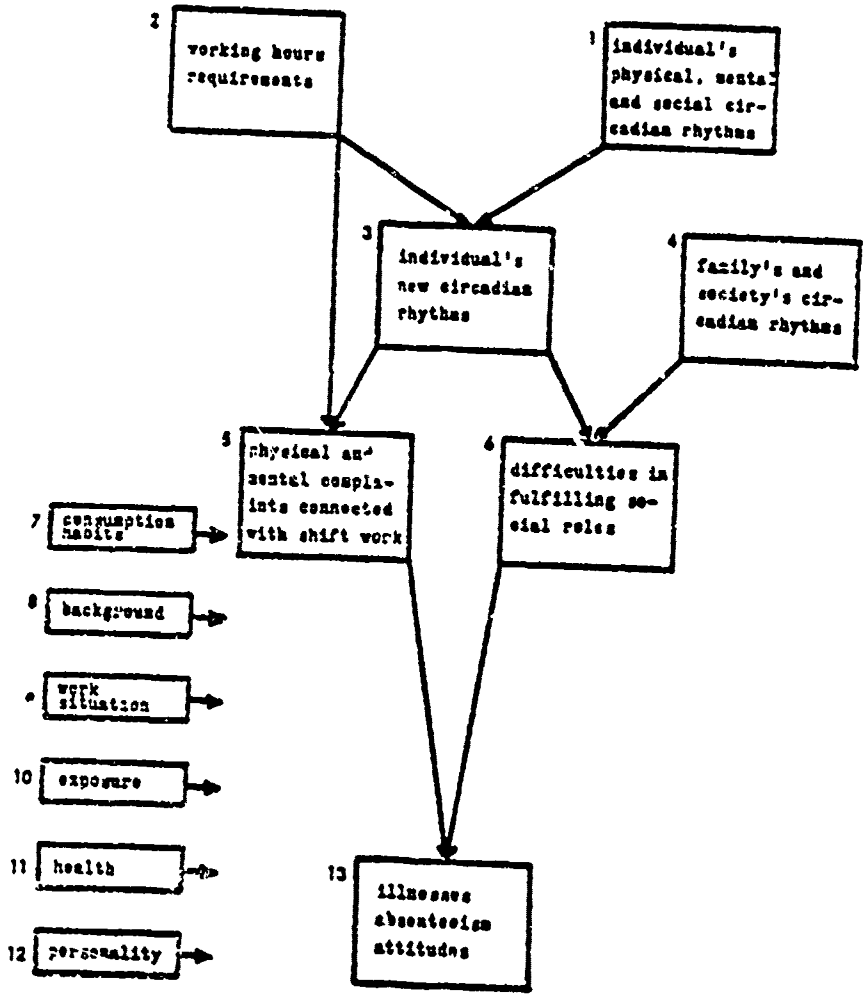

Figure 4. Model of the mechanisms behind the consequences of shiftwork (From: Åkerstedt et al., 1977).

activation in the middle of the night, means that during the night shift, a worker must be active when his psychophysiological functions are not in an appropriate state. This may lead to a drop in performance capacity (as, for instance, has been shown by the increase in the number of emergency stops made by engine drivers at night: see Hildebrandt, Rohmert, & Rutenfranz, 1974, 1975). Sleep-deprivation studies have shown that it may be as bad to work at night as it is to work in the daytime without having slept at all the previous night. And Johnson and MacLeod (1973) found that performance capacity and wellbeing were still considerably reduced when sleep was allowed, if it was limited to approximately 5 hours only.

Besides the difficulties resulting from conflicts between physiological and psychological daily rhythms and working-hour requirements, the model takes into account the difficulties resulting from conflicts between the new social rhythm of shiftworkers and those of the family and society. Shiftworkers are excluded from a great deal of community life and may thus be placed in a kind of "stress" situation through social role conflicts. Although it has been pointed out that such conflicts may lead to psychosomatic disorders (Mott et al., 1965), their effect on the health of shiftworkers has not been investigated in detail.

The model also indicates that the whole process is modified by a number of variables. These include consumption habits: smoking, coffee intake, and meal timing; demographic factors: age, sex, marital status, dwelling conditions, children; exposure: frequency of night shifts, full- or part-time experience of night work, etc.; health state; personality factors: neuroticism, extraversion. Finally, the authors state explicitly that the model has been radically simplified, and that interactions between the variables are not included.

Our own model (Kundi et al., 1979) may be used to demonstrate the second line of evolution of complex models. We started by computing canonical correlations between groups of relevant variables. For this purpose, categorical data were transformed (McCall method) and qualitative information was coded on arbitrary scales. The discussion of possible mechanisms can begin with a description of the resulting network of relationships between variable groups. This network is shown in Figure 5.

The variable group "health state" is correlated significantly with most other variable groups. It shows two significant canonical correlations with the variable group "work strain". The first one indicated an interaction between mental work load and digestive disorders. The second one indicates a relation between the fear of not being able to continue to bear the work load until retirement and feelings of tiredness or exhaustion. "Family life" also shows two significant correlations with health state. The first one reflects a relation between difficulties in fulfilling the expected social role within the family and psychosomatic symptoms. Among the risk factors, smoking, and the tendency to change eating habits under stress, are particularly related to health state. Sleep problems are related to family problems, and both are correlated with job satisfaction and attitudes towards shiftwork, which in turn are both correlated with health state.

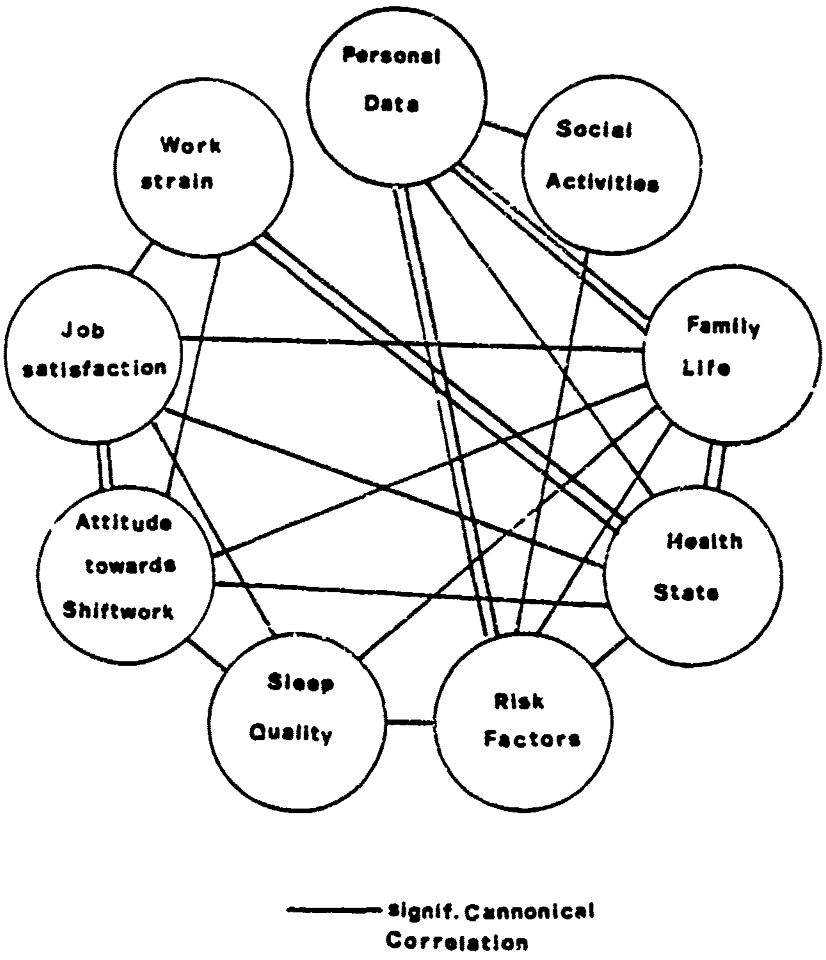

Figure 5. A network of relations between 9 "variable groups" in shift-workers.

If we now start to build a model for the complex interaction structure of shiftwork effects on this descriptive information, it must be made clear that this model is mainly hypothetical though it is based on our empirical findings and other experimental and nonexperimental data as well as on known facts. The model is illustrated in Figure 6.

In this model, we assume that family life, sleeping behavior and attitudes towards shiftwork are central in the process of adaptation for shiftworkers. Obviously, shiftwork alters the daily rhythms (as described earlier in the discussion of the Swedish model). This results in a reduction in sleep quality (as shown by Rutenfranz & Knauth, 1972). Sleep problems may affect health and wellbeing, but may also lead to reduced contacts within the family. If the shiftworker tries to improve family relationships by increasing his contact time, this may leave him with less time for sleep. Furthermore, difficulties with sleep and with family relationships are likely to result in increasingly negative attitudes towards shiftwork, and in more job conflicts, both of which may in turn lead to reduced sleep quality. This complex of feedback mechanisms may interact directly with wellbeing and health, or it may work indirectly through an increase in risk factors like nicotine and coffee consumption. The whole process is differentially modified by personality factors, as well as by characteristics of the work situation and the social environment.

Empirical tests of many of the components of this model, as well as the Swedish model described earlier, are at present, still lacking. Because of the many constraints described above, these tests are very difficult to perform; Thus, their absence should not be attributed solely to laziness on the part of the respective authors of the models.

The Dynamic Structure of Time-Contingent Shiftwork Effects

One of the major methodological problem areas in shiftwork research arises from the fact that it involves many time contingencies. On the one hand, there are the circadian rhythms already described. On the other hand, there are the long term variables of age and exposure to shiftwork. If shiftworking increases the probability of complaints, one should find a deterioration in health as the amount of shiftwork increases. This does appear to be the case in some studies, including our own. This deterioration, however, could be simply an effect of age, because amount of shift experience and age are positively correlated. However, Figure 7 shows that the reduction in "health score" with age is more pronounced in shiftworkers than in day workers, and that the difference is especially pronounced in older workers.

Similar results have been found by other authors. Aanonsen (1964) and Åkerstedt et al. (1977) noted that older people slept less and that their sleep was inferior when they were on night shift. One interpretation of this was that the effort involved in switching between day and night work may start to become intolerable at the age of 45. Similarly, Wever (1974) observed that with increasing age, the time taken for circadian rhythms to adapt to shift changes becomes longer.

As mentioned in the introduction, in the ideal cases, we would have complex statistical procedures available for analyzing repeated measurements ob-

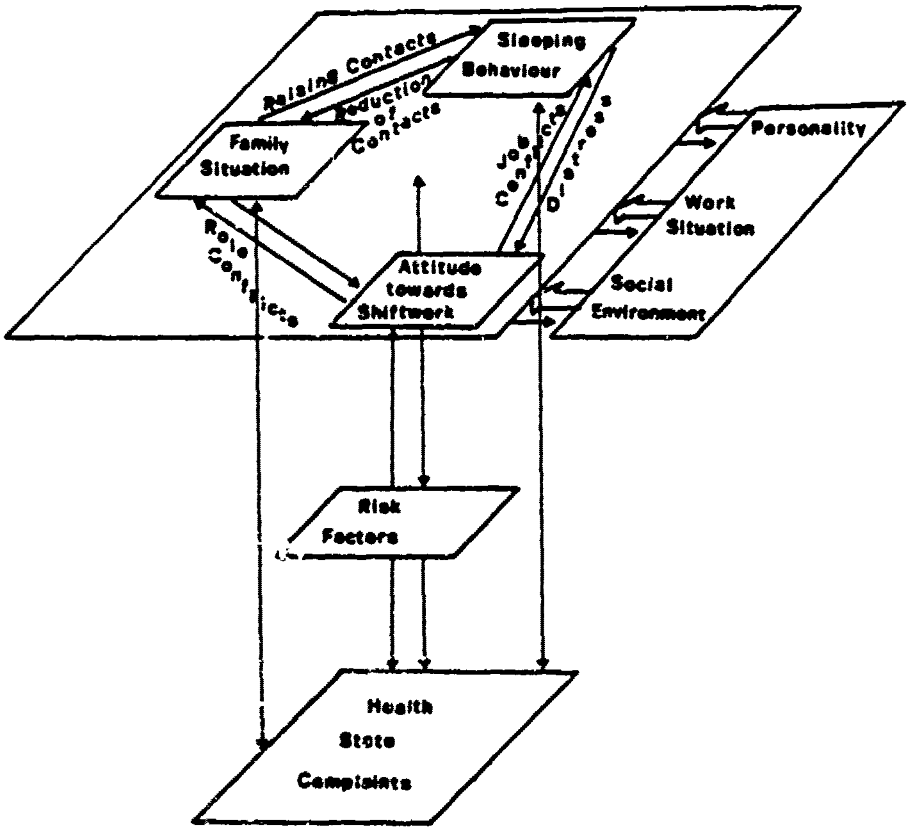

Figure 6. A model of the complex interaction structure of shiftwork effects.

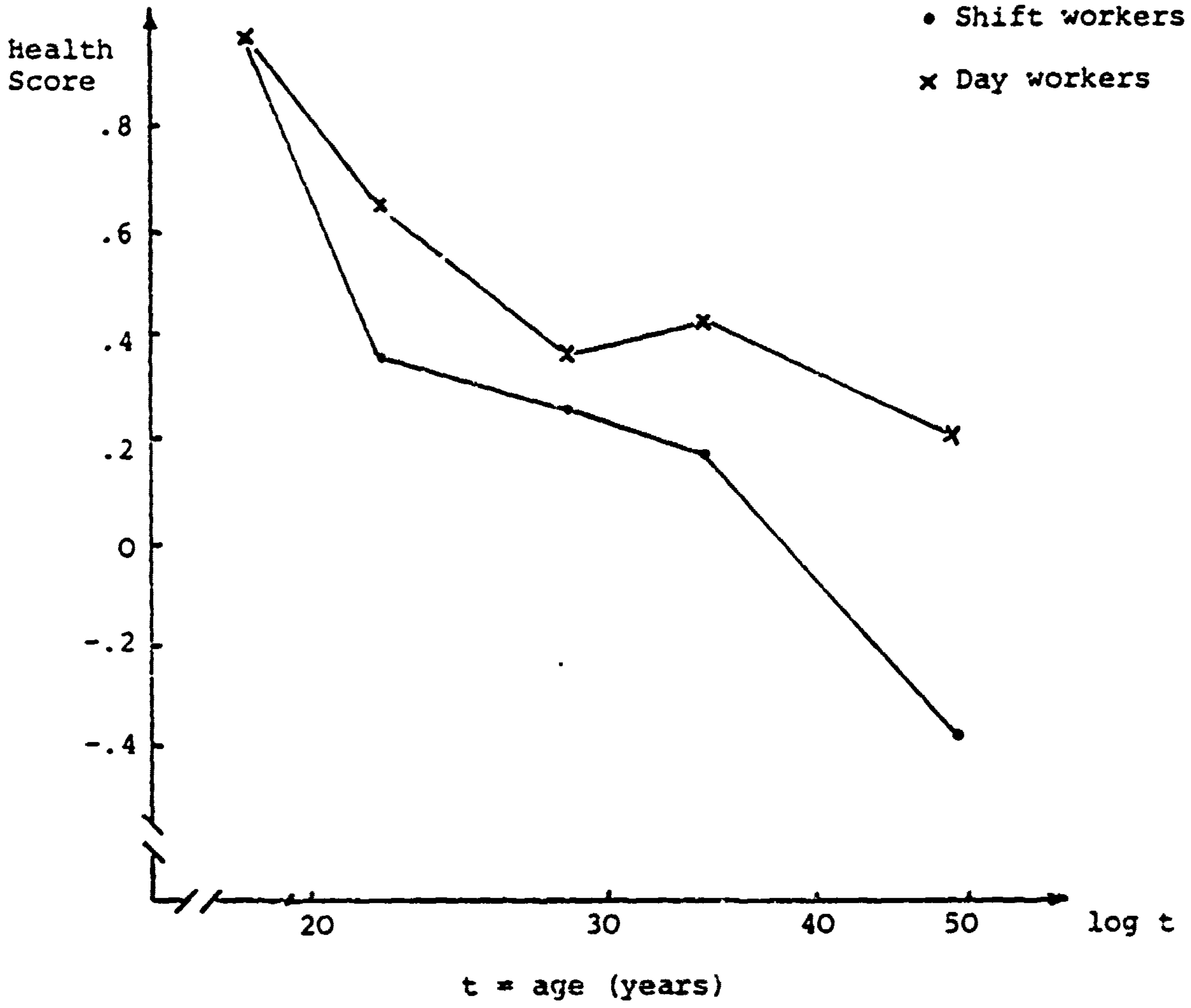

Figure 7. The deterioration of health with age in shiftworkers and dayworkers.

tained from many subjects in multifactorial designs that include time as a variable. In our study, we tried to analyze the dynamic properties of the relational structure described above by the use of Nonlinear Iterative Partial Least Squares (NIPALS) modelling (Wold, 1973). In a 3-step iterative process, we obtained weights for each variable group which characterized their power in predicting health state for different numbers of years on shift.

It was found that the different variable groups were not equally strongly related to health state and that these relationships were not stable over time. Figure 8 demonstrates these dynamic features of the relationships.

In the sequential development of interactions between health state and other variable groups, we may hypothesize different phases: In the first phase, which one might call the "Adaptation Phase", the main covariation is between sleeping behavior, work strain, social activities, and health state. In the second phase, which one might call the "Sensitization Phase", the variables 'attitudes towards shiftwork', 'job satisfaction', and 'family situation' become highly important. During this phase, the variables 'sleeping behavior', 'risk factors', and 'Morning-Evening Type' also start to increase in importance and, after between 23 and 40 years of work on shift, these 3 variables, together with attitudes towards shiftwork, have the greatest power in predicting health state, whereas all other variable groups drop in their importance. Figure 7 clearly shows this dichotomizing effect which characterizes the third phase or "Accumulation Phase".

One of the conclusions of this model is that there exist groups of variables like "job satisfaction', 'work strain', and 'family situation' which seem not so much directly related to the eventual reduction in health state, but rather act by making the shiftworker more susceptible ("sensitize him") to the "primary risk factors" of disease.

A "Destabilization Hypothesis" for Shiftwork Effects

In discussing mechanisms for shiftwork effects, it must be clearly remembered that many of the results of studies are conflicting, that a large proportion of the shiftworking population does not show an obvious reduction in health and wellbeing, and that many shiftworkers actually prefer shiftwork to other kinds of work. Therefore, we cannot expect to arrive at general causal explanations for shiftwork effects. We must assume rather that the whole process of such effects may, under certain conditions, lead to complaints and to reduced health state, but that it is also possible for this process to be stopped, for the feedback-mechanisms to be stabilized again, and for resultant adaptation of the worker to occur. This means that, methodologically, we should not look simply for causal chains between shiftwork on the one hand and health or wellbeing on the other, but rather try to establish the whole network of significant relations between the different parts of the process, and to then evaluate the conditions and possibilities for stabilization and destabilization of the complex interactional structure.

The interactional network obviously has dynamic features. We must, therefore, try to explore the time-contingent sequential development of the whole structure. Our data indicate that the processes of Adaptation, Sensitization, and Accumulation are important in this development. Some people are obviously

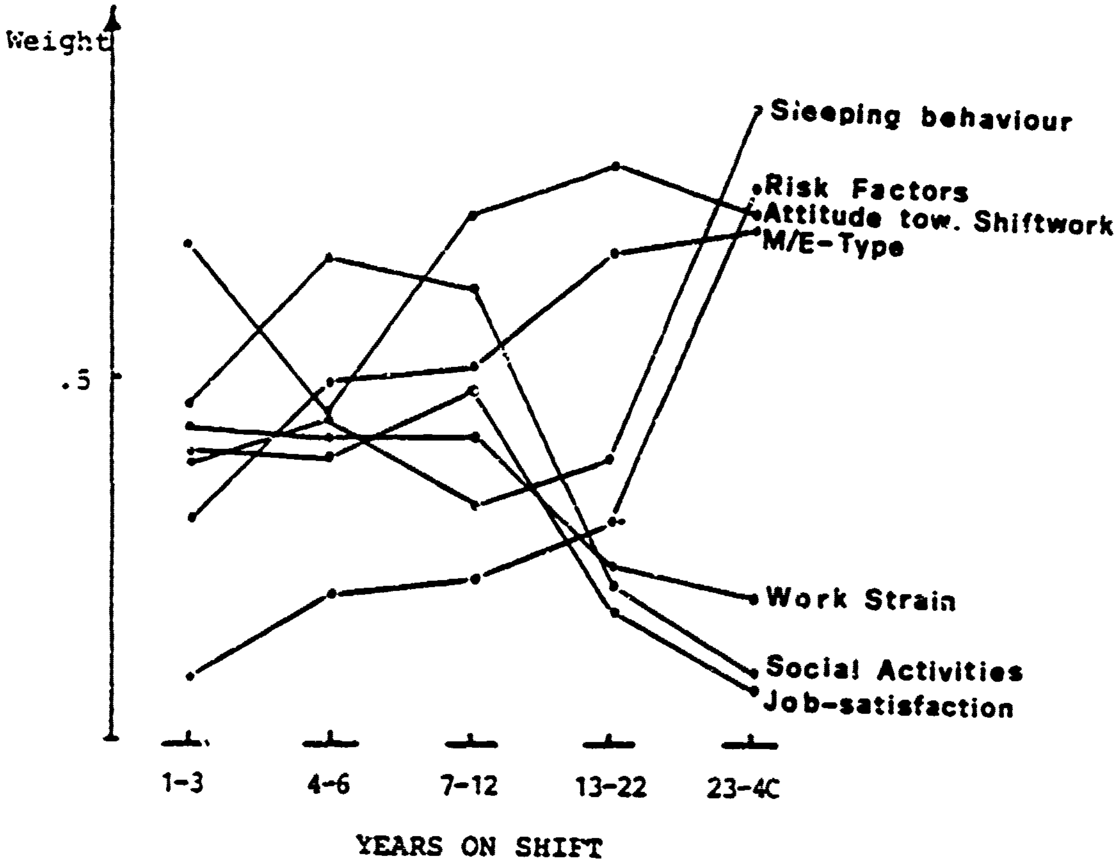

Figure 8. Weights for different variable groups, characterizing their power in predicting health state following different degrees of exposure to shiftwork (years on shift).

able to adapt to the problems of shiftwork and to stabilize their "person-environment relationship" at a new "steady state". Others may reach the Sensitization Phase, but fail to exhibit complaints and symptoms related to work strain. [But it should be noted that those people may still be sensitized for other risk factors: we have demonstrated that "drop-outs", even many years after quitting work, have higher sensitivity to noise than dayworkers; see Koller et al., 1978.]

A certain proportion of shiftworkers finally reach a stage in which complaints and symptoms accumulate, and the probability that they will have sleep problems or develop diseases of the gastrointestinal, circulatory and/or nervous system, increases. In this group, long exposure to shiftwork may then be associated with more sick leave and the "accumulated" complaints may eventually lead to absenteeism (Åkerstedt et al., 1977).

Methodologically, it must be pointed out that our data on time-contingent effects are based on a cross-sectional study of different groups of workers at each of a number of levels of shift experience. The idea that there are different phases of the complex dynamic structure can therefore only be proposed as a working hypothesis. Further studies of a longitudinal, prospective nature are clearly needed to confirm the hypothesis. But it seems to us that such a model of time-contingent sequential development of destabilization, with some variable groups as "sensitizers", could be tested on different kinds of health disturbances and diseases which are known to be related to chronic influences. This seems to be specially true for psychosomatic disease patterns, but conflicting views on the importance of "psychosocial influences" in the etiology of coronary heart disease may also be clarified by the use of such a model.

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SHIFT WORK RESEARCH ISSUES

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In the last ten years shift work has become, both for practical and theoretical reasons, a matter of increasing interest to a growing number of scientists in different countries, mostly in Europe. Because of this, a group of Institutes have organized several shift work symposia during this period, usually under the auspices of the International Association of Occupational Health. Our conference follows this tradition in many ways, because the selected themes (and indeed some of the individual speakers) are identical with those in previous symposia Oslo 1969 (Swensson, 1969); Slanchev Bryag 1971 (Swensson, 1972); Dortmund 1974 (Colquhoun, Folkard, Knauth, & Rutenfranz); Dortmund 1977 (Rutenfranz & Colquhoun, 1978).

As a result of these symposia, the Scientific Committee of Shiftwork of the International Association of Occupational Health decreed at its session in Dubrovnik 1978 that the main themes to be pursued in current research should be:

- the implications of circadian rhythm research for shift work problems;
- methodological problems in conducting both experimental and field studies of shift work;
- individual differences in adaptability to shift work;
- socio-psychological problems created by shift work;
- development of criteria for optimal shift systems and their evaluation;
- development of non-monetary techniques of compensating for the effects of working unsocial hours.

The general theoretical background for these topics is given in Figure 1. In terms of the stress-strain concept of modern occupational medicine, shift work problems can be described as:

1) The Objective Stress of Shift Work. This means the exposure of everybody working in shifts to the phase shifting of working and sleeping hours in relation to the normal phases of the circadian rhythms of physiological or performance functions; a special aspect of this problem is the time course of the adaptive processes in physiological functions after a shift in working hours, i.e., their re-entrainment.
2) The Subjective Strain Caused by This Stress. This strain may express itself in complaints, lowering of well-being and possible adverse health effects. At this moment, many governments are mainly interested in the health effects of shift work. This can be seen from the discussions about shift work as a possible cause of disease, especially gastrointestinal disease, although there is very little evidence of this. Nevertheless, shift work does produce many non-clinical complaints because of disturbed sleep, changes in eating habits and disruptions of family and social life. But the importance of these disorders for a particular person depends on
3) Intervening Variables, such as:
   - housing standards (especially sleeping conditions);
   - the family situation (age of children, acceptance of shift work by the family as a whole);
   - personality;

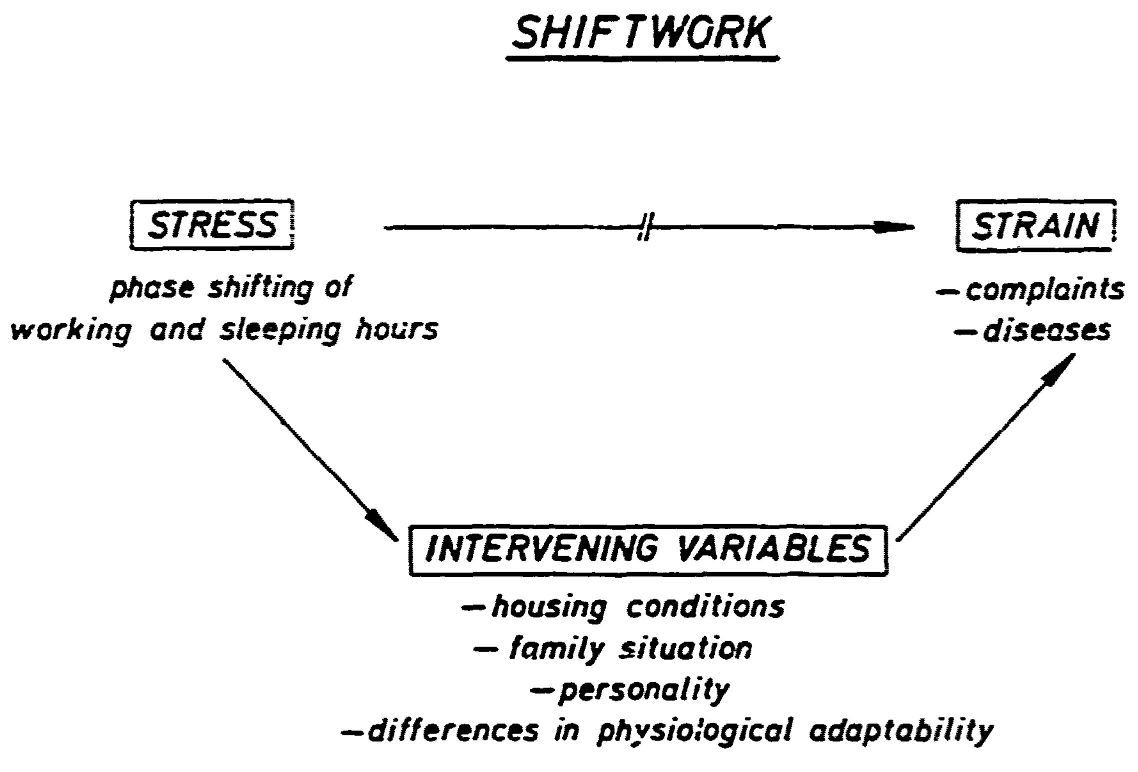


Figure 1. Model of relations between stress, intervening variables and strain in connection with shiftwork (Rutenfranz, 1976).

-differences in physiological adaptability.

These intervening factors determine if a particular person is able to cope with shift work, or if the disturbances of well-being will be augmented to such a degree that actual diseases will occur (Rutenfranz, 1976).

To cope with these problems, it is necessary to develop research-based principles for selection of shift workers, compensation for shift work, and construction of shift work schedules.

Therefore, I shall try to represent the actual position of research, including questions still open in relation to the following problems:

1) Re-entrainment of physiological functions during experimental shift work and in real life situations;
2) Effects of shift work on well-being and diseases;
3) Personal and situational differences in shift workers;
4) Chronohygiene of shift work.

Re-Entrainment Problems During Shift Work

If stress in shift work results from the discrepancy between the time-structure of behaviour (work, sleep) and the circadian rhythm of physiological functions geared to the normal daily routine, this stress can only exist as long as the circadian rhythm remains unadapted to the changed living conditions.

From numerous re-entrainment experiments with phase-shifting of the synchronizers, we know that the re-entrainment of most physiological functions takes place within a period of 3-14 days (Aschoff, Hoffmann, Pohl, & Wever, 1975). As far as shift work is concerned, the possibility of such re-entrainment has been disputed for a long time, since certain of the synchronizers essential to man, namely, time-consciousness and social contact, cannot be altered in real life. However, it is undisputed that shift work initiates adaptation processes of the circadian rhythm. The number of studies dealing with this question is surprisingly small at the moment, and it is useful to differentiate between those conducted in the field and those carried out in the laboratory, i.e., experimental shift work studies.

Results of Field Studies

As an example of field studies, we would like to take the findings on the oral temperature rhythms of a total of 133 experienced shift workers, which, depending on the shift system, were measured over 1-7 consecutive days of night shift (Knauth, Emde, Rutenfranz, & Smith, in prep.). The investigation lasted for 387 days altogether.

Figure 2 shows that the circadian rhythm of body temperature on the day of the first night shift remained practically unaltered in all groups and that up until the day of the 7th night shift, no indications of an inversion could be seen. However, it was striking that 'masking-effects'(Aschoff, 1978) could be recognized in both sleep and work, from the day of the second night shift onwards. Thus during the working period, there is a possible relative rise of the body temperature level, which clearly depends upon the energy expenditure

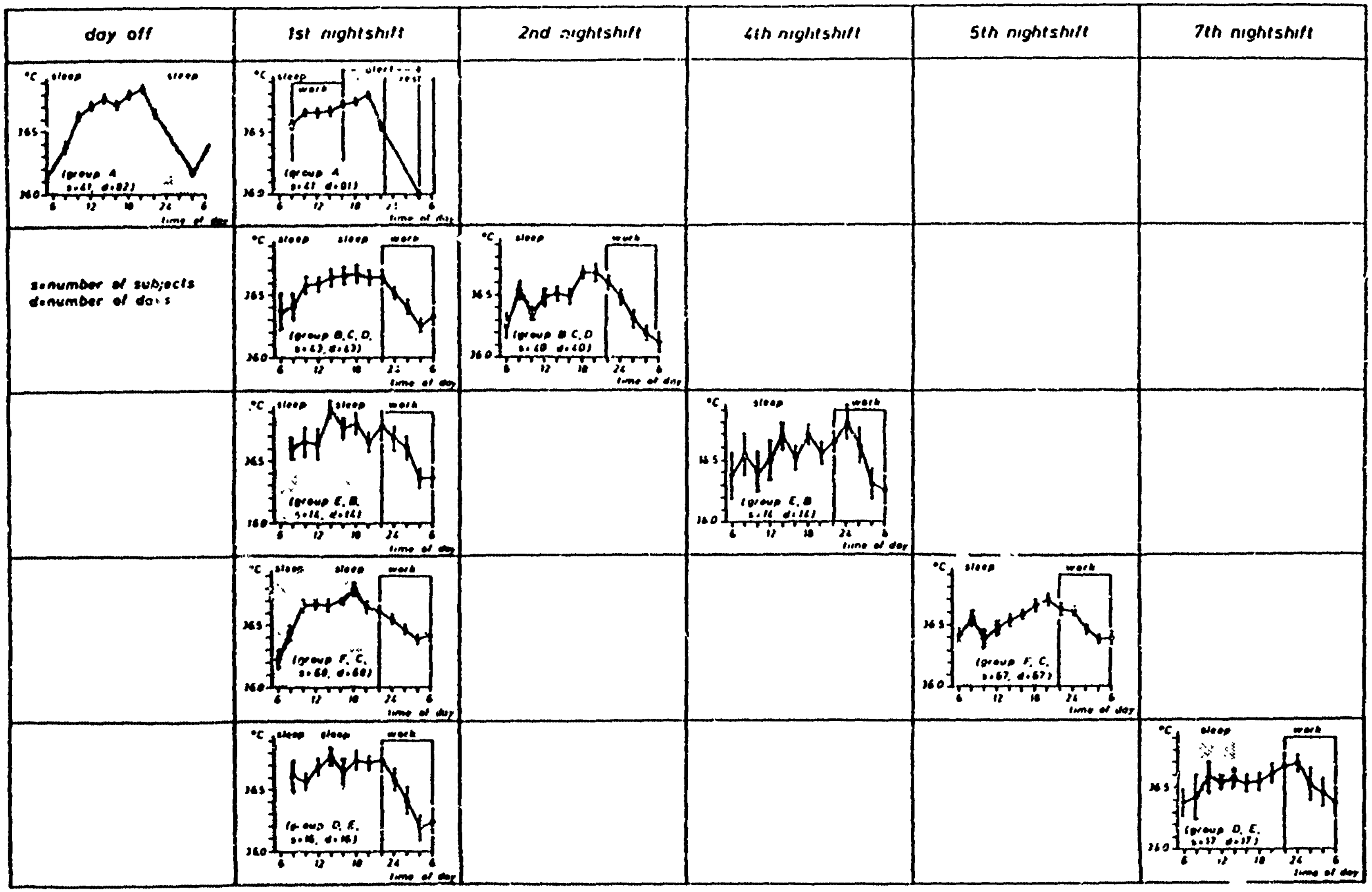


Figure 2. Circadian rhythms of oral temperature in 6 groups of shift workers studied in the field (Knauth et al., in preparation).

and the climatic conditions of the working place.

The upper part of Figure 3 shows the results from four other investigations of body temperature rhythms in field studies of shift work. It is evident at once that the picture is not homogeneous; however, only a few studies containing 24-hour recordings of body temperatures over several periods of night shifts have been carried out, and the number of subjects in these studies is very small (Åkerstedt, Patkai, & Dahlgren, 1977; Benedict & Snell, 1902; van Loon, 1963). Other experiments lack records about single days (Smith, 1979) or only cosinor values of the rhythms are given (Reinberg, Vieux, Laporte, Migraine, Ghata, Abulker, Dupont, & Nicolai, 1976).

From the data of field studies which so far have been considered, we may conclude that:

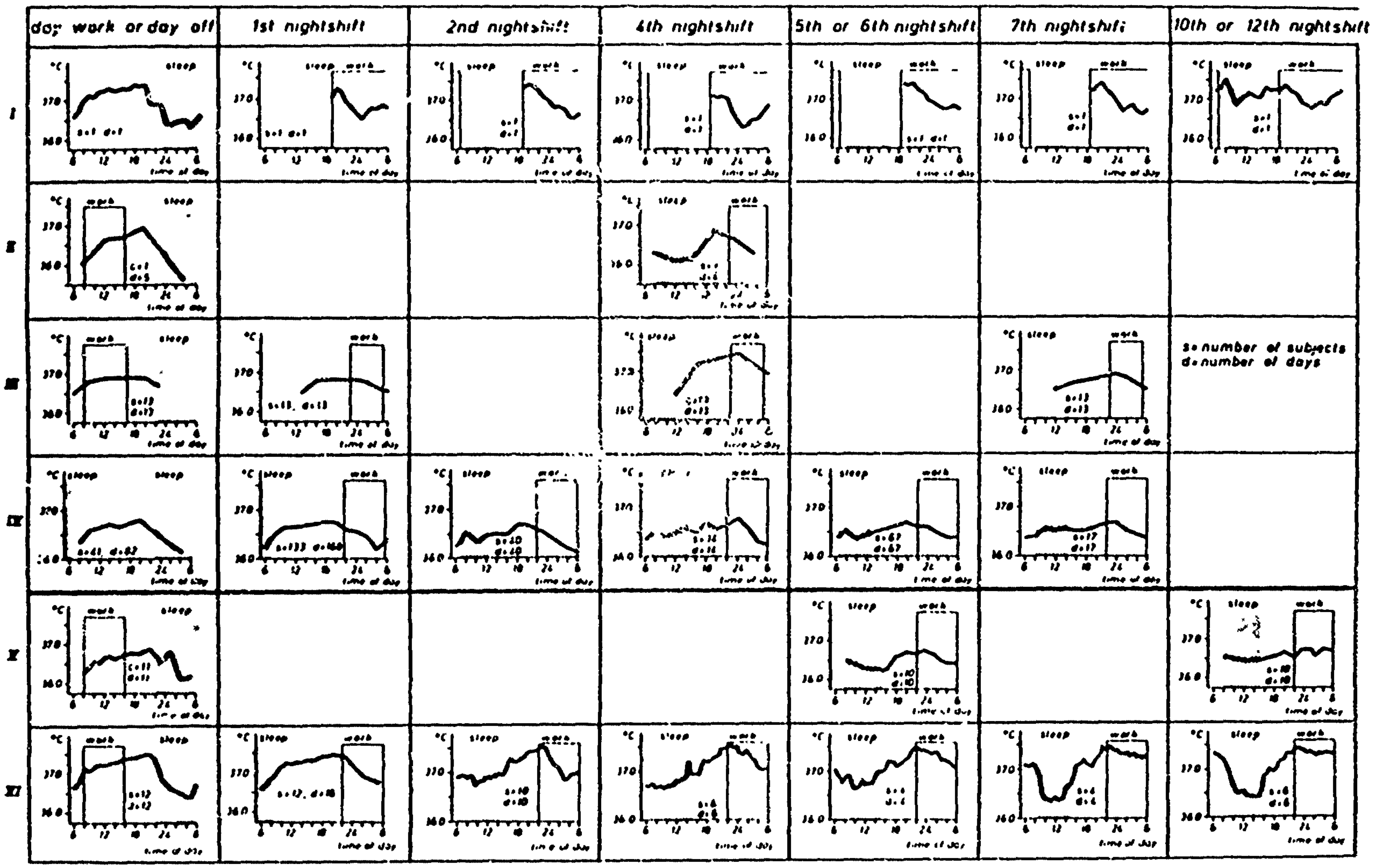
- one group of authors find no inversion up to the 7th night shift but only a flattening of the circadian rhythm (Benedict & Snell, 1902; Knauth et al., in press; van Loon, 1963; Smith, 1979). This group had at its disposal the largest number of subjects and, in most cases, complete records (often from two-hourly readings) over a period of several days;
- other authors report that oral temperature shows a tendency towards an 'adjustment (increase)' (Akerstedt et al., 1977) or an 'unusually fast adjustment' of the circadian rhythm of rectal temperature over a week of night work (Reinberg, Chaumont, & Laporte, 1975). Unfortunately, the data from this group are incomplete, as measurements for parts of the 24-hour period are missing, so that it is difficult to establish a clear picture of the re-entrainment.

Investigations resulting from field studies with more than 7 consecutive night shifts have not been published in Europe, since the laws of most of the countries do not allow such longer sequences of night shifts.

Experimental Shift Work Studies

For the reason given above, repeated attempts have been made in experimental shift work studies, to follow the circadian cycle of physiological functions over a sequence of night shifts longer than 7 days. In these studies, initiated more than 15 years ago by the late Michael Blake and his colleagues, an attempt is made to simulate shift work in the laboratory using, in the majority of cases, 'naive' test subjects. This is done either with work at taxonomically-built test-batteries or with work at actual industrial tasks carried out in the laboratory. The subjects normally live in the Institute in an "open-door" situation and sleep in controlled conditions; the latter allows sleep to be either limited or disturbed by controlled noise, if required.

Results of such experiments are shown in the lower part of Figure 3 and in Figure 4. The experiment by Colquhoun, Blake and Edwards (1968) shows, for example that on the 12th night shift day, a transference of the minimum body temperature rhythm was not evident even at this stage. In experiments by Knauth and Rutenfranz (1976) or by Knauth et al. (1978), which in some cases were continued for 21 consecutive night shift days, the same tendencies were found. Here an incipient migration of the body temperature was observed



field studies

I Benedict and Snell (1902)*
II van Loon (1963)
III Akerstedt et al (1977)
IV Knauth et al (1979)

experimental shiftwork studies

V Colquhoun et al (1968)
VI Knauth et al (1978)*

* rectal temperature

Figure 3. Circadian rhythms of body temperature in several field and experimental shift work studies by various authors (Knauth et al., in prep.).

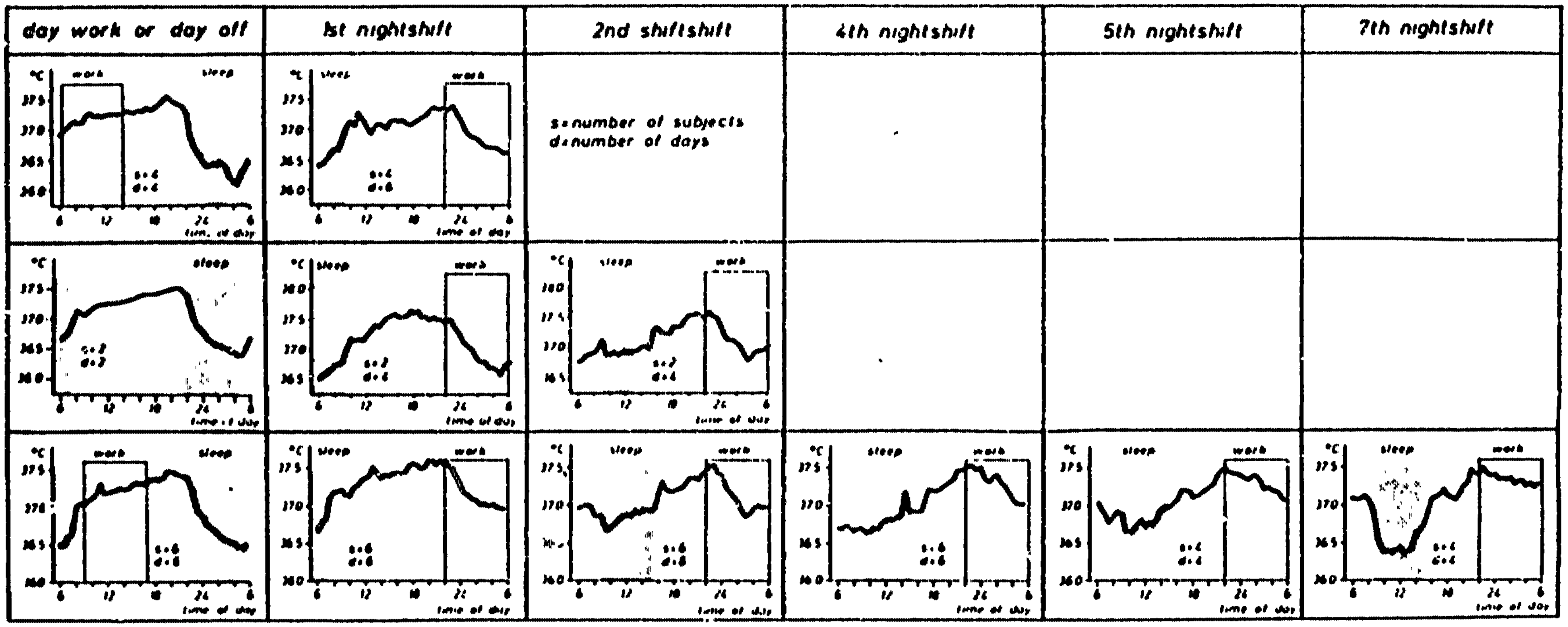


Figure 4. Circadian rhythms of rectal temperature during three experimental shift work studies (Knauth & Rutenfranz, 1976; Knauth et al., 1978).

from the 2nd night shift onward; this progressed during the following days, but was still not totally complete even on the 21st night shift day.

If one follows the changing position of the minimum of body temperature in relation to the middle of the sleeping period over the very long re-trainment period studied in certain of these experiments (Knauth & Rutenfranz, 1976; Knauth et al., 1978) it becomes apparent that the phase-alteration of this value to the expected value under the conditions of experimental shift work takes from about 7-14 days (Figure 5).

In this connection the question of the duration of the "re-re-entrainment" physiological functions in the reverse transition from night shift to day shift is of interest. Our results (Knauth et al., 1978) show that the duration of this second re-entrainment under the experimental conditions was related to the length of the night shift period. In experiments with 21 night shifts, re-entrainment had not, in fact, been completed even after 4 days (Figure 6).

Comparing the results from shift work under field conditions and from experiments under laboratory conditions, it emerges clearly that re-entrainment is more quickly, but only partly achieved with experimental shift work. We assume the reason for this to be that within the relatively closed group of persons participating in these laboratory experiments, a more or less unconscious displacement of the social synchronizers occurs, while in actual shift work, the phase position of the synchronizers within their normal time structure remains more stable because of family and social pressures. It should be noted also that the subjects in the studies of experimental shift work were always of a younger age group than the shift workers in the field studies.

Long-Term Adaptation to Shift Work

Finally, the question is as yet unsolved whether experienced shift workers develop special adaptation mechanisms to shift work, if for a long period they only work night shifts (i.e., if they are "permanent" night workers). From studies of night nurses who had been working 8 ('part-timer') or 15 ('full-timer') night shifts in every 28 days over many years, Folkard, Monk, and Lobban, (1979) came to the conclusion "that full-timers do show long-term adjustmen relative to part-timers, and that this is manifest in an enhancement of short-term adjustment, rather than a general flattening of the rhythms. It would appear to be even more apparent on the second night shift in a run of night work than on the first. However, the nature of this short-term adjustment would seem to vary with the variable considered, taking the form of a reduction in slope for temperature, but an increase in mean level for alertness and well-being, over the first night shift. In contrast, the changes from the first to the second night shift were in level for temperature, but in slope for alertness and well-being."

Desynchronization of Physiological Functions in Shift Work

From fundamental studies on re-entrainment of physiological functions (Aschoff et al., 1975; Wever, 1979), as well as from experiments on trans-atlantic flights (Klein, Wegmann, & Hunt, 1972), one can conclude that during the re-entrainment after a phase-shifting of working and sleeping times a

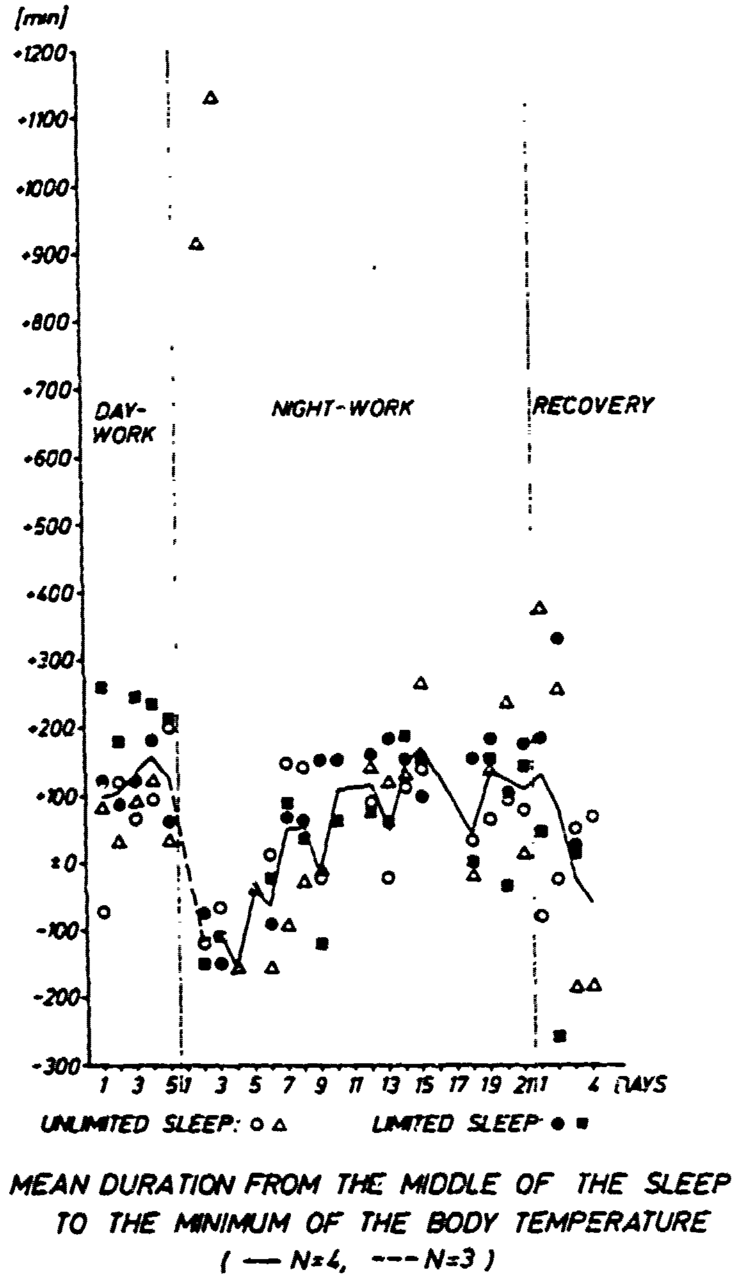


Figure 5. Mean time from mid-sleep to minimum body temperature (Knauth & Rutenfranz, 1976).

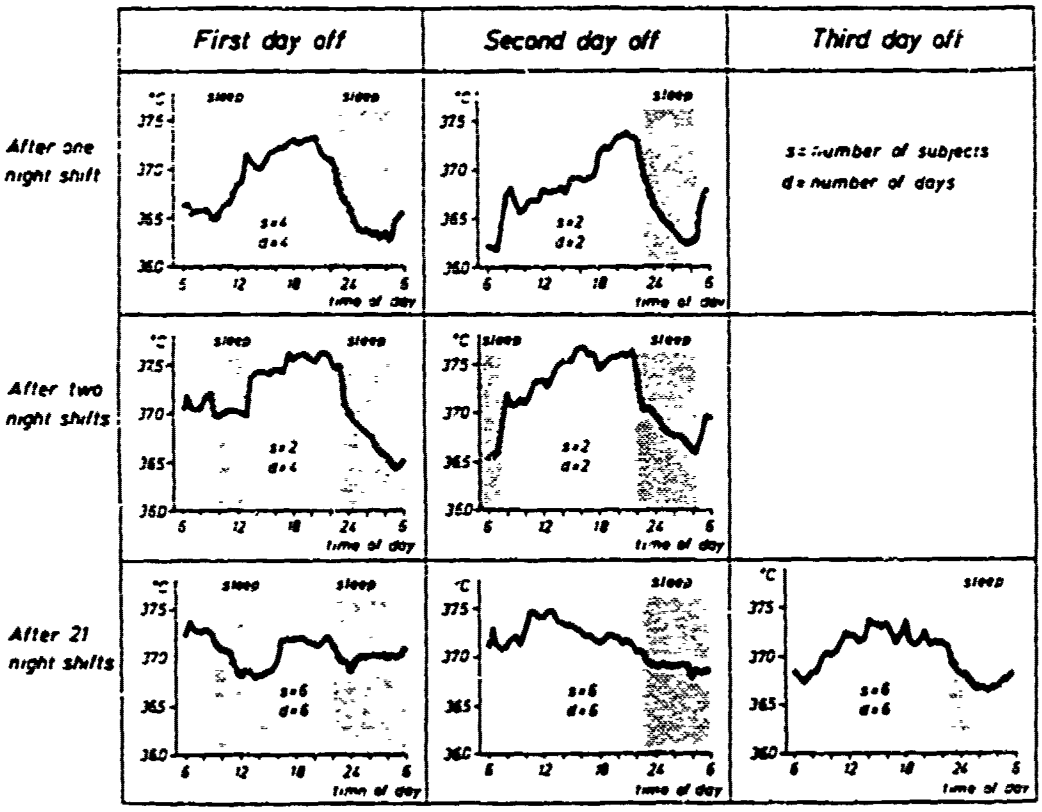


Figure 6. Circadian rhythms of rectal temperature after 1, 2, or 21 experimental night shifts (Knauth et al., 1978).

desynchronization can take place in the circadian rhythms of various physiological functions. Unfortunately, as far as shift work is concerned, there are only a few investigations into this important question, and these are still in an early stage (Åkerstedt et al., 1977; Patkai, Åkerstedt, & Pettersson, 1977; Reinberg et al., 1975; Rutenfranz, Klimmer, & Knauth, 1975). So far, the results have produced no uniform picture, so that the question must remain open, whether the subjective complaints reported by shift workers are possibly increased by desynchronization of circadian rhythms.

Changes in the Sleep-Waking Cycle in Shift Work

A further objective problem of stress in shiftwork is produced by the disruption of the normal circadian rhythm of sleeping and waking (Kleitman, 1963) by the enforced behaviour. In the first place, this results in a shortening of the sleep period during day time sleep; if in addition (because of living conditions) noise-induced disturbances of sleep occur, this shortening is accompanied by alterations in sleep quality (Williams, 1973). Data concerning this phenomenon, obtained from tests during experimental shift work were reported in 1972 by Knauth and Rutenfranz (Figure 7). The long term adaptation to such behaviourally- and environmentally-conditioned disturbances of the sleep-waking rhythm is being studied anew at present by various groups (Ehrenstein & Müller-Limmroth, 1975; Foret & Benoit, 1978; Lortie, Foret, Teiger, & Laville, 1979; Patkai et al., 1975).

Open Questions

As a result of the recent experiments described in the presentations, our knowledge about problems of re-entrainment in shift work has been widened considerably; nevertheless, discrepancies remain. For further clarification, the following experiments are urgently required;

- -Experiments with continuous night shift under field conditions over more than 7 consecutive days, in order to check the stability of the social and cognitive synchronizers;
- -Experiments with continuous night shift under conditions of experimental shift work with experienced shift workers for more than 7 days, in order to check problems of long-term adaptation;
- -Experiments with continuous night shift under field and/or experimental conditions for more than 7 days in which the circadian rhythm of several physiological functions are recorded, in order to study the problem of desynchronization in shift work;
- -Investigations into the sleeping behaviour pattern in night shift periods of longer duration with experienced shift workers in field, as well as laboratory studies, including stress through noise, in order to check the importance of qualitative or quantitative sleep reduction in relation to the intensity of sleep disturbances complained of by the workers.

Effects of Shift Work on Well-Being and Disease

According to modern biology, life exists in coming to terms with the environment (Uexküll & Kriszat, 1956). Man is generally in a position to adapt himself not only to natural but also to artificial environments. Occupational medicine proceeds from the fact that there is a spectrum of possible adaptations between the two extremes of complete physical, psychical and social

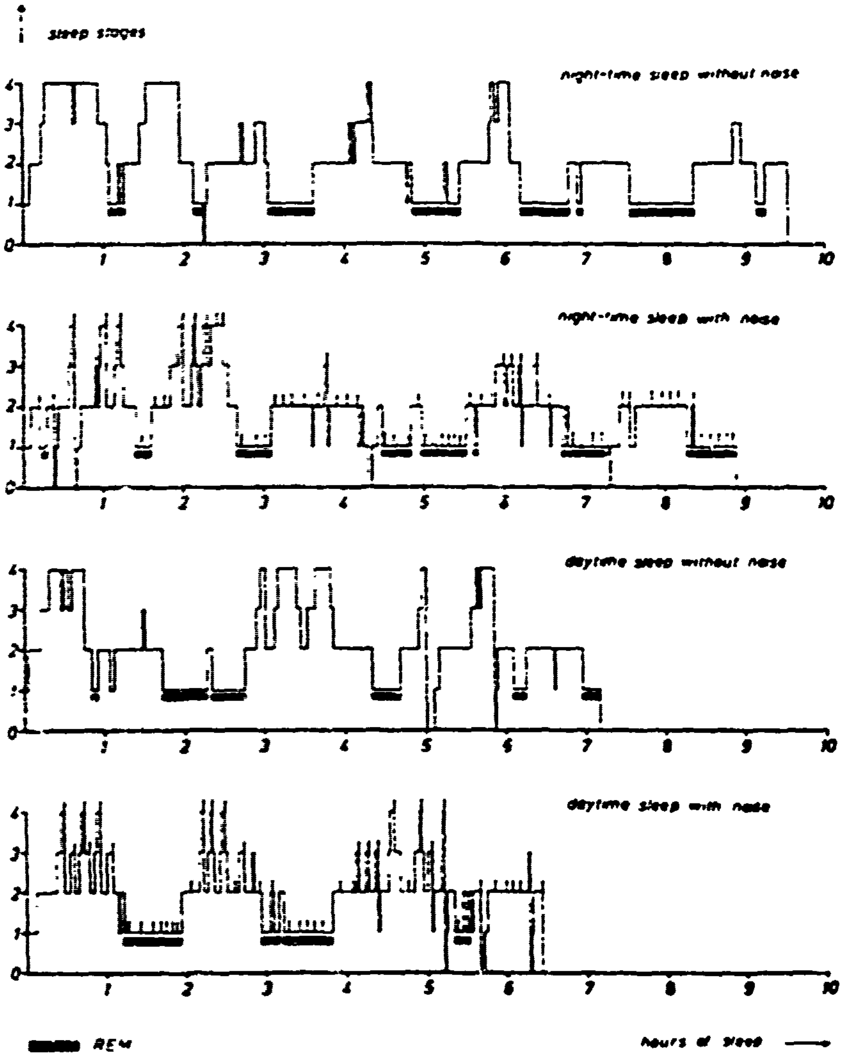


Figure 7. EEG sleep stages of one subject recorded in connection with an experimental shift work study (Knauth & Rutenfranz, 1972a).

well-being on the one hand, and death on the other (Karvonen, 1979).

It is possible to think of several degrees of adaptation between the two extremes. Should well-being, for instance, not be achieved in certain spheres of life (physical, psychical or social)--the term discomfort is used in epidemiology in order to describe this--a lowering of well-being, which is not illness, becomes likely. Conditions which are outside the normal limits of adaptation capacity, and which, therefore, do not meet the criteria of long-term endurability, will, eventually, lead to illness. In this context we describe innate characteristics, acquired patterns of behaviour, or pregiven conditions of daily life, all of which might decrease the physical capacity of adaptation of a person, as risk factors. This means that the presence of one or more of such factors does not at first cause any particular illness, but generally makes the eventual occurrence of an illness statistically more probable. In this sense, shift work may be regarded as a risk factor (Rutenfranz, 1967).

Health-Relevant Types of Shift Work

One may generally assume that shift work, or work at constantly unusual times, is disagreeable to the majority of human beings. Shift work has this in common with all other forms of work which differ from our average expectations of working conditions. Despite this, however, it cannot be denied that even shift work is expressly sought after by a small number of persons, because they believe that only with this kind of organization of their work can they realize certain expectations or enjoy certain hobbies. The best known examples are the farmers shift working in the chemical industry in Germany, and the fishermen shift working in the paper industry in Norway. According to Harrington's (1978) findings, it generally may be assumed that 20-30% of all workers decline shift work, approximately 10% see certain advantages in it, and the rest simply tolerate it.

Apart from this, it may be assumed that any working at changing times of day disturbs the order of our social life, and partly the order of our biological functions as well; this does not, however, mean that in every case it entails danger to health. If we consider the various forms of shift work listed in Figure 8, where the classification according to kinds of organization is similar to that in Rutenfranz, Knauth, and Colquhoun (1976), and if we bear in mind the problems of biological rhythms, we may set up the hypothesis that all forms of shift work, including night work, deserve special attention from the point of view of occupational medicine. Irregular forms of shift work, "continuous" shift work, and "permanent" night shift work should be examined particularly closely, because of their special psycho-social problems; no noticeable influence on health, however, may be expected from forms of shift work which exclude night shifts.

In considering the health effects of shift work, one tends to forget that shift work, as a special time-oriented organization of work, is superimposed upon the most varied activities. Thus, when discussing the possibilities of harmful effects from this work-organization, it is necessary to distinguish these from the stresses and possibilities of harm caused by the kind of work in itself, in the sense of the so-called 'confounding factors' as used by epidemiology (MacMahon & Pugh, 1970). On the other hand, stresses which otherwise lie within the range of harmlessness (Hacker & Macher, 1977) as, for in-

I. Systems without night work
  Two-team ("double-days")
    a. nonoverlapping (e.g., 0600—1400, 1400—2200)
    b. overlapping (e.g., 0600—1400, 1330—2130)

II. Systems with night work
  Two-team (up to 12-h shifts) ("days and nights")
  Three-team (8-h shifts)
  One-team (night work only) ("permanent night shift"): is often combined with I to provide complete coverage of the 24-h period

III. Systems with night work and including weekend work ("continuous shift work")
  Regular
    a. three-team (12-h shifts)
    b. four-team (8-h shifts)
  Irregular (varying number of teams and cycle lengths)

Figure 8. Types of shift system (Rutenfranz et al., 1977).

stance, work in climatic conditions below certain temperature figures, work with health-endangering substances within the limits of MAK, work with noise, etc., may possibly lead to health-endangering situations in night work conditions.

In all disturbances of health caused by shift work, it is however, advisable to distinguish between lowering of well-being and disease proper.

Lowering of Well-Being

Sleep Behaviour Patterns in Shift Work. Numerous investigations (e.g., Menzel, 1962) have shown that average sleeping time amounts to 7.5 hours before a morning shift, 8.5 hours after an afternoon shift and approximately 4-6 hours on the day after a night shift (Figure 9). The need for sleep, independent of the form of shift work, varies considerably with the individual human being and is also related to age. The amount needed is, however, definitely longer than any sleeping time which can be achieved with night work, as we have demonstrated with engine drivers (Rutenfranz, Knauth, Hildebrandt, & Rohmert, 1974) (Figure 10).

This shortening of sleeping time is brought about on the one hand by the transference of sleep to a time of day which is unfavorable for it in respect to circadian rhythms, and on the other hand through disturbances of sleep during the day time caused by noise (Figure 11); children and traffic are usually mentioned as most important sources of this disturbing noise (Knauth & Rutenfranz, 1972a,b).

On the basis of these facts, one would expect the frequency of sleep disturbance to be determined by the type of shift work. In Figure 12 [illegible] ve plotted the reported frequency of sleep disturbance according t[illegible] shift work among 5766 persons, on the basis of various investigations of our own or studies published by others (Aanonsen, 1964; Anderson, 1958, 1970; Barhad & Pafnote, 1970; Graf et al., 1958; Häkkinen, 1969; Hettinger et al., Knauth & Rutenfranz, 1972b; Kolmodin-Hedman & Swensson. 1975; Loskant, 1970; Mann & Hoffmann, 1960; Monnier,1963; Nachreiner & Rutenfranz, 1975; Rutenfranz et al., 1974; Wyatt & Marriott, 1953).

The table shows that sleep disturbances were reported by:

-approximately 15-20% of day workers;
-approximately 5% of the shift workers, not doing night shift;
-approximately 10-80% of shift workers doing night shift;
-approximately 60% of workers doing continuous night shift;
-approximately 90% of former shift workers at the time of their night shift activity; in switching over to day shifts, the sleep disturbances decreased to less than 20%.

From Figure 12, we may conclude that shift work which excludes night shift and straight day work do not lead to sleep disturbance to any significant degree; but that shift work which includes night shift and continuous night work bring about special sleep problems for the shift worker. At the same time, there is an indication that the irregular systems of shift work prevalent in the service sector (radar controllers,engine drivers) very often lead to sleep disturbances, whereas living conditions in the area around a big chemical fac-

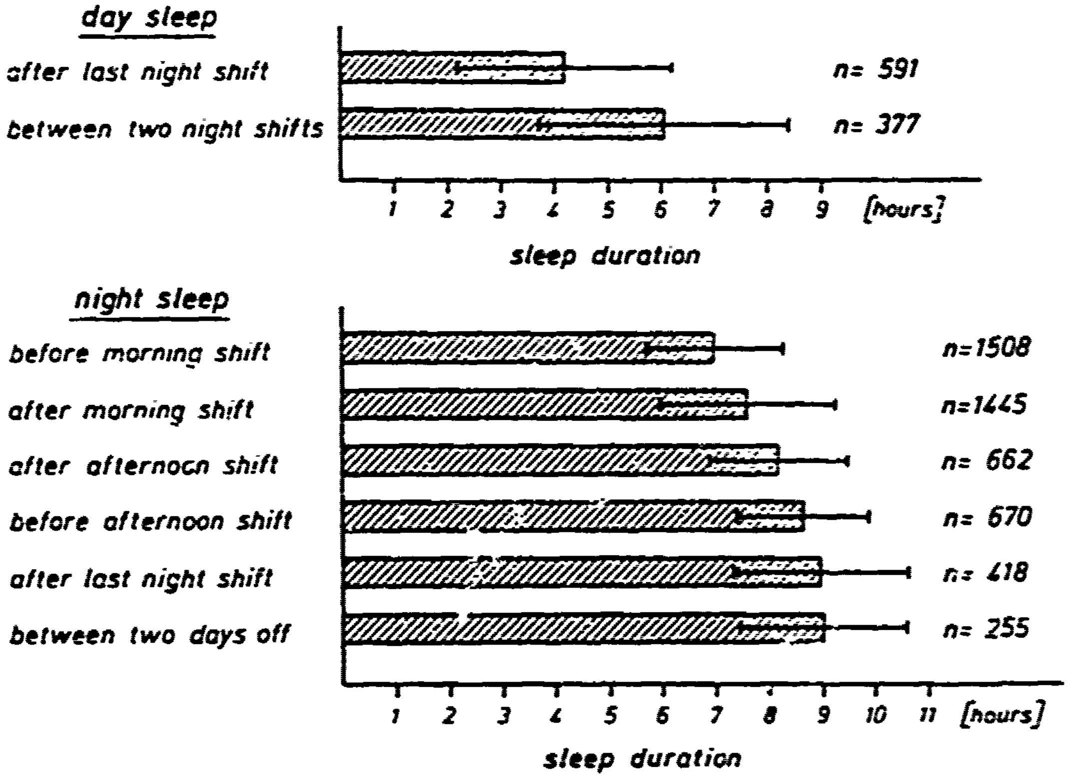


Figure 9. Sleep duration by shift type from diary records of 5926 days (Knauth, unpublished data).

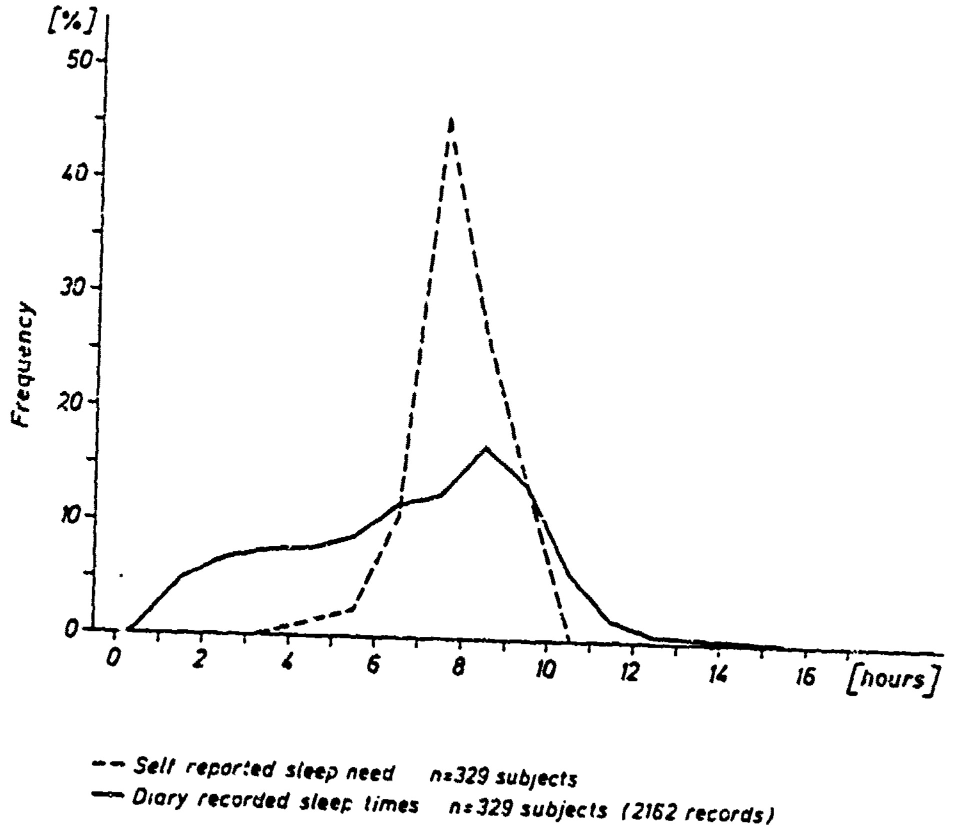


Figure 10. Frequency distributions of "sleep need" and of diary records of actual sleep duration between two consecutive shifts: Engine drivers (Rutenfranz et al., 1974).

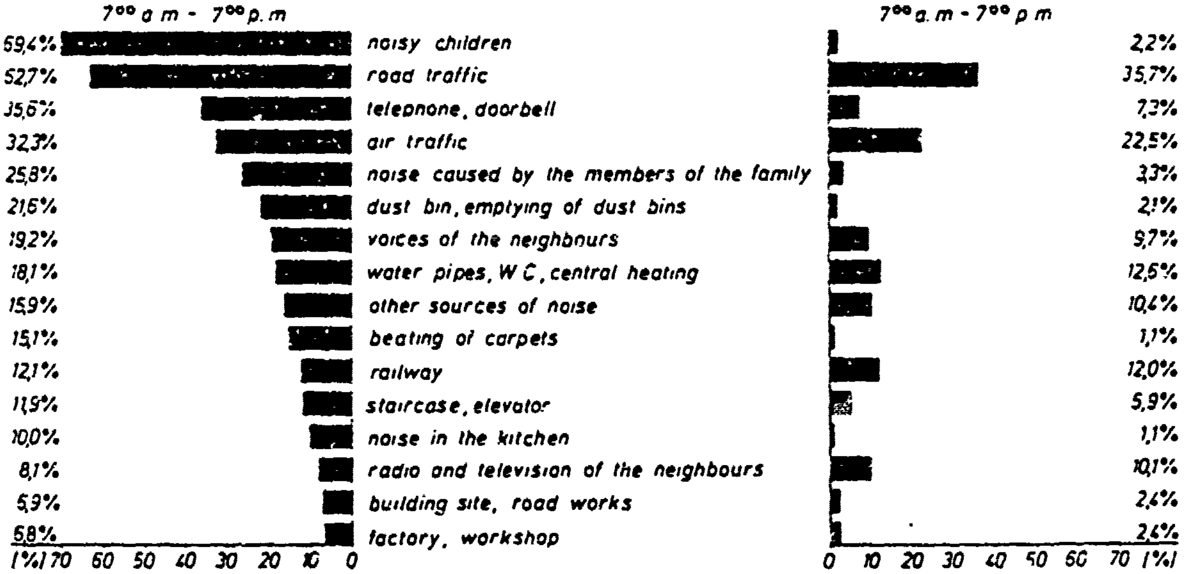


Figure 11. Relative frequency with which different causes of sleep interruptions were mentioned by 808 shift workers who complained about frequent noise disturbances during sleep (Knauth & Rutenfranz, 1972b; Rutenfranz et al., 1974; Knauth et al., 1975).

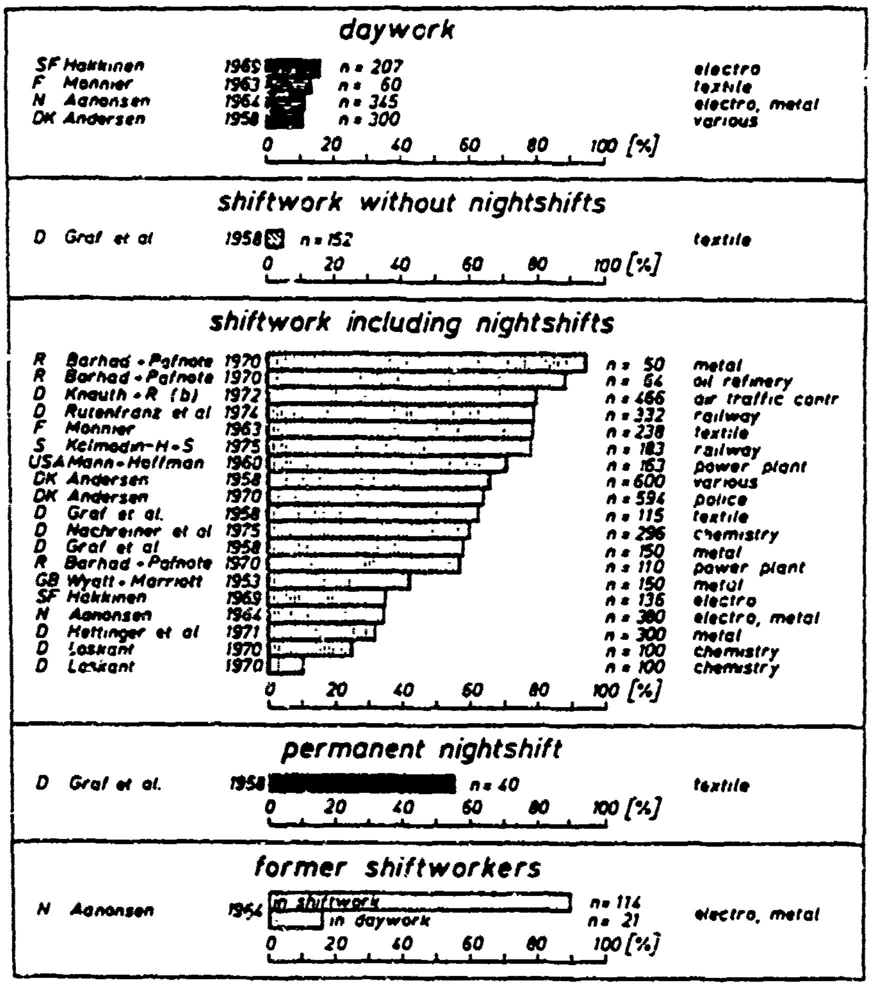


Figure 12. Frequency of complaints about sleep disturbances related to type of shift system.

tory with an advantageous shift work system apparently lead to favourable sleep conditions. The influence of other work conditions such as heat, noise, etc., cannot be clarified because of the variety of the types of industry.

These sleep disturbances with night shift workers are the dominant symptom of lowered well-being; compensation for which will have to be rethought anew.

Disturbances of Eating Habits. The time changes of work, sequence of meals and sleep very probably are the causes of disturbances in appetite during night work. On the basis of our own investigations and those of others, dealing altogether with 906 persons, we show the findings for various forms of shift work in Figure 13 (Graf, Pirtkien, Rutenfranz, & Ulich, 1958; Häkkinen, 1969; Wyatt & Marriott, 1953).

Figure 13 shows that disturbances of appetite occurred:
-in less than 5% of the day workers;
-similarly in less than 5% of shift workers not doing night work;
-in approximately 35-75% of shift workers doing night shift;
-in approximately 50% of workers doing continuous night shift.

The number of investigations concerning this problem is not very large. Nevertheless, Figure 13 shows that shift workers doing night shift or doing continuous night shift clearly suffer more from disturbances of eating habits than day workers or shift workers not doing night shifts.

Debry and Bleyer (1972) were able to show that these disturbances of appetite did not lead to a lessening of calorie intake; the disturbances of appetite have more to do with the dislike of having to eat at unusual times or with food that is often cold or which has to be taken outside the accustomed social environment.

Gastrointestinal Complaints. Irregularities in food intake can, as experience shows, lead to digestive disorders and gastrointestinal complaints; however, the reasons for this complex of symptoms are surely manifold. Nevertheless, complaints concerning the gastrointestinal system are often named as a predominant symptom in shift workers. On the basis of our own investigations and those published by other authors dealing altogether with 8060 persons, we have assembled in Figure 14 the findings for various forms of shift work (Aanonsen, 1964; Andersen, 1960; Bjerner, Holm, & Swensson, 1948; Graf et al., 1958; Häkkinen, 1969; Kolmodin-Hedman & Swensson, 1975; Loskant, 1970).

Figure 14 indicates that gastrointestinal complaints have been observed:
-in 10-25% of day workers;
-in approximately 17% of shift workers not doing night shift;
-in approximately 5-35% of shift workers doing night shift;
-in approximately 50% of workers doing continous night shift;
-in approximately 30-50% of former shift workers who have ceased work for reasons of health.

The striking factor in these findings is the wide overlap of the answers, which does not permit a clear differentiation between the various groups. This is especially noticeable in the day workers and in the group of shift workers

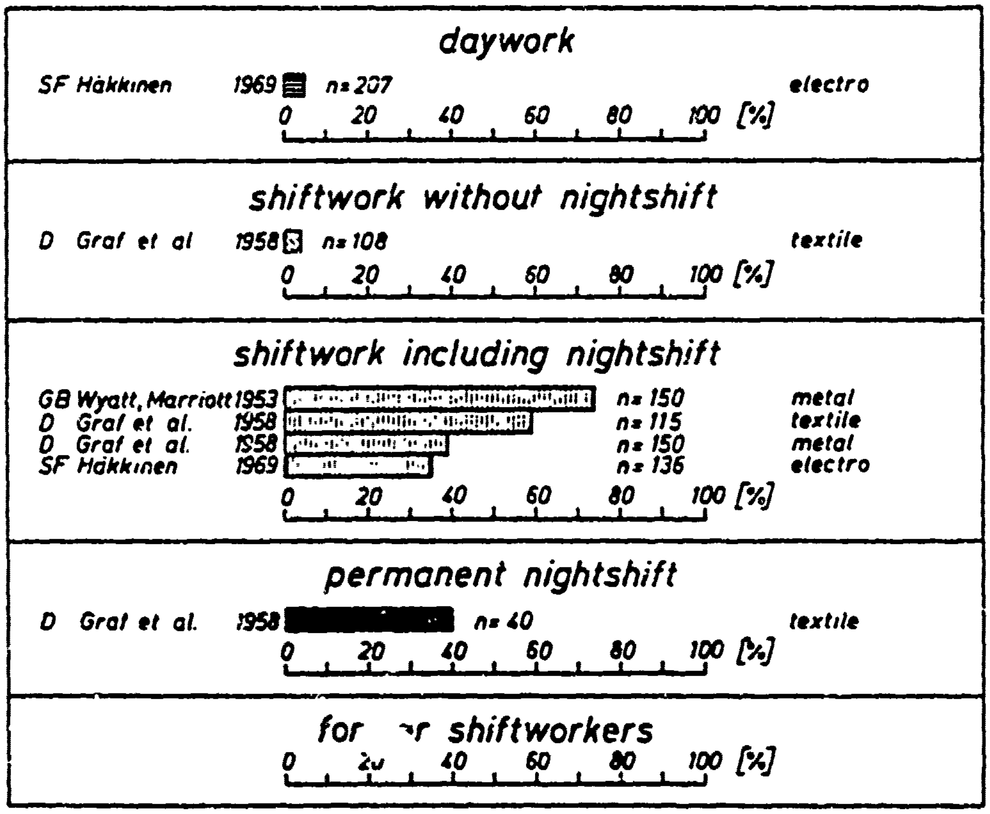
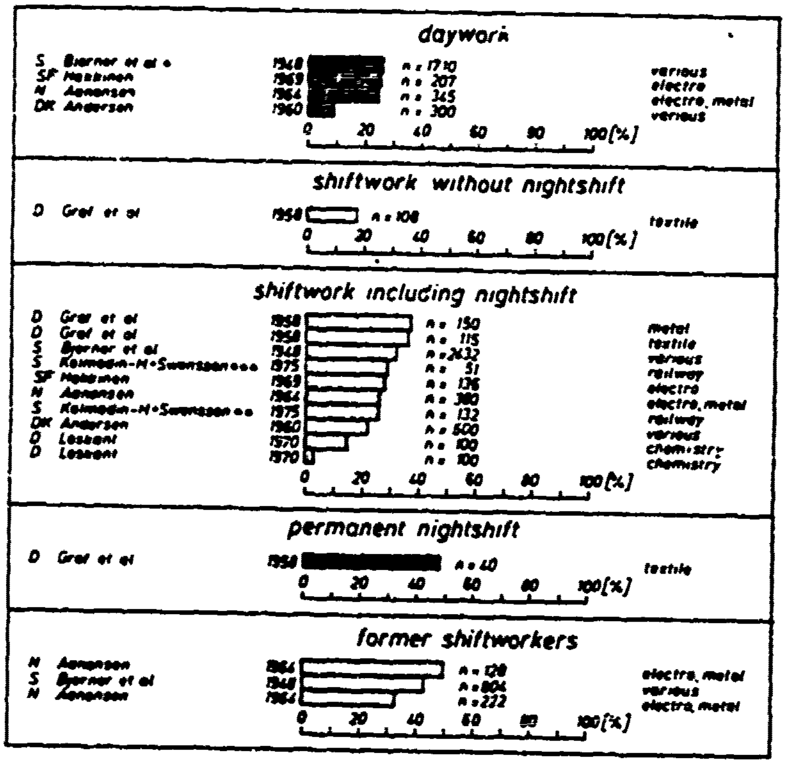


Figure 13. Frequency of complaints about disturbances of eating habits related to type of shift system.



* dayworkers without shiftwork experience

** irregular duty hours

*** regular duty hours

Figure 14. Frequency of complaints about gastrointestinal disturbances related to type of shift system.

doing night shift. It is conspicuous that (especially with the studies from Scandinavia) even day workers show a strikingly high percentage of gastrointestinal complaints. If one compares in groups investigated by the same authors, the groups of shift workers doing night shift with the corresponding groups of day workers (Aanonsen, 1964; Bjerner et al., 1948; Häkkinen, 1969), there are only insignificant differences. Contrary to this, the former shift workers [even taking the findings of the same investigations (Aanonsen, 1964; Bjerner et al., 1948)] show the greatest frequency of complaints; similar figures were found for a small group of shift workers doing continuous night work. Finally, gastrointestinal complaints were strikingly rare wherever experienced occupational physicians had been doing special medical examinations for years for beginners and follow-up tests with the shift workers (Loskant, 1970).

Dangers to Health

The adaptation disturbances in shift work, as detailed above, show that not all forms of shift work are similarly problematic, but, rather, that it is mainly those forms of shift work which include night shift that contain special risks. In these cases, shift work may become a risk factor as far as health is concerned if the unavoidable adaptation disturbances resultant on changes in the biological rhythms are augmented by other personal or situational factors at home or at the working place (Rutenfranz, 1976). Such transgressions of the adaptability limits of the human organism should show up in an excessive mortality rate or in an increased frequency of disease.

Studies of Mortality. Studies of mortality with shift workers are, so far, very rare. In an unusually careful study, Taylor and Pocock (1972) compared mortality rates in shift workers and day workers in 10 factories over a 13-year period; with 1578 deaths occurring in 8603 persons, they found no difference in rates between shift workers and day workers. Shift workers, however, who had given up shift work prematurely showed a higher mortality rate (standard mortality ratio: 118.9 against 101.5). A certain excessive mortality due to neoplasmas was found among shift workers and due to pulmonary complaints among the day workers. Further studies seem necessary here.

Gastrointestinal Diseases. On account of the high frequency of disturbed appetite and gastric complaints, special risk to the gastrointestinal system among shift workers appears probable and plausible, should other aggravating factors accrue.

Duesberg and Weiss reported, in the basis of health insurance company statistics in 1939, that workers who, under the conditions prevailing in the German armament industry, were employed in shift work doing heavy physical work, succumbed to gastric ulcers eight times as often as non-shift workers. Duesberg and Weiss (1939) mention in their publication: "Workers who, with only a short lunch break, often doing continuously heavy physical work, partially in shifts or in over-time, include among them approximately 8 times as many persons suffering from an ulcer as members of professions which permit a regular daily life and a sufficient lunch break with physically less exacting work."

In the discussion of this result it is often overlooked that the relative frequency of falling ill in the studies of Duesberg and Weiss (1939) was extremely low compared with that in other investigations. In evaluating material provided by health insurance companies, they found an ulcer frequency of approximately 0.3% among day workers; among shift workers doing heavy physical work while leading irregular lives, the frequency was approximately 2.4%. Reckoned altogether, this amounts to an eight-fold increase, but in investigations made after the second world war, there were significantly increased frequencies even among day workers, which indicates that there was an underlying upward trend.

This time trend may partially account for the completely different results found by Aanonsen in Norway in 1964. He established that shift workers and non-shift workers did not differ in any significant way from day workers as far as gastric ulcers were concerned, but that among day workers, the highest frequency of such diseases was to be found within the group of former shift workers.

Figure 15 shows the findings for ulcer incidence, compiled from investigations by various authors, in a total of 32550 persons doing various kinds of shift work (Aanonsen, 1964; Andersen, 1958, 1960; Bjerner et al., 1948; Bruusgaard, 1949; Duesberg & Weiss, 1939; Ensing, 1969; Kolmodin-Hedman & Swensson, 1975; Rietschel, 1978; Thiis-Evensen, 1958). According to this figure, gastric ulcers were found among:

-approximately 0.3-7% of day workers;
-approximately 5% of shift workers not doing night shift;
-approximately 2.5-15% of shift workers doing night shift;
-approximately 10-30% of those shift workers who had given up shift work, probably for health reasons.

These data make it evident that there is a wide overlap in the incidence of ulcer among shift workers and non-shift workers. It can generally be said that the material provided by health insurance companies shows exceptionally low percentages of ulcers, while investigations in plants produce significatly higher percentages in shift as well as in day workers, which cannot be explained merely by the different sizes of the populations studied. If one compares the different groups within the populations studied by individual researchers, Andersen (1960) found a slightly higher morbidity among shift workers doing night shifts than among day workers and former shift workers; however, Bruusgaard (1949) observed an identical frequency in day workers and shift workers doing night shift, but a small hyper-morbidity among former shift workers. In an exceptionally careful study, Aanonsen (1964) found the lowest frequency of ulcers in shift workers doing night shift, a slightly greater frequency in day workers, and a significantly higher incidence in former shift workers. These findings are confirmed by the data of Thiis-Evensen (1958).

Other Diseases. As far as other illnesses are concerned, a significant hyper-morbidity caused by shift work would seem unlikely. So far, investigations of cardiovascular diseases, neurological disturbances and psychiatric illnesses have been made, and, as a new assembly of the facts by Harrington (1978) shows, no effects of shift work can be demonstrated in these aspects of health.

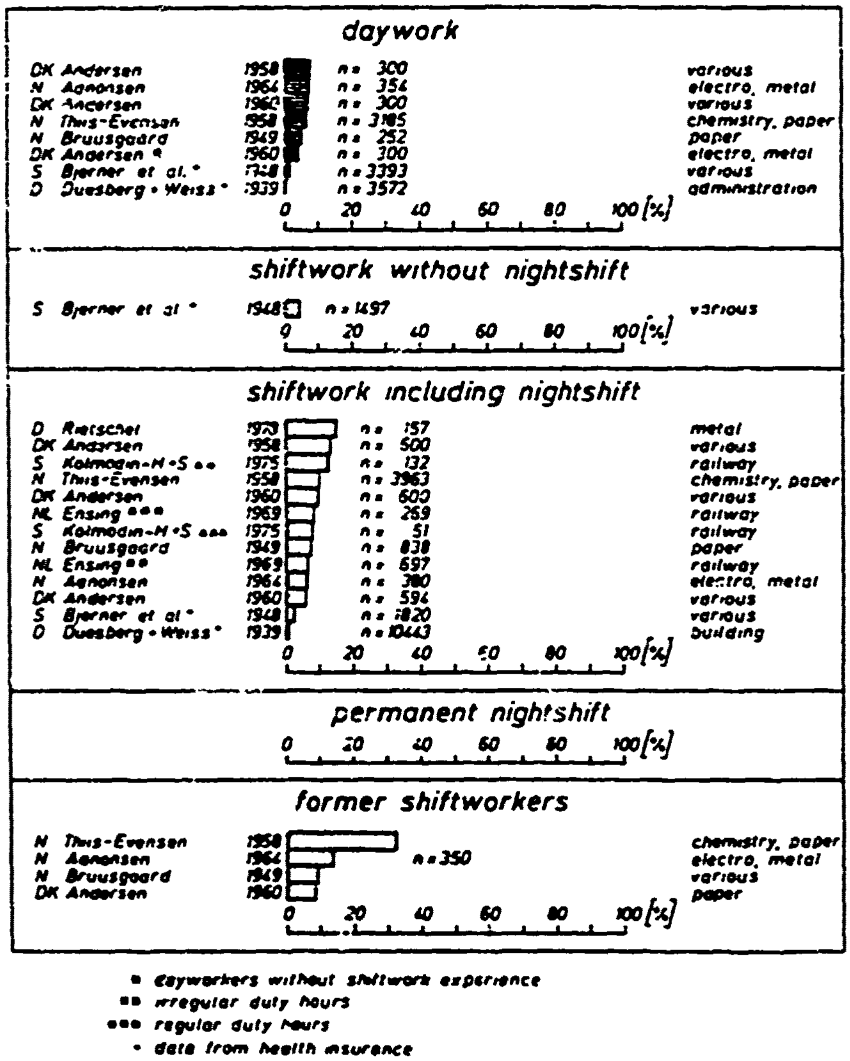


Figure 15. Frequency of gastric and duodenal ulcers related to type of shift system.

Open Questions

The question of whether health is damaged by shift work has not, as yet, been satisfactorily answered. The discussions have concentrated so far on gastrointestinal diseases; the possibility that shift work has a co-responsibility for other illnesses is considered by only a few authors (for instance Carpentier & Cazamian, 1977). The investigations published so far reveal the following deficiencies:

- -the diagnosis of diseases is based on very different kinds of facts (questionnaires on subjective health, medical history, x-ray, endoscopy);
- -so far, only cross-sectional studies have been made, very often without control groups.

As regards the latter, since it can be deduced from the investigation that test-groups of shift workers represent self-selected groups, it is clearly very difficult to answer the question by cross-sectional studies. As in epidemiology, retrospective--or better--prospective cohort studies, as well as case-control studies, are necessary.

One of the first studies using one of these techniques in shift work (Angersbach, Knauth, Loskant, Karvonen, Undeutsch, & Rutenfranz, 1980) supports the assertion that health data of shift workers can be evaluated only in relation to time, since it was found that the process of self-selection had not come to an end even after 10 years. The group of workers who for reasons of health had changed from shift work to day work, proved to be of special importance. The true reasons for the withdrawal of shift workers from shift work can only be found by a follow-up of the losses through prospective cohort studies of all workers. Such extremely work-intensive studies are especially necessary today.

Effects on Family and Social Life

Shift work affects, not only the workers themselves, but also their families. Time budget studies in families of shift workers (Knauth, Romahn, Kuhlmann, Klimmer, & Rutenfranz, 1975) have made it clear that the wives of shift workers have to try to keep the family together by altering meal times to fit in with the shift system (Figure 16).

From the investigations of Barhad and Pafnote (1970), Mott, Mann, McLoughlin, and Warwick (1965), Nachreiner and Rutenfranz (1975), and Wedderburn (1967), it can be concluded that shift workers consider the disturbances of their social life to be more serious than the physiological or organizational disturbances. Our studies (Figure 17) show that complaints are voiced relatively more often about disturbances in the wider social sphere than in the immediate family circle (Nachreiner & Rutenfranz, 1975). The importance of psychosocial disturbances as a cause of disease among shift workers has not been dealt with sufficiently.

Effects on Industrial Performance Rhythms

It has been shown many times that there are circadian rhythms in human performance (Colquhoun, 1971; Kleitman, 1963; Rutenfranz & Colquhoun, 1979).

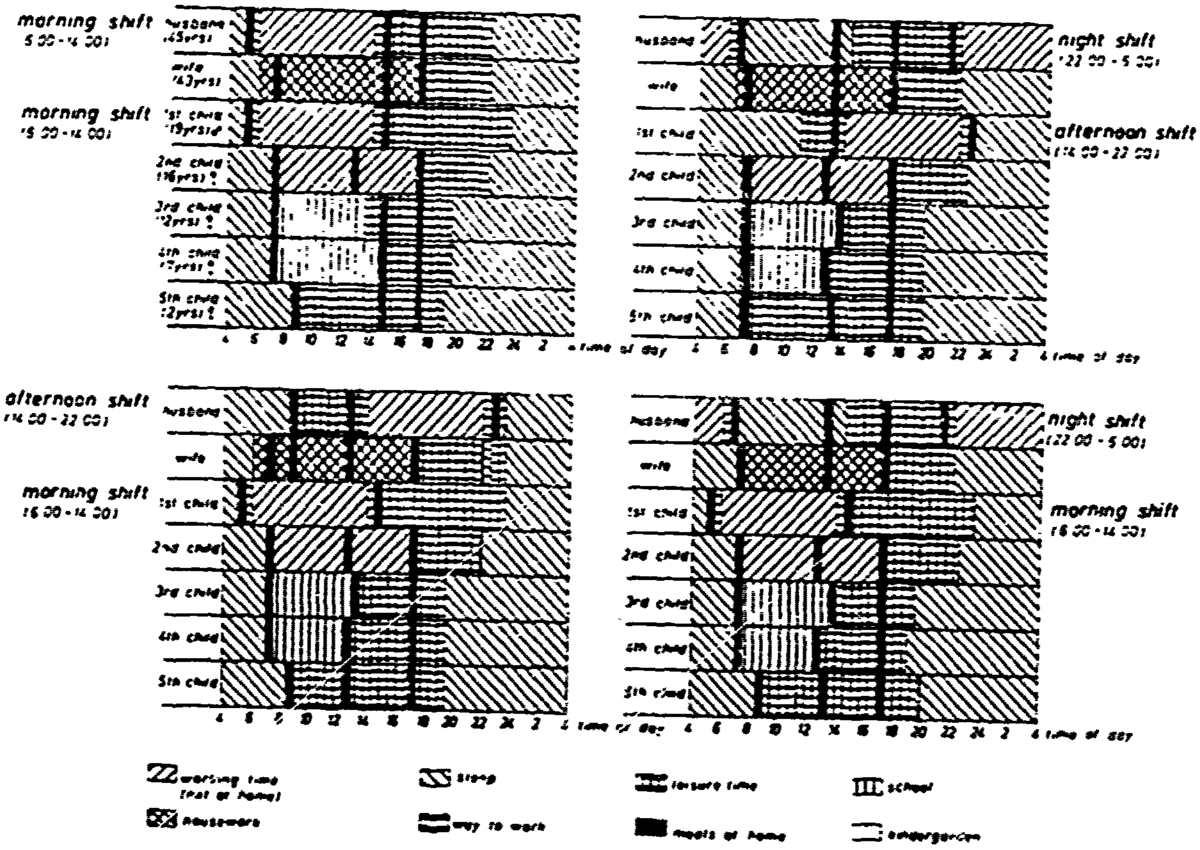


Figure 16. Activities of different members of a shift worker family related to time of day (Knauth et al., 1975).

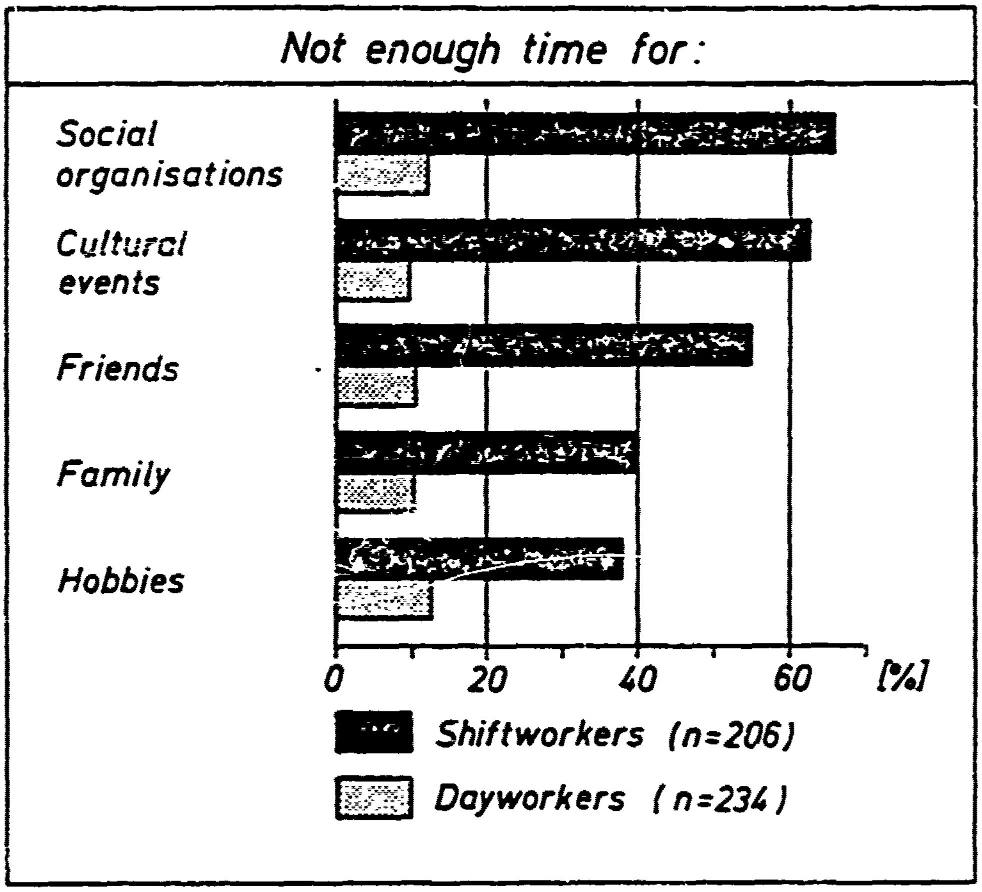


Figure 17. Frequency of reports of "not enough time" for different social activities of day workers and shift workers (Nachreiner & Rutenfranz, 1975).

This means that the same kind of work is carried out at different hours of day at different psychical and physical 'costs', so that "experienced industrial workers unconsciously adopt habits of work which tend to the production of a maximum output with a minimum of effort" (Vernon, 1921). Despite this, very few industrial performance rhythms have been described so far (Bjerner, Holm, & Swensson, 1955; Goldmark & Hopkins, 1920; Graf, 1943; Link, 1933). This is due to the fact that "workers attempt to mask such variations in productivity out of fear of changes in their piecework wages" (Graf, 1943).

Until now, therefore, we do not have a definitive answer to the question whether, during the period of re-entrainment in change-over to a night shift, regular changes in the "basic processes of performance rhythms"—similar to those in physiological processes—occur independently of other factors in the job situation which can affect observed output.

The difficulty of investigating this question lies in the fact that industrial performance rhythms can be masked by the mechanisms referred to, as well as by motivational factors. Understanding of these mechanisms, and of the extent of the physical and psychical cost is, however, very necessary in order to assess the strains to which a shift worker doing night shift is subjected.

Personal and Situational Differences Among Shift Workers

In spite of equal stresses, it is quite apparent that workers react to shift work in very different ways; this fact can only be explained by individual and situational differences. If such differences can be identified and are of importance for adaptation to shift work, it should be possible to use them as criteria for selection.

Health Differences

Because it is an established fact that persons with certain diseases suffer under shift work more than others, the following groups of persons (see Collier, 1943) should be excluded from shift work if possible (Rutenfranz, Colquhoun, Knauth, & Ghata, 1977):

-People with a history of digestive tract disorders. Shift work produces special psychophysiological problems and also involves unusual meal times; both of which may affect gastric functions (Andersen, 1958; Collier, 1943; Dervellee & Lazarini, 1958; Menzel, 1962; Thiis-Evensen, 1958).

-Diabetics and thyrotoxicosics. Regular food intake and correct therapeutic timing can be difficult to maintain under shift work conditions (Cook, 1954);

-Epileptics. Reduction of sleep increases the incidence of fits (Cook, 1954).

The validity of these criteria for selection can be proved only by prospective cohort studies; standard medical examinations before starting work have (according to Taylor, 1968) only limited predictive value for sickness-absence. Loskant and Knauth (1976) have therefore proposed that shift workers should be subjected to another health examination no later than one year after starting shift work, in order to assess their degree of adaptation to it.

Personality Differences

Individual differences in adaptation to shift work have, over the past few years, repeatedly been linked with differences in personality structure. Most of the studies in which this link is alleged take the time needed for the re-entrainment of physiological functions—usually body temperature—as a measure of the capacity to adapt to shift work. Thus, Blake (1971) found "small but significant differences in certain aspects of the mean body temperature rhythms of introverts and extraverts." Later Colquhoun and Folkard (1978) were able to show that "neurotic extraverts exhibited the greatest degree of adjustment" as far as the trend of body temperature during night shift was concerned. Oestberg (1973), on the basis of preferences for, and habits of, activity, made the distinction between "morningness" and "eveningness", and stated that "the morning type of subject had the most pronounced difficulty in adapting to night work." Patkai (1971) found "a significant relationship between morningness and introversion and eveningness and extraversion" so that it is probable that both factors have a common basis. The observations of Folkard (1975) about rhythms of subjective alertness relating to extraversion or introversion must be interpreted in the same sense. Nachreiner (1975) used the personality variables identified in these studies in order to classify attitudes towards shift work among groups of shift workers. He found that "if a shift worker is rather introverted and tends to be emotionally unstable, the probability that he feels uncomfortable with shift work and would like to get out of it is fairly high."

The facts presented here are all based on cross-sectional studies and have not been used, so far, to make any predictions about the capacity to adapt to night work. Folkard, Monk, and Lobban (1979) have recently developed a predictive test of adjustment to shift work which is based on the hypotheses referred to above and Nachreiner (1975) has formulated a test of attitude to shift work using these hypotheses. Validation of these tests, however, will only be possible by projective cohort studies. Such studies still have to be carried out.

Physiological Differences in Adaptability of Circadian Rhythms

Various parameters of circadian rhythms have been discussed as possible physiological yardsticks for the prediction of adaptability to shift work. Breithaupt, Hildebrandt, Dõhre, Josch, Sieber, and Werner (1978) used the circadian phase position and concluded that in evening types (as defined by Oestberg, 1973), the normal maximum and minimum body temperature appear later than in morning types. Evening types also show fewer sleeping problems and better adjustment to shift work than morning types.

Reinberg et al. (1976, 1978) used the circadian rhythm amplitude as a measure of individual capacity to adjust to shift work. They found that a smaller amplitude of body temperature on normal days increased the probability of a quicker adaptation of this circadian rhythm to shift work.

Neither of these measures of the capacity to adapt have been validated so far in prospective studies.

Situational Differences

Living conditions are of special importance for adaptability to shift work. As we (Knauth & Rutenfranz, 1972b; Knauth et al., 1975; Rutenfranz et al., 1974) have shown, approximately 60–80% of shift workers complain of sleep disturbance by noise on the day after the night shift, the most frequent sources of noise mentioned being traffic and children. Both these kinds of noise have been shown to disrupt sleep (Griefahn et al., 1976; Knauth & Rutenfranz, 1972a, 1975; Williams, 1973). It is therefore hardly surprising that people with unfavourable living conditions, especially those with badly insulated bedrooms, near roads carrying a lot of traffic, and with small children in the family, should complain more often about lowering of well-being and about health than people in more favourable living conditions. The value of living conditions as a predictor of good or bad adaptability to night work so far has only been investigated by Angersbach in a retrospective cohort study; prospective cohort studies are also needed here.

A situational factor which has hardly been investigated so far is the family's acceptance of shift work. If night work is not accepted by the members of the family, it cannot be expected that the worker himself can adapt to night work conditions without at least some effect on his well-being.

Chronohygiene of Shift Work

The technological, economic and social reasons for which shift work exists means that it will not be possible to eliminate it. But one can ameliorate the discomforts of shift work by selecting suitable personnel and one can also influence the organization of shift schedules. Over the last few years, more than 500 different shift systems have come to our notice; it is a priori improbable that all of them are equally good. One cannot, therefore, leave the construction of shift schedules to the plants alone. In order to assist them in their task, we (Rutenfranz et al., 1977) have put forth the following points:

> It is impossible to construct one single shift schedule which is optimal for all shift workers and for all working and living conditions. But, based on present knowledge, some criteria can be set for schedule construction.

The following statements are based on results obtained mostly from experimental studies of shift work:

1. Single night shifts are better than consecutive night shifts (a) because a single night shift does not significantly disturb circadian rhythms and (b) because more than seven consecutive night shifts are required for re-entrainment of the rhythms (Colquhoun et al., 1968, 1969; Knauth & Ilmarinen, 1975; Patkai et al., 1975). It could be argued that a sequence of consecutive night shifts longer than seven days would therefore be acceptable. However, for psychosocial reasons, most workers need either to change their shift or to have some rest days after no more than one week, so re-entrainment is not normally possible in practice.
2. At least 24 hours of free time should be allowed after each night shift. Sleep disturbances and reduction of sleeping time are the

most common complaints of shift workers, particularly of night workers. The resultant accumulation of sleep deficit over several days may be a risk factor. Thus, for preventing the harmful effects of sleep deprivation, a substantial recovery period is necessary after each night shift (Graf, 1955; Knauth & Rutenfranz, 1972b; Knauth et al., 1975; Rutenfranz, 1973). A similar problem can arise with the morning shift when the starting time is so early that the worker gets an insufficient amount of sleep the night before; in this case, a 24 hour break after each such shift should be allowed. (Alternatively, of course, it may be possible to delay the starting time of the shift by reorganization of the system.)

3. The length of the shift should be related to the type of work, particularly to the energy expenditure required by it. If the work is light, the length of the shift may (with caution) be extended to 12 hours, but it normally should not exceed 8 hours (or even 6 hours for certain types of work, e.g., work involving particularly heavy physical energy expenditure or a considerable mental load).
4. The cycle of a shift system should not be too long (4 weeks, for example, is better than 40 weeks). It is also better to have a regular system of rotation than an irregular one. Short cycles and regular systems make it easier for the worker and his family to plan their social life.
5. In case of continuous shift work, it is important to arrange as many free weekends as possible for the worker in order that he can participate at these times in the normal social life of his friends who do not do shift work.

Knauth et al. (1979) have recently proposed a systematic methodology for evaluating shift systems in relation to these criteria.

A final problem is the question of 'compensation for working unsocial hours'. Until now, night work has been almost universally rewarded only with money. Thierry et al. (1975) were the first to point out that this mechanism of compensation is no longer adequate for industrialized countries of Europe, since the shift workers there have begun to realize that sleep, and social contacts, cannot be bought with money. It must be seen as one of the tasks of psychosocial research to develop and to test alternative compensation mechanisms. Since social synchronizers are of particular importance for adjustment to shift work, mechanisms of compensation for the discomfort of shift work, based on psychosocial arguments, without any doubt, must be of special value not only in their own right, but also from the physiological point of view.

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METHODOLOGICAL AND PRACTICAL ISSUES RELATED TO SHIFTWORK RESEARCH

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The literature describing the impact of shiftwork on employee safety and health can best be described as equivocal. Although there is some evidence to suggest that shiftwork may adversely affect individual well-being (e.g., Wyatt & Marriott, 1953; Thiis-Evensen, 1958; Dirken, 1966), equally compelling evidence suggests that it does not (Harrington, 1978; Taylor & Pocock, 1972). The confusion in this field was recently noted by Murphy (1979) who, in a letter to the editor of the Journal of Occupational Medicine, cited two contemporary reviews of the shiftwork literature that reached quite opposite conclusions regarding the optimal scheduling of work shifts: one set of authors recommending that shifts be fixed or at least rotated gradually (Winget, Hughes, & LaDou, 1978), the other set of authors advocating rapid shift rotation to ensure that the individual does not work two consecutive nights (Rutenfranz, Colquhoun, Knauth, & Ghata, 1977).

To a large extent, the controversy pervading the shiftwork literature can be attributed to certain methodological limitations in field investigations which greatly restrict the generalizability and reliability of the data. This is not so much an indictment of earlier researchers, as it is an accurate reflection of the difficulties involved in conducting well-controlled field studies of shiftwork. Experimental or statistical control presupposes that the area of investigation is sufficiently defined to permit an identification of the relevant variables. Although this may not have been true for earlier studies of shiftwork, the field has now matured to the point that we can begin to apply some degree of structure to the design and interpretation of research efforts.

The purpose of the present paper is to suggest some methodological considerations for the evaluation and implementation of cross-sectional shiftwork research. Although many of the points to be discussed reflect current trends and practices in shift management in the United States, they hopefully will have relevance to other cultures as well.

In 1975, the National Institute for Occupational Safety and Health, in conjunction with the Stanford Research Institute, initiated a three-phase study of the health consequences of shiftwork. The first phase was aimed at identifying the nature, frequency, and distribution of shiftwork practices among the major U.S. industries (Tasto & Colligan, 1977). Phases 2 and 3 involved a record and questionnaire survey, respectively, of samples of shiftworkers from "high risk" industries (as identified in Phase 1) to determine the effects of the more prevalent shifts on select measures of individual physical, psychological, and social adjustment (Tasto, Colligan, Skjei, & Polly, 1978).

The approach to Phase 1 was relatively straightforward. The Department of Labor, members of national trade associations, and the major labor unions were contacted to ascertain the types of shifts employed in the major U.S. industries and the number of workers on each shift. The goal was to establish a shiftwork taxonomy that could then be used to set directions for future research. The result was extremely disappointing. In general, neither trade organizations or labor unions maintain quantitative data on the type and distribution of shiftwork practices in their industries. Even where information was available on shift schedules, it was cumbersome and complex. For example, the International Association of Fire Fighters reported that approximately 150 different types of work schedules were used among members of their organization alone.

More comprehensive data were maintained by the Bureau of Labor Statistics (BLS), Department of Labor, which provided a comprehensive list of the distribution of workers by starting times for the major U.S. industries. For purposes of interpretation, it was decided to define "shiftworker" as any individual who began work at a time other than between 7:00 to 9:00 am. Based on this criterion, approximately 26.8% of American workforce is in some type of shift system. Table 1 presents the number and relative percentage of shiftworkers for the major U.S. manufacturing and service professions for the year 1975.

Although this information can be used as a rough scheme for identifying occupations for future shiftwork research [e.g., based on these findings, we studied nurses and food processors in our own investigation, (Tasto et al., 1978)], it is woefully inadequate for characterizing industries by types and distribution of shift system. For example, no data are available regarding the rotational schemes employed by the various industries, and some industries and occupational categories are subsumed and included under others, making systematic comparisons difficult.

The most obvious conclusion to draw from this effort, is that current data sources describing the use and distribution of specific shift regimes among U.S. industries are skeletal at best. Shift routines appear to vary considerably from industry to industry depending on the nature of work being performed. For example, split shifts are common in certain service industries such as the restaurant and transportation trades, where customer demands vary considerably as a function of time of day. Such shifts are virtually non-existent among those occupations involving work of a more continuous nature (e.g., health care, manufacturing). Even within an industry, however, there may be considerable variation in work routines as a function of local labor-management agreements, geographic characteristics, regional customs, or simply tradition.

A second lesson learned from our efforts was that "shiftworkers" do not easily arrange themselves into "a priori categories". For purposes of interpretation, we arbitrarily defined a shiftworker as anyone who began work other than from 7:00 to 9:00 am; but there is nothing absolute or immutable about this classification and other researchers may have preferred a more liberal or conservative criterion. Further complicating the issue is the recent trend toward flexitime in U.S. industry whereby the worker has some degree of flexibility in terms of starting and stopping times provided that he or she is present during certain mandatory core hours each day. Are these individuals "shiftworkers" or should they be viewed as an inconsequential variant of the permanent day work population?

Table 1

Manufacturing and Service Industries

Grouping	Number (1,000s)	Shift Workers (percent)
Hospital	1,117	36.9%
Education	1,115	17.0
Other transportation services	763	39.6
Food and kindred products	593	42.7
Health	572	29.9
Private household	507	40.7
Transportation equipment	498	29.9
Primary metal industries	402	37.5
Machinery except electrical	363	18.9
Printing and publishing	327	28.5
Electrical equipment and supplies	278	14.8
Postal	277	45.8
Fabricated metal products	261	23.6
Other professional services	246	17.3
Welfare	221	21.8
Textile mill products	216	34.4
Chemical and allied products	199	19.7
Railroad and railway express service	177	32.6
Paper and allied products	176	32.4
Rubber and plastic products	174	35.0
Stone, clay, and glass products	154	28.5
Lumber and wood products	130	25.4
Instruments and related products	56	12.9
Apparel and other textile products	54	5.2
Miscellaneous durable industries	49	12.0
Petroleum and coal products	42	17.7
Furniture and fixtures	33	7.7
Ordnance	29	15.1
Tobacco	20	32.8
Leather and leather products	17	7.3

Sources: Current Population Survey, BLS, May 1975; SRI

The point is that "shiftwork" has no universally understood referent. There are a wide variety of work routines and rotation schedules, each of which may produce unique effects on some dimension of human performance and adjustment. For purposes of communication, generalizability, and replicability, it becomes mandatory that researchers operationally define "shiftwork" as that term applies to their particular investigation. Unfortunately, this has not always been the case in previous reports, and the resulting ambiguity may account for at least some of the confusion in the shiftwork literature. Rutenfranz et al. (1977) have recently proposed a nomenclature for describing various types of shift regimes, and this system is quite useful. For purposes of data presentation, however, it would be helpful if shift starting and stopping times were reported along with information about the direction and frequency of rotation. This would greatly facilitate the communication and generalizability of these findings.

A more subtle consideration in the investigation of work regimes involves not only the hours of work but also the days of the week that the work system entails. Shiftwork, in addition to the strains created by working at irregular hours, frequently requires that the individual work on weekends. This creates a new set of problems that must be treated separately from those created by shiftwork per se. As noted by Brown (1975), the weekend remains the primary period for social synchrony. Family, social, and cultural activities are structured around the weekends, as these are the times when the majority of the individuals in our society are free of conflicting role responsibilities. Shiftworkers who are also weekend workers are therefore likely to find that the strain experienced from disrupted circadian physiological rhythms during the week is compounded by feelings of social isolation arising from having to work through the weekend. Chadwick-Jones (1969) studied a group of Welsh steel workers who had moved from a 6-hour, 5 day a week schedule to a continential shift system (Rutenfranz et al., 1977) involving rapid rotation and weekend working. He found that the conversion to weekend working was as aversive to the workers as were the variable working hours. This suggests that investigations of shiftwork in addition to detailing the specific hours of work and sequence of rotation, should examine worker satisfaction with the scheduling of off days. This becomes especially relevant in terms of shift management where workers may opt for a shift that is compatible with social and family customs, but particularly disruptive in terms of individual physical functioning. Future investigations should treat the time of work and days of work as orthogonal components, particularly when examining the effects of shift schedule on social and psychological adjustment.

Given the ambiguities in the conceptualization of the independent variable in the shiftwork literature, it should come as no surprise that the dependent variables have been equally elusive. Studies investigating the effects of shiftwork on worker safety and health reveal a wide variety of approaches. Absenteeism records (e.g., Taylor, 1967; De La Mare & Walker, 1965), self-report health inventories (e.g., Dirken, 1966; Tasto et al., 1978), company medical records (e.g., Wyatt & Marriott, 1953; Taylor, 1967), physical examination and physiological monitoring (e.g., Aanonsen, 1959; Froberg, Karlsson, & Levi, 1978), interviews (e.g., Wyatt & Marriott, 1953; Thiis-Evensen, 1958), accidents (e.g., Tasto et al., 1977), and mortality (Taylor & Pocock, 1972) have been used as data sources to evaluate worker well-being. Given these diverse and disparate measures, it is not surprising that conclusions about the "health" consequences of shiftwork are far from consisent. There is no a priori reason to assume that these measures are equally valid indices of employee health, or that they will be equally sensitive to inversions of the sleep/work cycle. Absenteeism, for example, may be as much a function of worker motivation and competing recreational and leisure opportunities as it is a function of health. Company medical records vary considerably in detail, completeness, and compensable coverage. Self-report health inventories, although perhaps sensitive to transient physical complaints, are rather obtrusive and subject to response bias. Biomedical monitoring is costly and time-consuming if one is conducting an incidence study and may prove inconclusive if one is merely monitoring variations in select physiological processes. The point is perhaps an obvious one, but it has been overlooked in many of the cursory reviews of the literature: these different measures of "health" are not interchangeable and are perhaps providing different kinds of information about the effects of shift work. Future investigators might consider obtaining multiple measures of health. The resulting data base would provide information not only about the independent relationships of the various measures to shiftwork but also would shed some light on the interrelationships among the health measures themselves. From this inductive process, researchers could then begin to identify reliable dependent measures for future investigation.

In addition to the need for greater specificity in the definition of the independent and dependent variables, field researchers must become more concerned about the potential influence of conditioning variables in examining the relationship between shiftwork and health. Shift assignment is rarely random, and a variety of factors such as age, seniority, job classification, and employment history which might be expected to covary with shift may exert independent effects on worker health. These covariates, while not easily amenable to experimental control in the typical field investigation, can be controlled statistically using a multivariate design. Demographic information describing the shift populations under study is usually available from site records or from the workers themselves, in the case of questionnaire surveys. A more subtle source of variance across shifts involves ergonomic, organizational, and environmental conditions that might differ drastically in the work setting as a function of time of day. Shift differences in the nature and demands of the work being performed, the psychosocial and organizational climate (e.g., supervisor/employee ratio, production pressures), and the physical characteristics (e.g., noise and chemical exposure levels) of the work setting may be considerable, yet these factors are rarely discussed in research reports of the health consequences of shiftwork. In addition to generating novel hypotheses for future research, the inclusion of this type of information in study descriptions might help to resolve some of the inconsistencies in the current literature regarding the impact of shiftwork on worker well-being.

The selective accretion of workers as a function of shift is another potential source of bias warranting closer scrutiny by shiftwork researchers. Mott et al. (1965), contrary to their expectations, found a higher incidence of self-reported ulcers among day and afternoon shift workers than among workers on nights and rotating shifts. The investigators attributed this to a crossover effect, suggesting that the day and afternoon shift workers reporting ulcers may have developed them during prior experience with night or rotating shifts. Support for this position is provided by Aanonsen (1959) who found a significantly greater incidence of a variety of health problems (e.g., neurosis, peptic ulcer, alimentary tract disorders) among day workers with previous experience on other shifts as compared to day workers with no prior shift experience. By obtaining information about the individual's shift history and illness onset, future researchers may be able to shed some light on the extent and magnitude of the crossover effect on cross-sectional research designs.

Workers not only transfer from one shift regime to another, but they also occasionally leave the work setting entirely. When conducting a retrospective record study of the effects of shiftwork on worker-being, it would be important to report whether or not these terminated individuals were included in the record system used. A study by Fox and Collier (1976) of workers exposed to polyvinyl chloride indicated that those who terminated their employment had a standardized mortality rate 50% higher than those who remained in the industry, when their health status was evluated 15 years after termination.

In terms of shiftwork research, this suggests that a high absenteeism rate among short-term employees might be more a function of pre-existing health status than shift assignment. If new employees tend to be differentially assigned to a particular shift, the strains of adapting to a new job may mask or distort the health effects of their shift scheduling.

Finally, recent trends in the composition of the U.S. labor pool necessitate a reexamination of the shiftwork issue. The steadily expanding numbers of women entering the workforce, and presumably who are working shifts, points out a major deficiency in the shiftwork literature. There is virtually no information about the effects of shiftwork on female workers. A corollary consequence of the influx of women into the labor force is the potential this poses for shift conflicts among spouses. Individual working men and women are likely to find that they must not only adapt to their own work schedules but to that of their spouses as well. The impact of shiftwork on individual adjustment and domestic stability in families having multiple shiftworkers has yet to be established.

In conclusion, I would only like to say that the present discussion was not meant to be exhaustive or comprehensive in its treatment of current issues regarding shiftwork research. It was merely intended to suggest some areas for future consideration in the design and conduct of such investigations. It is hoped that a consequence of the present conference will be a greater understanding, appreciation, and hopefully, resolution, of some of the methodological pitfalls involved in field investigations of the health consequences of shiftwork.

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RESEARCH MOTIVES AND METHODS IN FIELD APPROACHES TO SHIFT WORK

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There is an increasing dependence of industrial activities upon night and shift work. Shift work is obviously one of the most demanding work schedules and the focus of field investigations has been on the potential deterioration of work capacity and health of the workers (Colquhoun, Folkard, Knauth, & Rutenfranz, 1975; Rutenfranz, Knauth, & Colquhoun, 1976; Rutenfranz, Colquhoun, Knauth, & Ghata, 1977; Kogi, 1962, 1971; Winget, Hughes, & LaDou, 1978). Most of these field studies have been undertaken with a view to minimizing the deteriorating effects of phase shifting in the work-sleep cycles, usually making use of a set of practicable methods (van Loon, 1963; Wedderburn, 1967; Mori, Kato, & Sudo, 1974; Colquhoun et al., 1975; Kogi, Takahashi, & Onishi, 1975; Koller, Kundi, & Cervinka, 1978; Åkerstedt & Torsvall, 1978; Reinberg, Vieux, Ghata, Chaumont, & Laporte, 1978; Matsumoto, Sasagawa, & Kawamori, 1978). The diversity of field research strategies, however, has really been remarkable, particularly in terms of the parameters selected for study and the methods for measuring such parameters.

It may be argued that the diversity of methods and parameters reflects the complexity of the changes in the biological circadian rhythm, the implications of these changes for safety and health, and divergent opinions about the relative importance of the various components of circadian periodicity. On the other hand, shift work is also a social form of human activity. Many field studies of it are, as a matter of fact, based on more or less common expectations, which in turn are closely associated with current social concerns about shift work. At least, it seems that the understanding of research results is dependent on a combination of interests in both biological and social variables (Wedderburn, 1967; Taylor, Popock, & Sergean, 1972; Kogi, 1971,1977; Rutenfranz et al., 1977; Carpentier & Wisner, 1976). The trends, if any, in current field research methodology regarding shift work reflect the fact that shift work potentially affects the social as well as biological functioning of the worker, and that to a large extent, the nature of the problem dictates the types of research strategies available to the investigator.

Diversity of Shift Systems

A recent report by the Shift Work Committee of the Japan Association of Industrial Health (1979) revealed that distribution of shift workers varied greatly between different industries and between different enterprises, though some changes in practice had been noted since similar previous studies (Kogi, 1962, 1971). Of a total of 743,000 workers working in 1426 undertakings surveyed 23.3% were engaged in shift work. A breakdown of the ratio of shift workers to the total workforce by industry showed that the ratio was 70% in mining, 23% in manufacturing, 36% in electricity and gas supplies, and 36% in hospitals, while it was only less than 4% in finance. Of the shift workers surveyed, those in the non-night systems (mainly in the form of day and afternoon systems) accounted for 2.0%, those in the night-including two-shift systems (day or afternoon and night) which are known as day-night systems 6.8%

(including both full and part-time types), three-shift systems 13.6% (non-weekend-work type 4.0% and continuous type 9.6%), and other systems 0.9% (mostly in alternate-day systems). As shown in Table 1, the distribution of shift workers differed much between industries.

Table 1

Percentage of Workers Employed in Various Shift Systems by Industry, by Age and by Night Shift Frequency

Subgroups	Double day systems	Day-night systems	Three-shift systems 3-team	4-team	Others	Other shift systems
(Night work)	-	+	+	+	+	-,+
(Weekend work)	-	-	-,+	+	-,+	-,+
By industry						
Mining	0.4	4.7	51.6	3.7	0.1	0.1
Manufacturing	2.2	7.2	3.1	8.7	0.5	1.0
Power supply	0.1	2.5	---	30.5	3.3	---
Finance	0.3	2.4	0.6	---	---	0.3
Hospital	0.5	0.9	---	---	33.0	1.7
By size of enterprise						
Manufacturing 1000~	2.2	8.4	3.4	10.7	0.5	0.9
~999	2.3	3.7	2.2	3.0	0.2	1.3
By age						
Male, 34 or less	47.9	60.2	38.5	47.5	58.4	53.9
Female, 34 or less	93.2	---	---	---	65.4	---
By night shift frequency						
6 or less/months	---	24.7	21.9	28.2	64.3	29.4
7-10 months	---	13.7	57.5	60.7	12.9	43.6
11 or more	---	29.3	6.3	2.2	1.3	17.0

(Results of a survey by the Shift Work Committee of the Japan Association of Industrial Health, 1978).

The non-night-work systems, usually in the form of non-weekend-work double dayshift systems, were found in manufacturing, particularly in textile, food products, and transport machinery and equipment industries, but also included other manufacturing industries such as chemical, electrical machinery and equipment, iron and steel, and others. The night-including two-shift systems were seen in various industries, indicating that these systems are widely employed, second in frequency only to the three-shift systems. But in finance the two-shift systems were the most frequently reported type of shift work. Also noteworthy was the variability of three-shift systems by industry, which are most common in mining, manufacturing and power supply plants. Most of the 3-team 3-shfit systems were of the non-weekend-work type, and only in a small portion in manufacturing, of the continuous type. The continuous 4-team 3-shift systems, on the other hand, were more popular in manufacturing and power supply plants. It should be noted that the 4-team 3-shift systems have become widely used in Japan only since the late 1960's (Kogi, 1971). The other more irregular types of 3-shift systems were found in a small percentage in manufacturing and public service sections, such as hospitals. Alternate-day systems and 'other' shift systems were found in all trades, but were most common among gate-keepers, guards, and power source maintenance workers.

Table 1 also shows that the variability of shift systems is related to workforce variables, such as enterprise size, age and sex of workers. Current practice seems basically unchanged from previous reports, though relatively more elderly people are now engaged in shift systems (Kogi, 1971). In the manufacturing industries, all types of shift systems were found in both large-sized, medium, and small-sized enterprises, but the day-night systems and the 4-team 3-shift systems were more prevalent in larger enterprises. Notable was the similar rates of non-night-working shift workers for both large, medium, and small undertakings. The relative frequency of non-night systems was largest in small-sized enterprises with less than 300 workers. Further, a clear tendency was found for the double-day systems to be used in industries employing young female workers. In the case of males, the day-night systems were most frequently worked by those under age 35.

The frequency of night shifts per month varied with shift system type, as shown at the bottom of Table 1. The day-night systems had a higher percentage of workers working 11 or more night shifts per month, whereas 7-10 or less night shifts per month were more usual among three-shift workers and a substantial portion of workers working 6 or less night shifts per month are found in all of these types.

A more explicit picture pointing to the diversity of shift systems is shown in Table 2, which gives the numbers of different shift systems by industry. Of the 1426 enterprises studied, 716 of them adopted 1235 shift systems. As the table shows, in the mining and manufacturing industries all of the major forms of shift systems were found. There were sharp differences in the distribution of the kinds of shift systems between different industries. The non-night-including shift systems, indicated as double dayshift systems in the table, were found in the textile and food products industries and in many branches of manufacturing and in finance. The night-including shift systems, mostly in the form of day-night 2-shift systems without weekend work, were found in mining, finance and all manufacturing branches. Of the 185 cases of semi-continuous systems without weekend work in full-day operation, normal practice was weekly rotated 3-team 3-shift systems, though 2-shift systems accounted for 32 cases.

Table 2

Number of Shift Systems Adopted by Different Industries in 1426 Undertakings Surveyed by the Shift Work Committee of the Japan Association of Industrial Health (1978)

Shift System	Mining	Manu-facturing	Power supply	Finance	Hospital	Total
(No. of undertakings studied)	43	1275	24	62	22	1426
(No. of undertakings having shift systems)	31	620	24	20	21	716
Double dayshift system	3	106	1	9	1	120
Day-night shift system	17	241	-	21	-	279
Semi-continuous system						
2-shift system	1	30	-	1	-	32
3-shift system	16	131	-	1	-	148
Others	-	5	-	-	-	5
Continuous system						
2-shift system	3	63	13	1	4	84
3-team 3-shift system	4	35	-	-	-	39
4-team 3-shift system	7	147	23	-	-	177
Other 3-shift system	7	33	2	-	20	62
Alternate-day systems	1	177	-	-	2	180
Other shift systems	1	100	-	4	4	109
Total	60	1068	39	37	31	1235

The continuous full-day systems amounted to 362 cases, which were composed of 84 2-shift systems, 39 3-team 3-shift systems, 177 4-team 3-shift systems, and 62 other 3-shift systems. Characteristic were 3- or 4-team 2-shift systems seen in petroleum products and chemical industries as well as in electric and gas supplies. The 4-team 3-shift systems were prominent in continuous operation industries including chemical, paper-pulp, iron and steel, and others. Alternate-day systems and 'other' systems were observed widely in all trades. Only 3 cases of the permanent night shift type were included in the latter.

The distributions by shift system type of the number of consecutive night shifts and the length of portal-to-portal hours for a normal night shift are given in Table 3. In the case of day-night systems and semi-continuous systems, those with consecutive 5 night duties and those with consecutive 6 night duties were approximately equal, indicating a tendency towards the 5-day week system. A few, mostly with weekend work, were of 4 or shorter sequence of night duties. In contrast, the continuous systems were characterized by a large difference in the number of consecutive days of night work between different types. Typical were 1 or 2 days for 3-team 2-shift systems, 1 day for 4-team 2-shift systems, 3-7 days for 3-team 3-shift systems, and 2-6 days for 4-team 3-shift systems. In the case of 4-team 3-shift systems, four main divisions were 2, 3, 4, and 5 consecutive days, having sharp differences in their distribution between trades.

Table 3

Number of Different Shift Systems by Number of Maximum Consecutive Night Shifts in a Rotation Cycle and by Length of a Night Shift

Shift System	No. of consecutive night shifts							Length of a night shift (portal-to-portal hours)				
	1	2	3	4	5	6	7	8.9	9 10.9	11 12.9	13 23.9	24
Day-night shift system	6	13	8	7	116	111	3	195	57	10	4	-
Semi-continuous system												
2-shift system	6	1	-	-	12	12	-	6	1	11	8	-
3-shift system	1	1	5	-	49	89	1	94	45	3	1	-
Others	-	-	-	1	2	-	-	-	1	1	1	-
Continuous system												
2-shift system	27	14	10	2	1	5	7	4	2	34	31	-
3-team 3-shift	1	1	7	3	11	6	7	23	12	1	-	-
4-team 3-shift	4	36	56	33	41	5	1	91	77	5	-	-
Other 3-shift	8	15	7	3	8	5	3	29	23	5	2	-
Alternate-day systems	168	-	-	-	-	-	-	-	1	-	4	122
Other shift systems	32	6	5	2	-	2	1	1	3	2	23	20

(Results by the Shift Work Committee of the Japan Association of Industrial Health, 1978).

The portal-to-portal hours of night work were also very variable and a night shift of more than 9 hours in a 3-shift system or a night shift of more than 13 hours in a 3-shift system were uncommon.

The observed diversity of shift systems may in part be determined by technical reasons (such as necessity of continuous production or social service) but it also seems to be determined more essentially by socioeconomic conditions including labour customs, social habits, and traditions. The lack of labour standards for shift work schedules, except for labour standards law regulating night working hours for minors and females, as well as specifying extra payment for midnight hours, accounts for this variability. Nevertheless, the variabilities of shift systems doubtlessly represents the influence of common social concerns about the physiological, psychological and social life implications of working in such systems. The presence of so many kinds of shift rotation with respect to night work, weekend work, number of teams, night shift frequency, night shift length, number of straight night shifts, conditions of rest and freetime activities, is by itself evidence of the significance of these factors in selecting a shift system.

Areas of Shift Work Research

As indicated by the extent of the variability in shift work schedules, subsequent research strategies and methodologies are really diversified. It is guided by various implications the shift systems have for work performance, health, and daily life. It seems suitable that most field studies on shift work pay attention to the multiple consequences of shift working. Attention should also be paid to the structure of all of these research variables.

Consequences of Shift Working as Problems

The major problem areas of shift work have been reviewed in many previous papers. There seems to be a general concensus as to what areas should be taken into consideration. These areas range from effects on work performance, safety, health risks, physiological re-entrainment, insufficient sleep, family and social life, and professional relationships (Akerstedt & Torsvall, 1978; Colligan, Smith, Hurrell, & Tasto, 1979; Kogi, 1971, 1977; Koller et al., 1978; Matsumoto et al., 1978; Reinberg et al., 1978; Rutenfranz et al., 1976, 1977; Taylor et al., 1972; Wedderburn, 1967; Winget et al., 1978). The methods applied and questions posed by field researchers, however, may vary greatly according to the research design as well as between countries. At the same time, it is reasonably assumed that selection of methods is being guided by actual consequences of shift work. The meaning of those specifically selected methods or specifically posed questions becomes understandable when their relation to the whole 'shiftworker problem' is made clear, the structure of the problem areas being similar to any shift working situations. Thus, what matters is not the similarity or uniqueness of methods, but rather the place of questions in and the relation of methods to the whole structure of problem areas.

In this respect, the general aspects of the problems confronting shiftworkers seem universal for worker groups engaged in different kinds of shift systems, the relative importance of each problem being naturally different when the situations differ. This may be confirmed by many previous reports mentioned above as well as by the results of another survey on day and shift workers conducted by the Shift Work Committee (1979) of my country. Some examples for male workers are given in Figure 1.

This survey was carried out using a health questionnaire form with the purpose of studying the effects of different types of shift work on the health and life of workers. Valid responses were received from 2152 regular daytime workers and 7964 shift workers of which 1837 and 7565 were male, respectively. The respondents were workers of coal mines, food processing, pulp and paper products, publishing and printing, chemical and machinery manufacturing industries, transport and communication, post offices and others. Of the male workers, 1563 were on non-night 2-shift systems, 4749 on 3-shift systems, 219 on night-including 2-shift systems, and 1034 on other shift systems. Figure 1 shows for male day and shift workers the percentages and causes of absence from work due to sickness during the past one year period, the rates of those complaining of subjective symptoms, and rates of those mentioning problems of working life. Only typical results are indicated here.

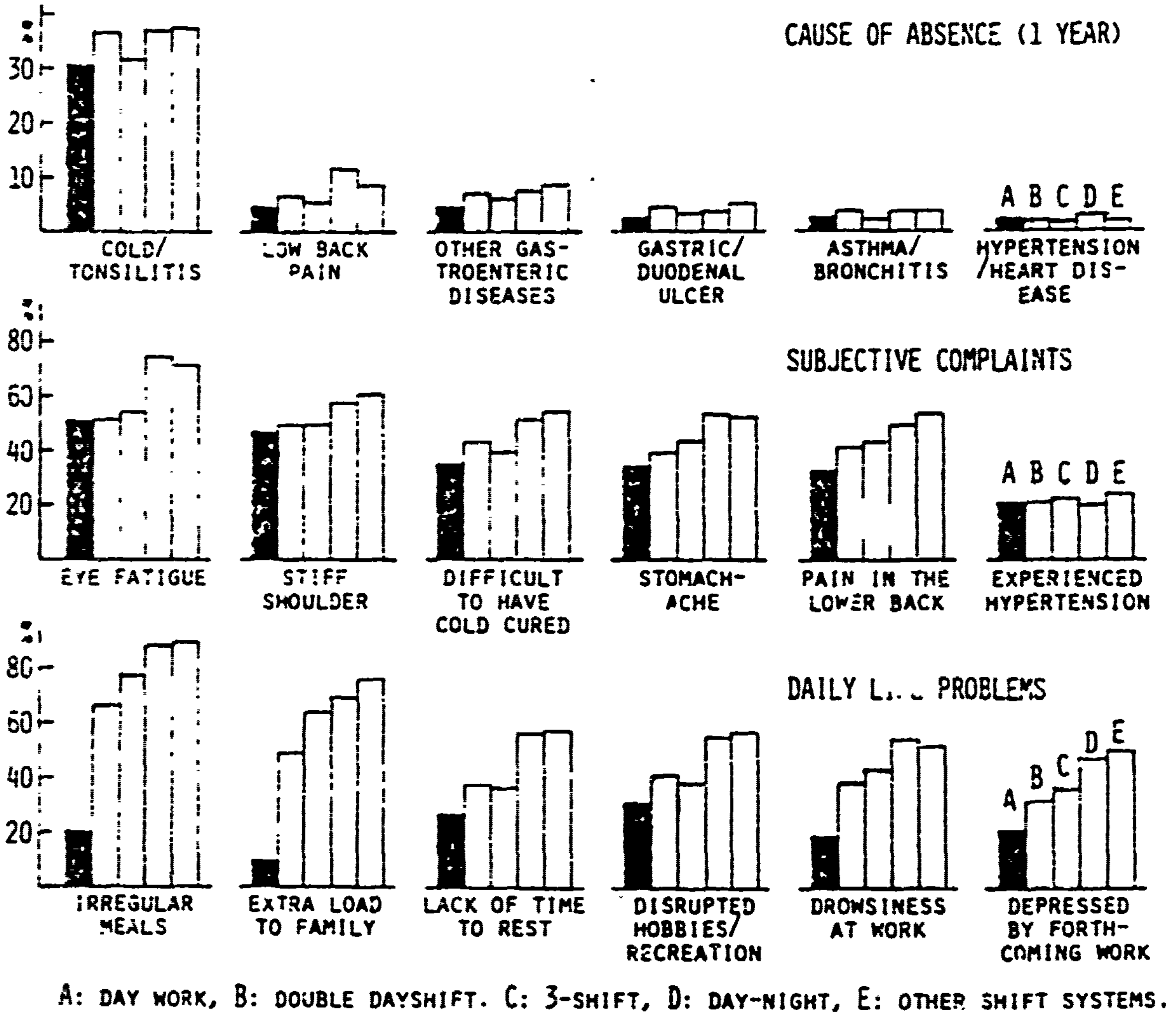

Figure 1. Percentages of causes of absence from work due to sickness during the past one year period, rates of those complaining of subjective symptoms, and rates of those mentioning problems of working life among industrial male day workers and shift workers on different types of shift schedules (results of a health questionnaire survey by the Shift Work Committee of the Japan Association of Industrial Health). [Not significant for 'Hypertension/ Heart Disease' and 'Experienced Hypertension'; significant at the .01 level for 'Asthma/Bronchitis'; the others significant at the .001 level by the Chi Square test.]

Those who were absent from work due to sickness during the one year period constituted 43.2% of male daytime workers, as against 51.9% of double day-shift workers, 45.6% of 3-shift workers, 53.0% of day-night 2-shift workers and 52.8% of other shift workers, indicating higher rates of sickness absenteeism among shift workers. The mean frequency of sickness absence was 0.81, 1.20, 0.88, 1.09, and 1.22, respectively. As causes of absence due to sickness, the descending order of frequency was: colds, gastro-enteric disorders, disorders excepting ulcers, dental problems, low back pain, gastric-duodenal ulcers, and asthma and bronchitis for both men and womem. Colds, gastro-intestinal diseases, low back pain and gastric-duodenal ulcers were especially more frequent among shift workers than among day workers, as opposed to heart diseases or hypertension and some other illnesses which showed no distinct differences between the day and shift worker groups. The rates of subjective complaints related to such illnesses were apparently higher among shift workers than among regular daytime workers, which was also the case for common gastro-enteric complaints such as frequent diarrhea and constipation or common respiratory complaints such as coughs or phlegms as well as for eye fatigue, stiff shoulders and sleeplessness.

As for the effects of shift working on the workers' family and social life, complaints concentrated on the irregularity of life and disturbances of rest and freetime, the rates of such complaints being very high among shift workers, as shown at the bottom of Figure 1. Particularly high rates among shiftworkers were: 'meals become irregular', 'irregular shifts bring extra burden to family members', and such items as 'lack of time to rest', 'disturbed to engage in hobbies or recreational activities', 'embarassed by becoming very drowsy while working' and 'sometimes feel depressed to think of the forthcoming work'. The questionnaire also revealed that the shift workers were concerned about the harmful effects of shift work and that points raised as components of the effects of shift work on daily life were closely correlated with the state of health of the worker.

Major Problem Areas and Current Questions

In view of the fact that shift working gives rise not only to disturbances in daily activity cycles but also produces harmful effects on the health of the workers, the Japanese Shift Work Committee has identified seven major problem areas of shift work. These are shown in the left column of Figure 2 along with suggested ameliorative strategies as proposed by the committee which are presented at the corresponding righthand end.

In the context of the Committee report, which referred to both literature at home and abroad and the results of its own two surveys, the following seven questions may be extracted as those pertaining to the seven problem areas. These questions are added to Figure 2 in connection with the corresponding problem areas.

1) In the area of physiological disorders: To what extent is the phase shifting of circadian physiological rhythm controllable? (What are the limitations and what are the important consequences thereof despite the efforts of improving work schedules to reduce physical and mental disturbances resulting from the phase shifting?)

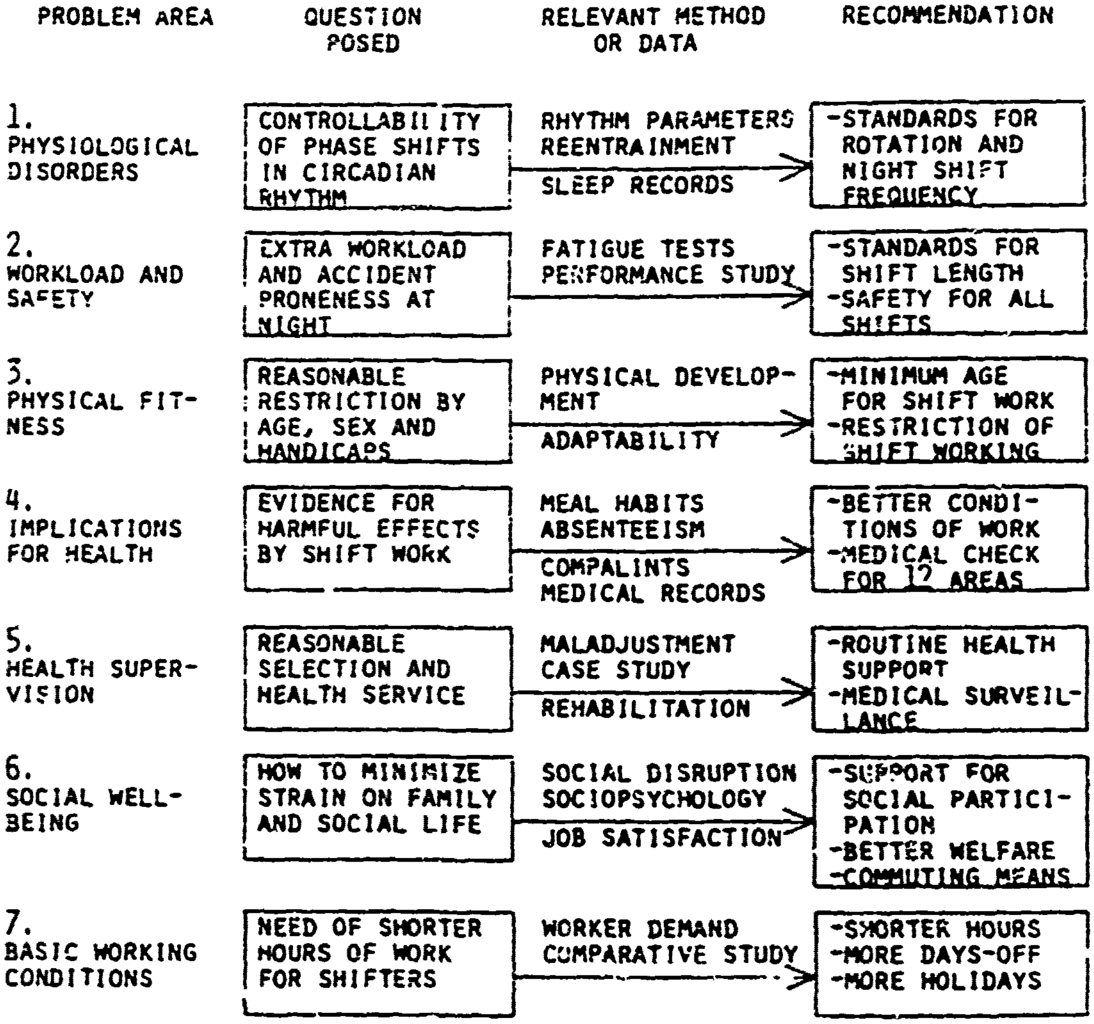

Figure 2. Major problem areas and recommendations by the Shift Work Committee report of the J.A.I.H. and related questions and methods in the author's view. [Differences significant at the .001 level.]

2) In the area of workload and safety: Is the notion significant that the night or early morning shift work imposes on workers an extra workload leading to actual deteriorations of working performance and an enhancing of their accident proneness?

3) In the area of physical fitness to shift work: What kinds of reasonable restrictive measures for shift work are required for very young or aged workers, for maternity protection, or with respect to the handicapped in view of the present level of knowledge on such people and individual differences?

4) In the area of implications for health: What evidence is available concerning harmful effects by shift work on health and what are the implications thereof? (What aspects of health are endangered by shift working and what are the differences in harmful effects, if any, between different shift work schedules?)

5) In the area of health supervision: How must the occupational health services for shift workers be organized to prevent harmful effects and to promote good health, especially with respect to selection, routine health measures, medical checkups, rehabilitation and others?

6) In the area of social wellbeing: How can the strain on family and social life be minimized by organizational efforts? (How serious are the social disruptions of shift workers and what supportive measures for individual workers are useful?)

7) In the area of basic working conditions: What standards of shorter hours of work, days off and holidays for both day and shift work will be helpful in promoting the health and wellbeing of shift workers?

These questions must be answered using factual data collected from shift workers on various shift schedules. The available information is by no means satisfactory. However, some concrete recommendations can be suggested based on the present state of knowledge. And according to reviews by Carpentier and Wisner (1976) and Rutenfranz et al. (1976, 1977) and the Japanese Committee report, recommendations do seem possible for at least two aspects of working conditions, i.e., criteria for schedule construction and provision of health services. Examples of methods usable to attain data for considering such recommendations are illustrated in Figure 2.

As for the establishment of criteria for optimizing the scheduling of shifts, the questions one, three, and six are specifically relevant, though other questions will also have to be taken into account. Accordingly, methods dealing with rhythm parameters and their changes in re-entrainment, fatigue and performance study methods, methods for basic work capacity measurements as well as field methods including questionnaire, records study and interviewing, are all important, application of multiple methods having obviously particular importance. Sleep records, for instance, in accordance with measurements of functional changes during and between night and daytime sleeps and registrations of subjective evaluation of quality sleeps and of various complaints about sleep, are one of the primary materials for considering any of these questions (Morioka, 1969; Matsumoto et al., 1978). Relations of sleeps in different stages of shift rotation with work performance, physiological and psychological changes and accidents are only a small part of the whole picture. Thus, development of improved methods for sleep records, including daily life time budget analysis, subjective rating, autorhythmometry and continuous measurement techniques, are very much required. It is noted there are many reports already available on sleep records.

With respect to health services, where questions four and five are specifically relevant and other questions listed above are also closely related, methods for looking into behavioural and symptomatological changes at the daily life level are of critical importance. Analysis of daily life habits and their variations, absenteeism, complaints, cumulative symptoms, maladjustment, disturbances in rehabilitation, etc. seems essential in addition to medical records analysis and case studies. The effects of repeated exposures to night-work-daytime-sleep schedules and their cumulative effects in terms of chronic fatigue, decrease of resistance to gastro-enteric, respiratory, motor-organ, circulatory or neurogenic diseases, and daily habits changes should be made focuses of future methodological study.

Because the purpose of this paper is to discuss the general features of research methods, details will not be elaborated here. But it may be said that we need methods pointing directly to functional changes in terms of rhythm parameter variations and test results, as well as a series of methods for the study of various complaints, symptoms, malajustment and disruptions of the basic human needs of shift workers are essential. The relation between methods and research objectives will be discussed later.

Again, in the author's view, the seven questions listed above may denote the directions of field research on shift work at present and in the near future. Suggested recommendations and possible standards (Shift Work Committee, 1979; Rutenfranz et al., 1976, 1977; Carpentier and Wisner, 1976) will be effective in reducing the adverse effects of shift work, but more research efforts seem necessary to elucidate the long-term effects of shift work schedules, research motives being oriented towards real-life situations and to the needs of the workers. It is naturally impossible to find a single appropriate set of methods, but a need of applying multiple methods of different categories is felt even when replying to only one of those questions.

National and Regional Features

One important facet of shift work research is that the shift work schedules are more or less subject to national or regional trends, so that social concerns and research motives may be dependent upon such trends. This problem, however, must be placed in the perspective of the 'shiftworker problem' as a whole, as discussed above.

A review of the shift work schedules in developing countries of Asia (Kogi, 1977) has revealed not only a diversity of shift practices, which are quite different between countries as well as between enterprises, but has also revealed a wide range of impacts resulting from these practices. Typical examples of shift work schedules in manufacturing industries of some Asian countries are shown in Table 4.

Table 4

Examples of Typical Shift Rotation Types in Manufacturing Plants in Developing Countries of Asia (Kogi, 1977)

Country	Plant	No. of shifts	No. of teams	No. of straight shifts	Shift time I	Shift time II	Shift time III
Semi-continuous shift systems (without weekend work)							
Indonesia	Textile	2	2	6	6-14	14-22	
		3	3	6	6-14	14-22	22- 6
	Wheatflour	3	3	6	7-15	15-23	23- 7
	Paper	3	3	6	7-14	14-22	22- 7
	Paper and plastics	2	2	5.5	8-16	16-24	
		3	3	5.5	8-16	16-24	24- 8
	Synthetic textile	3	3	6	7-15	15-23	23- 7
	Tobacco	2-3	2-3	5	7-15.30	15.30-24	23- 7
Philippines	Automobile	2	2	1 mo	6-14	14-22	
	Food products	2	2	1 mo	8-17	17-24	
	Rubber	3	3	4 wks	6-14	14-22	22- 6
	Wire and cable	3	3	2-3 mos	6-14	14-22	22- 6
Thailand	Iron	2	2	6	7-15	15-23	
		3	3	6	7-15	15-23	23- 7
Pakistan	Industrial	2	2	6	5-13	13-21	
		3	3	6	7-15	15-23	23- 7
India	Manufacturing	2	2	6	8-17 30	17.30-3	
Bangladesh	Jute	2	2	6	6-11.30 14-16.30	11.30-14 16.30-22	
Continuous shift systems							
Indonesia	Textile	3	4	5	6-14	14-22	22- 6
	Textile	3	4	3	6-14	14-22	22- 6
	Synthetic textile	3	4	2	6-14	14-22	22- 6
	Synthetic textile	3	multiple	5	7-15	15-23	23- 7
Philippines	Textile	3	3	2 wks	6-14	14-22	22- 6
Thailand	Textile	3	3	7	7-15	15-23	23- 7
Pakistan	Industrial	3	3	7	7-15	15-23	23- 7
Sri Lanka	Tyre	3	4	4	6-14	14-22	22- 6
Bangladesh	Cotton	3	3	6	6-10 14-18	10-14 18-22	22- 6

Shift practices and their impacts reflect both past and present practices of shift work in industrialized areas. The basic rotation patterns found are either two-dayshift systems or three-shift systems, the shift length being about 8 hours. The choice of system types depending largely on factors peculiar to each country. The textile industry is an example. Two-shift systems are popular in the textile mills of Japan which exclude midnight hours. Three-team, three-shift systems are commonplace in other countries of Asia such as India, Sri Lanka, Thailand and Philippines, and continuous four-team, three-shift systems are seen in Indonesia which has a 40-hour work week. Another marked difference is found in the length of the period of rotation, or number of consecutive night shifts. Even in the case of semi-continuous two- and three-shift systems where most countries tend to adopt weekly rotation, the shift change in the Philippines takes place at much longer intervals of two weeks, one month, or even longer. In contrast, with continuous systems in Indonesia and some other countries including Japan, there is a tendency to reduce the number of consecutive shifts to less than 5 using four teams for the three-shift systems. Further, modifications of basic patterns are not infrequent in all the countries studied. Weekend work, cycle period, times of shift changes, extension to midnight hours and assignment of days-off and holidays, are some of the modifications observed. A special type of shift system not uncommon in the textile mills of Bangladesh divides the daily working time of a crew into two periods separated by a fairly long break. Especially notable in these countries is the fact that a large number of young female workers are engaged in the continuous three-shift systems.

Many of these 'national' features and modifications are apparently brought about as a result of efforts to alleviate the disruptive effects of shift work (Kogi, 1977). These effects on and the problems of shift workers in developing countries are by and large similar to those experienced by industrialized countries, but considerable differences are observed according to climatic and social conditions in which the new practice is introduced. These conditions appear to be related to the rapid increase of shift schedules in the local economy as a means of utilizing costly equipment and expanding employment (Kabaj, 1968) as well as changing job organization, relative lack of medical and welfare facilities and commuting means, effects of poor allocation of holidays, conflicts arising from religious customs and the attitudes of workers towards shift work. Worker dislike for shift work is clearly relevant to strain of night work, incidence of ailments, inconveniences in social life, as well as to unconcerned supervisors and other socio-psychological factors (Kabaj, 1968; Kogi, 1977). The basic problem areas and types of current questions regarding shift work are compatible with those of Figure 2, though close attention must be paid to social conditions and restrictions by national legislation and custom. Those local circumstances and the specific needs for first-hand information greatly affect the priorities of action-oriented research. This is especially true in countries where the full impact of shift work is not known and the elements of dissatisfaction are often dealt with merely from personnel management viewpoints. It appears important to consider research design with reference to the common structure of the shiftworker problem as well as the specific conditions of industrialization, local legislation and custom.

Field Research Motives and Methods

Selection of a set of methods in field research of shift work is usually based on the question posed by the researcher and its relation to the whole shift work problem structure. The use of methods, on the other hand, is based on the realities of conducting the study (Smith & Colligan, 1979). These realities are in fact very important, since, for example, a study procedure requiring a lengthy period of time would not be acceptable to the enterprise nor to the workers. Likewise, application of research methods must, apart from their validity and reliability, comply with the time, place and opportunity limitations of the working schedules and rest intervals, possibility of repeating measurements or recordings, availability of worker consent and training, cooperation of personnel and others (Gordon, Tepas, Stock, & Walsh, 1979; Walsh, Gordon, Maltese, McGill, & Tepas, 1979). A field research protocol for the study of shiftworkers is thus selected only after painstaking procedures. Also taken into account are the representativeness of the sampled data, the expected variability of critical measures, and the financial considerations (Colligan et al., 1979; Smith & Colligan, 1979). The final set of methods are usually a result of deliberations of the realities and inevitable compromises, but at the same time it reflects the research objectives and background motives in a very realistic way.

An interesting result has been obtained from a recent survey report by the Industrial Fatigue Research Committee (1977) of the Japan Association of Industrial Health (J.A.I.H.) on fatique studies conducted by its members,mostly in the 1970-1976 period. The replies were collected for the purpose of mutually discussing the field study methodologies of fatigue assessment. Excepting laboratory experiments, reports of 85 such studies from 20 research institutions were analyzed. These institutions included 12 university departments, 4 public and private research institutes and 4 industrial medical departments. Of the 85 field studies, 55 dealt with daytime work only and 35 with shift work in various industrial workplaces. Eight institutions dealt only with day work, 6 only with shift work, while 6 other institutions dealt with both kinds of work.

Table 5 gives the primary research objectives of these field studies as provided by the committee members. In the case of day work studies, the emphasis of conducting a fatigue study was on health hazard study or specific problem solving rather than on job load analysis or work schedule evaluation. Themes for most health hazard studies were mainly cause analysis or ergonomic assessment with respect to health hazards resulting from improper working methods or overwork, such as low back pain, neck-shoulder-arm syndromes (occupational cervicobrachial disorder) and circulatory diseases. The aims of specific problem solving studies were diverse and included studies of training effects or drug effects, assessment of anti-heat-stress measures, ergonomic improvement of consoles or visual displays, and others. This rather heavy weight on specific studies in the case of day work studies contrasted with shiftwork studies, which had in 70% of the total 30 cases a primary objective of job load analysis or work schedule evaluation. The difference in emphasis may have resulted from a specific interest in shift work studies on general workload, cumulative effects and need of assessing shift schedules. Moreover, as the number of institutions dealing with respective categories of research objectives in the parentheses of Table 5 shows, each category involves a certain number of research groups, implying the results of the table are reflecting a more general trend in research efforts.

Table 5

Primary Research Objectives of Day or Shift Work Studies Undertaken by Members of the Industrial Fatigue Research Committee of the Japan Association of Industrial Health, Mostly in the Period of 1970-1976

Primary Research Objective	Day Work Study	Shift Work Study
Job load analysis	12 (7)	11 (7)
Work schedule evaluation	5 (4)	10 (6)
Health hazard study	20 (8)	6 (4)
Specific problem solving	18 (8)	3 (3)
Total	55 (14)	30 (12)

(In parentheses are numbers of institutions involved.)

Figure 3 gives percentages of research methods applied in those fatigue studies, separately for 55 day work studies and for 30 shift work studies. The percentage A of the figure shows rates of questionnaire, self-reporting and medical examination methods, percentage B those of continuous data-sampling or recording methods, and percentage C those of functional testing and blood or urine studies. In each of the three portions, there are found certain methods characteristically applied to shift work research in contrast with day work research.

In A, self-reporting of subjective fatigue feelings, primarily using the 30-item Fatigue Scale self-report form by the Industrial Fatigue Research Committee of the J.A.I.H. (Kogi & Saito, 1971; Yoshitake, 1971) was the most popular in both day work and shift work studies, being more predominant in the latter. Similarly, general questionnaire surveys were also common to both shiftwork studies and day work studies. But a very remarkable difference was found in time budget analysis, i.e., study of time spent for daily life activities and sleeps by means of self-reporting. Medical checkups and fatigue-site reporting were of almost equal weight in both groups of research.

In B, motion and time study of working behaviour as well as continuous recording of heartrate, electromyogram, eye movement, etc., were frequently used by both day work and shift work studies, though more frequently in the latter. It is shown that analysis of work in situ and that of physiological changes at work are deemed as important in shiftwork research where such techniques are not easy to implement. Then, contrasting rates are seen in subsidiary behaviour study and oxygen consumption measurement, in the case of shiftwork studies the former being dominant and the latter almost out of consideration. This is perhaps because subsidiary behavioural study is increasingly used in overfatigue studies and because the oxygen consumption measurement is

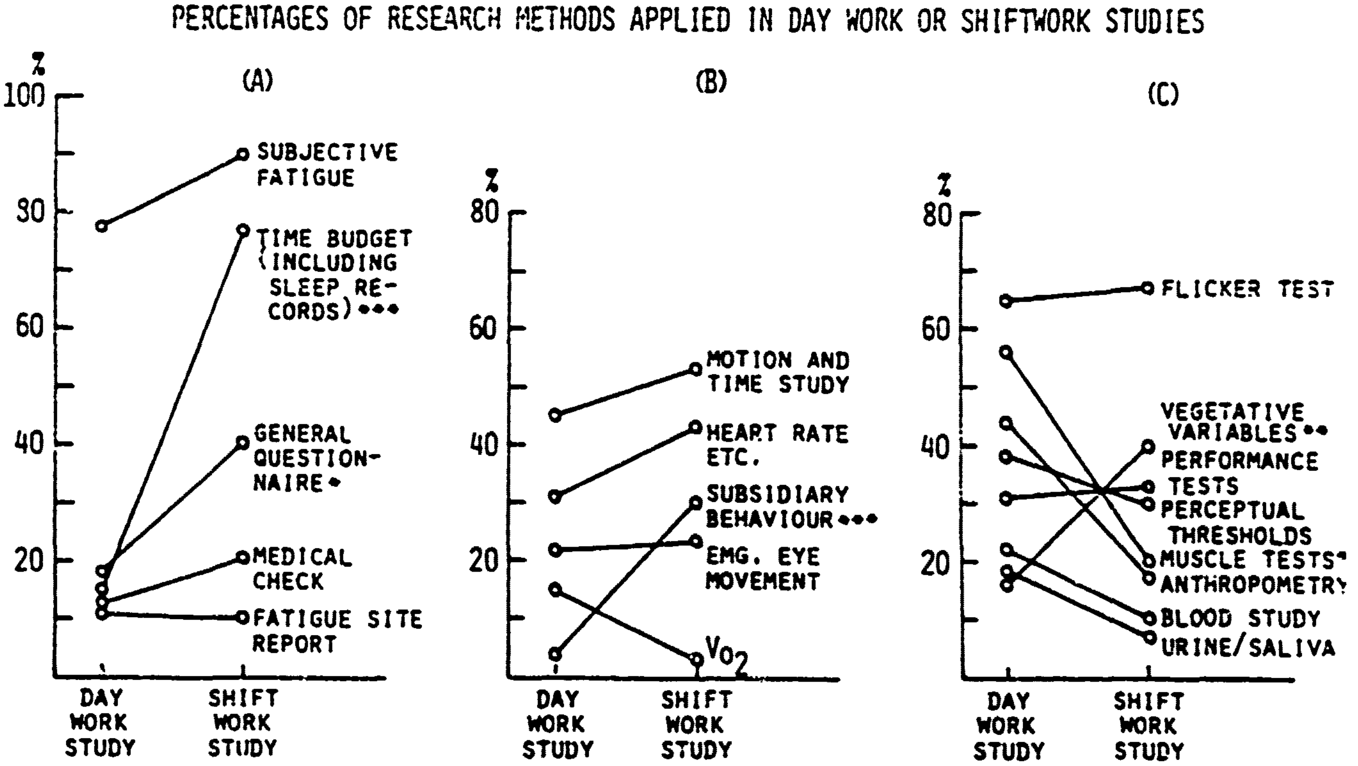

Figure 3. Percentages of research methods applied in field day work and shift work studies conducted by members of the Industrial Fatigue Research Committee of J.A.I.H. mostly during the 1970-1976 period for the purpose of fatigue research. (A) Self-reporting, questionnaire and medical examination methods, (B) Continuous data sampling or recording methods, (C) Functional testing and blood, urine or saliva studies. [* significant at the .05 level; ** significant at the .01 level; *** signigicant at the .001 level.]

usually related to physical load analysis which is seldom a matter of central concern in shiftwork problems.

The results of methods of group C may be interpreted in a similar manner. While muscle tests, which included measurements of muscle forces, tendon reflex thresholds and others, or anthropometric studies were far less popular in shiftwork research than in day work research, the flicker test as a means of activation level study as well as examinations of vegetative variables including blood pressure, body temperature and other autonomic functions were predominant in shiftwork research. Performance tests of various types (such as addition test, aiming tests, tracking performance to choice reaction times or mental capacity measurements) are frequent in both groups. Blood analysis or biochemistry measurements of urine or saliva contents such as electrolytes, mucoprotein, corticosteriods and others were relatively less dominant in shiftwork research. Presumably this is related to the fact that those analyses are more dependent than other tests on laboratory policies. Needless to say, the problem of validity is also important (Colligan et al., 1979; Rutenfranz et al., 1977; Kogi et al., 1971, 1975; Sakamoto & Matsui, 1972).

In summary, the common types of shiftwork research make use of self-reports of subjective fatigue and time budget, motion and time study at work, continuous recording of heartrate and other physiological changes at work, the flicker test and vigilance measures, questionnaire surveys, subsidiary behaviour study and performance tests. Another important method area would be the record study approach (Colligan et al., 1979; Taylor et al., 1972; Walker & de la Mare,1971). Thus, in comparison with day work studies, shift work research may be characterized by more frequent, combined utilization of these methods. The trend in methodologies of field studies of shiftwork is clearly associated with their practicality. Based on the results, the field research methods applicable to a shiftwork study may be classified into the following categories.

a) Self-reporting and questionnaire survey; subjective fatigue, fatigue sites, general questionnaire on working life and health.
b) Time budget analysis and sleep records study.
c) Motion and time study and subsidiary behaviour analysis.
d) Continuous measurement at work of physiological changes; heart rate, autonomic changes, electromyogram, eye movement, electroencephalogram, oxygen consumption, etc.
e) Intermittent application of tests before, during and after work and at rest intervals; anthropometric measurements, muscle tests, perceptual thresholds, activation tests, vegetative variables, blood tests, urine or saliva tests, and others.
f) Specific examination and records analysis; nutritional study, environmental assessment, medical checkups, medical and management records analysis, accident and near-accident records study, etc.

A typical field study of shiftworker problems may use a number of methods from the above categories, though of course, selection of concrete methods and their combinations are determined by research motives and ways of approach, such as comparison of different schedules or study of effects of short sleeps. As discussed earlier, research motives in relation to social concerns on shift work play a vital role in influencing the parameters and measurement strategies selected for study which in turn affect the quality and nature of the subsequent data on which shiftwork decisions are based. Common approaches are to compare the results with certain criteria established earlier or to compare between different schedules. These criteria or comparisons are based on and related to the whole structure of the shiftworker problem. The importance of another approach looking into the human ecology of shiftworkers is thus suggested.

Conclusion

The existing diversity of shift systems and associated means for alleviating worker difficulties were examined to illustrate the extent of physiological, psychological and social life implications of night work and rotational work schedules. The areas of concern regarding shiftwork as indicated by the literature and recent surveys involve the effects of phase shifting, workload and safety, reasonable restriction, harmful effects on health and health service needs as well as strain on family and social life, point to the need of placing the field research methods in the whole structure of the 'shiftworker problem'. This structure, which is suggested to be universal for various shift system types, would constitute baselines for research motives, as guided by current concerns. Shiftworkers are inevitably exposed to these structured disruptions, which offset whatever other merits the shift work organization may have. This leads us to believe that recourse to night work or shift work should be kept to a socially required minimum, and that ways and means of reducing such disruptions must be searched for using field studies in real-life conditions.

Therefore, each field research study should deliberately pay attention to the current questions of shift working which derive from both the problem structure and the local conditions such as legislation, custom and adjustment habits. Since the actual methods employed in field studies of shift work are shown to reflect these structured aspects of the shiftworker problem on the one hand, and the researchers' own concerns over working life qualities on the other, it seems useful to discuss the special features and limitations of each pertinent method. In addition to evaluative and comparative approaches,a human ecological approach based more on information concerning relatively successful and unsuccessful adjustment of shiftworkers should be put forward in planning a field study on shift work.

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SHIFT WORK AND IRREGULAR WORKING HOURS IN SWEDEN: RESEARCH ISSUES AND METHODOLOGICAL PROBLEMS

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When the Swedish Work Environment Fund started its activities in 1972, it was considered that research on the problems connected with irregular working hours, particularly their social effects, seemed to be a neglected area. A book will be published shortly (Magnusson & Nilsson, 1979) which reviews and summarizes the findings to date in a form convenient for all those concerned with these problems (an English version will hopefully appear in the near future). The present paper contains a review of the results of this Swedish research over the last eight years, and also considers the methodological aspects of the work. Since the author was a member of the publishing committee for the book, this review relies heavily on the material collected for it.

The working party (The Swedish Work Environment Fund, 1975), appointed to present a research program for the Fund in the area of hours of work, concluded that high priority should be given to the following studies:

- A broad survey of how working hours are presently scheduled in Sweden, and an analysis of ongoing developments in this regard.

- A study of compensatory payments made for shift work and inconvenient working hours.

- Research into the effects of shift work, rostered-duty work and other inconvenient working hours on social patterns and activities. This program should concentrate primarily on the effects on family relationships at different stages of the life cycle (man-wife, parent-child, etc.), and also on such things as opportunities for education, contacts off the job, etc. Consideration should also be given in this context to general changes of attitudes and value judgments in the community, not least as regards sex roles.

- Research into the medical consequences of shift work, etc. This program should analyze ill health and sickness-absence in depth, especially in relation to their social consequences Comparisons within work-scheduling systems (rather than, as in the past, between day working and shift working) should be made since the results would be more directly applicable to the real-life situation.

- Research on individual differences in adjustment to work at different times of day. This research would aim to develop instruments for identifying people who can adapt to shift work without significant physical and mental consequences.

- An evaluation of the economic consequences of shift work and different forms of inconvenient working hours. This program would include a study of the cost aspects of alternatives which do not have the drawbacks attached to existing procedures.

- Assessment of the social and economic consequences of overtime work. After a preliminary survey, this program should concentrate on defining the costs incurred by firms and the social consequences for employees who do a great deal of overtime work.

Fields of Study

The research work was conducted in the following areas:

- Biological rhythms and their adaptation to different types of working hours;
- Health effects of inconvenient and irregular working hours, including sleep problems, gastrointestinal and psychic symptoms or diseases, and other diseases and symptoms;
- The relationship between work hours and absenteeism;
- Accidents and work hours;
- Social consequences of irregular and inconvenient work hours, including family relationships, care of children and house work;
- Consequences for leisure-time activities;
- Effects on participation in political and union activities;
- The reasons why people start working shifts, and why they leave.

In the different projects, the concern was with one or more of the following kinds of irregular working hours arrangements:

- Three-shift work, including continuous three-shift (with four or five shift teams, sometimes referred to as four-shift or five-shift work, respectively);
- Two-shift work, and overlapping day shifts;
- Rostered-duty work, i.e., schedules with extremely irregular work hours;
- Night, early morning, and late evening work;
- Flexible work hours;
- Part-time work;
- Overtime and moonlighting.

The present paper considers the various effects of the irregular work hours imposed by shift work and rostered-duty scheduled work.

Statistics on Working Hours in Sweden

According to an investigation by the Work Environment Fund in cooperation with the Board of Statistics (Ribbing, 1974), about 33% of the working population (i.e., about 1.2 million) is involved in different forms of "abnormal" working hours, such as shiftwork, night work, or irregularly timed working hours. The incidence of irregular working hours has tended to increase somewhat over the years (data from 1968 to 1974 confirm this).

About one-third of the group referred to above have a stable working hours arrangement (i.e., night work, early morning work, or evening work), while the remaining two-thirds have irregular work hours (shiftwork, etc.). The largest proportion of shiftworkers are men, while women dominate in the other forms of work hours arrangements. Only 5% of the working population are involved in shiftwork, but as much as 8% have rostered-duty work with even more irregular hours, including work at night.

Methodological Considerations

One of the difficulties involved in the interpretation of results from shiftwork studies is the fact that there is a 'selection' of people into (and out of) shiftwork. Individuals with health or social problems leave shiftwork. People who do not consider themselves "strong" enough to be able to adapt to the irregular schedules stay in day work. Thus, comparisons between shiftworkers and dayworking control groups may be misleading. Nevertheless, most studies in the field are 'transverse' studies using dayworkers as control groups. In a 'longitudinal' approach, information on the selection process is obtainable, which allows this factor to be controlled for.

The use of 'experiments' also seems to be relatively scarce in shiftwork research except in laboratory studies. In the field, it is possible to mount 'intervention' studies where the whole (or parts) of the shift system is changed in order to assess the effects of different parameters in the system (e.g., speed of rotation, length of shifts, etc.).

Since the problems of shiftwork are both medical, social and psychological, a 'multidisciplinary' approach may be fruitful, since this allows e.g., the social and physiological drawbacks or advantages of a certain shift system to be compared.

As was said above, the selection processes may make the results of transverse studies difficult to interpret. Comparisons of different shifts within a given system have already been mentioned as one solution to this. Another method would be to study groups where the "amount" of shiftwork varies in order to examine individual differences in the number of night shifts that lead to particular levels of disturbance.

In many of the earlier studies of effects of shiftwork on health, the dependent measures were diagnosed illnesses only. The use of 'questionnaires' on health, symptoms and disturbances may give quite different results, since it is known that shiftworkers do not consult physicians as frequently as other workers, considering e.g., stomach dysfunctions as a normal part of their lives.

A further approach is to investigate the relationship between the duration of exposure to shiftwork and the frequency of different indicators of dysfunctions.

Circadian Rhythms and Adjustment to Shiftwork

Since the shiftworker lives in an environment where the usual 24-h rhythm is maintained, the shiftworker's adjustment to an altered time schedule has been considered to be of great importance.

Methods

Most of the studies in this field have used both physiological and psychological measures as indicators of adjustment to shiftwork or to experimental changes in the 24-h pattern. The physiological measures were usually body temperature and the excretion of different hormones such as adrenaline and noradrenaline. In one of the projects, changes in the EEG pattern were measured, as well as in cardiovascular variables. Psychological tests have been applied to measure variations in performance, subjective fatigue, and mood changes assessed by means of ratings or interviews. The adjustment process was studied by taking repeated measurements. There have also been longitudinal studies in which the data collection was repeated after e.g. one year, in order to study long-term adjustment to the shift system. In one study, dayworkers who temporarily worked night shifts were investigated. Most of the investigations were field studies where measures were taken under relatively controlled conditions in the factories, but laboratory studies with experimental changes in the subjects' sleep/wake pattern were also undertaken, as were combinations of field and laboratory studies. It is mostly three-shift work, and especially continuous three-shift, that has been the focus of investigation.

Results

In most shiftwork systems in Sweden, people work about one week on each of the different shifts. There is, however, a trend towards shift systems with shorter cycles. The studies of the adjustment of 24-h patterns to changes in work hours have shown that a certain degree of adjustment may take place towards the end of a week on a particular shift (Patkai, Åkerstedt, & Pettersson, 1977; Åkerstedt, Patkai, & Pettersson-Dahlgren, 1977; Dahlgren & Patkai, 1978). The circadian curve was, however, flattened and body temperature and other physiological variables never approached the maximum level of dayworkers. In one study (Östberg, 1973), it was found that the body temperature rhythm changed during the afternoon-shift week, while there was only a slight change during the week on the morning shift and no "adaptation" at all in the night-shift week. Åkerstedt, Theorell, and Thorsvall (1976a) showed that, in a group of dayworkers who were transferred to night work for a couple of weeks, there were only marginal changes in 24-h patterns after a week.

In a study of long-term adjustment to shift- and night work, measures were repeated one year after the workers had started shiftwork (Dahlgren & Patkai, 1978). The 24-h curves were found to have somewhat flattened, especially during the night shifts, and there was no change <u>during</u> the night-shift week (as had been the case when the workers had just started working shifts). A flattening of the EEG rhythm was observed in one study where measures were taken first in the laboratory and then at work. No variation over the 24-h cycle was found on the evening shift.

No studies have yet been performed on adjustment to fast rotating shift schedules, but such a study is now being planned.

Morning and evening active people. In some of the studies referred to above, scores on a "morningness-eveningness" factor were obtained by questionnaires, and related to types of working hours and adjustment to shift- or other irregular working hours. The majority of night and shiftworkers were shown to be "evening type" people (even before they started shift work: cf. Patkai & Dahlgren, 1977). It seems that this factor acts as a selection agent, so that "evening active" people start working shifts and stay in shiftwork more often than "morning active" people. It was also shown that morning active people who work shifts tend to have more disturbances; and in one study, where measures of different dysfunctions were obtained before and after the night shift was discontinued, morning types showed the largest improvement (Åkerstedt, Fröberg, Levi, Thorsvall [illegible]more, 1978; Appel & Östberg, 1974). It was further shown that evening types were in better physical and psychic shape during the night shift than morning types.

Age. Age is important in the etiology of dysfunctions and symptoms related to shiftwork. It seems as if 45 is about the critical age in this aspect (Åkerstedt & Thorsvall, 1977a, 1977b). It has been speculated that this may be due to a change towards "morningness" with increasing age.

Shiftwork and Health

The research on health problems in shiftwork was mainly centered around sleep disturbances, gastrointestinal dysfunctions and psychic symptoms, although, in some of the studies, a broader approach was taken.

Methods

Sleeping habits and sleep disturbances were mainly investigated by means of questionnaires, interviews and diaries. EEG indices were used in some studies, one of which also investigated the interrelationship between these indices and subjective measures of sleep quality. Experiments on sleep at different hours of the day, as well as a field study on sleep quality, used EEG and other electrophysiological measures, and also the excretion of hormones, and self-ratings, in order to investigate the relationship between sleep and circadian rhythms.

The methods used in the study of gastrointestinal malfunctions were essentially questionnaires and interviews. In one study, nutritional analyses were made of the shiftworkers' diets.

Different psychic symptoms such as fatigue, restlessness, etc., as well as subjectively felt health hazards, were also assessed by means of questionnaires and interviews.

One study used the Swedish twin register (32,000 individuals born between 1926 and 1958) to study subjective symptoms and illnesses.

Sleep Disturances

The amount of sleep obtained in shiftwork varies considerably with the shift. During the night-shift week, there is a clear deficit, which is, to some extent, compensated for during the other shifts and on days off. There may be up to three hours' difference in sleep length between the shifts (Åkerstedt & Thorsvall, 1977a). Three-shift workers report sleep disturbances more often than day-workers; these disturbances have been shown to occur mainly on the night shift, but also, to some extent, on the morning shift. In an intervention study where the night shift was discontinued, total sleep time was increased and sleep disturbances diminished (Åkerstedt & Thorsvall, 1977a). Another investigation showed that starting to work on shifts leads to an increase in sleep problems (Åkerstedt, Thorsvall, & Theorell, 1976b).

Even in a case where sleep on the night shift was no shorter than on the morning shift, it was the former that caused the sleep problems (Åkerstedt & Thorsvall, 1977a, 1976). This implies that sleep difficulties are not only a matter of sleep length, but also depend on time of day and perhaps on the interaction between circadian rhythms and quality of sleep. The fact that housing conditions do not interact with sleep problems may also be taken as evidence that internal factors rather than external disturbances are the main causative factors.

In an EEG study of two-shift and night workers' sleep, it was shown that day sleep had a different distribution of sleep stages than normal sleep during days off; the proportion of Stage 1 sleep diminished while Stage 2 and REM sleep increased during the week. The deviations from "normal" sleep were considered to be less pronounced in night workers than in shiftworkers (Patkai & Dahlgren, 1977; Dahlgren & Patkai, 1978).

One experimental study (Åkerstedt et al., in preparation) investigated the effect of sleep at different hours of the day on sleep quality (EEG and self-ratings). The same investigators also monitored sleep in subjects on rostered-duty schedules in order to investigate the effect of very irregular working hours on sleep length and quality.

Rostered-duty schedules, which often imply an extremely irregular distribution of work hours and include night work, have also been shown to cause shortened sleep and sleep disturbances (Kolmodin-Hedman & Svensson, 1973; Svensson, 1977; Gardell, Aronsson, & Ryden-Lodi, 1977; Åkerstedt & Zamore, 1976). These sleep problems are most frequent in connection with night shifts. In one study (Åkerstedt & Zamore, 1976) about 50% of the employees said they often had difficulties getting to sleep after a night shift and 64% said they could not sleep as long as they would like to.

Gastrointestinal Dysfunctions

Food habits of three-shift workers were studied in one project, the aim of which was to develop dietary recommendations for people on night work or with irregular work hours (Appel & Östberg, 1974). As one would expect, there was wide variation between individuals. The time for the main meal was different for the different shifts. Also, "evening-active" workers tended to change their food habits more than "morning-active" types when working shifts.

On the other hand, investigation showed that shiftworkers tried to maintain "normal" meal hours and other dietary habits, and that the difference in meal time between the shifts was only a couple of hours. Appetite is reduced during night shifts and very few workers take a full meal then (Åkerstedt & Thorsvall, 1977a). A nutritional analysis showed that the food habits of shiftworkers were, on the whole, satisfactory and that they showed about the same slight deficiencies as those of the average Swedish population.

In several of the investigations, significantly more stomach disorders and complaints were recorded in shiftworking groups than among dayworkers. In one case, three-shift workers reported much more gastrointestinal dysfunction than a group of former three-shift workers (Appel & Östberg, 1974). When the complaints were related to specific shifts, the night shift was considered the worst although the morning shift was also bad (Åkerstedt & Thorsvall, 1977). When people stopped working shifts the problems diminished, while they increased on starting shiftwork (Åkerstedt & Thorsvall, 1977a, 1977b; Åkerstedt et al., 1976a). One interesting finding was that those shiftworkers who tried to change their meal habits to fit the work hours better had a higher frequency of disturbances.

"Morning-active" three-shift workers were shown to differ in several respects from "evening-active" with regard to food habits (Appel & Östberg, 1974). Thus, they had less variation in meal times, etc. between the shift weeks and less variation during the shifts. In other words, the morning-active workers had more stable dietary habits than the evening-active. The former also had fewer gastrointestinal complaints.

Psychic Symptoms

In most of the studies where sleep and gastrointestinal disturbances were shown to exist, there were also more psychic symptoms. Thus, three-shift workers reported fatigue, irritation, and aggression more often than dayworkers. These mood symptoms were mostly ascribed to sleep deprivation, but also to the fact that spare time did not coincide with that of other people (Appel & Östberg, 1974). The symptoms were more common in connection with night-shift work (Åkerstedt & Thorsvall, 1977a, 1977b). When the night shift was abolished (Åkerstedt & Thorsvall,1977a), this had a clear positive effect. A group of workers with a rapidly rotating shift schedule (so-called four-shift), who were transferred to conventional three-shift schedule, showed a moderate increase in symptoms.

A direct correlation between well-being (work satisfaction, less sleep disturbances) and adjustment of the circadian body rhythm was obtained in one study (Patkai & Dahlgren, 1977).

Other Illnesses

In one large project (Åkerstedt & Thorsvall, 1977a, 1977b), no differences were found in the occurrence of diagnosed illnesses in three-shift, four-shift, two-shift, and dayworkers (despite the existence of differences in subjective symptoms between the groups). One explanation given for this apparent anomaly is the selective mechanism referred to above.

Within a larger research program on environmental effects on health (Sörenson, unpublished), a study was undertaken on the relationship between shiftwork and medical complaints. The group investigated consisted of 32,000 individuals born 1926-58 (the so-called twin register). The results show that those who work shifts also have higher frequencies of medical symptoms, such as gastric catarrh and low-back pain, than have non-shiftworkers. Shift workers were also found to have had more sick leave. When the data were examined in terms of the number of years in shiftwork, those who had worked shifts for less than six years were found to have a higher frequency of symptoms than those who had been exposed for a longer period. The obvious interpretation of this is that those who get ill leave shiftwork and those remaining will be a selected group as far as health is concerned.

Shiftwork and Absenteeism

Methods

In studies on the relationship between working hours and absenteeism, comparisons between two-shift, continuous three-shift, overlapping day shifts, late working hours and daytime work were made. Interviews with employees were included in this research to supplement data from company absenteeism records. The different reasons for absenteeism, such as illnesses, fatigue, illness due to work conditions, family problems, child care, education or participation in union or other activities, were also examined. In one study of the interrelationship between absence from work and different background variables such as the number of children, occupation, etc., 150,000 individuals in the ages 15-67 were sampled by selecting people who were born on the 15th of each month.

Results

Two-shift workers have higher sickness rates, not only than dayworkers, but also than three-shift workers or people with rostered-duty schedules. This is true for long-term but not for short-term absenteeism. Where three-shift workers are concerned, the results vary and it is not possible to draw any firm conclusions. Absence for reasons other than sickness was generally more common among people who worked irregular hours (Eriksen, 1978; Bostrand, 1978).

Accidents and Shiftwork

Methods

In projects on accidents, both interview data and data from official or company statistics were used. In one case, employees were interviewed regarding their accidents during the last three years and on their views on the causes of the accidents. Data on different work environment factors were also collected by interviews and/or observations, and these data were then correlated with accident frequency. In one case, the distribution of accidents over hours of the day was studied.

Results

Although there was no difference in accident frequency between three-shift workers and dayworkers (Bostrand, 1978), the three-shift workers considered themselves to be more exposed to risk of accident than did dayworkers and two-shift workers. They also indicated that there was greater risk at certain hours of the day, with a peak between 3 and 6 am. In the two-shift group, the accident frequency was somewhat higher than in that of dayworkers.

Social Consequences of Shiftwork

Methods

In the projects on social consequences of shiftwork, the main tools were questionnaires and interviews, and usually involved substantially sized groups of shiftworkers and dayworker controls. The investigations were in most cases transverse studies but, in a few cases, repeated measures were taken, e.g., after a change in the work hours schedule. One researcher, in cooperation with the workers and management, set up a plan for changing the shift system and conducted a follow-up study after some of these changes had been made. Time budget techniques were applied in some cases.

Participant observation was used for collecting data in one study, and, in other studies, wives and other family members of the shiftworkers were questioned about the different problems that shiftwork presented for them.

Results

Family relationships. One difficulty, found to be especially pronounced among young shiftworkers, is getting enough time to spend with one's children (Gothenburg Psychotechnic Institute, 1975; Åkerstedt & Thorsvall, 1977a; Magnusson, 1978). More than one-third of the three-shift workers in one study considered this to be a major drawback. Fifty percent of those who had school children said their work hours made it impossible for them to see the children every day (Magnusson, 1978).

Similar results were obtained concerning time spent with spouse or fiancee. In about half the shiftworking population, the spouse also works, in many cases on shifts that do not coincide in time. Marital problems were considered to be related to work hours in about 10% of the three-shift workers in one investigation (Magnusson, 1978), and the same proportion said that shiftwork affected their sexual life (see also Appel & Östberg, 1974).

When a continuous three-shift system was changed to a so-called five-shift system with longer spells of spare time and fewer night shifts per cycle, there were clear improvements in family relationships, and the ability to plan and carry out common activities was facilitated (Wallertz-Nilsson, 1978).

The above-mentioned problems with family relationships were also found to exist among two-shift workers (Magnusson, 1978; Gardell, Bostrand, Nilsson, Gehlin, & Magnusson, 1978; Åkerstedt & Thorsvall, 1977a; Gothenburg Psychotechnic Institute, 1975). Families where husband and wife work different shifts were specifically investigated in some of the studies (Dahlgren & Styrborn, 1976a, 1976b; Magnusson, 1978).

Child care. Since nurseries are not open at times when shiftworking families need their services, the care of children is a great problem where both parents work. In one project, this problem was intensively studied and the local community government was persuaded to keep the nurseries open around the clock (Dahlgren & Styrborn, 1976a, 1976b). In all studies in this field, the situation was found to be most unsatisfactory for families with small children (cf. Andersson, 1975; Magnusson, 1978). This was the case for three-shift workers as well as for those who worked two-shifts.

Housework. Housework in families where one or both parents work shifts does not differ from the pattern of dayworkers, i.e., in the great majority of cases, the wife is responsible for all or most of the work at home. The extent to which shiftwork affects housework seems to depend on the amount of work done outside the home rather than the distribution of work hours (Magnusson, 1978).

A number of studies concentrated on female shiftworkers (Gardell, Baneryd, Gombrii, & Lundqvist,1968; Gothenburg Psychotechnic Institute, 1975; Holmgren, unpublished). In some of these investigations the effects of changes in the distribution of work hours, including "unconventional" schedules, were studied.

Social relations outside work. Several investigations were concerned with the shiftworker's ability to build up and retain interrelationships with other people during his spare time. In three of those studies (Gehlin, 1978; Åkerstedt & Thorsvall, 1977a; Gothenburg Psychotechnic Institute, 1975), 40, 49 and 65%, respectively, of the three-shift workers considered that their work hours interferred with social relationships, while the corresponding figure for dayworkers was only 1%. The number of social relationships was also shown to be smaller in shiftworking groups.

Leisure. The results as regards leisure time activities are somewhat contradictory. In one investigation, three- and four-shift workers considered that they had too little time for spare-time activities in comparison with two-shift and dayworkers (Åkerstedt & Thorsvall, 1977a, 1977b). In contrast to this, another investigator (Gothenburg Psychotechnic Institute, 1975) concluded that shiftworkers were rather more satisfied in this respect than were non-shiftworking groups. On the other hand, they were forced to plan such activities in advance, which was considered a negative aspect. Three-shift workers were less engaged in club activities and had fewer commissions than other work-hours groups (Gehlin, 1978).

Participation in political and union activities. Three-shift workers hold fewer Union offices than other groups (Nilsson, 1978), and 25% of those who do hold an office claim that they cannot conduct it properly (as compared to 6% in dayworkers). They also consider that their work hours prevent them from attending union meetings and other activities. The same general findings apply to political activities (Nilsson, 1978; Sundberg, 1977).

The Dropouts

As was mentioned in several contexts above, one difficulty when evaluating the effect of shiftwork on health, etc. is the selective mechanism which makes people who enter shiftwork differ from the rest of the (day) working population in certain respects, and shiftworkers who are adversely affected by shiftwork leave it.

In spite of awareness of this selection problem and its effect on interpretations of results from shiftwork studies, there are very few investigations on this matter.

Two projects looked specifically at the questions of why people start working shifts, and who the dropouts are (Bostrand, 1978; Herbert, 1977a, 1977b). The reason for starting to work shifts most frequently given by three-shift workers was that there had been no alternative for them. About one-fifth of those below 40 said the primary reason was that, at the time, the work hours seemed to be attractive. About 30% of people who started working shifts in a new factory said that they had chosed that job because of the work-hours system. A follow-up study is being performed at this factory to investigate who the dropouts are and why they leave shiftwork.

Conclusions and the Need for Further Research

Summary of Results

The results of the research on irregular working hours have shown that:

- Shiftworkers have more physical, psychical and social problems and symptoms than dayworkers.

- These problems and symptoms increase on starting shiftwork and decrease when night-shift work ceases.

- The effects on health and well-being of two-shift work seem to have been underestimated. These workers have more sickness absence than any of the other groups, and their social inconveniences are pronounced.

- The inconvenient work hours allow people very little opportunity to utilize the services of child care organizations, which means that the situation for the shiftworkers' children becomes more unstable, irregular and less secure.

- Leisure-time activities, especially those that are restricted to certain hours of the day, are less accessible.

- There is less time for building up and retaining relations with other people (including family members), and thus the social network is reduced.

- Certain factors interact with irregular work schedules in producing disturbances. Age, morningness-eveningness, age of children, and whether the spouse works or not, have been shown to be significant.

- The problems are, to a large extent, produced by the mismatch between work hours and circadian rhythms. The specific design of the shift system (number of consecutive night shifts, starting time, etc.) is, thus, important for adaptation to irregular work hours.

The Need for Further Research

Although a considerable amount of research has been directed to the problems of irregular work hours, it is apparent that we still need more knowledge to fully understand the mechanisms by which shiftwork, etc., gives rise to illnesses and social problems, and thus to be in a position to give practical recommendations to those concerned. I think that the following areas or problems should receive special attention in future research:

- The relationship between circadian rhythm changes and different medical and social complaints should be further elucidated. Research should focus on two-shift workers and people with rostered-duty, since there are definite health problems in these categories.

- The problem of day sleep and measures to improve it should be investigated more intensely. Sleep disturbance is one of the most common complaints among shiftworkers, and it seems clear that external factors such as noise, etc. are not the main causes.

- Since one of the typical complaints of shiftworkers is gastric dysfunction, we need analyses of food intake, and intervention studies in which different ways of changing dietary habits are tested.

- The negative effects of shiftwork on social relations and on participation in different activities in the community must be studied further, and to the same extent as effects on health.

- Previous research has concentrated on three-shift work. Other forms of irregular work hours, such as two-shift and rostered-duty schedules, should receive more attention, not least since the number of workers in these categories is even greater than the number in shiftwork.

- More knowledge is needed on age in relation to circadian rhythm changes, sleep and other factors pertinent to the health and well-being of shiftworkers. Since geriatric research is primarily concerned with the rest-retirement period, studies on middle-age developments in these respects are needed.

Notes on Methodology

Most of the research reviewed utilized conventional methodologies for studying shiftwork problems. However, experimental methods and interventions, longitudinal studies and multidisciplinary approaches tended to be used to a somewhat larger extent than in earlier investigations.

In my opinion, methodological aspects should be given much more attention than has been the case up to now. Although substantial funds have been spent on research in this area, relatively few firm results and recommendations can yet be made to those responsible for planning and designing shiftwork and other irregular work schedules. To this end, I think the following factors should be taken into consideration:

- There are still relatively few intervention studies. Interventions may be conducted as "field experiments", as was the case in some of the studies reviewed. Here, the researcher utilizes changes in shift systems, etc. that occur "spontaneously". However, there is also the possibility that a change in the system could be made deliberately, for experimental purposes. This would, of course, require that both employees and employers took a very active role in the investigation.

- Although previous studies on the effects of irregular work hours on health were inconclusive, it seems now to be established that there are such effects, and that the main methodological problem here is that of selection into and out of such work-hours systems. One way to tackle this would be to conduct longitudinal investigations where shiftworkers are followed over two or more years and the dropouts are studied specifically. There are a few Swedish studies of this kind under way, although no results have been reported so far.

- Up to now, most of the studies have concentrated either on medical or on social effects. However, the results of some of the investigations indicate that physical and social disturbances are interrelated. Thus, in order to discuss possible changes in shiftwork, we need knowledge about both factors. A multidisciplinary approach to the problems of shiftwork therefore seems to be one important goal in a future program.

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SHIFT WORK AND THE JET-LAG SYNDROME:
CONFLICTS BETWEEN ENVIRONMENTAL AND BODY TIME

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In today's highly industrialized societies, we are frequently exposed to acute time shifts of our 24 hour daytime schedule. Since World War II, many nations have introduced shift-work as an effective way to increase industrial productivity. In the United States, for example, it is estimated that 16% of all workers are on some form of shift-work schedule (Hedges & Sekscenski, 1979). Millions more individuals around the world subject their bodies to sudden shifts in time zones by the rapid travel made possible by the jet age. These changes in the nature of man's temporal environment have occurred over the last 40 or 50 years--a mere instant on the evolutionary time scale when compared to several million years of exposure to only the regular 24 hour period of the earth's rotation. We are discovering that humans have consequently developed a physiological apparatus which cannot always satisfactorily meet the demands imposed by external time shifts.

During the last 20 years, a considerable body of knowledge has accumulated on the circadian timing system which schedules man's body functions. Many physiological variables show oscillations, called "circadian rhythms", which are normally synchronized to the 24 hour external environment and persist with an approximately 24 hour period in environments without time cues (Halberg, 1960). Each is the product of the circadian timekeeping system within the organism (Pittendrigh, 1974) which enables animals to predict the major daily changes in environmental conditions which occur as a result of the 24 hour periodicity of the earth's rotation. Thus adaptive physiological and behavioral responses which may take several hours to be activated, can be initiated in advance of a predicted environmental challenge. The formal properties of the circadian timing system have been extensively described over the last 20 years (Aschoff, 1960; Bruce, 1960); however, relatively little is known about the physiological basis for circadian time measurement. Moreover, we are just now beginning to understand the role that this timekeeping system plays in a variety of pathophysiological conditions, including some induced by these acute time zone shifts of shift-work and jet-lag.

Varied degrees of stress may be imposed by different schedules. An individual flying from one time zone to another is exposed to a single acute shift in external time and may have ample time to adjust to the new schedule. A more complex challenge to the body's timing system may occur with rotation shifts where the individual works a few days on each shift and thus is exposed to regular, repeated shifts in external time. The most demanding challenge, however, is a random work shift schedule where work time and time available for sleep bear no relation to the previous or subsequent days. Figure 1 presents the record of sleep time, work schedule and eating times of two airline pilots plotted against their normal 24 hour home time. As can be seen, the work, sleep, and eating schedules vary rather randomly when compared with the individual's home time, and all three of these variables occur with different time relationships to each other throughout the course of the records.

Unfortunately, current pilot duty schedules such as these are designed irrespective of body time, and are governed by FAA regulations in which rest time is computed solely on the basis of accumulated duty time with no account taken of the individual's circadian or body time. Such schedules create a conflict of external timing information with the internal time of the individual. The external time of the environment, as created by work demands, is rapidly and randomly shifted on a day to day basis from the individual's home time. At the same time, the individual's meal timing, which may constitute another environmental input influencing body time, is also shifted but not always to the same degree as the work schedule. Finally, the social time frame of the individual's life at home, interspersed with his schedule as off-duty days, remains fixed to his domicile time. As a result, as one can see from the sleep records of the pilots, they fail to adapt to any particular fixed schedule.

Three factors appear to underlie the body's response to these timing conflicts. We will refer to as Factor 1 the fatigue and/or sleep-loss directly consequent to the travel or start of a new shift, which are independent of the timing conflicts. For example, flying from north to south does not result in a time zone shift; however, the actual stress of the flight itself will influence the individual's performance.

The other two factors are a result of the shift between external and internal time. Factor 2 is the direct effect of the disparity between external and internal body time. For example, an individual's minimum daily performance capability may be at 4:00 am, the time of day when there are normally no external challanges. However, after a flight across six time zones to Europe (a phase advance of six hours) the circadian timing system takes several days to resynchronize. Before it starts to adjust, the person's body time will be at 4:00 am but local environmental time may be 10:00 am, a time of day when the individual may be expected to operate with maximum effectiveness at an important business meeting or combating rush-hour traffic.

Factor 3 is more subtle. Because the circadian timing system is composed of several separate oscillators or "clocks", and each resets at a different rate to the new environmental time, there are timing conflicts between the rhythmic functions of the various physiological systems which further reduce the individual's optimum abilities.

Studies in a Primate Model

To study the factors described above it is necessary to perform precisely controlled experiments in which the individual contributions of each factor

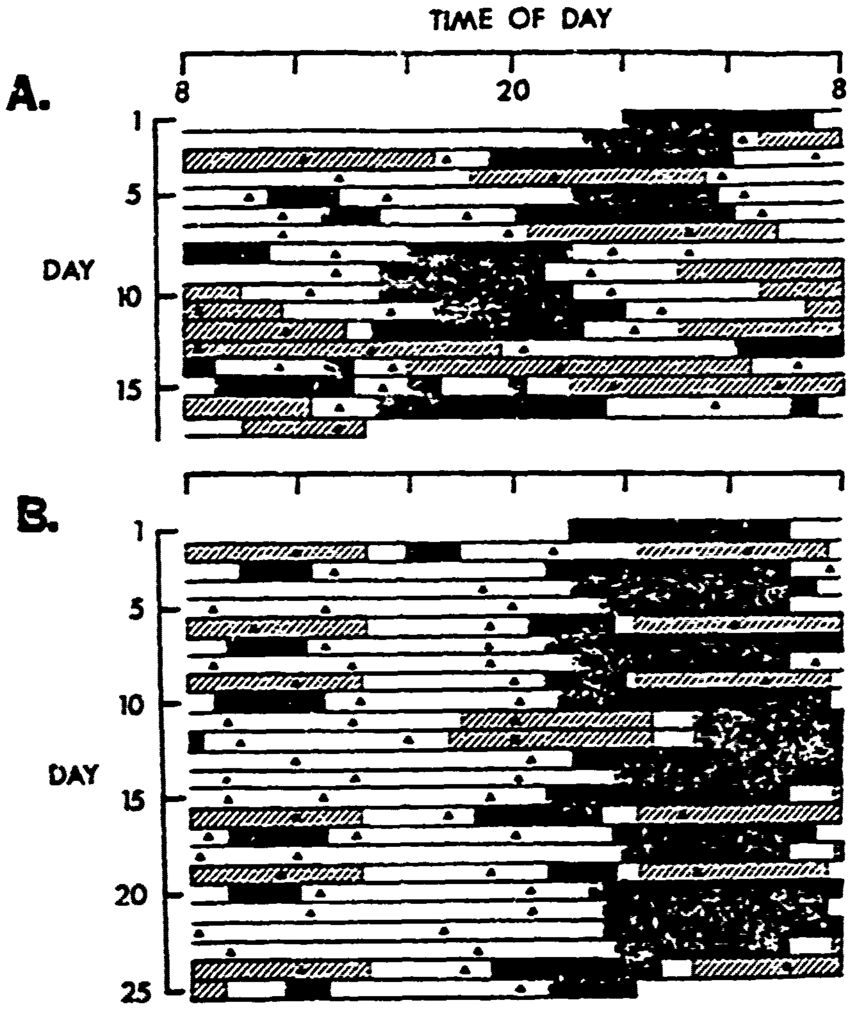

Figure 1. This figure depicts the sleep (■), eating (▲), and work (▨) schedules of two commercial pilots over a series of consecutive days. Each 24 hour day is successively plotted underneath the previous starting with day 1 on top. The time of day (indicated at the top) begins on the left with 0800 in the morning of the pilot's home time. As can be seen, the work schedule imposed on the pilot and the resulting rest and eating schedules do not fall into any coherent pattern but instead are relatively random throughout the period depicted.

can be isolated, measured, and analyzed. To do this one must both control the environment and monitor all the various biological functions continuously. Because of the severe limitations imposed by doing such rigorous research in man, we have utilized a non-human primate model, the squirrel monkey (Saimiri sciureus), a small (approximately 1 kilogram), day-active, South American animal. Using these animals we have investigated a series of questions regarding the influences of Factors 2 and 3 in shift-work and jet-lag and their resulting implications for physiological regulation. We will not be discussing here in great detail the potential implications of Factor 1 as they have been discussed widely elsewhere and are a generally recognized contributory factor (Aldama, 1977; Day, 1976; Grandjean, 1968).

Effects of a Single Environmental Time Shift

Using this animal model we first examined the effects of a single phase-shift of the light-dark (LD) cycle (Moore-Ede, Kass, & Herd, 1977). The rhythmic patterns of seven different physiological and behavioral variables are shown in Figure 2A. Plotted at the bottom of the graph is the light-dark cycle to which the animal is subjected. As indicated, the animals were in a 24 hour light-dark cycle with lights off from 2000 to 0800 each day and the lights on from 0800 to 2000. The cycle thus consisted of 12 hours of light and 12 hours of dark (LD 12:12). During the second day the animals were subjected to the equivalent of an 8 hour phase shift in time zone. An additional 8 hours of light were added from 2000 to 0400 following which the lights were turned off and the LD 12:12 cycle was reinstituted at this new phase (lights on from 1600 to 0400 hours each day) for the rest of the experiment. Before LD phase-shift all of the variables were rhythmic wit 24 hour periods. After the phase-shift, each of the rhythms moved over to match the new phase of the LD cycle but not immediately or at the same rate. For example, the behavioral rhythms of feeding, drinking, and activity along with the body temperature rhythm moved over and resynchronized at a faster rate than the urinary excretion rhythms.

The average rate or resynchronization for each of these variables (for a group of four different animals) is shown in Figure 2B. Plotted here is the time of occurrence of two phase markers (the time the rhythms moved upwards and downwards through their average value) from each successive cycle of each animal. Before the 8 hour phase-shift it can be seen that the phase of each rhythm occurs at approximately the same time each day as indicated by the minimum deviation of the time of occurrence of the phase points from the phase scale on the abscissa. After the 8 hour LD phase-shift all of the phase markers began to move over to the new LD phase which was -8 hours displaced. However, some variables moved over faster than others. To clarify the rate of shift, an exponential curve has been fitted to each set of data. As indicated in Figure 2 the activity feeding and drinking rhythms were all essentially resynchronized to the new light-dark cycle within 48 hours. The temperature rhythm took approximately 24 hours longer to resynchronize. The urinary potassium, sodium, and volume rhythms on the other hand took approximately 7 days to completely resynchronize. Similar results have been found in man (Wever, 1979). Thus, when an individual is exposed to an abrupt shift in the light-dark cycle he does not become completely resynchronized with the new environmental time for at least a week. Additionally, since resynchronization is occurring in some variables at a faster rate than others, a phenomenon of in-

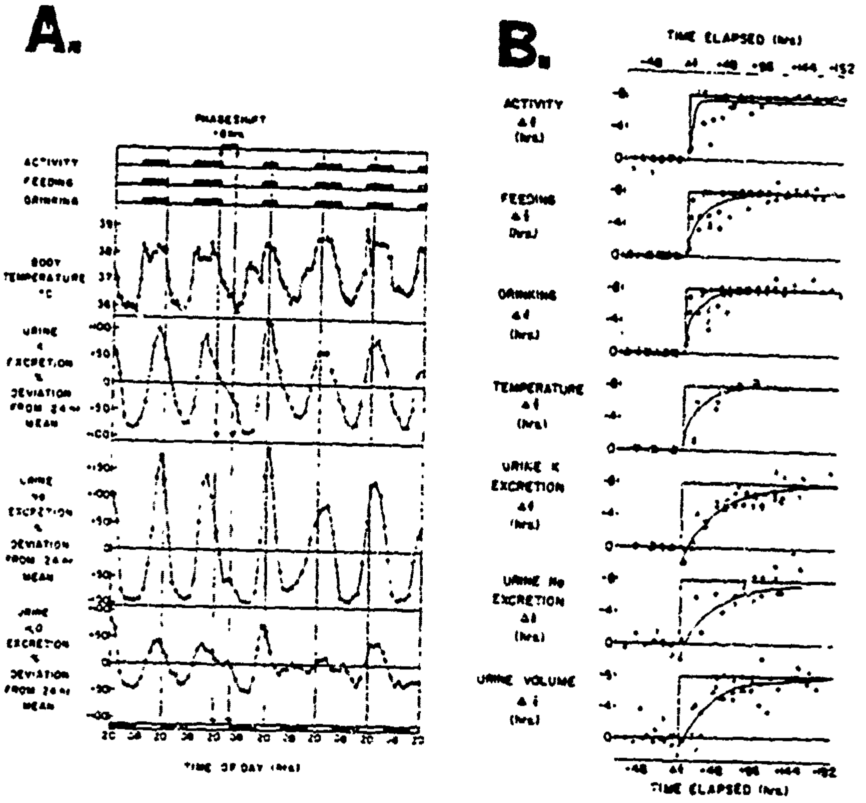

Figure 2. Response of a monkey to an 8-hour phase-delay of the light-dark cycle. Plotted in A are the circadian rhythms of activity, feeding, drinking, body temperature, and urinary potassium, sodium, and water excretion during 2 control days with the lights on from 0800 to 2000 hours,and then for the first 4 days after a light-dark cycle phase-shift where lights were now on from 1600 to 0400 hours daily. Each circadian rhythm gradually resynchronized with a new light-dark cycle phase. In B the changes in phase of 2 phase markers on each successive cycle, of a group of 4 animals, as compared to the phase of the same markers during control days, were plotted as a function of time elapsed after light-dark cycle phase shift. An exponential function was fitted to the phase shift of the rhythm markers. Circadian rhythms of activity, feeding, drinking, and body temperature phase-shifted significantly ($p < .05$) more rapidly than urinary rhythms to the new light-dark cycle phase.

ternal desynchronization between the various rhythmic variables is observed. As a result, after a phase-shift. individuals are externally desynchronized from the environment (Factor 2) due to the drag from the internal timekeeping mechanism and internally desynchronized (Factor 3) because of the different rates of resynchronization of the components of this timekeeping mechanism.

Factor 3, internal desynchronization, particularly becomes a problem when there are no time cues in the environment. In this rather unnatural state the organism is said to be "free-running" and expressing its own internal circadian period via its endogenous timekeeping system. The circadian timekeeping system of mammals is composed of a group of potentially independent oscillators, which are normally coupled to one another as well as being synchronized with the external environment (Moore-Ede & Sulzman, 1977; Pittendrigh, 1974). However, occasionally, these oscillators can be separated by internal desynchronization and free-run with different periods since the internal coupling mechanisms are not always sufficient to maintain appropriate synchronization between the rhythms. We have previously demonstrated internal desynchronization between the circadian rhythms of body temperature and urinary potassium excretion in squirrel monkeys maintained in constant environmental conditions (Sulzman, Fuller, & Moore-Ede, 1977a), and Aschoff and co-workers (Aschoff, 1965; Aschoff, Gerecke, & Wever, 1967; Wever, 1979) have demonstrated internal desynchronization between the circadian rhythms of activity and body temperature in man. Even when internal desynchronization is not seen, some change in internal phase angle relationships between different rhythms is found when animals are placed in environments free of time cues (Kreibel, 1971; Mills, Minors, & Waterhouse, 1977).

Several different elements of the environment are capable of providing temporal information to an individual. In addition to light-dark cycles, we have previously shown that one of the key elements in the environment which can affect the timing of an organism is the rhythmic availavility of food (Sulzman, Fuller, & Moore-Ede, 1977b). That is, when monkeys were allowed access to food for 3 hours a day at the same time of day, and fasted the other 21 hours (eating-fasting; EF 3:21), they become synchronized to the 24 hour cycle even in the absence of any light-dark cycle. However, we have also shown that these environmental synchronizers do not couple all of the oscillators in the organism in the same manner (Sulzman, Fuller, Hiles, & Moore-Ede, 1978). For example, Figure 3 shows the differential coupling which can occur when a monkey is exposed to conflicting zeitgebers (a situation which is analogous to some shift schedules). Here the rhythms of drinking, colonic temperature, urinary potassium, and urinary volume are averaged from several cycles of a group of 4 animals. All of the animals were exposed to a normal LD 12:12 cycle as indicated in the drawing. However, these animals were at the same time exposed to an EF cycle at two different times of day. The animals on the left were allowed access to food for the first 3 hours of lights on from 0800 to 1100 in the morning while the animals on the right were allowed food only from 1600 to 1900 in the evening before lights out. Figure 3 shows that the drinking and urinary volume and potassium rhythms moved their phases to match the phase of the EF 3:21 cycle, while the timing of the temperature rhythm was not affected by the different EF schedules and kept the same phase relationship to the LD cycle. This indicates that although both environmental variables supply temporal information to the organism, they do not affect all rhythms in the same way and thus create a disparity in phase

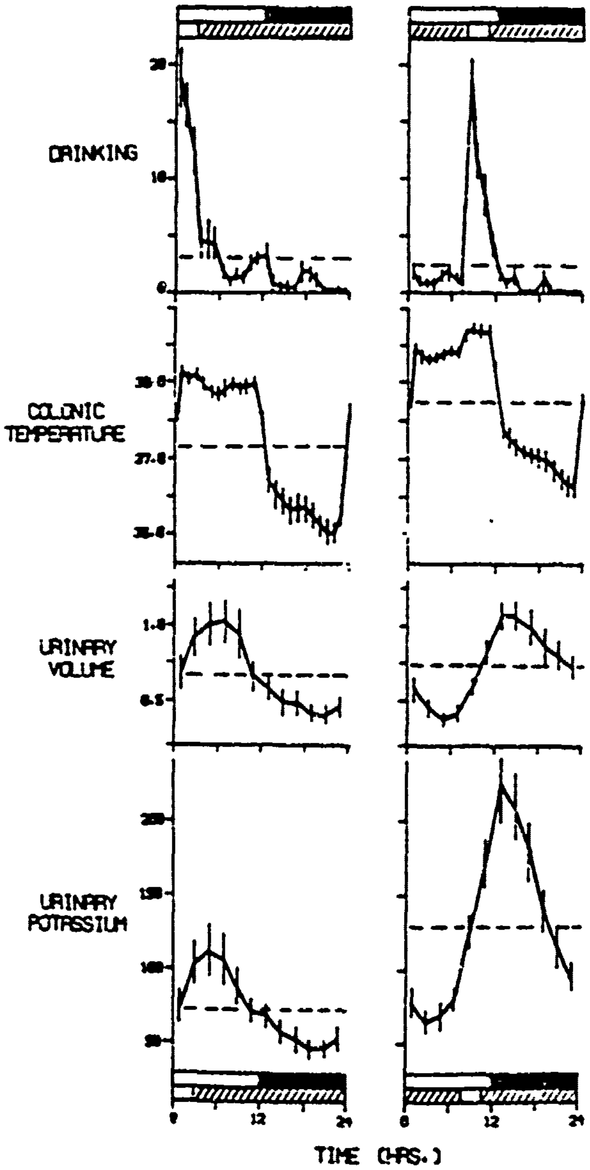

Figure 3. Average waveforms of rhythms of drinking, colonic temperature, urinary volume, and urinary potassium (mean ± S.E.) of a group of 4 monkeys concurrently entrained to an LD 12:12 and EF 3:21 cycle. Lights were on from 0 to 12 hours and off from 12 to 24 hours. Animals on the left had food available from 0 to 3 hours and animals on the right had food available from 8 to 11 hours. Drinking is plotted in mls of water consumed per hour, colonic temperature in degrees centigrade, urine volume in mls per hour, and urinary potassium in microequivalents per hour. From 24 to 26 cycles of data were used to calculate each waveform. As can be seen, the timing of the temperature rhythm was not affected while the other rhythms were phase-shifted by the EF cycle.

angle between these variables. In addition to applying multiple synchronizers with conflicting phases, it can also be shown that applying the synchronizers with conflicting periods can have a similar effect in producing internal desynchronization (Sulzman et al., 1978). The message for the shift workers is that disorders of internal timing (Factor 3) may occur if some time cues shift, such as the LD cycle; but others, such as the timing of meals, do not.

Effects of Repeatedly Shifting Schedules

There are many more extreme examples of external time shifts than the single shift in one environmental parameter that we have just described. For example, rotating shift schedules exist where an individual may be rotated through a successively later shift every week. Thus, the individual never becomes totally acclimated to the shift he is on. If the sequence of shift time changes daily the average effect is that the individual will not be working on a 24 hour day, but instead on one that has a day length significantly different from 24 hours. Enlisted men in U.S. Navy submarine crews are typically assigned work schedules with an 18 hour day-night cycle. This constitutes a phase shift of 6 hours on each successive day for the individual compared to his normal 24 hour time. However, one of the key properties of the circadian timekeeping system is that circadian oscillators are only capable of synchronizing to environmental cycles with periods close to 24 hours (Enright, 1965; Mills et al., 1977; Wever, 1979). This phenomenon, known as range of entrainment, means that the primates and man will free-run when exposed to environmental synchronizers with periods outside the range of approximately 22 to 26 hours. Thus, when an individual is exposed to an 18 hour day, his body time cannot synchronize to this period but rather reverts to a free-running behavior determined by his internal timekeeping system. This is a far from optimum state and the individual will consistently be out of synchrony with the demands of his environment.

The picture is complicated further because the environment has a direct influence on the expression of the various rhythms. An example of this type of direct environmental influence is seen in Figure 4. Here a monkey is exposed to an 18 hour day (LD 9:9). Figure 4A shows the resultant body temperature levels of the monkey during 5 successive LD 9:9 cycles. What can be seen is a relatively complex rhythmic behavior resulting from two different sources. The first component is a circadian rhythm free-running with an approximate 24 hour period since an 18 hour period is outside the monkey's range of entrainment. When the circadian phase of each successive 24 hour cycle is computed mathematically and plotted as a time of day occurrence as shown in Figure 4B, one can see the maximum is occurring with consistently different relationships to the LD cycle. On Day 1 the maximum occurs during the lights on; on Day 2 the maximum occurs after lights off; on Day 3 the maximum occurs just after lights on; and on Day 4 the maximum occurs about the same time as it did on Day 1. This circadian component is thus showing 4 cycles superimposed on the 5 18-hour LD cycles. Simultaneously, however, we are seeing a direct influence of the light (and dark) on the body temperature rhythm such that when the lights are on, the body temperature is higher than when the lights are off.

To show both of these rhythmic components (the free-running circadian components generated from the endogenous timekeeping mechanism and the pas-

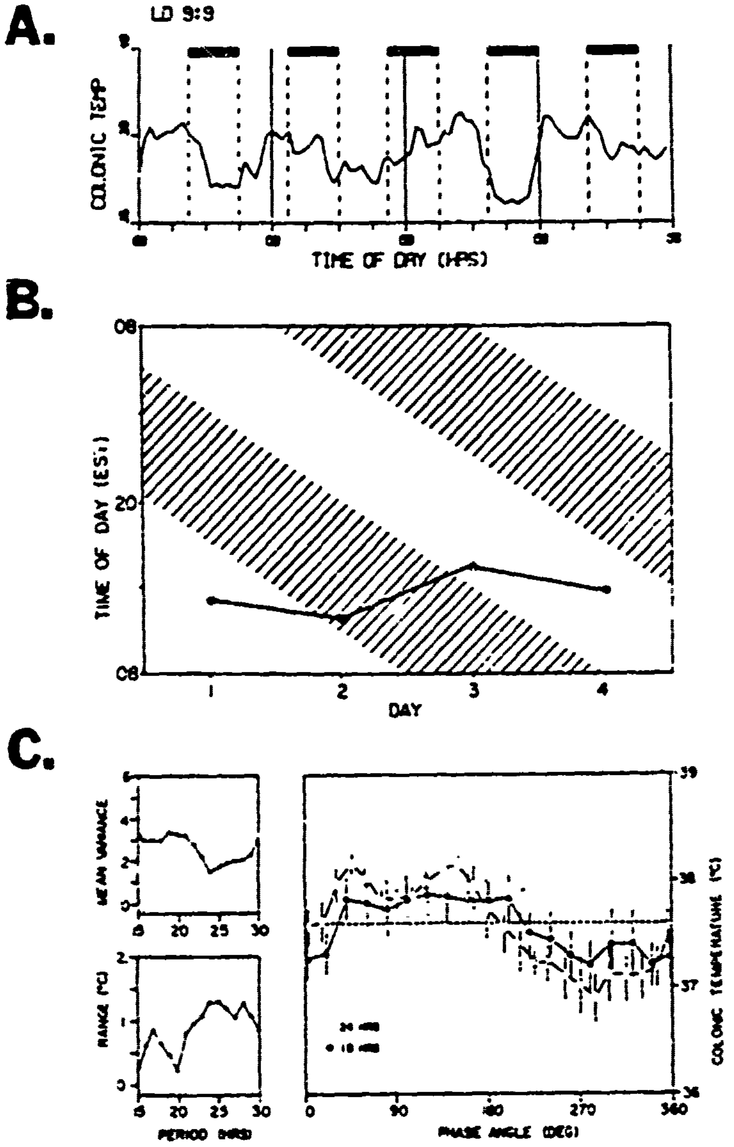

Figure 4. Plotted in A is the colonic temperature response of a monkey exposed to an 18-hour light-dark cycle (LD 9:9). The phase plot in B indicates that a circadian rhythm of body temperature (shown by the phase points) is persisting with a free-running period independent of the 18-hour light-dark cycle, (indicated by the clear areas for the light and the hatched areas for the dark). Autocorrelation analysis of the data in C shows both by the mean variance and range maximum plots over a period range of 15-30 hours that there is no clear indication of any single periodicity in the data; rather there is an indication of periodicity at around 18 hours and again at about 24. When the 24 hour and 18 hour averaged rhythms are simultaneously plotted we see that a significant rhythm at both of these frequencies is occurring.

sively driven 18 hour component by the imposed environmental light-dark cycle) we have performed the autocorrelation analysis of the body temperature pattern in Figure 4C. This analysis shows minimum mean variances and maximum ranges occurring at 18 and 24 hours. Thus, both of these calculations indicate that there are rhythmic components in this body temperature data with these two periods. To quantify these influences we have plotted on the right in Figure 4C the average waveforms in the body temperature data at periods of 18 hours and 24 hours. The internally timed component (the 24-hour cycle) shows the largest amplitude, but there is still a significant rhythm occurring at the 18 hour period as a result of the concurrent LD cycle. Thus, from these types of studies we recognize two conclusions can be drawn. The first is that a range of entrainment phenomenon exists and must be taken into account for rapidly repeating shift work schedules. Second, besides the active synchronization of the biological rhythms these external time cues can have direct passive influences on the rhythms themselves (Aschoff, Klotter, & Wever, 1965).

To further investigate these passive influences of light-dark cycles on the body temperature rhythm of the squirrel monkey we have examined the extreme case of exposing a group of monkeys to 4 hour light-dark cycles (LD 2:2). As is shown in Figure 5, when the body temperature rhythm of the animals in the LD 2:2 cycle was compared with the same group of animals exposed to an LD 12:12 cycle it was found that the light intensity had two specific influences on body temperature regulation. First, when the lights were off the body temperature was always lower than when the lights were on. Second, there was a circadian variation in this passive response in that the light intensity had a greater effect in changing body temperature during the night than it did during the day. Thus, body temperatures comparing lights on and off during the day were different by only a few tenths of a degree centigrade while this difference was over 1 C during the night. We have also found that these light intensity effects were present when the animal was free-running in constant light. Under these conditions, the body temperature rhythm amplitude and mean level was a direct function of light intensity.

Pathophysiological Implications

As of this date we do not know the answer to the question whether shift-work or jet-lag have life-threatening or otherwise major health impact in humans. No rigorously controlled long-term follow-ups on a large population of shift workers have been performed. Data on other organisms, however, do exist which indicate that Factors 2 and 3 may play a significant role in some health problems. For example, Aschoff et al. (1971) have shown that flies exposed to continously shifting LD schedules have shortened life spans as compared with flies in a 24 hour LD cycle throughout their life. Halberg has extended these findings to mice (Halberg & Nelson, 1976). Moreover, organisms exposed to light-dark cycles which are outside the circadian range of entrainment also display shorther life spans than animals within the circadian range (Pittendrigh & Minis, 1972).

Regulation of behavioral and physiological functions within primates and man have, however, been shown to be susceptible to effects of timing disparity. For example, we have shown that when circadian synchronizing cues are removed from the environment, temperature regulation in the squirrel monkey is markedly impaired (Fuller, Sulzman, & Moore-Ede, 1978) as is seen in Figure 6. Animals

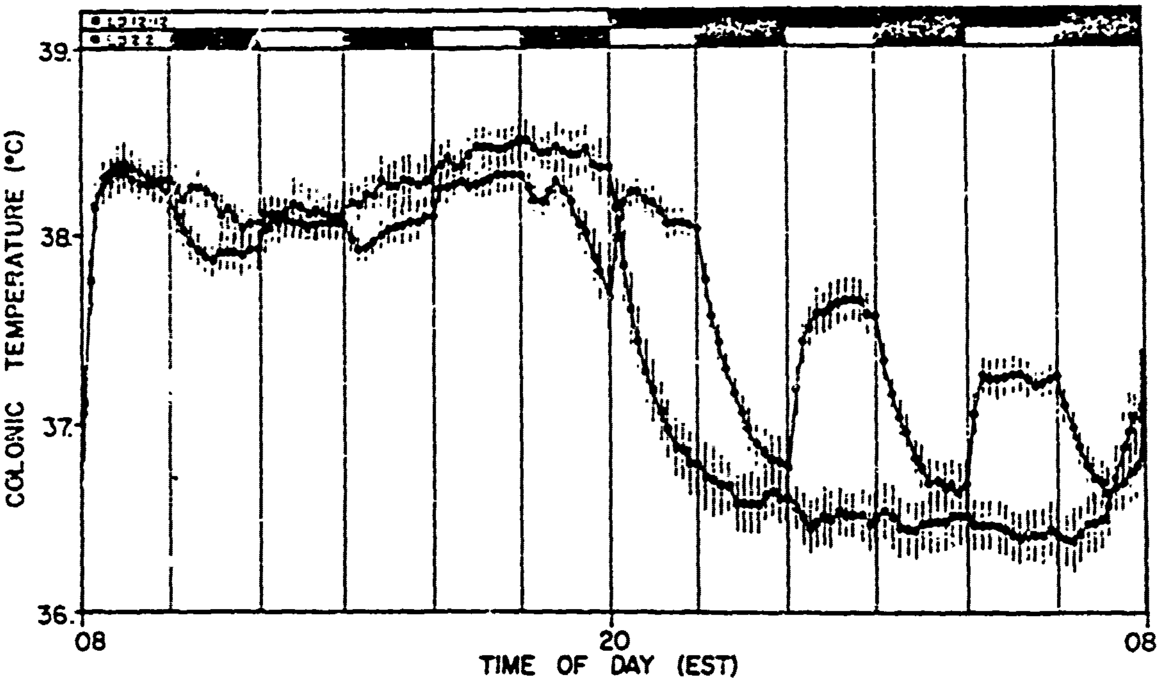

Figure 5. Plotted here are the average body temperature waveforms of a group of 4 monkeys initially exposed to an LD 12:12 cycle followed by an LD 2:2 cycle. The passive effects of light on the regulation of body temperature can be seen by comparing the superimposed curves with each other. The temperature was sampled every 10 minutes and plotted are the means (± S.E.) of approximately 10 cycles from each light regime. As can be seen the body temperature is always lower when the lights are off and the greatest effect of light is observed during the animals night.

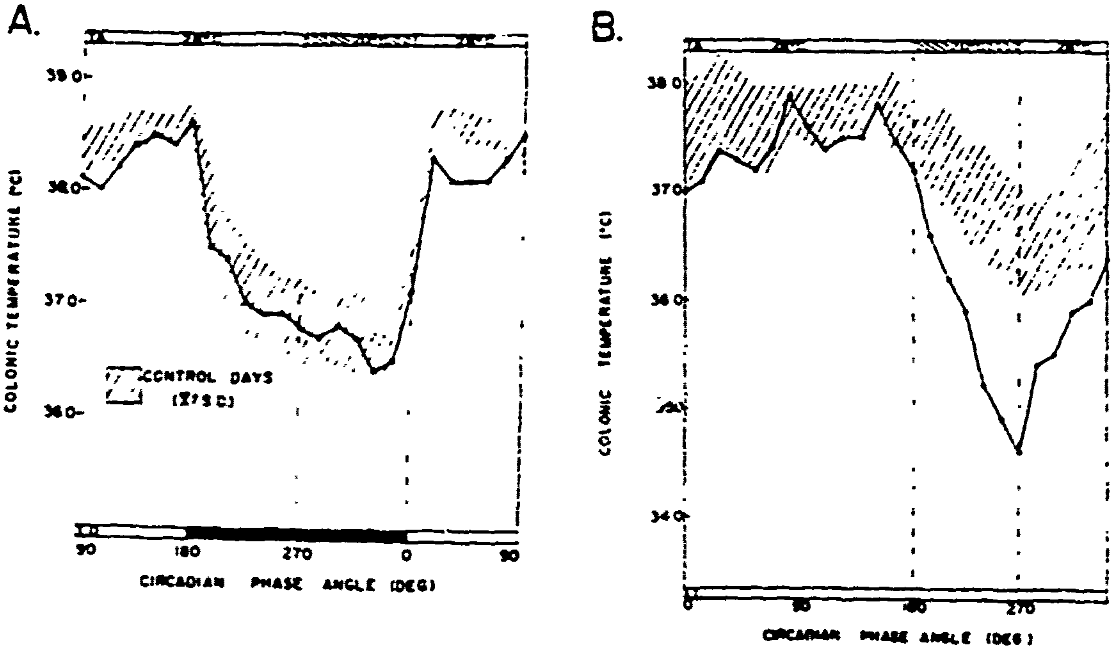

Figure 6. The effects of 6 hour cold exposures on body temperature in a monkey entrained to an LD 12:12 cycle in A and a monkey free-running in constant light in B. At the top of each graph the ambient temperature is indicated on the day the cold exposure was instituted; light conditions are indicated on the bottom of each graph. Since the periods of the rhythms were different in the 2 lighting conditions (that is, 24 hours in A and 25 hours in B), the data were normalized so that each cycle was set equal to 360 . The shaded area represents the mean (± S.D.) of the previous 3 cycles (ambient temperature equals 28 C). As can be seen the animal in light-dark cycle showed very little effect of the cold exposure, maintaining its body temperature in the shaded region while the animal in constant light showed a major inability to maintain body temperature during the cold esposure.

synchronized to the environmental time cues are able to maintain body temperature without difficulty during cold exposure. An example of this can be seen in Figure 6A where an animal is exposed to an 8 C drop in ambient temperature during the night. The body temperature is maintained at the previous control levels (shaded rhythmic area) throughout the cold exposure. In contrast, Figure 6B, shows that when circadian synchronizing cues are removed from the environment some monkeys cannot maintain body temperature when exposed to this same mild cold stress. That these results are not a direct consequence of isolation of the animal of constant light per se has been shown in monkeys synchronized to a 24 hour period by EF cycles in constant light (Fuller, Sulzman, & Moore-Ede, 1979). These animals were able to defend body temperatures during similar cold exposures. Finally, another group of animals, in which forced internal desynchronization was consistently produced, showed an inability to maintain body temperature during cold exposure. Yet, when these same animals were synchronized to a light-dark cycle they were quite capable of maintaining body temperature (Fuller et al., 1979). The results of these studies indicate that effective thermoregulation requires the proper temporal synchronization of the various physiological systems responsible for the maintenance of body temperature.

A large body of literature exists which indicates that psychomotor performance of both primates (Rohles & Ptacek, 1973) and man is less than optimal during rapid phase shifts of the external environment. For example, Nicholson (1973) has shown that pilots exposed to shift schedules such as those in Figure 1 may suffer an increase in physiological tremors after many successive shifts in body time. Klein, et al. (1970) have also confirmed that acute shifts across time-zones lead to decrements in pilot performance.

Thus, while major health and longevity problems have not been directly implicated with shift work schedules or jet-lag per se, the potential does exist for problems to occur. Decreases in behavioral and physiological performance can be documented as a result of conflicts between environmental and body time. Further, the combination of these individual deficits which are just now being recognized may contribute to more subtle changes which may result in long term health problems yet to be identified.

Conclusions and Recommendations

As we have discussed, there are a number of implications for human health of the shift-work schedules or the acute time zone shifts seen with jet travel. We have no final answers, yet we can suggest several tentative conclusions. It is apparent that further studies need to be performed both on animal models and man. These studies need to isolate Factors 1, 2, and 3, for individual study and in combination with each other in a rigorous manner. We need further to characterize the structure and function of the human circadian timekeeping system and determine its performance limitations. The environmental parameters which have direct influences on man must also be isolated to determine both their active and passive effects on each of the various physiological systems. Finally, we need to develop effective therapeutic techniques to aid in the readjustment to new schedules.

Even though no final answers exist, several recommendations could be made at this time to help individuals who must endure these types of schedules.

The first would be to minimize Factor 1: the fatigue factor or sleep loss. Sleep is beneficial and should be optimized whenever possible. This may mean for a traveller, whenever practical, choosing a daytime flight which does not impinge on the sleep period of either home or visiting time zone. Unfortunately, transatlantic flights are largely at night taking more into consideration the expediencies of maximizing aircraft use than the health and comfort of the passengers and crew. Secondly, because of the potential conflicting nature of time cues from the environment, it would be helpful whenever feasible to shift all environmental parameters maximally so that even though an individual is working at a new shift schedule, or is in a new time zone, his entire temporal environment (i.e., social, lighting, temperature, food timing, etc.) is synchronized in such a way that it presents a single unified 24 hour environment for the body. This will help the individual resynchronize to the environment and maintain that synchrony. Finally, if a shift is required for only a relatively short period of time (i.e., one or two days), the individual is better off not attempting to shift at all but maintaining himself as much as possible on his own time. Thus, he would already be synchronized to his domicile time when he returns.

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HOW IMPORTANT ARE THE SOCIAL EFFECTS OF SHIFTWORK?

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The question that I have raised breaks down into at least four separate questions:

1. How *many* shiftworkers complain about the social effects of shiftwork? What is the *incidence* of feelings of social hardship in groups of shiftworkers?

2. How *severe* are the social effects, compared with sleep, health, and other physical effects? Are they at the level of petty irritations, like stony beaches that would be softer on the feet if they were sandy? Or do they loom over people's lives, as bad housing conditions can, pervading and poisoning the quality of their lives in every aspect.

Importance, then, I take to be some combination of incidence and severity. A very common complaint that does not upset anyone seriously is more important than a less frequent complaint. A minority complaint that indicated real hardship to a few is also important, and should not be overlooked. How these two views of importance are balanced is a matter of opinion. As only a minority of the working population has to undertake shiftwork at present, I am inclined to think that incidence is more important than severity. The minority with severe complaints should be advised to move to alternative employment.

3. What is the *relative* importance of different social effects of shiftwork? Clearly some social activities are more valuable to individuals than others, and they also vary in flexibility, and therefore in how much they are dislocated or totally displaced by shiftwork. Discussing the relative social effects may also illuminate what is meant by social effects.

4. How do the physical and social effects of shiftwork interact? It should be noted at this stage that it is possible for the causal direction to be bilateral. Packing an active social life into the day period of a night shift worker, for example, can curtail his time for sleep. And a short or dissatisfying sleep can color his subjective appreciation of his social life. I am not aware of any work that has attempted to tackle this problem of causal direction, but some can be suggested, and some inferences can be made from cross-sectional survey data. Demographic variables are also relevant here.

Previous work on the social effects of shiftwork is, on balance, gloomy, with rotating three-shift work receiving the most depressing criticisms. Mott, Mann, McLoughlin, and Warwick (1965) found that "the rotating shift shares the disadvantages of both the previous (afternoon and night) shifts, and the workers on that shift report relatively greater difficulty in all activity areas." The rotation period was a modified weekly one. Maurice (1975) cites figures from his own work with Monteil showing a progression of interference with social and leisure activities from 29% on two shifts to 49% on semi-continuous three shifts to 62% on continuous three-shift systems. An Indian study (Shri Ram Centre, 1970) found greater role-performance interference among its rotating shift workers, although this was less in a small sub-group on a rapidly changing system. Andersen (1970) reported that with the greater part of 600 weekly-rotating three-shift workers, shiftwork had an unfortunate influence on family life and leisure hours. Carpentier and Cazamian (1977) point out that rotating shiftwork is appreciated by workers separated from their families, whom they visit on accumulated rest-days, and by couples whose married life is already in difficulties by reducing the time spent together. They reserve their main attack for the physical effects of night work, and for the notion of nocturnalising the activities of the family and community, "leading ultimately to the pollution of the whole community by the ill effects of industrially motivated night work." Their conclusion continues: "The real difficulty thus clearly appears: the overriding requirement is that human activity, like that of all the higher animals, shall conform to a daily cycle of 24 hours during which 12 hours of activity are followed by 12 hours of rest and sleep. This alternation ought to apply simultaneously and synchronously both to factory life and to the life of the community. As they are in breach of that law, continuous or semi-continuous work schedules cannot be regarded as either biologically or sociologically acceptable." Tasto, Colligan, Skjei, and Polly (1978) conclude that "rotators seem to consistently fare the worst...It is a system that imposes excessive physical and psychological costs on shiftworkers." Rotation for nurses in their sample included oscillating between two shifts, and was at periods from one to four weeks. It is not clear what rotational period the food processors in their sample followed. Blakelock (1967) surveyed 490 refinery workers in a small town in Canada, on a weekly rotating system, and found relatively high satisfaction with shiftwork and social life. Work and community characteristics are thought to have contributed to this unusual finding.

There have been important surveys recently in Austria, Germany, and the Netherlands, where language difficulties inhibit me from taking excerpts or conclusions. The background, methods, and operational measures are difficult to assimilate in other languages, and furthermore there are distinguished representatives from all three research programmes here whom you can question about them.

Against this background, my own two surveys (Wedderburn, 1967; 1975) in the steel industry have found relatively positive attitudes towards shiftwork by men on rapidly rotating systems. Yet there are problems and complaints, and I want to try to answer my four questions with illustrations from my own material. I suspect that there are still enormous problems of generalizability, certainly between work locations and regional areas inside one country, and probably even more dauntingly between different countries with major differences in climate, diet, family systems, and preferred social activities. To many of us, an 120° phase shift across time zones followed by a working period extending over 13 1/2 hours at a time equivalent to normal night at a temperature more than two standard deviations above our normal mean should imply a severe threat to our personal well-being. Yet this symposium appears to be considered a worthwhile and pleasant activity for most of us.

Method

Our survey was an interview study of 315 production and ancillary workers in the British steel industry, conducted over the summer months with Dr. Peter Smith of the University of Bradford. The sampling frame for this was based on work groups, initially attempting to compare shift systems using groups of workers whose work was hot/not-hot, and self-paced/process-paced. We worked alternating day and night twelve hour shifts to carry out our interviews, either in the work situation or in some nearby office. The first fact we found was that the distinct characteristics of the work groups that we had selected did not stand up to close examination. On one of the cool jobs, for example, a special batch of alloy steel that was being processed at that time required the men to work on it while it was still uncomfortably hot. Another group that was supposed to be self-paced was in fact intensively process-paced, because of a temporary bottleneck in production and transport arrangements.

The completed sample consisted of thirteen individual work groups, and a total of 315 people. Only one work group that we wished to include was refused to us, apparently because of a local administrative problem. In two of the groups, the mobility of the group made it difficult to count refusals exactly. In the other eleven groups, the refusal rate was never more than 16%, and in 8 of the groups the acceptance rate was over 94%.

The sample is probably typical in demographic characteristics of British production and ancillary steelworkers. Only 3% of the sample were female, employed as industrial nurses. Only 13% of the sample were single, and 84% were currently married. Fortythree percent of the married shiftworkers had working spouses, almost equally divided between full-time and part-time work. Seventy four percent had children, and children living at home were evenly divided across pre-school age, primary school age, secondary school age, and post-school age. The steel industry tends to acquire long service employees, after an initial period of fairly high turnover, so the sample included 11% who had worked for 30 years or more on shiftwork that included night shift, 51% who had worked between 10 and 30 years on shiftwork, and only 38% who had worked for less than ten years. Only 9% of the sample was under 25. Eighteen percent were over 55 years, and a further 29% between 45 and 55 years old. In summary, they were mostly mature married men, with a long experience of working on full three-shift work.

One of the two main shift systems compared was the 2-2-3, where crews rapidly rotate from morning shifts to afternoons to nights to days off. The week is split into three sections, Monday-Tuesday, Wednesday-Thursday, and Friday-Saturday-Sunday. Over the weekend, the pace of rotation is slightly decelerated, so that three consecutive days of the same shift-type (or days off) cover the weekend. The other system was locally invented, and involved four or occasionally five of each shift-type being worked consecutively. One small contrasting group worked 6 of each shift type followed by 2 days off, before rotating to 6 of the next shift type. This used to be a common pattern in the British steel industry, and this small group was sticking to it (by a narrow majority) on the grounds that more than six days of continuous work was bad in principle. The 2-2-3 requires 7 consecutive days of work, if you ignore the 24-hour break at each rotation of the shifts. This small group of 26 men was the only group where a sizeable number were critical of their shift system.

Results

Along a five-point scale of attitude to shiftwork, 18% liked it very much, 29% more than they disliked it, 22% were neutral, 23% disliked it, and 8% disliked it very much. If it is argued that these positive attitudes could be a defensive response to an inescapable fact of their way of working and living (which it might be), this defensiveness did not inhibit them from other complaints and reports of felt disadvantage.

Table 1 shows that the biggest single complaint was about their social life, endorsed by 61%. Complaints about irregular sleeping times comes second, with 47% mentioning it. Working at night, irregular meal times, and early rising (for, in most cases, a 6 am start on morning shift) attracted complaints from over a third of the sample. Only 17% complained about effects on their health, and 9% had no complaints at all.

Table 1

Specific Dislikes About Shiftwork

Question 7 "What things do you dislike about shiftwork?"

	Steelworkers	N.B.P.I.	N.B.P.I.
	Survey	Dislikes	Disadvantages
Effects on social life	61%	22%	27%
Irregular sleeping times	47%	8%*	14%
Working at night	44%	20%	11%
Irregular meal times	38%	11%	11%
Early rising	35%	11%	11%
Effects on health	17%		8%
Other	7%		
No dislikes	9%	23%	10%

*In the NBPI question about dislikes, this was "sleeping in the daytime".
Source National Board for Prices and Income (1970)

This level of complaints is much higher than was found in a sample of 180 continuous three-shift workers studied by a national government agency in 1970. (National Board for Prices and Incomes, 1970). On the other hand it is difficult to be sure that minor differences in questionnaire procedure do not produce major differences in endorsement rates.

In answer to my first question, then, it is quite clear that the social effects of shiftwork have a higher incidence of complaint than the physical effects. I have no material on severity to answer my second question. The only indirect index I have, the relationship with overall attitude to shiftwork, is tipped slightly in favour of the physical effects (Table 2).

Table 2

Specific Dislikes About Shiftwork Tabulated by Overall Attitude to Shiftwork

Q.7. "What things do you dislike about shiftwork?"	Q.8. "On the whole, how do you feel about working shifts?" I like it very much	I like it more than I dislike	I neither like it nor dislike	I dislike it more than I like it	I dislike it very much	Total	tau
Irregular sleep	16%	38%	44%	68.5%	88.5%	47%	-0.46
Effects on social life	29%	51%	64%	84%	89%	61%	-0.44
Irregular meals	5%	34%	39%	60%	58%	38%	-0.39
Working at night	11%	47%	40%	60%	73%	44%	-0.36
Effects on health	2%	6%	21%	30%	42%	17%	-0.29
Early rising	30%	27%	44%	36%	46%	33%	-0.11
Something else	11%	9%	6%	4%	0%	7%	0.07
Nothing	29%	9%	4%	1%	0%	9%	0.19
Number (100%)	56	90	70	73	26	315	
	18%	29%	22%	23%	8%	100%	

Attitudes to health effects, probably the most worrying sort of physical effect, are more inconsistent and contradictory. Only 17% reported that they disliked the effects on their health. Yet at another point, a shift description scale, 37% describe shiftwork as "unhealthy". At the other extreme, when asked, "How do you regard your own general health?", only 4% chose the answer "below average for your age." 56% were safely average, 19% above average, and

20% in very good health. The most parsimonious interpretation of these inconsistencies is perhaps that many more people are alarmed by popular stories of the health dangers of shiftwork than are aware of ill-effects on themselves.

It is perhaps worth reporting, in view of some concern expressed about excessive self-medication by shiftworkers, that our sample appeared to be strongly opposed to drugs of any kind. 96% said that they never took sleeping pills, 66% said that they never took any pills or medicine for indigestion (and only 4% "often"), and 38% said they never took pills or medicine for pains. Questionnaire answers are not the most accurate way of obtaining this information, no doubt, but the answers are reassuring to those who are worried about shiftworkers becoming too pill-propped. Incidentally, the industrial nurses and the laboratory chemists were the two groups with the lowest proportion of "never" answers on these questions. This is probably as much a matter of awareness as of access.

Relative Social Effects

Turning to the relative social effects, one page of questions was concerned to find out for a wide range of activities whether the shiftworkers felt themselves "worse off", "better off", or "not affected". The results fall, in ascending frequency of bad effects, into four groups. First are the activities where a clear majority of the sample reported that they were worse off. Table 3 lists the seven activities in this category. Working at weekends, which happens to most continuous shiftworkers on three weekends out of four, is the most widely felt disadvantage. The cultural pull of the weekend of relaxation, and the peaking of popular mass activities then make this an extremely widespread problem, in spite of extra pay at weekends.

Table 3

Activities in Which a Majority of Shiftworkers Said They Were Worse Off

Activity	Worse Off	Not Affected	Better Off
Weekends	77%	21%	2%
A full social life	69%	28%	3%
Watching Sport	66%	31%	3%
Attending social organinzations	61%	38%	1%
Planning social engagements	55%	35%	10%
Following a regular TV series	51%	49%	0%

N: 315

Yet here too there are individual differences. There have been some instances near my home of factories manned by different crews at weekends, using people who were willing to work then, and were consequently free from Monday to Friday after working two 12-hour shifts at weekend rates. Weekends are also clearly open to variations between cultures and over time, and in different locations. I have a son who is working at the moment on a sheep farm in New Zealand, where work stops for a 2-day weekend. As he is remote from any focus of social activity, he reports that he would prefer to be working. I suspect that alternative manning systems for weekends would be very popular among most shiftworkers, and will spread more widely.

It is also worth noting that at least three of the items with a majority reporting that they are worse off are of the fixed time kind: watching sport, attending social organizations, and following a regular T.V. series. In Blakelock's (1960) terminology, such events have low "liquidity", although the spread of video-recorders may ease the problem of regular T.V. programmes.

The two remaining items also require some explanation. "Planning social engagements" is more a matter of problems of synchronization rather than of not knowing when they will be working. Even in the most complex-looking rotas, shiftworkers rapidly become expert in working out where they will be on future dates. Occasionally they mean the kind of problems that special occasions such as weddings cause, where a shiftworker knows in advance that he can not easily participate. Here the flexibility of management in permitting the exchange of shifts, and the humanity of co-workers in agreeing to this are the kind of unstated variables that make the difference between tolerable and intolerable shiftwork.

The last item, "a good sound sleep", is not usually thought of as a social activity, primarily. Some objective non-social activities like this were included to provide contrasts. It should be noted that although this gets into the top seven in the table, it only just scrapes in.

Two items were felt as disadvantages by a substantial proportion of shiftworkers but not the majority. Table 4 shows that although only 1 shiftworker in 5 claims to be better off for time with the family (and these are mostly the parents of young children whose activities may be largely missed by the average dayworker), 42% claim that they are "not affected". It is quite possible to carry on a normal family life with rotating shiftwork. The other item, "a night out with the boys" is an interesting contrast. Rapidly rotating shiftwork allows some evenings off every week, and this probably accounts for its greater popularity and rapid spread, compared with the traditional weekly rotating systems where the week of afternoon shift followed by a week of night shift has been called the "dead fortnight" (Walker, 1966). Some shiftworkers pointed out to us that the other disadvantage of the weekly changing systems is that few of them could afford to go out every night of the week in their morning shift week. Lastly, it should be pointed out that a "night out with the boys" is incompatible with "time with the family". Sometimes it seems to me that the model dayworker with whom the poor shiftworker is contrasted can have no time to relax at all because of his active social life. This pair provide an illustration of a possible role-conflict for dayworkers too.

Table 4

Activities in Which the Majority of Shiftworkers Were Divided

Activity	Worse Off	Not Affected	Better Off
A night out with the boys	49%	48%	2%
Time with the family	33%	42%	19%

Table 5 lists the third group of activities where the majority of shiftworkers reported that they were not affected. These fall into two main groups: first, where there are more worse off than better off, including both fixed-time activities, like going to church and study classes, as well as generally pervasive matters like a happy family life and enough time with your wife. Television, incidentally, and cinema are scorned by the majority, and it would be interesting to know how many dayworkers escape into these activities rather than into the active social lives envisaged by some researchers.

Secondly are a group of activities where more claim to be better off than worse off, ranging from fixed time activities that can be difficult to fit into a dayworking routine, such as visiting banks, business offices, and shops, and two work-related topics, pressure at work and overtime. The advantage of shiftwork in escaping the heavy hierarchies of daywork is not to be scorned. Shiftworkers were probably operating in autonomous working groups long before anyone else thought about inventing them. The answer on overtime is more ambiguous. In my earlier survey (Wedderburn, 1967), the reduction in overtime made possible by well-paid shiftworking jobs in a new steelworks was seen as a great advantage in giving more time off. But certainly some of our shiftworkers had plenty of opportunities for overtime, and some used them. It is perhaps a peculiarly British tradition to work long hours, and probably equally as harmful on social life as shiftwork is. It was recently reported that 13% of male manual workers still work more than 54 hours a week, and a further 14% work between 48 and 54 hours (Equal Opportunities Commission, 1979). For many men, this is seen as a way of making extra money and thus providing richer lives for their wives and families. For employers, even in times of high unemployment, it provides a way of keeping basic labour costs under control, and providing temporary rewards to good employees. It will not easily be changed.

Lastly, in one group of activities a majority of shiftworkers reported that they were better off than dayworkers. One of these, variety in working hours, is ambiguous. Three are quite clearly related to the advantages of being free in the day time, when it is light and the social activities of the community are not at a peak. Perhaps it is wrong to include "time for yourself" under social effects, but there are certainly some personal and psychological advantages to be had from being free when everybody else is not.

Table 5

Activities in Which Majority Reported Being Not Affected by Shiftwork

Activity	Worse Off	Not Affected	Better Off
Television	44%	51%	5%
A chance to join a local club	40%	48%	2%
Enough time with your wife/friend	39%	52%	9%
Communications with daytime management	37%	60%	3%
A happy family life	34%	60%	6%
Playing sport	26%	69%	5%
Health	23%	75%	2%
Going to church	23%	76%	1%
Study classes relevant to work	16%	82%	2%
Cinema	12%	86%	2%
Pressure at work	16%	63%	21%
Overtime	12%	63%	25%
Shopping	10%	57%	33%
Getting to the bank	4%	57%	39%
Getting to business offices	5%	56%	39%

Table 6

Activities in Which Majority of Shiftworkers Report Being Better Off

Activity	Worse Off	Not Affected	Better Off
Pay	5%	7%	88%
Freedom in the Daytime	18%	16%	66%
Time for yourself	19%	20%	61%
Free time	19%	24%	57%
Variety in working hours	26%	19%	55%

Pay is in a different category. Most shiftworkers are paid a premium for working at night and at weekends. More than that, being prepared to work shifts opens up a range of jobs, usually well-paid ones, that are otherwise ruled out. This is an area where one part of me insists that people should be free to choose such work if the balance of costs and benefits in their own personal equation leads to the result being positive. Pay is a very flexible kind of advantage too, and although many shiftworkers argue that their cars are totally necessary for travel to work at unusual times, their cars are one example of the opportunities they and their families have for greater mobility and an enriched social life. The other bit of me is well aware that we do not operate in a truly free market economy. Many shiftworkers are tied by their narrow skills to a shiftworking industry. Many are not aware of other better paid jobs that they could do. Many are tied to localities from which it would be costly and socially disruptive to move. Financial freedom and financial slavery are closely intertwined, and it is easy to sympathise with the case put by Thierry, Hoolwerf, and Drenth (1975) for making more of the compensation for shiftworkers psychological rather than financial. In particular, many of those who dislike shiftwork may be tied to it by financial chains. Yet I hesitate to suggest removing financial incentives: It seems only fair to compensate those who undergo additional hardships, providing these are not causing them any real damage.

Demography

Some divisions by demographic sub-groups are illuminating. Deprivation of weekends is an exception, as it is felt equally by young and old, manual and white-collar, new and experienced shiftworkers. Access to banks, offices, and shops is less important to manual workers and older shiftworkers. Probably this reflects a cultural shift in the use of banks and in the division of the shopping role in the family (Marsh, 1979). There were also regional differences here, with the older community in Scotland showing more traditional attitudes.

Demographic variables obviously moderate effects on the family. Married shiftworkers with no children liked shiftwork most, and those with children under 5 least, with many exceptions. Married people are less inclined than single ones to describe afternoon shifts as "sexless", and 52% of them reject that description for night shift too. Single people seem to be more restricted to morning shift for such activities.

However the interaction of the pair-bond relationship with shiftwork is extremely complex. Clearly a good and stable relationship can overcome the minor obstacles created by shiftwork, and is an important support for the shiftworker; shiftwork may even be an important reinforcer of shared roles and activities. It is also clear that the spouse and family are more closely affected by the hours of work with shiftworkers than with most dayworkers. However, it has recently been reported that "there is evidence that the school performance and the emotional adjustment of children of fathers working shifts or of working mothers is not impaired", (Equal Opportunities Commission, 1979), unlike the children of fathers who are away from home (Sutton-Smith, Rosenberg, & Landy, 1968). Certainly until some marriages have been experimentally arranged, it seems wrong to come to any bold conclusion about the effects of shiftwork on marriage.

The next circle of relationships, keeping in touch with friends, has been quite widely investigated. Our data suggest that some obvious relationships are supported: those with more shiftworking friends have less dislike of the effects of shiftwork on their social lives; and those travelling longest in time from home to work have fewer shiftworking friends (which may be a special feature of steelworks communities, which tend to dominate their immediate surroundings). Questions must be asked, again, about the individual's freedom of choice. If some people choose to travel further to work and live among non-shiftworkers, in spite of the increase in problems in their social lives, then providing they know what they are doing, surely this is a basic freedom? Even some ancient universities that used to insist on residence within a small radius of the university by staff and students tend to relax these rules nowadays.

The next circle of relationships, belonging to and attending social organizations and clubs, produced the finding that there was a linear relationship between number of organizations belonged to and difficulty in attending them. This must be true of dayworkers too. It does again raise primary, and perhaps unanswerable questions. What should the level of organizational commitment outside work be? Democracy depends upon some level of this, but essentially there is never enough of it for some people; and its conflict with husband and father roles in the home is obvious, if not always stated.

Physical Interactions

Lastly, many of the positive advantages of shiftwork, in terms of more pay and more time off at uncrowded times, seem to be restricted if there is a higher awareness of circadian dysrhythmics and disturbed sleep. The relationships are not simple, and indeed long sleepers (on a questionnaire self-report basis) appear to be just as handicapped as disturbed sleepers. There is at least a possiblility that the "tough" and "hard" image that led me to describe shiftworkers recently as "supermen" (Wedderburn, 1979) also leads to under-reporting of sleep difficulties and social problems, giving a spurious correlation.

It is also of concern for the practical side that a particular type of shift system, such as rotation, should not be condemned on the basis of some instances where it is less successful. Rotation is open to a wide variety of systems, which not even shiftworkers always find easy to imagine. Rotation is fair in its distribution between individuals, and rapid rotation can be very flexible for individual needs. While there may sometimes be sound arguments for allowing rotating shiftworkers to polarize into voluntary day and night people (De la Mare and Walker, 1968), it is important to ask how such arrangements are related to the type of work and the domestic circumstances of those concerned.

Secondly, for research programmes, it seems important to carry out more detailed studies of shiftworkers to examine the relationship between "quality of life" and the physical effects of shiftwork. In some cases, it may be possible to carry out experiments, improving physical problems with some of the techniques developed to treat insomnia; or by varying the circadian effects by allowing a small group to alter their shift system. Natural experiments like this are occurring all the time, and the problem for the researcher is to achieve sufficient forewarning to undertake good before and after studies. It should also be possible to study some of the reverse interactions. Some groups of shiftworkers, on oilrigs, on extended military exercises, and on isolated construction sites, for example, have periods where the social distractions from perfect shiftwork and sleep patterns should be removed. This may, however, be a forlorn hope. The pattern of cultural pressure is so strong that some of these groups seem to simulate day-work social activities under ideal conditions for an isolated total inversion of day and night. It is almost as if the abnormality of their way of life makes the attraction of anything "normal" more powerful. There is also a need for more research into the problems of women who work on shifts. In an area of increasing and concerned debate in Britain, facts are thin on the ground, and valued societal institutions, such as the family, are even more vulnerable. Yet an increasing number of women are working industrial shiftwork, and many others have long experience of it in the service sector.

Thirdly, I have recently attempted to study the time priorities of matched shift and day workers, in an attempt to see how the exchange rate of time fluctuates. The preliminary conclusions are that shiftworkers and dayworkers have very similar values for different days and hours. Weekends and evenings do not lose their appeal if you are deprived of them regularly, and in fact there is some evidence that this contingent partial reinforcement leads to elevated values for them. Yet the sheer diversity and multiplicity of human situations and preferences is so enormous that there are clear problems about coming to conclusions. An intensive study of personal lives with anticipated and received values of different activities might clarify the picture, but would be intrusive into the privacy of people's lives. Tasto, Colligan, Skjei, and Polly (1978) conclude that "it should be relatively easy to assess shift worker preferences and then to maximize a successful match between those choices and all the possible permutations of shift work scheduling." I share the underlying value of flexibility and consultation, but suspect that the final equations may be better worked out by shiftworkers themselves than by any planners. Spilling over from the physical effects of altered work-sleep schedules into the social and personal lives of shiftworkers runs us into some of the most fundamental questions about the meaning and purpose and priorities of human life. Perhaps an avoidance of generalizations, and a continued search for better pictures of their experience to illuminate situations for their fellow shiftworkers is the best contribution that we can make to helping them to answer these questions for themselves. As one wise old shiftwork researcher concluded, "Personal, social, and organizational factors interact to an extent which makes generalizations about attitudes to shiftwork dangerous." (Sergean, 1970).

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HEALTH PROBLEMS IN SHIFTWORKERS

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When in 1972 a new wire mill came into operation, we took the opportunity to study a group of 104 male shiftworkers who were recruited to work in the plant on a semi-continuous four-shift system. These subjects were randomly selected out of a total work force of a few hundred workers. At the time of their first testing, they were in training and were working on normal day shifts. Forty-three of the 104 subjects had never worked in shifts before, but the remaining 61 had had various amounts of shiftwork experience. All subjects were extensively interviewed, and were asked to fill in some questionnaires and to rate themselves on various scales.

After six months in 1973, the subjects were examined a second time using the same test procedures. At that time, 96 out of the original 104 were still present, and had been working on the shift system since shortly after the time of the original examination.

A third examination took place in 1976, 4 years and 4 months after the first one. At the time of this third examination, 64 subjects were still working on the shift system. A report on the subjective health of these subjects at this stage was presented to the 4th International Symposium on Night- and Shiftwork, held at Dortmund in 1977 (Meers, Maasen, & Verhaegen, 1978).

A fourth examination was carried out in 1979, seven years after the first one. At the time of this fourth examination, only 51 subjects out of the original 104 were still working on the shift system.

These examinations form part of an ongoing longitudinal [illegible] the health of shiftworkers in this wire mill. Our aim is to study not only those who remain on shiftwork, but also those who leave the plant. We want to know the reasons (health or other) that lead the latter to the decision to quit.

Our subjects are carefully monitored by the medical service in the plant where they are employed, and were originally recruited according to certain medical criteria. Further, they are quite young: The mean age of the 51 subjects still working on shifts presently (1979) is 32.5 years. These facts explain why objectively ascertainable health disturbances related to shiftwork are only rarely (if ever) observed (though other health problems, namely, those related to high noise levels and to the biomechanical stress of weight lifting, do in fact occur in the plant).

A consequence of this situation is that we have to study health (or rather its inverse) as <u>subjectively</u> experienced, and as reported in the form of health complaints for which it is not easy to observe concomitant objective symptoms. Because of this, it might be suggested that we should use the term "subjective health". We are not opposed to doing this, although for some people "subjective" has a connotation of "not really important" or even "not true". Alternatively, it would be possible to use the term "well-being", but this term makes us think of <u>positive</u> health, whereas the complaints of our shiftworkers clearly have to do with <u>negative</u> aspects of health.

In each of the four examinations, the same measuring instruments were used. As already mentioned, we tried to include in these examinations the members of our original group who had left the plant. We did not completely succeed in this objective. On our last (fourth) examination, we were able to obtain the required information from only 40 out of the 53 subjects who had left the plant. Of the remaining 13, four had become white collar workers and for that reason, we did not consider them to be relevant information sources. Others we were not able to locate; a few declined to take part in further study and in a few cases, we only got incomplete or partial information. Thus, of the original 104 subjects, we have data on 51 who are still working on shifts, and 40 who have left.

In our 1979 examination, we extended our study by giving some of our questionnaires to 72 randomly chosen shiftworkers who had also started working in the wire mill seven years ago, but who were not included in our sample at that time (although they had filled in one of our questionnaires during the selection procedure before their enrollment). The mean age of this group is 33.5 years. Since this group was originally selected for shiftwork by the plant management and further self-selected over 7 years, in the same way as the first group of 51 subjects, the two groups can be considered as quite comparable.

We also asked 79 other shiftworkers who had filled in our most important questionnaires during their selection before enrollment in 1978 (i.e., one year previously) to fill in the same questionnaires again. For this group, mean age is 26 years.

We considered that the results from these two new groups of 72 and 79 subjects would serve as a useful check on some of the results obtained from our first group of 51 subjects. Basic characteristics of the different groups are given in Table 1.

Table 1

The Different Groups

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104 examined in 1972 after enrollment
51 still in shifts; mean age: 33.5 y
further examined in 1973, 1976, 1979
40 left the plant
further examined in 1973, 1976, on average 2.5 y after leaving
mean age when they left: 27.5 y
13 "lost"

72 examined in 1972 before enrollment
all still in shifts; mean age: 33.5 y
further examined in 1979

79 examined in 1978 before enrollment
all still in shifts; mean age: 26 y
further examined in 1979

The wire mill produces steel cord used for strengthening tires. Our subjects' work consists of tending wire drawing machines, i.e., keeping the machines running, taking the rolls of wire on and off, etc. Noise levels are very high, so ear-plugs are worn. The work is rather monotonous. From 1972 to 1976 a complete shift cycle consisted of 6 morning shifts (0800 - 1600), followed by 6 afternoon shifts (1600 - 2400), then 6 night shifts (0000 - 0800), and finally 6 days off. In 1976, the sequence was changed and became 6 afternoon shifts, 6 morning shifts, 6 night shifts, and 6 days off. Each working week of 6 shifts runs from Monday until Saturday, and is always followed by a free Sunday.

Measuring Instruments

Besides interviews, we used questionnaires on health, on neuroticism and on fatigue; and also several rating scales.

The first questionnaire was the Inventory of Subjective Health (ISH) known in the original Dutch version used as VCEG (Dirken, 1966, 1967). It consists of 56 questions about subjective complaints, to which the subject answers 'yes' or 'no'; 48 of these questions are used to compute a score which gives an inverse index of general (subjective) health. The other 8 items serve to stimulate concentration during the filling in of the form, and to obviate the development of a particular response set. The different complaints can be analyzed separately, and any patterns in them can be determined.

The second questionnaire was the Amsterdam Biographical Questionnaire (Wilde, 1963). This is a Dutch personality questionnaire, based largely on the Maudsley Personality Inventory and the Heron Two-Part Personality Inventory. The questionnaire yields many different scores; in this study, the N score and the NS score were considered the most important of these. Both scores are alleged to measure neurotic instability; the N score by assessing the frequency of psychoneurotic complaints, the NS score by assessing the frequency of functional somatic complaints. In this study, the NS score was considered simply as a measure of functional complaints, without necessarily implying neuroticism.

The first of two short fatigue questionnaires (Quayhackx, 1967) given consists of 7 statements concerning cumulative fatigue over the day, e.g., "I feel tired in the morning before I start working." The subject has to answer with one of five alternative responses ranging from "never" to "always". It should be noted that in 1979 we tried to make the questionnaire more relevant and more appropriate to the present shift system, by making the wording of the questions more specific. For example, the statement mentioned above became: "I feel tired before I start the morning shift." The second fatigue questionnaire given is concerned with the subject's general habitual level of fatigue, alertness, etc. (chronic fatigue?). It consists of 7 bipolar six-point scales. Each scale has short self-descriptive statements at its extremes, e.g., "I'm interested in everything--I'm intersted in nothing;" "I'm usually sleepy--I'm usually wide awake."

In addition to these questionnaires, we used several five-point rating scales of various functions, of which we shall discuss only the one on which our subjects were requested to indicate how good their appetite generally was.

Finally, the subjects had to report whether they suffered from four digestive symptoms: "never", "sometimes", or "quite frequently".

There is no doubt that the content of some of these instruments overlaps to some extent, but this has the advantage of providing an internal check on the reliability of our results.

Results

Inventory for Subjective Health

The mean ISH scores obtained in the different groups after different amounts of shiftwork experience (seniority) are presented in Table 2. In this and following tables, significant differences relevant to our research are indicated by lines joining the differing values; the actual significance levels are written alongside these lines. Two-tailed tests were used unless otherwise indicated. Tests used were the Wilcoxon matched-pairs signed ranks test, the Mann-Whitney U Test, and (in Tables 8-11) the McNemar test for the significance of changes (Siegel, 1959). Where it has some importance for our argument, values that do not significantly differ are joined by a broken line. It should be noted that all tables from Table 2 on are organized in the same way. In order to keep the tables as clear as possible, the calendar years during which data were collected are given in Table 2 only.

Table 2

Mean ISH-Scores in the Different Groups

Seniority		51 Workers	40 Workers	72 Workers	79 Workers
			.001		
0 y		6.55 (1972)	7.25 (1972)		3.16 (1978)
	.01		.03 one tailed		
6 m		8.10 (1973)	9.74 (1973) (N = 34)		.001
1 y	.001				6.72 (1979)
			.05 one tailed		
4y 4m		12.35 (1976)	19.00(1976) (N = 7)		
	.0002			.002	
7y		16.92 (1979)	.05	12.84 (1979)	
		.005	10.53		

In Table 2 we see that the first group of 51 workers shows a regular increase over time in the mean ISH score. The increase from each examination to the next is significant at at least p <.01. For the group of 40 workers who left the plant, the table shows mean scores computed from those still in service at the times the different examination took place, namely on 34 subjects in 1973 and on 7 in 1976. The increase from 1972 to 1973 (6 months seniority) is significant (p <.05, one-tailed) as is also the increase from 1973 to 1976 (after a further 3 years 10 month experience) (p <.05, one-tailed). At the bottom of this '40 Workers' column is the mean score obtained in these 40 subjects at an average time of 2 years 6 months after they had left the plant. This score is significantly lower than the present (1979) score of the 51 workers ($p < .005$), but it is higher than the first (1972) score of the group itself ($p < .002$). When we compare the last score obtained from this group of 40 subjects when they were still working in the wire mill with their score after having left the plant, we find no difference. [This last score obtained when still in the plant is not shown in the table: It is the mean of the scores of 34 minus 7 subjects examined in 1973 and of 7 subjects examined in 1976.] We may perhaps conclude that leaving this work situation leads to some stabilization of the level of complaints.

Turning now to the group of 72 subjects who started work 7 years ago in 1972, but who were given the Inventory for Subjective Health for the first time only this year (1979), we see that their mean score is 12.84. This score is significantly lower ($p < .05$) than that of the 51 workers having the same seniority in the same work situation. A possible explanation for this is that repeated exposure to a list of complaints increases the tendency to acquiesce and hence increases the number of complaints admitted to. [It must be remembered that there is some difference between answers to questionnaires and actual physical measurements.]

Finally, we have to consider the results of the 79 workers who started work in 1978, one year ago. At that time, they filled in the ISH as one of their selection tests. The mean score obtained then was 3.16. This value is significantly lower than the value obtained by the 51 workers when they also had 0 years seniority. But the latter filled in the ISH during an interview by a scientific researcher, whereas the former were probably not very inclined to complain about their health during a selection procedure, and moreover, some candidates who scored high on this test were probably not enrolled. The mean score obtained by these 79 workers after one year's experience has increased to 6.72, which is not significantly different from what the score of the 51 workers after 6 months was, namely 8.10.

We may conclude that the results from the two "new" groups of 72 and 79 workers confirm those obtained from our first group.

Amsterdam Biographical Questionnaire

The mean N-scores from this questionnaire are given in Table 3 and the NS-scores in Table 4. The N-score has significantly increased over the 7 years in both the 51 workers and the 72 workers, but for the group of 79 there has been no increase after one year, although their score is comparable to the score of the 51 workers after 6 months. The subjects who left the plant show a comparable increase. There is no significant difference between their last scores in the plant and their scores some time after leaving it. There are no signigicant differences between the last scores of the different groups. The N-score is not particularly relevant for our study, although there are reasons to think it has some small value in predicting the probability of leaving this work (and possibly other similar work). When we analyzed our 1976 data, we computed a point biserial correlation coefficient between the N-scores obtained in 1972 and presence or absence (having left) in 1976. The correlation was .169, which is significant at the .05 level.

Table 3

Mean N-Scores in the Different Groups

Seniority		51 Workers		40 Workers		72 Workers		79 Workers
0 y		34.24	.02	43.80		41.89		38.09
		.02		.02				
6 m	.0002	39.00		51.00				
				(N = 34)				
1 y		.02		.05		.05		38.52
4 y 4 m		39.24		63.86				
		.007		(N = 7)				
7 y		48.67				47.32		
				52.48				

The NS-score pattern is very similar to that of the ISH scores. The 40 subjects who left the plant show, some time after leaving, a significantly lower score than the 51 who are still in the plant. The 72 workers with 7 years seniority do not differ from the 51 with the same seniority. The 79 workers with one year seniority yield a mean score that has increased by an amount that is about what would be expected from the others groups' trends.

Table 4

Mean NS-Scores in the Different Groups

Seniority		51 Workers		40 Workers		72 Workers		79 Workers
0 y		15.12		14.83	.02	14.68		14.34
		.02					.03	
6 m	.001	16.39/		16.62				.03
			.0001	(N = 34)		.0001		
1 y	.001	.02		.002				15.56
							.003	
4 y 4 m		18.47/		24.86				
		.01		(N = 7)				
7 y		21.27				18.76		
			.04	18.03				

Fatigue Questionnaires

The scores obtained from the first fatigue questionnaire are given in Table 5, and those from the second in Table 6.

Table 5

Mean Scores on the First Fatigue Questionnaire in the Different Groups (Fatigue Over the Day)

Seniority		51 Workers		40 Workers	72 Workers
0 y		14.75		15.15	
		.002		.002	
6 m		16.14		17.24	
	.002	.0002 .05 one tailed	.02	(N = 34)	
4 y 4 m		17.02		18.86	
		.0001 .0002		(N = 7)	
7 y		19.53		16.88	18.71

Table 6

Mean Scores on the Second Fatigue Questionnaire in the Different Groups (Chronic Fatigue)

Seniority		51 Workers		40 Workers	72 Workers
0 y		13.20		14.15	
			.05		
6 m		13.20		15.29	
				(N = 34)	
4 y 4 m		13.80		18.86	
	.04		.05	(N = 7)	
7 y		15.63		13.98	16.14

On the first questionnaire, which assessed fatigue cumulation over the day, the 51 workers show significantly increasing scores from each examination to the next. The 40 workers show a significant increase from 0 to 6 months, and also a significant difference between baseline score and score obtained after they left the plant. There are no significant differences between the three groups on their latest examinations. These results suggest that there is perhaps somewhat more "fatigue over the day" than 7 years ago. But it must be remembered that we changed the wording of the questionnaire for the last examination of the 51 and 79 workers, so that we have to be somewhat cautious in comparing the scores from this examination with those from earlier ones.

On the second questionnaire, which assessed a sort of chronic fatigue, the subjects who were to leave the plant showed an early increase in their fatigue score. In this group, the difference between their last score in the plant and their (lower) score after leaving is significant at p <.02. So this "chronic" fatigue seems to disappear after leaving this work situation. By contrast, the subjects who are still in the plant have shown a significant increase in score during the last 2 years 8 months. The 72 workers do not differ from the 51, after 7 years experience.

Appetite

The mean scores from this scale are given in Table 7. High scores indicate poor appetite. For both the 51 and the 40 workers, appetite gets worse after 6 months of shiftwork, but for the 51 it is significantly better after 4 years 4 months than it was after 6 months. After 7 years, it is as good for the 51 as it was when they started working in the plant. In the 40 workers, appetite after leaving is significantly better than at the time they started shifts. The 72 workers do not differ significantly from the 51, after 7 years experience.

Table 7

Mean Scores on the Appetite-Scale in the Different Groups

Seniority	51 Workers	40 Workers	72 Workers
0 y	2.12	2.23	
	.01	.01	
6 m	2.47	2.56	
	.001	(N = 34)	
4 y 4 m	2.20	2.00	
	.01	.01 (N = 7)	
7 y	2.13		2.04
		1.75	

Digestive Symptoms

To assess the prevalence of digestive symptoms, our subjects were requested to indicate by checking "never", "sometimes", or "very frequently", whether they suffered from any of the following: heartburn, stomach-ache, a feeling of oppression in the upper abdomen, and difficulties with bowel motions. In Tables 8-11, the numbers of subjects replying "never" for each of these symptoms are given. Two-tailed significance levels for the differences between different groups and examinations are indicated. McNemar's test for the significance of changes (Siegel, 1956) was used here.

Table 8

Numbers of Subjects in the Different Groups "Never" Complaining of Heartburn

Seniority		51 Workers				40 Workers	72 Workers
0 y		46				32	
			.01				
6 m	.001	35				21 (N = 34)	
					.01		
4 y 4 m		26	.01	.001		2 (N = 7)	
7 y		19					36
						21	

In Table 8, we see that progressively fewer and fewer of the 51 workers say that they never suffer from heartburn. In the 40 workers who left, there are still more cases of heartburn than at the time they started working in the plant. The 72 workers do not differ from the 51, after 7 years experience.

Table 9

Numbers of Subjects in the Different Groups "Never" Complaining of Stomach-Ache

Seniority		51 Workers			40 Workers		72 Workers
0 y		50			36		
	.001		.05				
6 m		44			28 (N = 34)		
			.001	.01			
4 y 4 m	.001	29			1 (N = 7)		
			.05				
7 y		19				.01	45
			.01		27		

Table 9 shows the numbers of workers who never complain of stomach-ache. We see that the number progressively decreases in the 51 workers, whose situation after 7 years is worse than that of the 72 workers. In the 40 workers, there is some deterioration at first, but after leaving, their situation becomes better than that of the 51 workers.

Table 10

Numbers of Subjects in the Different Groups "Never" Complaining of a Feeling of Oppression in the Upper Abdomen

Seniority		51 Workers		40 Workers	72 Workers
0 y		40		32	
	.01			.01	
6 m		33	.05	14 (N = 34)	
4 y 4 m	.01	28		2 (N = 7)	
	.001				
7 y		18			41
			.02	24	

Table 10 shows a comparable result for feelings of oppression in the upper abdomen. The 51 workers have progressively more complaints. Their situation after 7 years is worse than that of the 40 workers after leaving.

Table 11

Numbers of Subjects in the Different Groups "Never" Complaining of Difficulties with Bowel Motions

Seniority		51 Workers		40 Workers	72 Workers
0 y		49		38	
	.05		.02		
6 m		40		25 (N = 34)	
	.01				
4 y 4 m		37		5 (N = 7)	
	.01		.01		
7 y		36			53
				30	

In Table 11 we see that there is an increase in complaints about difficulties with bowel motions between the start and 6 months seniority, but from that point on, there is some stabilization in the different groups.

Discussion and Conclusions

In this research, we made exclusive use of subjective methods (i.e., questionnaires and rating scales), thus raising some problems in interpretation of the results. As already mentioned, we may wonder whether people who are repeatedly requested to fill in the same health questionnaires do not become inclined to check more and more complaints. For that reason we have to be cautious when interpreting the continuous increase in complaints shown by our data. On the other hand, we have to note that there was no continuous increase in complaints about appetite, but in fact a decrease after some time; and for troubles connected with bowel habits, there was a stabilization. Another indication of the validity of our data may be found in the results obtained in the groups examined on only one or two occasions. The mean scores of these groups are roughly comparable to those of our original group if we take seniority into account.

Summarizing the data from our subjects with 7 years seniority, we may conclude that there has been a continuous increase in subjective health complaints, in neuroticism, in somatic neurotic complaints, in fatigue and in digestive symptoms. In most cases, the increases from enrollment to 6 months, from 6 months to 4 years, and from 4 years to 7 years seniority, are each statistically significant by themselves. It seems to us very difficult to give a definitive answer to the question of how seriously this continuous increase has to be taken.

Summarizing the data from our subjects who left the plant, we may conclude that during their period in the plant, their scores were in most cases not higher than those of the workers who stayed. In general, after leaving, their scores did not drop to their starting point (except for chronic fatigue and for appetite). Rather, they either decreased slightly or stayed at the level reached at the time they left. However, in many cases the scores after leaving are lower than the scores obtained from workers with 7 years seniority. [It should be mentioned that a few of the subjects who left the plant took up shift work again in other plants. But discarding the scores of these subjects from the analyses does not change the conclusions.]

Our study is meant to be a study of shiftwork. But are most complaints related to shiftwork and are people leaving because of the shifts? It is clear that a work situation is never completely defined by its shift system. In this plant some other aspects of the work are also possible stressors: physical effort in lifting, noise, monotony, work rhythm, etc. In interviews, we asked 46 subjects why they had left the plant. In only 9 cases were the first reasons mentioned directly connected with the shift system (3 subjects objected to alternating shifts; 3 suffered from sleep disturbances and digestive troubles; 2 had been counseled by their family doctor to change work; another worker's wife was afraid at night). In 7 cases, the main reasons for leaving were related to the work activity itself: monotony, too fast a work pace, etc. In 9 cases, the subjects had been dismissed by the plant management because of unsafe behavior, frequent absences, etc. Perhaps some of these cases are actually cases of difficulty in adaptation to the shiftwork. In the remaining subjects, the reasons for leaving were extremely varied. One subject had passed his exams for the Post Office before his enrollment in the plant, and only worked there because he had to wait several months for a vacancy in the office. Another subject suffered from a chronic skin disease and found it very disagreeable to have to use the common washing facilities in the plant. Some other subjects became white collar workers, and others succeeded in getting jobs for which they were trained at school and in which they expected opportunities for promotion, etc.

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SHIFTWORK AND PERFORMANCE

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The technological advances that have resulted in a doubling of the incidence of shiftwork over the past 20 or 30 years (Walker, 1978), have also produced a change in the type of task on which the shiftworker is typically engaged. In the past, the shiftworker's job was usually of a predominantly manual or perceptual nature (Wojtczak-Jaroszowa, 1977), and placed little reliance on higher cognitive processes. This, however, has changed with the advent of continuous industrial processes and costly complex machinery, like computers, that for economic reasons have to be run continuously. Today, many shiftworkers are required to perform complex cognitive jobs that tap very different information processing capabilities to those demanded by more manual tasks. This is also true in the social services sector where the demand for 'round the clock' services has produced a similar increase in the incidence of shiftwork.

The purpose of the present paper is to show how this change in the nature of the shiftworker's job may affect the optimal type of shift system in terms of maintaining adequate levels of productivity and safety. It is clear that in many situations, e.g., the control room of a large chemical plant, the cost of an error to society may be such that it is essential to maintain high levels of performance efficiency. Unfortunately, there is a paucity of data relating production efficiency and/or accident rate to different types of shift system, and what data there is is difficult to classify in terms of the cognitive load involved in the task. Thus, as Colquhoun (1976) points out we are forced to rely on evidence from laboratory studies, and hope that in the future we will be able to substantiate our conclusions from field studies.

Field Studies

The field studies that have been carried out do at least indicate that there is a problem of impaired efficiency on the night shift. Six of these studies have obtained relatively continuous (i.e., hourly or two hourly) measures of performance, and their findings are summarized in Figure 1. The studies have been ordered chronologically from the earliest (top) to the latest (bottom) study of which the author is aware. Arbitrary scales have been used and these have been chosen to approximately equate the amplitude of the six curves. Some of the curves have been inverted such that for all the curves, the lower the reading the worse was the performance.

In the earliest study, Browne (1949) examined the speed with which switchboard operators answered calls at different times of day or night. The data has been corrected by Browne to take account of the number of calls at any given time of day. Performance speed improved in a fairly linear-manner from 0800 to 1800, and dropped sharply after about 2200 such that it was slower during the night than at any other time of day. The trend in the frequency of making errors when reading meters (Bjerner & Swensson, 1953) shows a rather different trend over the normal waking day, performance decreasing over most of this period and there being evidence of a slight 'post-lunch dip'

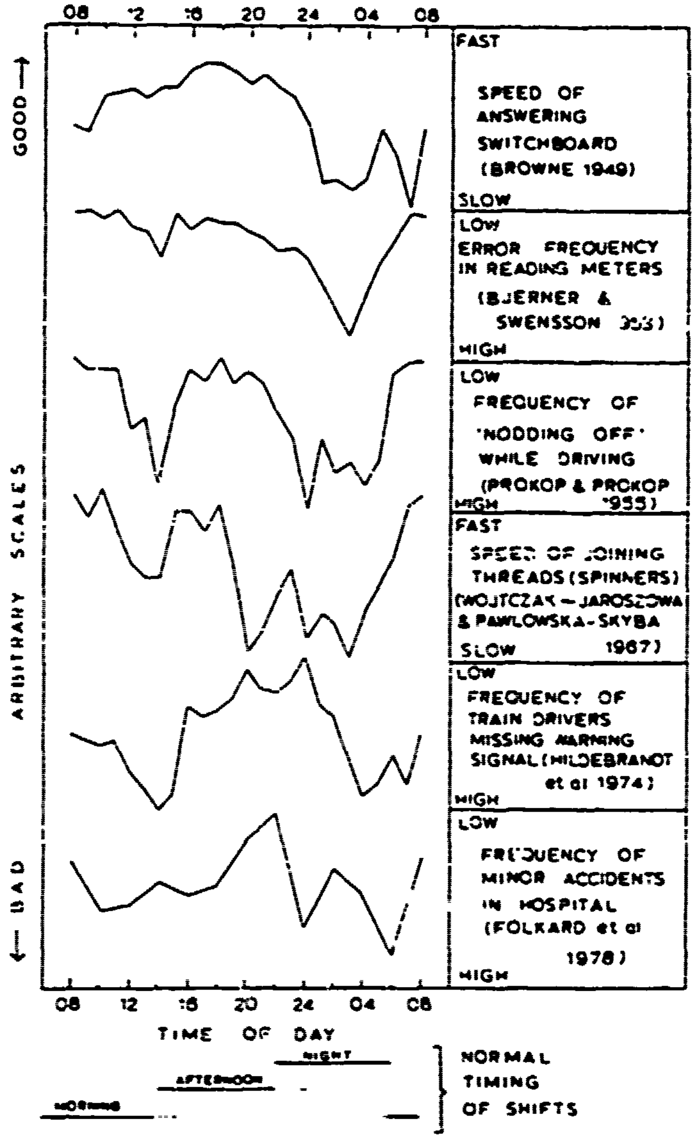

Figure 1. 24-hour performance curves from field studies of shiftwork (From Folkard & Monk, 1979).

(Colquhoun, 1971) in performance. However, again there was a fairly sharp drop in accuracy after about 2200, and performance reached its minimum level during the night hours. The difference in the trend over the normal waking period has apparently been ignored in the past, but may reflect the rather different nature of the task being performed.

The third panel down shows the frequency with which professional drivers reported having 'nodded off' while driving at different times of day (Prokop & Prokop, 1955). In this data the 'post-lunch dip' is even more apparent, with the frequency of 'nodding off' being almost as high at 1500 as during the night period. The reason for this is uncertain, although it has been suggested that the post-lunch dip is more marked in people who are relatively sleep deprived (Hildebrandt, Rohmert, & Rutenfranz, 1974). Again, however, there was clear evidence of an impairment during the night hours. This was also the case in the study of Wojtczak-Jaroszowa & Pawlowska-Skyba (1967) who examined the speed with which five spinners joined broken threads. This study was a particularly detailed one, with about 5,000 measurements being taken in all. The shiftworkers studies had all been on shiftwork for at least 10 years, and were highly proficient at their task. They were studied on the morning (0530 to 1330), afternoon (1330 to 2130) and night (2130 to 0530) shifts, although it is unclear how rapidly they rotated through these shifts. In Figure 1 the data from these three shifts had been combined to give a continuous 24 hour curve. As the authors point out, performance speed was about 10% slower on the night shift than on either the morning or afternoon shift.

The results of another detailed study are shown in the next panel. In this study (Hildebrandt, Rohmert, & Rutenfranz, 1974), automatic recording devices were fitted to the cabs of ten locomotives. Approximately every twenty minutes a warning light appeared for 2.5 seconds, followed by an auditory warning signal for a further 2.5 seconds. If neither of these signals were heeded, there was a thirty second sounding of the hooter in which the driver had to operate the safety gear to avoid an automatic braking of the locomotive. Hildebrandt et al. were able to record a total of 2,238 occurences of the hooter sounding, that indicated that neither of the warning signals had been responded to. Despite the fact that the warning light was more visible at night, more warning signals were missed, i.e., hooters sounded, during the night than in the day, apart from the period immediately after lunch.

The final panel of Figure 1 shows the frequency with which patients incurred minor accidents during their stay in hospital (Folkard, Monk, & Lobban, 1978). In this study, the records of a large modern hospital were examined for a five year period. A total of 1,854 'unusual incidents' occurred during this period, of which 1,576 were minor accidents involving a patient, and for which there was a clear indication of the time of occurrence. Only 30% of these accidents resulted in any injury to the patient, and in the majority of these cases (80%) only minor scratches or bruises were sustained. As can be seen from Figure 1, the frequency of these incidents tended to decrease over the normal waking period, and to increase over the night, despite the fact that most patients are asleep during the night hours. The two 'peaks' at 2200 and 0800 appeared to be due to the patients need to 'pass water' before going to sleep at night and on awakening in the morning.

In this last study it is, of course, unclear whether the data represents variations in patients 'accident proneness', or variations in the 'vigilance' of the nursing staff. Nevertheless, taken together the results shown in Figure 1 suggest that there is a problem of impaired efficiency and reduced levels of safety during the night. This conclusion is supported by the results of other studies that have examined performance efficiency on different shifts but have been unable to extract relatively continuous data. Thus, for example accidents on the night shift have been found to be more serious but, for some reason in this study, less frequent than on the morning or afternoon shift (Andlauer & Metz, 1967), while production quality has been found to be poorer at night (Meers, 1975). However, in many of these studies, and in those summarized in Figure 1, there are a large number of potentially confounding factors. Thus, for example, Meers (1975) not only reports lowered production quality at night from a sugar refinery and wire pulling factory, but also notes that there was less adequate maintenance of the machinery at night. It is therefore unclear as to whether the lowered quality was due to the impaired efficiency of the shiftworkers themselves or to that of the machinery they operated.

Experimental Studies

In order to overcome the potential contamination of performance measures by other factors, a number of researchers have conducted experimental studies, often using naive shiftworkers in laboratory settings. These experimental shiftwork studies have examined the disruption of the subjects' circadian (around 24 hours) rhythms in performance efficiency on various tasks. Before considering the results of these studies, and their implications for the optimal scheduling of shift systems, it is necessary to consider the evidence for circadian rhythms in the performance of different types of task.

Circadian Rhythms in Performance

Since it is impossible to obtain performance measures from individuals when they are asleep, most studies in this area have only examined performance efficiency over the course of the "normal working" day. Nevertheless, there is a marked tendency to consider the "time of day effect" or 'diurnal variation' observed as reflecting an underlying circadian (i.e., 24 hour) rhythm in performance efficiency. Many of the earlier studies were reviewed by Freeman and Hovland (1934) and Kleitman (1939). More recent general reviews have also appeared, e.g., Kleitman (2nd edition, 1963), Colquhoun (1971), Hockey and Colquhoun (1972), Broughton (1975), as well as more specialized reviews that have considered only particular types of performance, e.g., Monk (1979), Folkard (in press). The purpose here is not to duplicate these reviews but to summarize their conclusions and to draw attention to certain points that seem to have important implications for shiftwork.

Perceptual-motor performance. Many of the studies reviewed by Freeman and Hovland (1934) examined performance on relatively simple perceptual-(or sensory-)motor performance. Freeman and Hovland classified the studies they reviewed in terms of the trend in performance over the day and concluded that "the balance of evidence apparently favours an afternoon superiority for sensory and motor performance" (p 786). Thus, for example, in one of the better of the early studies Gates (1916a) found performance on letter cancellation and maze tracing tasks to improve fairly steadily over the whole of the school day. A similar conclusion was reached by Kleitman (1939), although he failed to distinguish between different types of task; an omission, which has had serious consequences on subsequent research and theory in this area.

Kleitman (1939) ignored the fact that many studies had found certain types of performance to deteriorate over the day. He emphasised those studies of a perceptual-motor kind that had found performance to improve over the day, and drew attention to the parallelism between such diurnal variations in performance, and the circadian rhythm in body temperature. Indeed, Kleitman argued for a causal relationship between these two, suggesting that "either (a) mental processes represent chemical reactions in themselves or (b) the speed of thinking depends upon the level of metabolic activity of the cells of the cerebral cortex, and, by raising the latter through an increase in body temperature, one indirectly speeds up the thought process" (Kleitman, 2nd Ed., 1963, p160). Thus both body temperature and performance efficiency were held to be low immediately after awakening in the morning, and to improve over the day to reach a maximum in the afternoon.

The most direct evidence that Kleitman presents to support his view of a causal relationship between temperature and performance is correlational data between spontaneous changes in body temperature associated with time of day, and the corresponding changes in simple reaction time. This data, representing 120 pairs of readings from a single subject, confounds changes in temperature due to the circadian rhythm with other spontaneous changes mediated by both endogenous and exogenous factors. Subsequently, Rutenfranz, Aschoff and Mann (1972) have controlled for circadian changes, by summing over the different times of day, and have failed to find any relationship between day to day changes in temperature and corresponding changes in reaction time. This suggests that there is no causal relationship between temperature and performance, and that the correlation observed by Kleitman (1939) was due to independent circadian rhythms in temperature and performance that happend to be 'in phase' with one another. As Rutenfranz et al. (1972) point out, such synchronization could well result from the two variables being under the control of the same 'Zeitgebers' or environmental 'time givers'.

Colquhoun (1971) also rejected the idea of a causal relationship between the circadian rhythm in body temperature and that in performance efficiency. However, like Gates (1916b) he argued that both may reflect a circadian rhythm 'sleepiness'. Evidence to support this argument was gleaned from the finding that circadian rhythms in performance are more pronounced in relatively sleep deprived subjects. Colquhoun interpreted this finding in terms of an inverted-U shaped relationship between arousal level and performance efficiency. In view of this postulated relationship, a given change in arousal level may improve, have no effect, or even degrade performance depending on the 'starting' level' of arousal. Sleep deprived subjects were seen as suffering from a lowered 'starting level' of arousal and thus showed a greater effect on performance of circadian variations in arousal level. Colquhoun (1971) therefore supported the idea of a parallelism between the circadian rhythm in temperature and that in performance efficiency, although rejecting the idea of a causal relationship between the two.

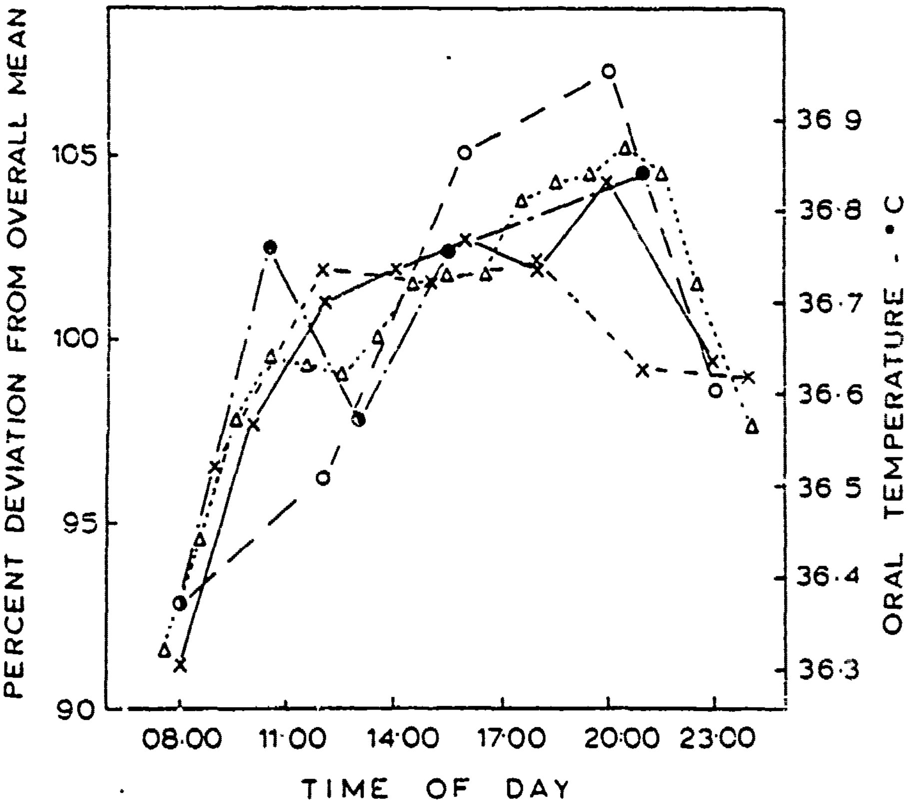

Figure 2. The trend over the day in visual search speed after Blake, 1967 (●——●), Fort & Mills, 1976 (x——x), Hughes & Folkard, 1976 (o— —o) and Klein et al., 1972 (x----x), together with the trend in oral temperature after Colquhoun et al., 1968a (Δ----Δ)(From Folkard, 1980).

The best evidence for a parallelism between temperature and performance changes over the day comes from studies of visual search performance. These studies have all involved subjects searching through alphanumeric characters to find particular 'targets'. The precise nature of the 'targets' appears to be relatively unimportant, and has varied from tilted 'O's embedded in a background of upright ones (Hughes & Folkard, 1976) to the successive occurrence of a particular alphabetic character in random lines of such characters (Fort & Mills, 1976). The results of these studies, in terms of the speed with which subjects searched through the characters, are shown in Figure 2 together with the results of similar studies by Blake (1967) and Klein, Wegmann, and Hunt (1972). Also shown is the normal trend over the day in oral temperature after Colquhoun, Blake, and Edwards (1968a).

Two main points should be noted from this figure. First, these studies of visual search performance agree fairly well with one another that performance is low first thing in the morning, and improves over the day to reach a maximum at about 2000. Secondly, this trend over the day in visual search speed parallels fairly closely the trend in oral temperature. Unfortunately, this latter point does not hold true for other measures of perceptual-motor performance. Thus, for example, Klein, Wegmann, and Hunt (1972) report that reaction time was fastest at 0900 while temperature reached its maximum at 2100. Similarly, Buck (1976) found response speed to reach a maximum considerably earlier than the normal peak in body temperature. Against this, it should be noted that Blake (1967) found fairly similar trends over the day on a range of different perceptual-motor tasks, with performance on these tasks reaching a maximum at 2100, the latest time tested. It is unclear why these different studies have yielded inconsistent results. However, it seems probable that the precise information processing demands of the task employed may influence the phase of the circadian rhythm.

Cognitive performance. The best evidence that the information processing demands of a task may determine the phase of the circadian rhythm in performance comes from studies of more complex, cognitive performance efficiency. In their review, Freeman and Hovland (1934) recognized the need to classify studies according to the type of performance measure taken, but concluded that "...there is little agreement as to the time when complicated mental work can be done most efficiently" (p. 786). Subsequently, the effects of task demands have been largely ignored by reviewers in this area (e.g., Kleitmen, 1963; Broughton, 1975) although Hockey and Colquhoun (1972) noted that performance on memory tasks may show a rather different trend over the day to that for other tasks. Detailed examination of this area suggests that this is indeed the case.

In one of the early studies, Gates (1916a) noted that although performance on simple perceptual-motor tasks improved over the whole of the school day, that on two tests of short-term memory reached a maximum at about 1100 and then decreased over the remaining times tested. Gates (1916b) found a similar function for college students tested over a greater range of different times of day. As a result, he suggested that "in general the forenoon is the best time for strictly mental work" (Gates, 1916a, p. 149).

While there is some cause to doubt the generality of this conclusion (see below), subsequent studies of short-term memory (e.g., Blake, 1967; Baddeley,

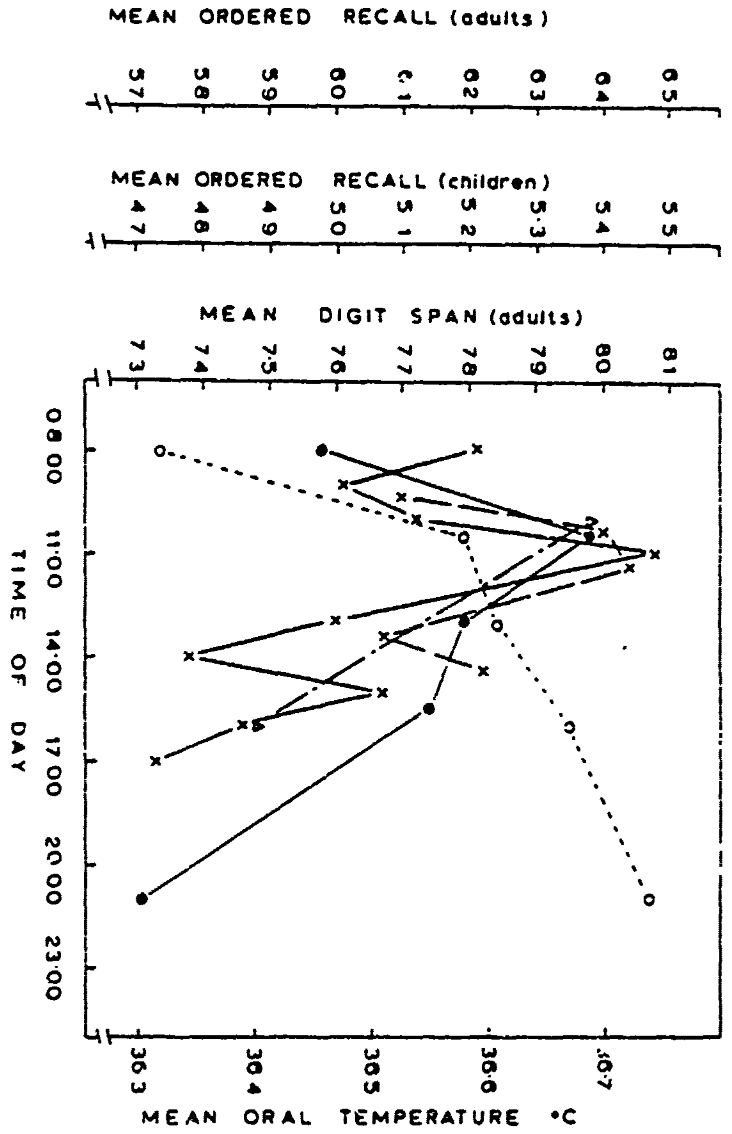

Figure 3. Digit span/sequence performance as a function of time of day after Baddeley et al., 1970 (Δ—·—Δ), Blake, 1967 (●——●), Gates, 1916a (x——x) and Gates, 1916b (x— —x), together with the trend in oral temperature after Blake, 1971 (o·····o)(From Folkard, 1980).

Hatter, Scott, & Snashall, 1970) have found very similar trends over the day. These findings are summarized in Figure 3, together with the temperature readings from Blake's (1967) study of short-term memory. There is considerable agreement between these studies as to the trend in short-term memory over the day. In addition, there is no evidence for Blake's (1967) results that the mid-morning peak in short-term memory was due to the testing of an atypical sample of subjects, since their temperature readings reached a maximum in the evening.

Other studies, e.g., Laird (1925), Folkard and Monk (in press) have examined the immediate memory for information presented in prose. In both studies university or college students were given a scientific article or short passage to read, and then either gave a verbatim written recall, or completed a multiple-choice questionnaire. The results from these two studies show considerable agreement with one another, although the trend over the day differed somewhat to that shown in Figure 3. Immediate memory for information in prose fails to show the initial improvement from early to mid-morning apparent in this figure, and decreased from the earliest time tested, namely 0800 (see Folkard, 1980, for a fuller review).

Further studies have examined the delayed retention of information presented at different times of day and, unlike immediate memory, have found it to be superior following the original presentation of the material in the afternoon or evening (e.g., Folkard, Monk, Bradbury, & Rosenthall, 1977; Folkard & Monk, in press). These findings have also been interpreted as reflecting an increase in arousal over the day. This follows from the finding of a number of studies, using a variety of methods of manipulating arousal level, that high arousal at presentation benefits delayed retention, despite the fact that it sometimes impairs immediate recall (see Craik & Blankstein, 1975; Eysenck, 1977, for reviews of this literature).

More importantly, from the present viewpoint, the short-term memory or storage load involved in the performance of a task has been found to have a substantial effect on the trend in performance over the day. A number of the early studies in this area (e.g., Laird, 1925) examined performance on various mental arithmetic tasks as a function of time of day. Recently, interest in this area has been re-stimulated by the 'working memory' model of Baddeley and Hitch (1974). These authors draw attention to the fact that many 'cognitive' tasks, while not of a 'pure memory' nature, involve the short-term storage of information. Such tasks include reading or listening to prose, as well as verbal reasoning. Often the measures of performance on these types of task of speed, rather than the accuracy measures that predominate in the memory literature. It thus seems reasonable to assume that these tasks involve information processing capacities similar to those tapped by the perceptual-motor tasks described earlier, but in addition involve short-term storage capacities. In view of this one might expect performance on this type of task to show a compromise between the increasing trend over the day found for many perceptual-motor tasks, and the decrease found for short-term memory. Indeed, the precise nature of this trend might be expected to vary systematically with the size of the short-term storage load involved.

The results shown in Figure 4 confirm that performance on memory-loaded 'cognitive' tasks shows a compromise function between that found for percep-

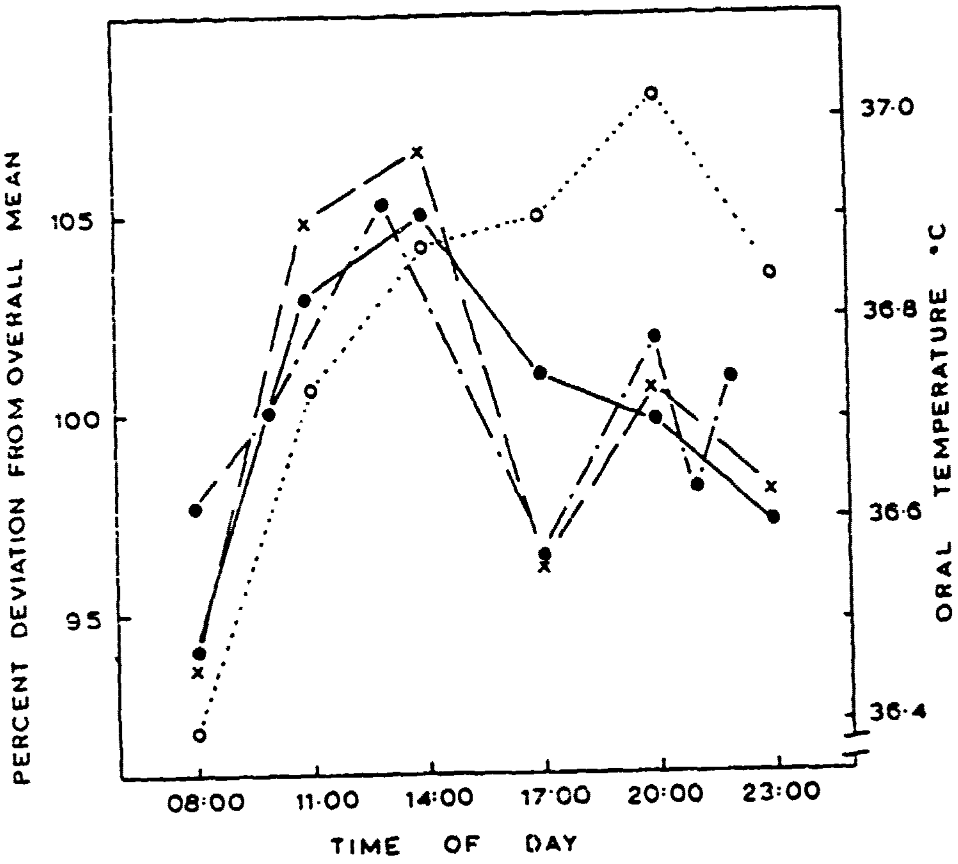

Figure 4. Performance speed on tasks involving 'working memory' as a function of time of day after Folkard, 1975 (x— —x and ●———●) and Laird, 1925 (●—·—●), together with the trend in oral temperature after Folkard, 1975 (c----c)(From Folkard, 1980).

tual-motor performance and that found for short-term memory. In this figure is shown performance speed, on double digit addition (Laird, 1925) and two verbal reasoning tasks (Folkard, 1975). Also shown is the trend in oral temperature for Folkard's subjects. Performance speed on this type of task clearly reaches a maximum considerably earlier than the peak found for visual search (see Figure 2), but somewhat later than that found for short-term memory (see Figure 3).

More direct evidence for the influence of short-term memory load in determining the phase of the circadian rhythm in performance was obtained by Folkard, Knauth, Monk, and Rutenfranz (1976). These authors used a visual search task in which the memory load could be systematically varied by varying the number of alphabetic characters defining the target. Two subjects on an experimental rapidly rotating (2-2-2) shift system performed low (2-target), medium (4-target) and high (6-target) memory load versions of this 'Memory and Search Task' (MAST) every 2 hours 40 minutes while on-shift. Since there was little evidence of any disruption of the circadian rhythm in body temperature, the results from the three shifts were combined to give relatively continuous 24-hour curves. These are shown in Figure 5, together with the circadian rhythm in body temperature. The correlation between temperature and performance changed from being significantly positive for the 2-target version, through being effectively zero on the 4-target version, to being significantly <u>negative</u> on the high memory loaded 6-target version.

Laboratory studies of circadian rhythms in performance have thus shown that there is <u>not</u> a single circadian rhythm in performance efficiency. Rather, the phase of the circadian rhythm in performance would appear to depend on the information processing demands of the task under consideration. There is a clear need for further systematic research in this area to isolate all the important characteristics of the task in determining the phase of the rhythm, although there is already ample evidence that the short-term memory load does so. Indeed, this latter finding would appear to be of prime importance in the shiftwork context in view of the increasingly cognitive nature of the shiftworker's task. The next section thus considers the adjustment of performance rhythms to shiftwork, and the influence of task demands in determining such adjustment.

Shiftwork and Performance

A number of experimental shiftwork studies have included measures of performance efficiency. Most of these studies have used tasks of perceptual-motor performance, and have found the adjustment of the rhythm in performance to follow that of body temperature fairly closely. For example, Kleitman and Jackson (1950) examined performance on choice reaction, colour naming and 'flight simulation' tasks on a rapidly rotating (4-day cycle) shift system, and observed a marked parallelism between colour naming speed and body temperature. Indeed, this parallelism was such that the authors argued that performance efficiency could be assessed indirectly by the measurement of body temperature.

More recently, Colquhoun, Blake, and Edwards (1968a, 1968b, 1969) compared 'permanent' and 'rotating' shift systems and found a similar parallelism between the circadian rhythm in body temperature and that in certain of their measures of performance. This parallelism persisted even though there was evidence of partial adjustment of the tempreature rhythm over successive night shifts on the 'permanent' system. However, there was no evidence of complete adjustment of the subjects' circadian rhythms even after twelve successive nights. Indeed, other studies (Knauth & Rutenfranz, 1976) indicate that it can take up to three weeks for the circadian rhythm in body temperature to completely adjust to night work.

The implication of these findings is that night-shift performance is low for two reasons. First, the phase of the circadian rhythm in the performance of perceptual-motor tasks is such that performance on these tasks is usually at a low ebb at night. Secondly, this circadian rhythm adjusts very slowly to night work, and thus shows little adjustment over the span of 4 to 6 successive nights that is typical of even 'permanent' night workers. It should, however, be noted that these studies have used naive shiftworkers as subjects, and that rather better adjustment might be expected in more experienced shiftworkers (see below).

However, perhaps the most striking prediction to be derived from the studies reviewed in the previous section is that night shift performance of memory loaded cognitive tasks might be expected to be relatively good (see, for example, Figure 5). This prediction is difficult to reconcile with the consistently poor night shift performance found in the 'real life' studies shown in Figure 1. It is, of course, possible that none of the tasks performed in these studies involved a high memory load, although this seems unlikely in the case of, for example, the meter reading study of Bjerner and Swensson (1953). Indeed, the tendency for performance on this task to deteriorate over the normal day is consistent with the view that it involved a fairly high memory load. How then can this apparent contradiction be resolved?

The answer would appear to be that although performance on memory loaded tasks may normally be high at night, the circadian rhythm in such performance adjusts very rapidly to night work, resulting in a <u>deterioration</u> of night shift performance. As far as the author is aware, the first evidence suggesting this rapid adjustment of cognitive performance rhythms was obtained by Hughes and Folkard (1976). They examined the adjustment of the circadian rhythm in body temperature and performance on four different tasks to an experimental 10-day period of an 8-hour phase delay in <u>both</u> the sleep/wake and work/rest cycles. All the measures were taken at 4-hourly intervals (0800, 1200, etc.) while the six subjects were awake for two days prior to the experimental period, and for the last two days of it. Two perceptual-motor (visual search and manual dexterity) and two 'cognitive' memory loaded (double digit addition and verbal reasoning) performance tasks were used.

Hughes and Folkard (1976) analyzed the data in terms of the 'time since getting up effect' which should be identical before, and at the end of, the experimental period if complete adjustment had occurred. Subsequently the author has re-analyzed this data using a novel statistical procedure based on analysis of variance. Briefly, this involves extracting a normal trend over the day for the 'pre-shift' data. The mean score at each time of day is expressed as a difference from the overall mean. These difference scores clearly sum to zero, and can be used as coefficients of orthogonal polynomials in extracting the pre-shift 'time since getting up' trend from the post-shift data (see Winer, 1970, pp. 70-77 for a discussion of trend analysis). The significance of the 'pre-shift trend' in the post-shift data can be assessed by an F test, and the proportion of the variance it accounts for can also be calculated. Finally, the significance of any deviation of the post-shift data from the pre-shift trend can be estimated. It should be noted, however, that this procedure (1) tests only the shape of the trend, not its amplitude and (2) assumes the pre-shift trend to be a perfect estimate of the normal trend over the day. Since this assumption is never valid, the technique will underestimate the degree of adjustment.

The results of this re-analysis of the Hughes and Folkard (1976) data are shown in Figure 6. Clearly all five measures showed considerable adjustment to the 8-hour shift, and the pre-shift trend accounted for a significant proportion of the variance for all measures. However, there was also significant deviation from perfect adjustment (i.e., from the 'preshift' trend) in the case of temperature, visual search, and manual dexterity, but not for either double digit addition or verbal reasoning. Thus, on the last two days of a ten-day phase shift of 8 hours, performance on two memory loaded cognitive tasks showed better adjustment than that on two perceptual-motor tasks.

Further evidence that the rate of adjustment of performance rhythms to night work is affected by memory load was obtained by Monk, Knauth, Folkark, and Rutenfranz (1978, Experiment II) using 2- and 6-target versions of the MAST test described in the previous section. In this study 2 naive shiftworkers took part in an experimental shift work study involving 21 successive night shifts. The two versions of the MAST test were given every four hours throughout the study. In analyzing the results, 24 hour cosine curves were fitted to successive four day windows. The phase estimates were then expressed as deviations (in hours) from perfect adjustment. The results, averaged over the two subjects, are shown in Figure 7.

The most striking finding shown in this figure is that even on the first four-night window the phase of the circadian rhythm in 6-target (high memory load) MAST performance was within 2 hours of perfect adjustment. Indeed this rhythm was perfectly adjusted, in terms of phase, by the tenth night. The performance rhythm on the 2-target (low memory load) version of MAST adjusted more slowly, as did rectal temperature, with both measures achieving complete adjustment only after 16 nights. As in the Hughes and Folkard (1976) study, the conclusion to be drawn from these results is that the performance rhythm for cognitive, memory loaded tasks adjusts more rapidly to night work than either that for simple perceptual-motor tasks, or the circadian rhythm in body temperature.

Both the Hughes and Folkard (1976) and the Monk et al. (1978) studies used naive shift workers, interpolated measures of performance, and relatively small numbers of subjects. It is therefore unclear whether their findings can be generalized to experienced shift workers and more realistic tasks. An opportunity to remedy these problems arose as part of a large scale shiftwork study (Folkard & Monk, in press).

Fifty nurses were shown an 'in-service' training film on the use of Radium therapy at 2030 or at 0400. Their memory for the information presented was tested both immediately, and after a period of 28 days. In addition, two-

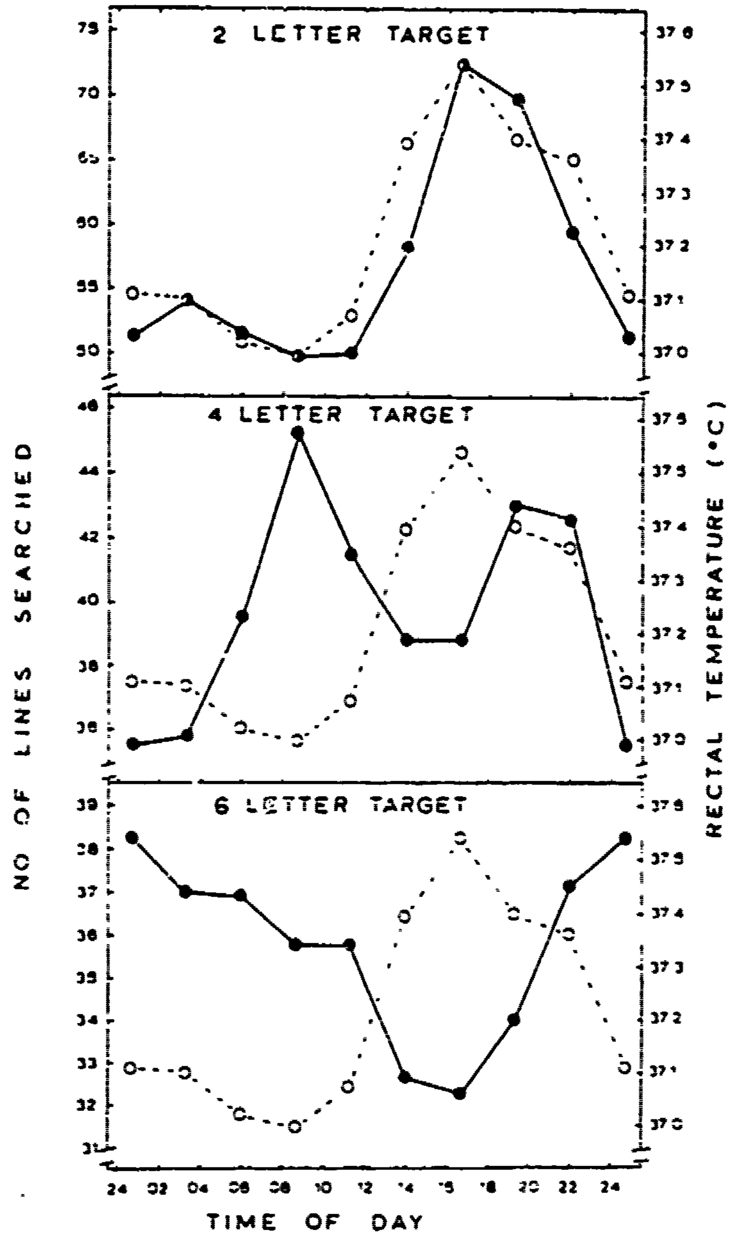

Figure 5. Performance speed on low (2-letter target), medium (4-letter target) and high (6-letter target) memory load versions of a visual search task as a function of time day, together with the trend in rectal temperature, after Folkard et al., 1975 (From Folkard & Monk, 1979).

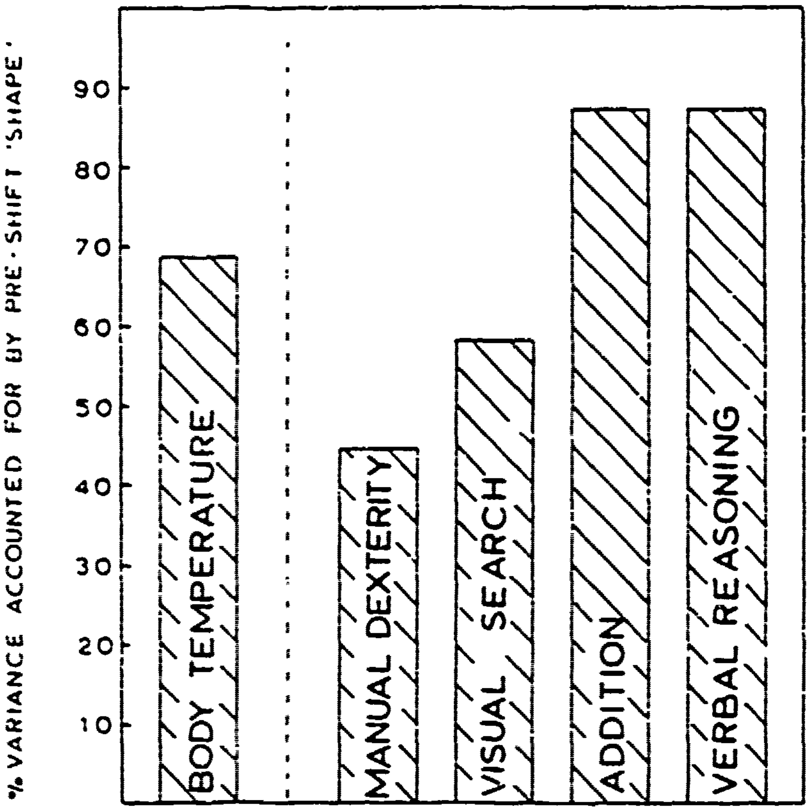

Figure 6. The degree of adjustment of the time of day effect in body temperature and four performance measures at the end of a ten-day period of an 8-hour shift in living routine after Hughes & Folkard, 1976 (From Folkard & Monk, 1979).

hourly measures of temperature and affective state were obtained over the course of the night shift on which the film was shown. All the nurses were 'permanent' night workers, half of them being full-timers who worked four nights a week, and the other half part-timers, who worked only two nights a week. The film was shown on the first or second night of any given nurse's span of successive night shifts.

The immediate memory results were scored simply in terms of the number of questions correctly answered (out of 20). Each nurse's 28-day delayed score was expressed as a percentage of her immediate score in order to provide an index of delayed retention that was unbiased by the level of immediate memory. The slope of the best fitting straight line to each nurse's temperature scores on the night she saw the film was taken as an index of adjustment to night work. These adjustment scores were used to divide the nurses into those showing 'good' adjustment and those showing 'poor' adjustment (on the basis of a median split) when they saw the film. The results are shown in Figure 8.

As predicted, the group showing poor adjustment had higher immediate memory scores at 0400 than at 2030, but the reverse was true for those showing good adjustment. In contrast, delayed retention appeared to be unaffected by the level of adjustment. Clearly these results confirm that the circadian rhythm in immediate memory adjusts particularly rapidly to night work. Thus, while the immediate memory scores of the good adjusters seemed to show complete adjustment, this was not the case for their temperature rhythms. These results also indicate that the circadian oscillator responsible for the effect of time of presentation on delayed retention differs from that responsible for immediate memory. Finally, it should be noted that the 'good' adjusters showed far better adjustment of their temperature rhythm than might be expected from experimental shiftwork studies (e.g., Colquhoun, Blake, & Edwards, 1968b, 1969; Knauth & Rutenfranz, 1976) given that the nurses were on only the first or second of a period of successive night shifts.

It seems clear that recommendations based on studies using simple perceptual-motor tasks cannot be generalized to situations where the shiftworker performs a more 'cognitive' memory-loaded job. Whereas poor nightshift performance on perceptual-motor tasks is due to the lack of adjustment of performance rhythms, on more cognitive tasks it would appear to be due to this very adjustment. Thus performance on cognitive tasks appears to be relatively good during the night provided people's rhythms are unadjusted. However, as adjustment occurs, so performance deteriorates. Indeed, this deterioration with increased adjustment is rather more rapid than the improvement found for perceptual-motor tasks. In view of this, the 'permanent' shift systems that may be best for maintaining adequate levels of perceptual-motor performance would seem to be far from ideal for more cognitive tasks. For these types of task rapidly rotating shift systems (e.g., 2-2-2) are probably better since they result in minimal disruption of the shiftworker's circadian rhythms (see Knauth & Rutenfranz, 1976; Smith, 1979).

Other Factors Affecting On-Shift Performance

It is clear from the results reviewed in the previous section that, whatever the nature of the shiftworker's task, his on-shift performance will be largely determined by the extent to which his circadian rhythms adjust to

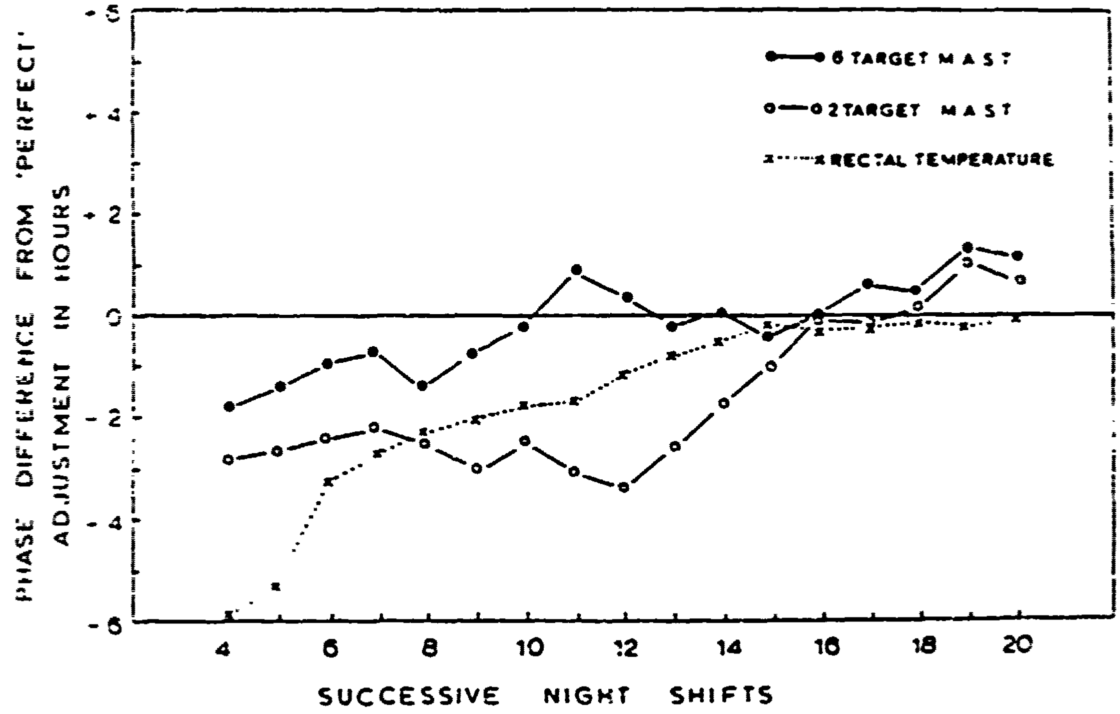

Figure 7. The adjustment of the phase of the circadian rhythm in performance on low (2-target MAST) and high (6-target MAST) memory load versions of a visual search task, and in rectal temperature after Monk et al., 1975 (From Folkard & Monk, 1979).

shiftwork. For simple perceptual-motor tasks any adjustment will result in improved night shift performance, while for more cognitive, memory-loaded tasks, adjustment might be expected to result in an impairment of night shift performance. The degree to which an individual's circadian rhythms adjust to night work will in turn depend on a number of factors, perhaps the most important of which are the type of shift system, and the 'type' of individual, i.e. individual differences. This section thus briefly considers the influence of these factors in determining the degree of adjustment of the shiftworker's circadian rhythms.

Shift System

As indicated above, Colquhoun et al. (1968b, 1969) found people's circadian rhythms to gradually adjust over a period of successive night shifts, although complete adjustment did not occur within the twelve-day period studied. This finding is typical of experimental shiftwork studies that have examined adjustment to permanent night work (e.g., Van Loon, 1963; Knauth & Rutenfranz, 1976). In general, these studies agree in showing that adjustment to 'permanent' night work takes place rather slowly over successive night shifts, but that re-adjustment to a diurnal pattern of life on rest days is very rapid (e.g., Van Loon, 1963). These experimental studies thus suggest that 'permanent' night work results in the shiftworker's circadian rhythms being in a continuous state of flux. In contrast, the available evidence suggests that rapidly rotating shift systems result in very little disruption/adjustment of the shiftworker's circadian rhythms (e.g., Knauth & Rutenfranz, 1976).

However, since these experimental shiftwork studies have used naive shiftworkers, they have been unable to examine potential 'long-term adjustment'. It has long been argued that such adjustment may occur as a result of prolonged experience of a particular shift system, and that it may enhance the 'short term' adjustment that occurs over a period of successive night shifts. Such enhancement might result in a permanent inversion, or at least a flattening, of the night worker's circadian rhythms. Alternatively, long-term adjustment may not affect the normal rhythm, but simply result in a speeding-up of short-term adjustment over successive night shifts.

Several authors have attempted to demonstrate the potential for long-term adjustment, although there are immense practical problems in doing so. Ideally it involves finding two groups of shiftworkers, one 'permanent' and one 'rapidly rotating', who are employed in the same section of a single institution/company, have the same timing of shifts, the same experience, and perform identical jobs. In practice, no-one has yet managed to achieve this. Nevertheless, Smith (1972, 1979) was able to compare rapidly (2 or 3 successive nights) and slowly (5 successive nights) rotating shiftworkers, while Åkerstedt, Patkai, and Dahlgren (1977) compared 'permanent' nightworkers with weekly rotating shiftworkers. Their findings suggest that rotating shiftworkers do not show any evidence of long-term adjustment. Indeed, Smith (1979) suggests that his subjects showed little evidence of any adjustment to night work. In contrast, permanent night workers did show some long-term adjustment relative to weekly rotating shiftworkers (Patkai, Åkerstedt, & Pettersson, 1977; Åkerstedt et al., 1977).

These studies were unable to determine whether long-term adjustment resulted in permanent changes to the circadian rhythm, or simply more rapid short-term adjustment. Some evidence that the latter is the case was obtained by Folkard, Monk, and Lobban (1978), who compared the adjustment of full- (4 nights per week) and part- (2 nights per week) time permanent night nurses in two separate studies. In the first of these studies clear evidence was obtained that the full-time staff showed better adjustment on the average than the part-time staff, even when the potential for short-term adjustment has been controlled for. In the second study, no difference was found between the groups in their normal circadian rhythms on a rest day, but the full-time nurses showed better adjustment on the first of a period of successive night shifts. Indeed, as in the Smith (1979) study, there was little evidence of any adjustment at all in the part-time staff. Thus long-term adjustment would appear to only occur in full-time 'permanent' night workers, and to take the form of a speeding-up or facilitation of short-term adjustment rather than a permanent flattening or inversion of the rhythm. It has been suggested that it occurs because of the relative stability of night-oriented synchronizers in permanent night staff (Åkerstedt et al., 1977), and that the scheduling of day sleeps may be particularly important in this respect (Folkard et al., 1978).

The implications of these various findings for on-shift performance are clear, although long-term adjustment of performance rhythms has yet to be demonstrated. In situations where adjustment is desirable, e.g., for perceptual-motor tasks, the optimal shift system may be a full-time permanent one that maximizes the potential for both short- and long-term adjustment. In con-contrast, when such adjustment results in impaired performance, as would appear to be the case for cognitive, memory-loaded tasks, rotating shift systems may be preferable since they appear to result in little disruption of the normal circadian rhythms. Indeed, it has been argued that the more rapid the rotation of a shift system, the less disruption occurs (e.g., Knauth & Rutenfranz, 1976).

Individual Differences

The second important factor in determining the level of adjustment of circadian rhythms to night work is that of individual differences. It has long been recognized that individuals differ from one another in both their 'circadian type' and the degree to which their circadian rhythms adjust to night work (e.g., Kleitman, 1939; Åkerstedt & Fröberg, 1976). From a practical point of view it is clearly desirable to be able to predict these individual differences on the basis of questionnaire scores. Many of the attempts to do this have been excellently reviewed by Åkerstedt and Fröberg (1976). In this section the earlier studies will thus be very briefly mentioned, and some recent developments will be noted.

As Åkerstedt and Fröberg (1976) point out, most of the research in this area has concentrated on differences in the phase of people's circadian rhythms, despite the fact that the amplitude and stability of these rhythms may also be important. Kleitman (1939) distinguished between 'Morning types' (M-types) and 'Evening types' (E-types) on the basis of phase differences in the circadian rhythm of body temperature, and found similar differences in perceptual-motor performance. Subsequently a number of questionnaires have been developed to distinguish between M- and E-types (e.g., Horne & Östberg,

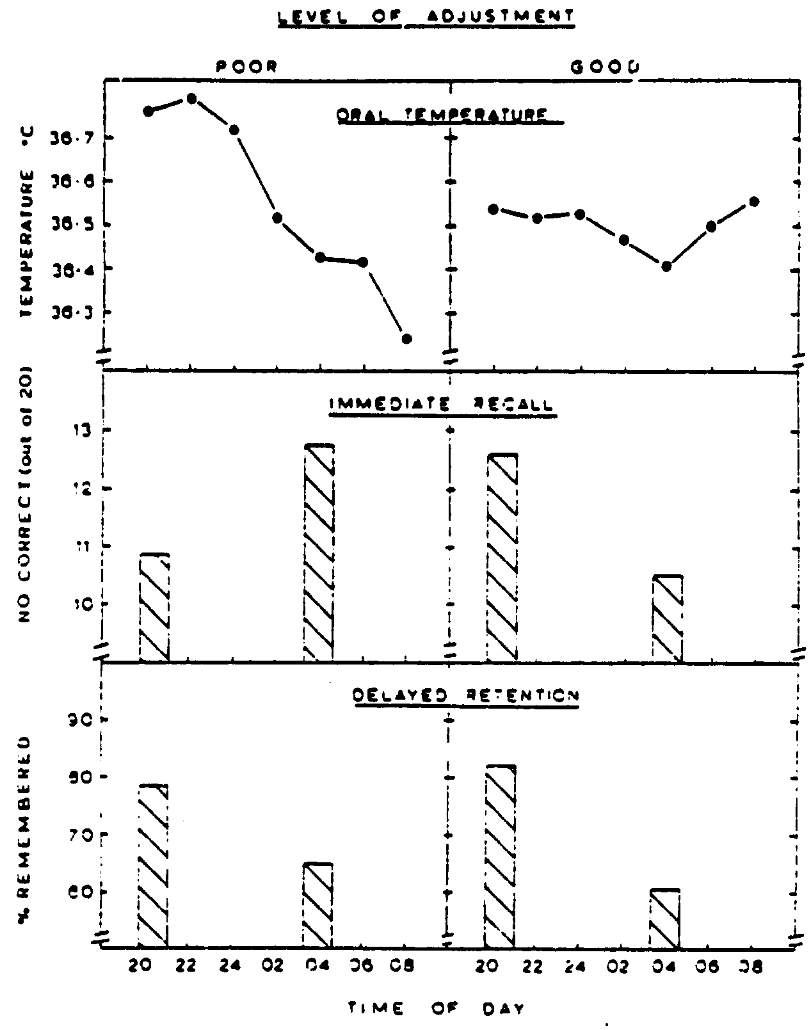

Figure 8. Immediate and delayed retention of the information presented in a film at 2030 or 0400, shown seperately for nurses showing 'poor' or 'good' adjustment of their circadian rhythm in oral temperature to night work. (From Folkard & Monk, 1980).

1976) and it has been suggested that E-types should adjust more readily to night work. However, as Åkerstedt and Fröberg (1976) note, early attempts to demonstrate this met with only limited success.

Since the review by Åkerstedt and Fröberg, a number of promising studies have been reported that suggest that it may prove feasible to predict adjustment to night work from questionnaire results. Thus, for example, Breithaupt, Hildebrandt, Dohre, Josch, Sieber, and Werner (1978) have reported fairly substantial relationships between scores on a morningness questionnaire and various characteristics of sleeps taken at unusual times. In addition, adjustment to night work has been shown to be better in 'neurotic extraverts' than in 'neurotic introverts' (Colquhoun & Folkard, 1978), and better in individuals with low amplitude rhythms than those with higher amplitudes (Reinberg, Vieux, Ghata, Chaumont, & Laporte, 1978). Adjustment to time zone transitions has been found to be more rapid in individuals whose normal rhythms show a late phase (Colquhoun, 1979), and an attempt has been made to develop a 'circadian type questionnaire' (CTQ) that taps aspects of the circadian rhythm other than that of phase (Folkard, Monk, & Lobban, 1979). Scores on this questionnaire have been found to correlate with various measures of adjustment to night work (Folkard et al., 1979) and have successfully predicted adjustment to the one-hour time-zone change involved in 'daylight saving' schemes (Monk & Aplin, in press).

In sum, there is good evidence that individuals differ in the degree to which their circadian rhythms adjust to night work, and some progress has been made towards being able to predict these differences from questionnaire results. It is, however, unclear whether these differences reflect differences in short- or long-term adjustment, and there is a clear need for further research in this area. In the future it may prove possible to select people whose rhythms adjust easily to shift work to man permanent shift systems in order to maximize the benefits of such systems for perceptual-motor performance. In addition, people whose rhythms show minimal disruption might be selected for rotating shift systems apparently desirable for more cognitive, memory-loaded tasks.

Conclusions

The main conclusion to be drawn from the studies reviewed in this paper is that there is no single 'optimal' shift system for ensuring adequate levels of productivity and safety. Rather it would appear that the universally low night shift performance observed in field studies may be due to rather different combinations of various factors. Of these factors, the demands of the shiftworker's task, the type of shift system, and differences between individuals would seem to be particularly important. These factors can be viewed as interacting with one another, via the shiftworker's various circadian rhythms, in determining 'on shift' performance. This is illustrated in Figure 9 in which the solid lines represent known connections, and the dashed lines probable ones.

Task demands may influence on-shift performance by (1) determining the phase of the normal circadian rhythm in performance and (2) affecting the rate at which this rhythm adjusts to night work. Rate of adjustment will also be affected by the type of shift system, and hence potential for short- and long-

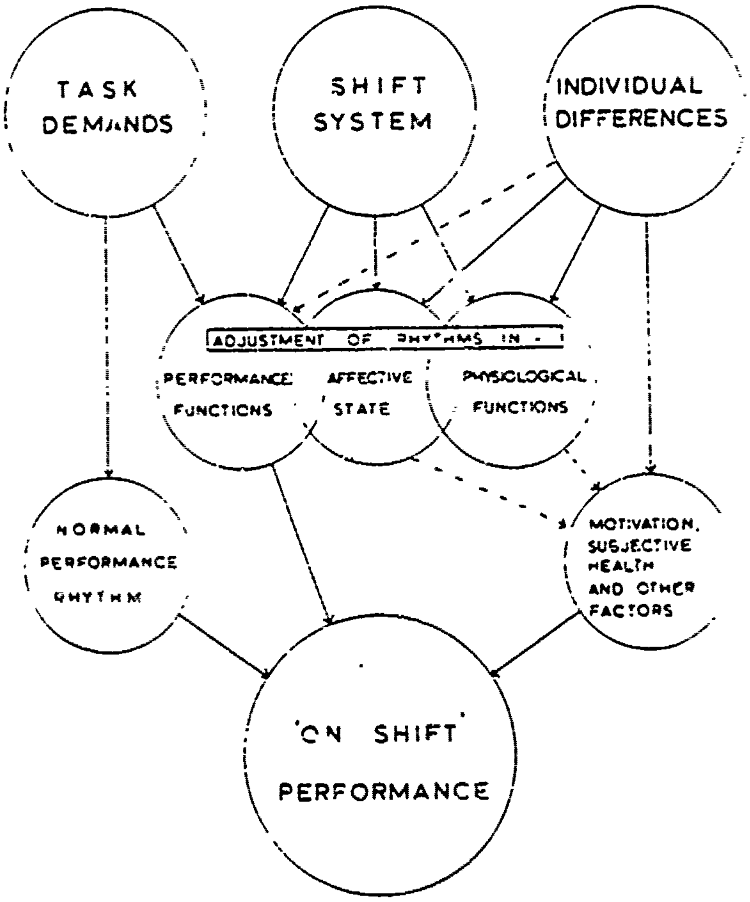

Figure 9. A descriptive model showing how 'on shift' performance may be affected by task demands, shift systems, and individual differences with these factors interacting via the shiftwork in circadian rhythms (From Folkard & Monk, 1979).

term adjustment, and by individual differences in such adjustment. In addition, the degree to which an individual adjusts to night work will affect his on-shift performance indirectly via his subjective health, and motivational level. As yet, little, if any, research has been done on this indirect effect of shiftwork on performance, although subjective health and motivation are clearly important factors in their own right (see, for example, Åkerstedt & Fröberg, 1976; Harrington, 1978; Walker, 1978).

Finally, there clearly are situations where high levels of performance efficiency and safety have to be maintained on the night shift. If all other factors are equal, the results reviewed in this paper favour 'permanent' systems for simple perceptual-motor tasks, but rapidly rotating ones for more cognitive, memory-loaded tasks. However, these conclusions *must* be regarded as extremely tentative. There is a clear need for further experimental and field studies of shiftwork that recognize the potential interaction of the various factors shown in Figure 9, and that take account of the influence of the effects of shiftwork on other factors such as subjective health and motivation that may also affect 'on-shift' performance. At this stage all that can be concluded with certainty is that the problem of impaired night shift performance is far more complex than has been recognized in the past.

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COMPENSATION FOR SHIFT WORK: A MODEL AND SOME RESULTS

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In the early sixties the results were published of the first large scale research project concerning shift work in the Netherlands (Banning, Bonjer, Bast, De Jong, & Van der Werff, 1961). The subject of shift work was studied from a medical, psychological, sociological, technical, and economic point of view.

Several years ago the results of a second encompassing research study became available. Problems regarding shift work were analysed from three different perspectives. The first one was macro-economic in nature (Iwema & Hoffman, 1974). The second one carried a micro-economic orientation (De Jong & Bonhof, 1974). The third perspective stemmed from an industrial and organizational psychology approach (Hoolwerf, Thierry, & Drenth, 1974).

Reports in the English language on some of the main findings of the psychological research study have been published elsewhere (a.o.: Thierry, Hoolwerf & Drenth, 1975; Thierry, 1975; Drenth, Hoolwerf, & Thierry. 1975; Thierry & Hoolwerf, 1976).

The current research study - a part of a field experimental project - is primarily designed in accordance with the main recommendations of our 1974 publication. Although its basic outline was available in 1975, the Dutch Ministry of Social Affairs - which had co-sponsored the earlier studies and stimulated the present one - was not allowed to spend the funds it had assigned to this experiment. Since the background against which these developments occurred provides for an illustrative understanding of the past and the current "climate" in the Netherlands concerning research on social matters of shift work, a very brief account of the events around the research proposal will be given.

The employers federations and the central unions in the Netherlands vary widely in the values, ideas, and preferences they have regarding shift work, and thus in their strategic policy on this subject. The unions have stressed for a couple of years the necessity of introducing a <u>5th shift</u> in the event that shift work is applied on a full continuous basis. This would cause a decrease in the average amount of working hours per week from 40 hours to 33.6 hours. In earlier years, representatives of the unions primarily stressed the probability that a considerably shorter working week would cause the living and working situation in shifts to be less unhealthy. More recently, another issue acquired equal or even more importance: the 5th shift will further the creation of more jobs and thus have positive employment effects. Unfortunately, hardly any 5 shift-work-scheme (with the qualifications as mentioned) is currently applied, and as a result empirical evidence to support or to oppose any argument is lacking.

The employers federations, on the other hand, are strongly opposed to the 5th shift, unless the shift workers would be willing to accept a rather considerable decrease in their pay. They fear that the application of the 5th shift on a large scale would eventually cause a considerable decrease in working hours for many other categories of workers as well, including not only workers in less progressive shift work schemes, but also workers and employees in permanent daywork. They held the view that both the employment rate and the economy at large might be thus greatly impaired.

Although our design does not deal in particular with the 5th shift - as will be shown in a later section - it would allow in principal to experiment with it. So a part of our research proposal was favored both by the unions and by the employers federations, but unhappily, each of them favored quite different parts. Summarizing now a long series of events: it ended with a complete dead-lock. The unions reject any study that may restrict even temporarily their freedon at the bargaining table with respect to the 5th shift; the employers federations opposed any study which results might be conducive to its introduction.

It is our luck however that the European Foundation is able to fund a part of our project on the basis of its four years rolling program on shift work. The present study started in the beginning of 1979.

The major part of this contribution deals with the model that serves as the core part of our research (Section 2). After a brief overview of the way in which interventions are being designed (Section 3) that constitute the framework of the experiment, some empirical results will be presented (Section 4). At this stage - the design of compensatory functions - just started, the evidence is more "illustrative" than "conclusive". The 5th and last section relates this study to the larger project in the years ahead.

The Compensation Model: Counter-weight versus Counter-value

Simple Counter-weight

In the Netherlands (and in most other European countries) shift work is exclusively or mainly applied on the basis of a rotating scheme. Practicing shift work implies that all employees concerned get a specific bonus, the amount of which is larger the more the shift work scheme in question is considered as "progressive" (in other words: the more the scheme implies working at "unsocial" hours). Generally, it is assumed that the shift work bonus compensates for the disadvantageous aspects of working in shifts. The bonus is supposed <u>to balance</u> for the inconvenient effects of shift work. This very assumption prevails in the usual bargaining situation: discomfort, negative characteristics, and so forth, that are related to shift work, are in a sense <u>translated</u> in terms of money ("labor costs" versus "income"). Such a process of translation not only manifests a recognized, and often welcomed, strategy to <u>summarize</u> a complex, multi-dimensional problem, but in doing so, it also tends at once to <u>reduce</u> the problem to matters of money (the size of the shift work bonus). As such, it may even <u>conceal</u> the very problem at hand, the more so since successful negotiations (as to the bonus amount), tend to sustain the <u>status quo</u>.

Now an interesting question involves the theoretical meaning that has been given to the concept of compensation, according to the line of thinking just mentioned. It seems that a rather simple, though intuitively-attractive

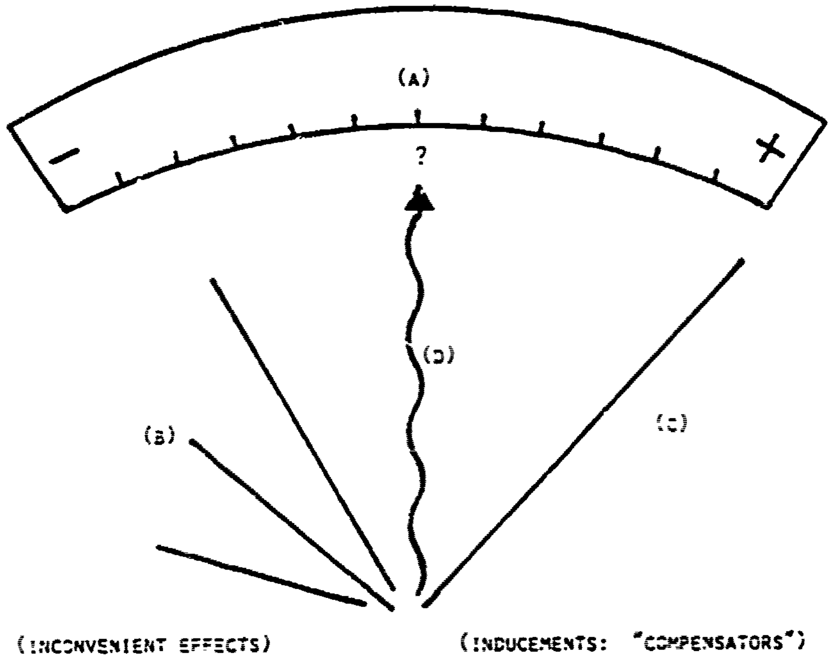

FIGURE 1. THE ASSUMED COMPENSATORY FUNCTION OF MONEY.

model is used as to the compensatory meaning and function(s) of money. The next figure illustrates this (see Figure 1).

Figure 1 reflects a weighting scale. The scale itself (A) indicates the "criterion behavior" one would like to predict or explain. As such, the decision of a person to start working in shifts or to quit shift work might be taken, or the motivational force to perform shift work, and so forth. Let's assume that (A) reflects the extent to which an employee is satisfied with working in shifts. At the left hand side the inconvenient effects (B) of shift work are outlined; the longer the length of a line, the more that effect is experienced and/or perceived as inconvenient by an employee. Let's suppose that several effects of the disrupting impact of the shift work rhythm - for example, a broken night - stands for (B).

The inducements of shift work - those positive rewards that are thought to compensate for (B) - are mentioned at the right hand side (C) of Figure 1. Again, the longer the length of the line (or lines), the more the outcome(s) which it reflects, is experienced and/or perseived as rewarding. In this case, the shift work bonus is the content of (C). The scale-indicator (D) reflects the end result of the weighting process in question, in terms of balance. The more the inconveniences outweigh the inducements, the more negative the resulting balance, and so forth.

Now the model underlying Figure 1 may be summarized as follows: "shift work is not an unfavorable living and working situation at all, since the shift work bonus compensates for inconveniences" (Hoolwerf et al., 1974). Several doubts may arise as to the validity of this statement. Firstly, the size of the bonus - which generally increases gradually over time in many countries - must be redefined time and again. Among several potentially determining variables would be at the one hand "objective" changes in inconveniences of shift work. At the other, changes in the perceptions and/or evaluations of disadvantages of shift work - for instance as an effect of changing societal values regarding work at unsocial hours - may affect the process of bargaining as to the bonus. Also, changes in status dimensions (and so forth) in the local area that reflect themselves in attitudes and opinions about shift work, may have an impact.

From a psychological point of view one wonders - as the second point - what the concept of compensation stands for. In other words, which inconvenient effects are compensated for by the shift work bonus? Is there any change in the variation of spare time periods (not to mention other aspects that are frequently experienced as negative)? Empirical data relevant to these questions, tend to show opposing evidence. The model underlying Figure 1 shows that apart from experiencing negative effects, the bonus is offered to provide for satisfactory rewards in other domains, that seem to be unrelated to the ones in which the negative effects occur. The potentially compensatory function of the bonus does not apply to specific sub-balances, in which a particular inconvenience - such as a broken night - must be "balanced" by a specific inducement. Rather, its significance might be better understood in terms of a global balance that pertains to the way in which a job as a whole is evaluated by an employee; on the one hand a variety of heterogeneous disadvantages are to be found, on the other a series of heterogeneous advantages are available. Now supplying more money usually cau[illegible] an increase in the "package" of advantages, although its meaning is dependent upon both the actual income position of the employee and his pattern of motivation (e.g., Lawler, 1971; Thierry, 1980). So the shift work bonus may "weigh against" (compensate for) a certain amount of dissatisfaction with the shift work situation in general. But its capacity to solve (that is: to eliminate or to reduce) effectively the specific negative effects of shift work, ought to be considered as small or negligable (some supportive empirical evidence for this statement is mentioned in: Thierry & Hoolwerf, 1976). Therefore this type of "global" compensator will be called: a counter-weight.

Extended Counter-weight

Gradually, the importance is stressed of other potentially compensatory variables in addition to this "simple" counter-weight. On the one hand the potential value is emphasized of a shorter average working week (for instance as an effect of introducing the 5-shift work scheme), more holidays (which results in less working hours per year), earlier retirement, and so forth. On the other, "humanizing" the working place of shift workers is advocated: leadership styles ought to be more considerate to the needs and wants of the workers; communication patterns should enhance the availability and the quality of information; workers' control and autonomy have to be increased; jobs ought to be enlarged or enriched, and so forth. This type of approach is illustrated in Figure 2.

Agian, a weighting scale is shown. Examples of inconvenient effects are: perceived health impairment; a broken night; varying spells of spare time. In addition to the bonus, inducements are provided like: more holidays; more control of workers over departmental decisions; a more considerate leadership style.

The model underlying Figure 2 is in a sense an extended version of the Figure 1-model: "since shift work causes inconveniences for the workers, the working place ought to be humanized, e.g. the amount of working hours has to be reduced".

This second approach may be considered as a more fruitful on than the "mere provision of a bonus" approach. On the one hand, humanizing the working place gradually becomes recognized as one of the major requirements for current work organizations. On the other, reducing the total amount of working hours - disregarding now its particular scheme - may be rewarding from the workers' point of view.

But still the psychologist wonders how the concept of compensation is suppose to work. Does each inducement of this nature - like job autonomy - reduce or even eliminate a specific inconvenient aspect of shift work (such as a broken night)? Or do these inducements add to the rewarding "convenient" side of the global balance that relates to the way in which the shift worker evaluates his working and living situation as a whole?

Empirical evidence in this area is very scarce. Both logically and theoretically one would expect that the capacity of this type of inducement to reduce or to eliminate specific disadvantageous aspects of shift work, is still rather weak. Then how would a compensator like job autonomy be conceived

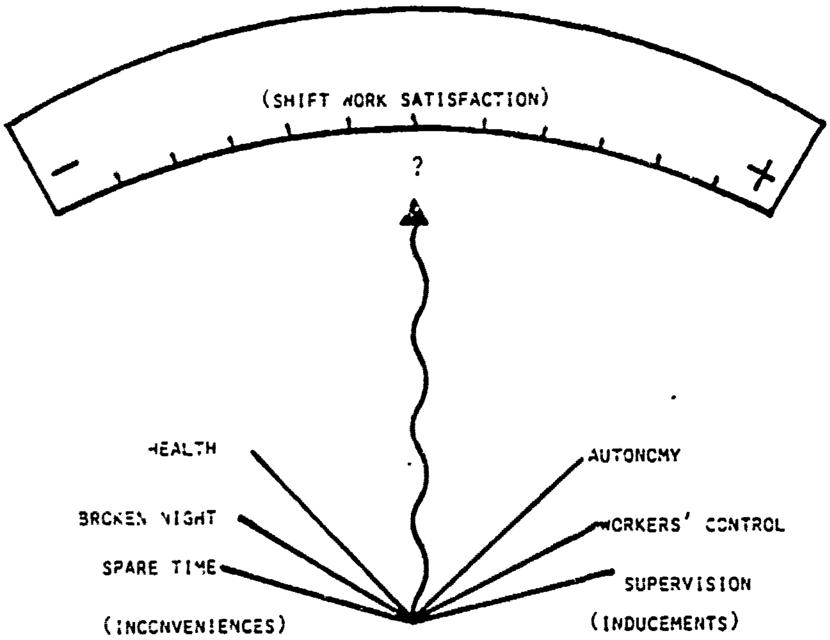

Figure 2. THE EXTENDED-BALANCE MODEL.

to operate in reducing, for example, one's perceived (or real) health impairment? Some slight evidence was found, however, in favor of the potentially inconvenience-reducing capacity of workers' control on departmental decisions. For instance, the more workers' control, the less varying spells of spare time are perceived as inconvenient (Thierry & Hoolwerf, 1976). Another, not yet published, analysis suggested that feeelings of isolation ("apartheid") within the organization may be reduced by the combined effect of increasing workers' control and a more dynamic leadership style of the direct supervisor.

Generally, however, we tend to consider the potential value of this second approach as mainly (or exclusively) contributing to the positive side of the global job balance, that is: the evaluation of the shift work situation as a whole. Therefore, it is called an "extended counter-weight" model. Its capacity to reduce specific inconveniences seems to be restricted to just a few cases. (It should be added though, that there has scarcely been any research study on the effects of reducing the amount of working hours. Thus the potentially compensatory effects of this type of inducements are still open to test.)

Consequently, this second model does not, or hardly, operate on the level of specific sub-balances. As was the case with the first model, the lack of "real" balance in these respects may cause a never-ending increase in the level and nature of wants and desired outcomes, precisely as each individual is striving - under normal conditions - <u>to achieve balance</u>. A variety of theories about work motivation stresses that a major determinant of an individual's behavior is provided by the need for balance, such as between his contributions and the rewards he gets. As these theories will not be treated here, the attention is called to just two categories of approaches: social-comparison theories, and the theory on self-esteem.

Counter-value

The concept of compensation as outlined in the two preceding models has been characterized as counter-weighting, that is, as operating on the global, general level on which costs and benefits relative to a job and its conditions as a whole, are weighted against one another. Providing for more beneficial weights may lead to more satisfaction, inducing the worker to <u>reconcile</u>, to <u>adjust</u> himself to his situation. But the costs in question - the inconveniences - remain unchanged. Another approach to compensation may operate more effectively, according to which the actual inconveniences are being reduced or eliminated. It focuses upon specific sub-balances, and not upon the global balance. To reflect its potential capacity to reduce or to eliminate a negative effect, it is called the <u>counter-value</u> model.

This model provides for the basis upon which our current research project is designed. In order to acquire counter-value properties, each <u>intervention</u> (that is, a purposefully-introduced change) should fulfill two requirements:

1. Its operation ought to produce positive effects (also called: rewards, inducements; conveniences) that tap on, i.e. belong to, the same category, the same <u>denominator</u> as the perceived and/or experienced unfavorable aspects of shift work in question. For example, if shift workers complain about psycho-somatic symptoms, then a counter-value type of

intervention should produce a decrease in (or elimination of) those very symptoms.

2. Its effects should be also rewarding in relation to the <u>motives</u> and situational outcomes the workers in question view as important. For example, an intervention that reduces (or eliminates) loss of autonomy for a worker, is ineffective to the extent that the worker does not value autonomy.

It is clear that the construction and experimental try-out of each intervention require extensive analyses and careful attention. It appears worthwhile to differentiate among <u>three types</u> of counter-value interventions, that obviously operate on <u>different levels</u> of analysis. As such, there exists a certain "hierarchical order", Type I being more encompassing than Type II, while Type II may cover more ground than Type III. These are:

Type I: Reducing or eliminating the causes of inconveniences.

A rather extreme, and unlikely, example would be to refrain completely from the application of shift work. A more realistic example might probably be a change-over towards a less progressive shift or work scheme, the reduction of night work, and so forth. Other interventions of this type relate to various changes in the rotating scheme, the length of each shift, and so forth. To illustrate the last point, current change-over times in many organizations (in the Netherlands as well as in other countries) provide a good case: when somebody would try to find those change-over times that would most harmfully affect the social, psychological, and biological rhythms of the average worker, his findings may, ironically, not diverge too much from 0600, 1400 and 2200 hours. As indicated earlier, in the Netherlands (and in many other European countries) shift work is primarily or exclusively applied on a rotating basis.

The current state of knowledge as to this area does not allow for any statement on the <u>general</u> effectiveness of any intervention of Type I (as well as Type II and III), although Knauth's, Rohmert's and Rutenfranz' proposal (1976) regarding schemes in which each night shift is followed by at least 24 hours of rest, provides for a case in point. Rather, the potential value of the most promising interventions has to be assessed first experimentally and under a variety of conditions. Its experimental applicability depends upon: (1) the actual inconveniences as experienced by the shift workers in question; (2) the opporturities within the organization for its provision and (3) the degree in which workers and managers expect its use to be instrumental to their situation. In other words, a comprehensive body of "locally-collected" data and experiences regarding a variety of interventions has to be created. This is the main reason why the present study has been designed as a case study.

Assuming that some Type I interventions can be introduced in an organization and do provide for counter-value compensation, we further suppose that several inconveniences have not been tapped on, and still exist. This is the moment to analyse the applicability of the second type of intervention.

Type II: Reducing or eliminating the consequences of inconveniences.

Since the causes of many uncomfortable aspects of shiftwork are not presently amenable to change, one might try to compensate for the effects of inconveniences. A few examples may illustrate this approach: firstly, suppose that a shift worker aspires to get advanced education and additional training. Usually, the courses which he has to take fit into the time schedule of the permanent day worker. Compensating for this negative effect may include organizing the courses in question according to the shift worker's time table (it is obvious that this example is realistic to the extent in which various shift workers - perhaps from different organizations - would apply for these courses). Secondly, assume that the shift work scheme does not permit a group of workers to watch a favorite TV program. Compensating along the Type II approach may imply taping the program, rebroadcasting it at a time of the day that suits the shift worker's schedule.

Again, it is assumed that some Type II interventions are to be "constructed" and subsequently introduced in an organization. Still several inconveniences could not be touched upon, neither by Type I nor Type II interventions. It is now time to turn the attention to a third type.

Type III: Compensating for the psychological meaning of inconveniences.

This type of intervention is illustrated in Figure 3. The first example in Figure 3 relates to status; suppose that one (or more) of the still existing inconveniences as experienced and/or perceived by a shift worker, reflects for him a loss in status. That is, regardless of both the causes and the consequences of this inconvenience, it is interpreted, evaluated by him in terms of having less status (for instance in comparison with others in his social community). Now an intervention that provides for counter-value compensation, should result in a gain in status for him. As was mentioned in relation to Type I intervention, it is not possible to indicate beforehand which specific interventions will produce a status gain for a particular shift worker in a particular organization. In some organizations the opportunity to attend educational courses (being transferred and/or promoted afterwards to a job in day work) may be a fruitful avenue, and so forth. The second example refers to a loss in perceived autonomy; a similar line of reasoning applies here. Again, one cannot identify beforehand which interventions will produce more (perceived) autonomy. Enrichment of the job, sharing in the decision-making power of a group or committee, and so forth, may provide for successful changes.

Earlier in this section it was stressed that any intervention should meet two requirements in order to acquire counter-value properties. So regardless of its type, each intervention should operate along the same denominator as the inconvenience it tries to compensate. The second point - the degree to which motives concerned are considered as important - is separately mentioned in Figure 3; the box on "valence of motives".

To conclude, the model of counter-value compensation seems to present a different approach for trying to improve the living and working situation in shift work. As indicated, its potential usefulness has to be tested experimentally in a variety of ways. Elsewhere (Thierry & Hoolwerf, 1976) some tentative evidence regarding Type III compensation was presented. It suggested that complaints about earnings in general might be offset by providing for more spare time. An unpublished finding related experienced sleep deficit to whether or not a shift worker has children; this last point of course should

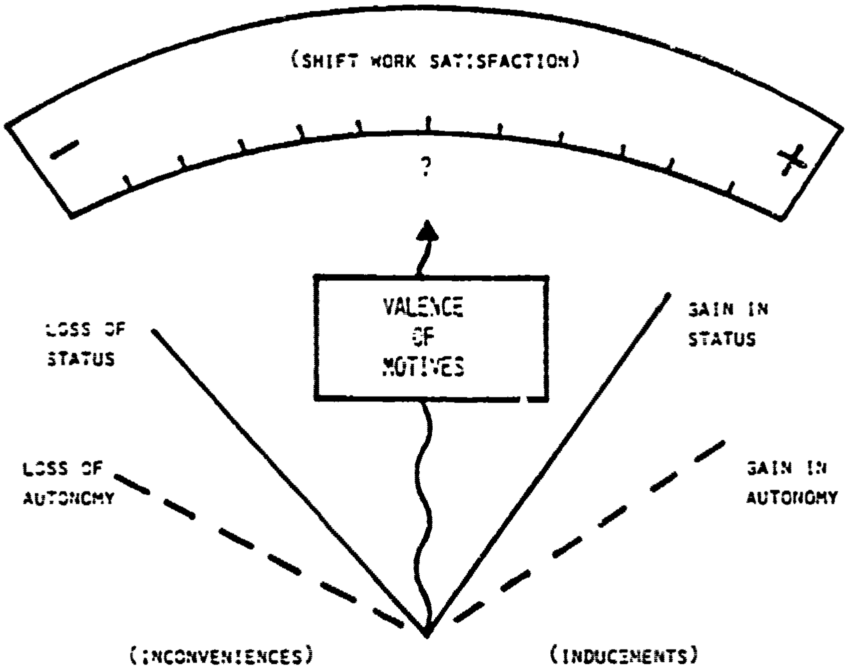

FIGURE 3. COUNTER-VALUEING PSYCHOLOGICAL MEANINGS.

not be considered as a "compensatory intervention", but may only be viewed as a potential selection device.

Current insights into this subject as well as current opportunities for change and experimentation cause me to emphasize that, at least in the near future (if ever), counter-weight compensations cannot be completely dispensed with. In other words, in order to reach an optimally designed shift work situation - although opinions and values on what is an optimum may diverge considerably among the parties concerned - perhaps major contributions may be made along the route of counter-value compensation, although "additional" compensations like a shift work bonus, reduction in working time, "humanitarian" rewards, and so forth, would appear to be needed.

Designing Interventions: A Short Overview

In order to design interventions that may provide for counter-value compensations, three different approaches are followed. The first one focusses upon major "objective" and "subjective" data as reported in various empirical research studies, for instance with regard to Circadian Rhythms. The second approach consists of an analysis, with respect to a variety of characteristics, of the working and living conditions that apply to the shift workers in the work organization concerned. Relevant sources are: records, documents, interviews with key-informants (managers and others) and the like. The third approach is tuned to the experiences, perceptions, preferences, and so forth, as reported by the shift workers (and in a variety of cases also by their spouse).

It is obvious that the data from these different sources are not necessarily in accordance with one another. it is not unlikely, for instance, that a particular intervention with respect to the rotation of shifts may produce positive effects from a psychological point of view, while those very effects may be considered as disadvantageous from a social or cultural perspective. This subject relates to the well-known issue of "objective" versus "subjective" criteria for designing a different shift work system. Among those that favor objective criteria, Knauth, Rohmert, and Rutenfranz (1976) state that "... as most workers voted for the shift system they were just working on (....), recommendations for optimal shift systems can rarely be obtained from questioning shift workers". On the other hand, Mott (1976) among others pleads as follows: "... we should encourage more worker participation in the design of their shift patterns. But we ought to make them aware of what the consequences are likely to be of their choices".

Our stand, put very briefly, is that this subject ought not to be viewed as an either / or matter. The three approaches mentioned at the beginning of this section reflect our position that both objective and subjective criteria have to be taken into account. Therefore, we consider it an essential condition to get a high degree of involvement of the shift workers concerned - in this study; around 100 workers from a paper mill facility - in experimenting with changes. In order to prevent "degrees of freedom" for installing an experiment being considerably restricted by the well-known phenomenon of resistance to change on the side of shift workers, sessions have been organized to provide for information and to offer opportunities for discussion. During these meetings, several major findings of previous research studies were presented, explained and discussed.

On the basis of the preceding analyses, a list of potential interventions is currently being designed that may produce counter-value compensations. These interventions probably pertain to the three types of counter-value compensations, mentioned in the preceding section.

In order to clarify how the potential usefulness of each intervention may be assessed, how certain interventions may be skipped and others invented, the design of the questionnaire is outlined in Figure 4.

Starting at the left hand side of Figure 4, Box 1 represents a series of biographical and demographical characteristics of the individual shift worker. Box 2 reflects a personality variable; the degree of Ambitiousness (Type A). The extent to which a worker is motivated in his work provides for Box 3. Boxes 4-6 refer to the way in which each shift worker describes the physical working conditions - like noise, temperature, and so on, his task activities (such as manual labor, process control, and the like), as well as how he perceives shift work arrangements. Box 7 contains a variety of satisfaction measures. With respect to each variable in Box 8 the worker is asked to indicate whether the aspect in question causes inconvenient effects for him. Then the worker is requested to assume that this very aspect indeed provides him with inconveniences (Box 9); he now has to assess whether each of 38 different interventions (or more, in the case he lists these) would lead to a change in effects (positively or negatively), no change at all, or would not apply. Since Box 8 contains 10 different variables, each worker has to evaluate 10 times the instrumentality of all potential interventions.

The "order" of the boxes (indicated by arrows) in Figure 4 is a tentative one. Empirical results may cause some revision.

To summarize, compensatory functions may be designed on the basis of three different perspectives:

1. Experiences with Type-I-interventions elsewhere (mainly as discussed in the literature). We also may profit from another on-going research study on some Type-I-interventions within our department.
2. The extent to which shift workers expect that Box 9 variables may be instrumental towards reducing or removing inconveniences as experienced or perceived.
3. Statistical analyses of the questionnaire data in order to locate various denominators, each of which encompasses both an inconvenient aspect and an inducement of a common nature.

Subsequently these results will be discussed extensively with the shift workers (and with management), the outcome of which provides for the core components of the interventions that constitute the major framework of the experiment.

Some Empirical Evidence

Orientational Phase

As mentioned earlier, this study currently bears upon around 100 shift workers in a paper mill facility that belongs to a large organization within

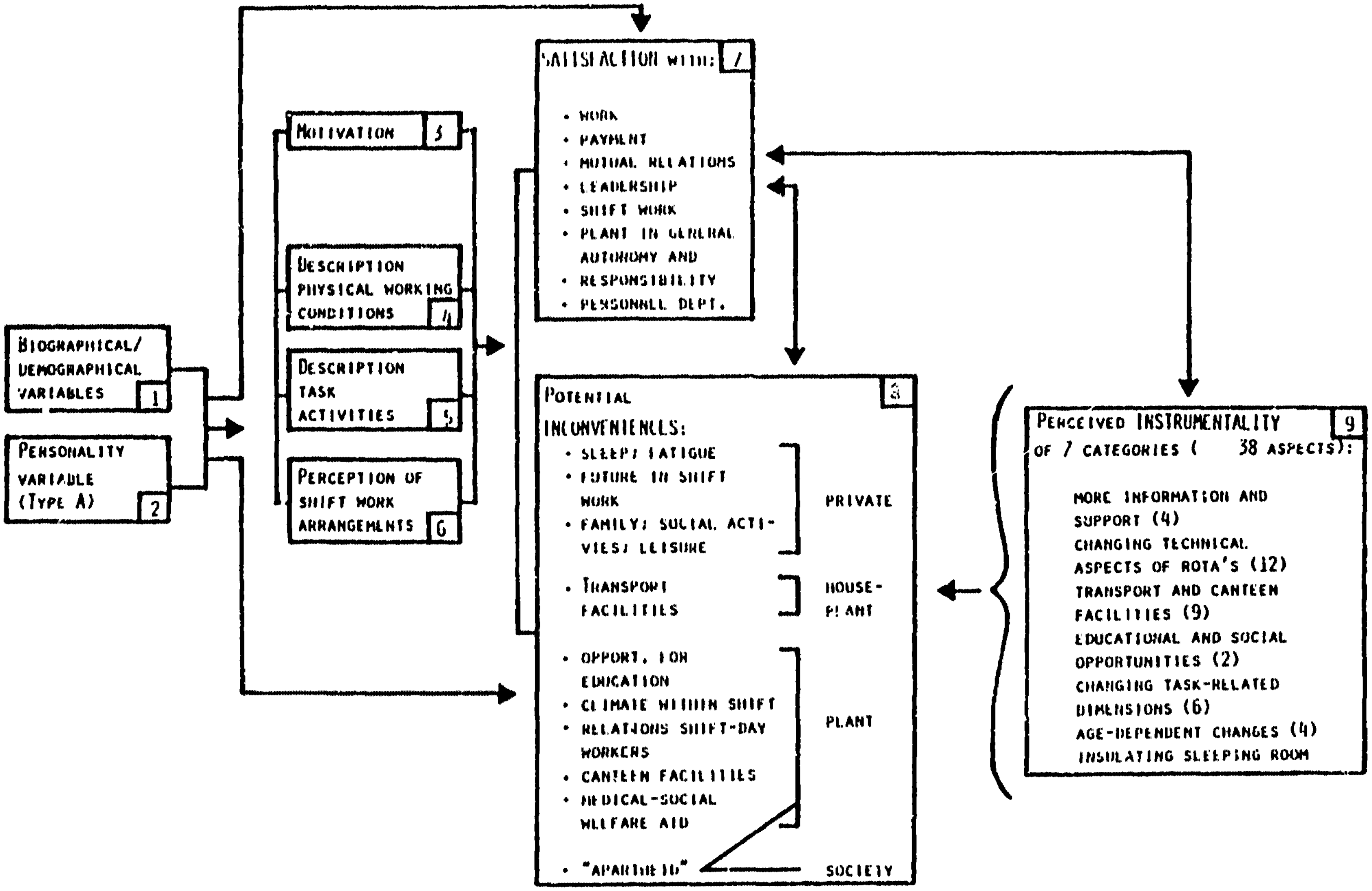

FIGURE 4. DESIGN OF THE QUESTIONNAIRE

the same branch. Firstly, the research team engaged itself in an intensive process of orientation within the plant in question, i.e. to learn whether a series of conditions concerning the shift workers, lower and higher management, and top management of the parent organization could be met. Likewise, these groups specified some criteria regarding the research team and the possible experiment. Eventually, both "parties" favored to start the experimental study. Top management indicated however that the next requirements had to be met:

- The introduction of a 5th shift is not permitted (see Section 1).
- A permanent raise in labor costs is unacceptable.
- Any change to be introduced should not be at variance with the conditions specified in the Collective Labor Agreement.

The research team on its side specified two requirements:

- Each shift crew will get one additional member (in order to allow for more flexible working arrangements).
- Around $150.000,—will be available for workers' home-work travel expenses (in the case different rotating schemes will be introduced).

All requirements were accepted by the "parties" concerned.

Inconveniences and Interventions

Concerning the potential inconveniences (as described in Figure 4, Box 8) questionnaire data show that aspects like transport facilities, climate within shift, and apartheid hardly cause any problems for the far majority of the workers. On the other hand both "subjective health" and "family, social activities and leisure" appear to provide for a lot of discomfort and complaints. Compared to national norms regarding subjective health, our respondents indicated nearly twice as many problems.

The method to select potential interventions on the basis of questionnaire data will now be illustrated with respect to one aspect in particular: subjective health. As this is a composite score (being very consistent, $\alpha = .87$), attention will be focussed upon one of its dimensions: "fatigue" $\alpha = .72$). It is on this dimension which respondents assessed the instrumentality of various interventions (Figure 4, Box 9).

Firstly, the pattern of correlations with other inconveniences (as well as with facets-satisfaction and the description of the work situation) is analyzed. These results will support or weaken the choice of interventions made on the basis of the fatigue-dimension. It turns out, among other things, that one's "future in shift work" and "family life" correlates significantly - but not very high - with fatigue ($.30 > r < .43$).

Secondly, the potential impact of major biographical and demographical variables is inspected. Results reveal that only plant tenure correlates with fatigue ($r = .24$; $p < .01$); the more tenure, the more complaints about fatigue. All other variables - like age, tenure in shift work, travel time, education, and so forth - do not affect fatigue scores.

Thirdly, cross-tabulations are made concerning the assessed relevance of each potential intervention. In Table 1 just some of these results are shown.

Table 1

Cross Tabulations (in Percentages) of Workers' Fatigue Complaints and Perceived Efficacy of Various Intervention Strategies

Fatigue Complaints	Permanent shifts *				Less than 3 consecutive nights **				More time off for education *			
	1	2	3	4	1	2	3	4	1	2	3	4
. a few	23	23	46	7	30	19	44	7	62	15	-	23
. moderate	37	27	13	23	31	41	3	24	63	17	-	20
. many	53	15	15	16	58	21	11	11	42	11	21	26

Meaning of Scores: 1, improvement; 2, no change; 3, deterioration; 4, not relevant. * p <.05, ** p <.01.

The first column in Table 1 shows that 53% of the workers with many fatigue complaints expect that the introduction of permanent shifts would improve their condition; on the other had 46% of those with just a few complaints indicate that permanent shifts would aggravate their situation. The second column reveals a comparable pattern; the more complaints, the more a scheme with less than 3 consecutive night shifts is expected to cause an improvement. The pattern in column 3 is different; more time off for education is welcomed by those with a few or a moderate amount of complaints, but assessed as considerably less beneficial by workers with many complaints. With concern to a variety of other potential interventions it appears that a large amount of workers expect these to cause an improvement regardless of their complaints. There is an overall tendency, however, that experiencing more complaints coincides with the expectation that an intervention will be more beneficial.

Fourthly, the score on each relevant intervention is considered in relation to major biographical and demographical variables. This will be illustrated with respect to one potential intervention; "a scheme with less than 3 consecutive night shifts". Table 2 refers to just some biographical variables.

Earlier in this section it was mentioned that none of the biographical variables of Table 2 affected the extent to which shift workers have fatigue complaints. The results of Table 1 showed, among other things, that a scheme with less than 3 consecutive nights is favorably assessed by those with many complaints. Although the data in Table 2 do not differ significantly per variable (taking all cells into account), they suggest for example, that this intervention is expected to cause improvement more by married workers, but not so much by workers with 10 years or less tenure in shift work. This method of splitting up data allows us to select one or more interventions that may apply to just one specified category of workers, and not to all workers alike. As such, this design may contribute to a less uniform, rather pluriform way of organizing shift work. It is obvious that not each intervention lends itself to be applied to a segment of the work force.

Table 2

Cross Tabulations (in Percentages) at the Perceived Efficacy of a Scheme with Less than 3 Consecutive Night Shifts as a Function of Biographical/Demographical Variables

		Less than 3 consecutive nights			
		1	2	3	4
Job Type:	Main machine	40	23	31	6
	Process preparation	39	31	8	22
Tenure in Shift Work:	0-5 years	57	7	22	14
	6-10 years	46	21	21	12
	> 10 years	19	44	19	18
Marital State:	Married	44	24	21	11
	Unmarried	8	50	17	25
Travel Time:	< 15'	27	18	37	18
	15-30'	43	41	13	3
	> 30'	38	12	12	38

Meaning of Scores: 1, improvement; 2, no change; 3, deterioration; 4, not relevant.

Based upon the 4 preceding "steps of analysis", several potential relevant interventions are being selected for each of the separate inconveniences. The following criteria have been set to determine whether or not an intervention will be chosen. Each intervention should:

- relate in a meaningful way to the inconvenience in question;
- not be assessed as detrimental by more than 20% of the workers (total sample);
- not be rated in terms of "no change" and "not relevant" by 50% of more of the workers (total sample).

When combining the seperate selections of interventions, also the expected detrimental effect "in other areas" should be taken into account. Since several interventions had to be presented in other general terms during this phase of the research - such as; a shorter rotating scheme - discussions with the shift workers on details per interventions ought to clarify whether they stick to their assessments. Moreover, results of other studies concerning comparable changes may also affect decision-making.

Data currently available suggest the relevance of at least 8 different categories of intervention:

- Age limits on shift work (including earlier retirement).
- Additional days off.
- Medical tests and social welfare support.
- Shorter cycle of rotation (including other change-over times, unequal

watches, and so forth).
- General advisory function within Personnel Department ("ombudsman").
- Introduction of job consultation.
- Leadership training (stressing a considerate style).
- Canteen facilities.

In terms of the section entitled Counter-value, these changes primarily bear upon Type I and Type II interventions. Future reports will deal with the actual effectiveness of the chosen ones as well as with potential Type III interventions.

Concluding Comments

Both prior to the start of the experiment (which is expected to last 1 1/2 years) and at later points in time, some physiological data will be assembled. Although the comparative effectiveness of our approach is being tested - and will be evaluated extensively - it is obvious that the counter-value strategy is not exclusively linked to shift work. As such, applying it in domains other than shift work, would be highly needed. But let me indicate, as a final point, some of the shortcomings of our present study.

The design of this case study belongs to the quasi-experimental category (O. XO.), for which the pitfalls are very well known. Even a control group is lacking (although control groups are being used as to specific issues, such as absenteeism and turnover); but serious ethical considerations prevent us from doing so.

The question thus prevails in which respects our results might be generalizable. As our focus is on the specifics of the local situation in a plant, generalizing according to actors is not sought for. Rather, we try to learn the validity of this model per se, which implies generalization as to behaviors and contexts (Runkel & McGrath, 1972).

Looking ahead we intend to enlarge the scope in two ways:
1. Applying the model of counter-value compensation in one or two other plants, in which other potential interventions - like the 5th shift - are open to test.
2. Applying another model - that is, survey feedback - under most comparable conditions in two or three plants. Then the design would look like:

$$\begin{array}{l}(O_1\ X_a\ O_2)\\(\qquad\quad)\\(O_1\ X_b\ O_2)\end{array}$$

This strategy will allow us to overcome at least the main soft points at present.

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PRESENTATION ON "VARIATIONS IN WORK-SLEEP SCHEDULES: FROM THE VIEW OF THE INDUSTRIAL WORKER"

Jack C. Lovett
The Communications Workers of America
San Diego, California

In my discussion today, I would like to briefly make a few observations about shift work — how it is dictated by economic and social conditions and has both positive and negative features. Then I want to turn to the subject of collective bargaining and shift work so that I might outline some suggestions which could ease the strain if shift work. I implore the scientists here to do additional research or to organize existing knowledge to make it more meaningful to labor, which will enable us to do a better job in this area of negotiations.

But first let me tell you a little about the Communications Workers of America. The Union represents over 600,000 workers in almost every state. It is one of the largest Unions among those affiliated with the AFL-CIO. Approximately 90 percent of the membership is employed in the telephone industry with the remaining 10 percent employed primarily in public service and general manufacturing industries. Workers on shift schedules comprise about 15 percent of the membership, including one-third of all telephone operators.

Shift work is a necessary part of some working people's lives. Because of the industry in which they are employed or the occupation that they have chosen, some people must conform to a shift work schedule. For example, capital-intensive industries often want to maximize the use of expensive equipment through continuous or near continuous operations. Thus, with the advent of the computer, shift work has expanded from a largely blue-collar phenomenon into the white-collar world. In addition, some industries use machinery that is very costly to shut down and start up each day or use machinery whose output is in constant demand. For example, the Phoenix, Arizona cable operation of Western Electric, represented by our Union, is on a 3-shift, 7-day coverage schedule due to the constant demand for its product. Public service workers, such as protective and health care employees, also work in shift schedules because their services are required irrespective of the time of day or night. In addition, consumers have been demanding extended hours in which to carry out commercial activities. To accommodate their customers, phone centers, which are the new phenomenon for merchandising telephone equipment, banks and food stores, among others,have assigned some of their employees to shift schedules. Phone center employees used to work from 9 am to 5 pm, but their schedules neither corresponded with the hours of the shopping malls in which the centers are located nor with the needs of their customers. Accordingly, two 10-hour overlapping shifts were introduced, as well as the use of part-time workers.

Shift work has both advantages and disadvantages, depending upon what schedule a person is assigned. I can personally attest to this. I began work in the telephone industry in 1941. Even in those early days of our Union, hours were chosen or assigned based on length of service. The nature of the job required coverage of the three basic shifts prevalent in those days which were 8 am to 5 pm, 4 pm to 12 midnight and 12 midnight to 8 am. The second and third shifts required lunch on the job because of constant attention required for the work. The shifts were rotated at six-week intervals among the junior employees. I learned very early in my career in the industry, the inconvenience and physical demands of working shifts were not compatible with normal life style.

Workers on the day shift need to make the least adjustment to shift work since their work hours allow them to fulfill their family and social roles.

Workers on later shifts, however, must adapt to leaving social events early in order to arrive at work on time or to having no evening hours at all for social activities. Parents who work afternoon or night shifts find it hard to be with their school-age children who are often in bed or at school when their parents are at home. Problems may also develop for these workers in fulfilling their sexual and protective roles as spouses. However, second and third shift workers are directly and indirectly compensated for their unpleasant working hours: They receive premium pay, have a greater opportunity to moonlight, or engage in additional employment, and can more easily attend to commercial activities than can their day shift counterparts. At Western Electric, for example, manufacturing employees whose shifts include any time from 3:30 pm to 8 am receive a 10 percent bonus if they work on operations having 7-day coverage.

Workers assigned to rotating shift schedules experience all these advantages and disadvantages as they go through shift change cycles. In addition, they may be inadvertently left out of some social activities because friends may find it hard to keep up with the rotating shift worker's schedule.

Let me momentarily look at the reaction of telephone operators to different shift assignments. As odd as it may seem at first glance, an evening shift ending after 10 pm is considered quite desirable. It is the shortest shift, 6 hours as compared to the normal 7 1/2 hour shift. The short hour tours were achieved in the telephone industry after many years of negotiating over this issue. The operators are compensated on the basis of 8 hours' pay. In addition, there is less supervision and an easier pace on the evening shift. For these reasons, many of the more senior operators bid for an evening shift. Split shifts, in which an operator may work from 8 am to noon and again from 4 pm to 8 pm, are among the least desirable assigrments. Unless the operator lives close to work and can return home or attend to commercial activities within the 4 non-work hours, the time off from work is not beneficial for the operator.

The relationship between a shift worker's physical and mental health should also be examined when discussing the advantages and disadvantages of shift work. Certain problems may develop because the working and non-working hours of people on shift work are out-of-sync with their normal 24-hour biological cycle. Upon coming home from a turn on the second or third shift, a worker will try to fall asleep while street traffic is roaring past his door and his family is watching television or doing noisy daytime chores. These distractions may result in fewer hours and poorer quality sleep than are required for maximum off- and on-the-job performance. Eating and digestive problems may also arise since shift workers are often unable to eat meals with their families. Ulcers and colitis may be the end-product if quick eating of whatever is around becomes a worker's steady diet. The shift worker's mental well-being may also be affected as evidenced by tension, nervousness, and iritability.

There are, however, moderating factors which should be taken into account when assessing the relationship between shift work and employee health and performance. Some individuals are morning types, others are evening types. One person may not be in very good health before starting on shift work, another may be in peak condition. Age is a third factor. It can operate in contradictory directions to influence an individual's adjustment to shift work: While health problems normally increase with age, a person's attitude toward his lot at work and at home improves with age. In addition, the degree of economic drive that a worker possesses may also raise or reduce his predisposition toward the demands of shift work.

Aside from the worker's individual characteristics, there are family and social factors that influence his ablilty to cope with a shift assignment. How the worker's family and friends look at shift work will affect how the worker perceives himself and his work schedule. For example, if a fairly low value is placed on shift work by associates, the shift worker may develop low self-esteem; this might, in turn, have a negative effect on his well-being and job performance. The extent to which other workers in a community are on shift schedules may also influence how a worker perceives his job and himself: If there are several plants operating of shift schedules, a shift worker's feeling of isolation from his family, friends, and society may decrease while his job satisfaction and performance may increase. If plants in a community are on shift work the community has a responsibility to provide supportive community facilities that accommodate family needs.

A specific example of worker and community reaction to shift work scheduling occurred when Western Electric started up its new Phoenix cable plant. The community and churches were unfamiliar with the idea of a continuous operation that required night work, and they vehemently opposed it. We had a long struggle in this plant because of shift work. Negotiations were prolonged and informational pickets were established for many weeks. However, the plant's present work force recently was upset by the idea of reverting to one shift because the 3-shift operation now suited the workers' economic life styles. Additional information relating to the adverse effects on shift work would probably place them in a position to make a more rational decision concerning their physical well-being. Again we look to these distinguished scientists for that guidance and information in this field where so little validated knowledge is available.

Practices negotiated in future collective bargaining agreements may also serve to moderate the disadvantages of shift work. Historically, workers have expressed their preference on their shift assignment based upon their length of service, and they have been partially compensated for unpleasant schedules by premium pay. Both these traditional concepts are compatible with innovations that can be introduced through labor-management cooperation at the bargaining table and in the workplace.

There are personal characteristics that make certain individuals better suited to shift work than others. In this regard, the Western Electric Manufacturing employees are periodically asked to indicate their shift preference. Seniority would then take precedence if a conflict for a shift assignment should arise.

Another option would be to permit a shift worker to voluntarily transfer to the day shift after having completed a predetermined period of shift work negotiated between the Union and the Company.

Thirdly, given the knowledge of health problems associated with shift work, increased medical supervision should be included in collective bargaining agreements so that early signs of intolerance to shift work will be caught before bigger problems have time to develop. Many plants have excellent medical facilities for first shift employees and although a substantial number are on 2nd and 3rd shift operations there are no medical support personal available for these workers who become sick or are injured.

The Unions have been led to believe, according to scientific findings, permanent shift schedules are better than rotating schedules so Union negotiators, should that be true, should try to bargain for permanent shift assignments; in the Bell System and Western Electric most workers are already on permanent shift assignments. In this area we need scientific data that clearly distinguishes whether rapid shift changes may serve a more useful purpose to promote the physical well-being for the worker.

If fixed schedules are not attainable,a fifth possibility includes simultaneously rotating all workers and supervisors who work together on a shift. Such a contractual arrangement would maintain the work team and social relationships developed on a given shift, permitting workers to adjust to new hours without also having to adjust to new people.

Many shift workers feel isolated form other workers in their own plant and in the community. To lessen the feeling of isolation, companies should be encouraged to communicate with all employees through company newsletters, notice boards and memorandums; visits of executives to all shifts; and addresses by executives to each shift on a regular basis. Union representatives should also be in touch with all workers, regardless of a worker's shift assignment. CWA has Union meetings scheduled that accommodate the convenience of shift workers; for instance, second shift workers generally meet at 12:30 am 1st and 3rd shift workers are usually covered by a joint meeting.

My Union, the Communications Workers of America, has been in the forefront in demanding a shorter work day without a corresponding reduction in pay. This goal has been only partially realized. We presently have some shift workers who work 30 hours for 40 hours' pay.

In closing, those assembled here have a great deal to contribute to the knowledge we need to do a better job at the bargaining table and to organize existing knowledge in a manner that can be used for the benefit of all workers in our society. Again, I implore you to continue your work in this field that is of such vital importance and where such little validated information is available to those who have the greatest need for information that goes beyond rumor, suspicion and speculation. On that hopeful note I want to thank you for your attention during my presentation.

SHIFT WORK RESEARCH NEEDS IN AVIATION: AN OPERATIONAL PERSPECTIVE

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In reviewing some of the literature to prepare for this conference, I learned that according to Aschoff (1965), Gierse first described the phenomenon of temperature periodicity in 1842. But, the great volume of papers is to be found in the twentieth century, and then largely in the last thirty years. There is a strange admixture of papers from workers in a wide variety of disciplines, ranging from physiology to sociology. The diversified disciplines have contributed to the study of work-sleep schedules in the fields of biologic rhythms, fatigue, stress, performance evaluation and performance decrement, biochemical and endocrinologic variations, multiple time zone shifts and other related areas. Despite the seeming olio of disciplines and techniques, it is evident that there has evolved a clearcut direction of research leading to a recognizable international effort. To those of us who must look to the research and theoretical constructs of scientists such as those gathered here, it is encouraging to see the purposeful direction taking shape. We hope your continuing work in basic and applied research will eventually result in the solution of at least some of these serious problems faced by professional airline pilots in the pursuit of their occupation.

The aviation community, including pilots, has long been interested in the findings in the related disciplines as they pertain to the operational mileau of private, military and commercial flying. The interest of pilots is longstanding and frequent inquiries and reviews of the literature by pilots is documented. No doubt they have searched for practical advice that would help them in the pursuit of safety in flight operations. Wiley Post sought advice of early workers at the Harvard Fatigue Laboratory in 1932, in preparing for his long distance flights (MacFarland, 1960). He recognized the importance of biological rhythms in pilot proficiency and fatigue. He tested his own fatigue reactions by sitting for long hours in the cockpit of his plane, cat napping, eating at irregular hours, and otherwise simulating the physiological problems he anticipated would be encountered while crossing many time zones during world flight. He is considered as one of the first to conduct human factors research in this area (Mohler, 1963). (One need only reflect on the untimely demise of Will Rogers and Post to wonder if Post might not have benefited by even <u>more</u> research.)

In 1963, the Air Line Pilots Association conducted a review of current knowledge in the areas of fatigue, biological rhythms and performance as related to the shift over in the commercial airline fleet from reciprocating engine aircraft to jet turbine driven aircraft (Ruby, 1970). It was felt that the emergence into the jet age had intensified many old problems of flight fatigue and had presented a host of new ones to which no solutions existed. A number of experts in aerospace medicine, such as H. Strughold, B. Hartman, G. Juin, and workers at the United States Air Force School of Aerospace Medicine were consulted. Besides the numerous factors affecting performance and fatigue and suspected intensification of problems with the then unknown variables of jet flight, the greatest problem found was that the aeromedical profession and related disciplines had insufficient information and were unable to test and measure fatigue and the elements affecting it and performance. It was recommended that the Association should develop and maintain an interest in these and other areas related to "human factors" in flight safety. One of the responsibilities of the Association's Executive Chairman for Aeromedical Resources is to maintain current knowledge of and interest in human factors as the subject relates to safetv, performance and health. The Aeromedical Office is charged with the responsibility of providing technical advice and assistance to the Association in the human factors area. The Safety Department of the Air Line Pilots Association has additional responsibility in human factors study. Hence, our interest in this symposium should be clear. We are less than satisfied with the sparce amount of research now being carried out which relates directly to aviation. We earnestly hope that more effort will be devoted to the aviation aspects of variations in work-sleep schedules, as well as related areas, in the future. One need reflect only briefly on the flight safety implications to understand the necessity for such study.

It has been pointed out that performance and alertness may be adversely affected by shift work (Winget, Hughes, & La Dou, 1978). Optimal performance and alertness are obvious requirements of the pilot. If problems occur during rotational shift work secondary to or in conjunction with disturbance in body physiologic rhythms by rapid disruption from inversion of the day-night cycle and the crossing of multiple time zones, then it is necessary to know what the problems are, what can be done to minimize them and what future studies are necessary to define the problems and provide accurate practical and usable advice and guidance to the profession and the industry.

We recognize that neither the Navy nor the National Institute for Occupational Safety and Health bear direct responsibility in the area of civil aviation safety, but surely the recognition of need will be understood here and elsewhere. In the Federal Government the Federal Aviation Administration (D.O.T.) is responsible for regulating air commerce and providing for air safety—but they do not have a substantial research budget or facilities. The air carriers apparently do not possess the facilities, manpower or financial means to support research studies. Faced with a need, but without the means, the Association has helped stimulate formation of a University Study Group on Human Factors in Air Line Air Safety, to be sponsored by Wright State University under the general direction of the medical school dean, Dr. J. R. Beljan, and chaired by Dr. Stanly Mohler, Professor of Aerospace and Preventive Medicine. The group will be composed of representatives of the airlines, safety organizations, the several interested government agencies, academic institutions and ALPA. It is anticipated that the study group would look to scientists such as are present here for advice, assistance and study.

My main purpose here is to describe some pertinent facts of the operational environment in which the professional airline pilot functions. Pilots may function while experiencing fatigue, working rotational shifts, and exposed to less than optimal weather conditions, sustaining the synergistic effects of multiple time zone crossings, while bearing the responsibility of performing safely in the public interest. A recent aircraft accident investigation revealed some of these factors, such as: 1) fatigue, 2) long duty hours, excessive workload, 3) inadequate nutrition, 4) poor and deteriorating weather. At the time of the crash, which resulted from landing in trees short of the runway, the pilots had been on duty fourteen hours and 43 minutes, of which nine hours and 27 minutes were actual flying time. They were on their fifteenth approach and landing of the day, under night and instrument flying conditions with weather near minimum permissible and deteriorating due to fog. There had been no time scheduled by the carrier for crew meals, and the food taken in brief breaks on the ground between flights consisted, for one pilot, of bananas and granola, and, for the other, coffee and a sweet roll. I am sure you can recognize the several classic accident enabling factors manifest in this scenario (Kowalsky, et al., 1974).

One need not look long into a study of previous jet aircraft accident records to elucidate a thread of human error occurrences which were made inevitable by such accident enabling factors as fatigue, poor nutrition in the immediate pre-accident time period, disruption of biologic rhythms and other interacting events (Kowalsky, et al., 1974). "The essential characteristic of air transport", according to Dhenin et al. "is that it rapidly crosses geographic, climatic and time boundaries; so that journeys cannot always begin and end at convenient hours" (Dhenin, et al., 1978). Further, if the economic demands necessitate such operations, and if the aircrew are to be utilized safely, "... it is necessary to pay special attention to such matters as hours on duty, flight time, rest periods, time zone and diurnal variations. Good scheduling is essential to the health, morale, and safety of flying personnel." Dhenin et al., continue: "The problems in scheduling aircrew on international airline operations have involved many bodies, professional and otherwise, for many years. As a result, several national and international agencies have reviewed the problems of aircrew scheduling, usually in the context of the industry rather than of physiology, and it is only in the last decade that physiological problems involved have been given any consideration. Even today, much of the physiological data are still ignored by some management, governments and aircrew unions, so that many of the present rules and regulations tend to be those that have been arrived at by negotiation and legislation rather than by scientific measurement and fact. The whole situation is at present, therefore, unsatisfactory as far as physiological mechanisms are concerned" (Dhenin, et al., 1978). This view of British authors bears serious consideration as a universal expression of the current state of affairs.

Environmental factors in jet flight include the relative hypoxia experienced at cabin altitudes ranging between 5,000-10,000 feet. This relative hypoxia can have adverse effects on performance and is believed to exacerbate a feeling of tiredness. Temperature extremes may be experienced, both climatic as well as radiant (from heat generated by electronic equipment). Low humidity, vibration and noise complete the list of commonly identified conditions. These and other variables (radiation, e.g.) interact with the physiologic characteristics and limitations of the human to produce unknown short-term and long-term effects on health, welfare and morale of aircrew. Consider also in your deliberations, these environmental constituents to sharpen the practical value in findings relating to shift work and dyschronism. The direct and indirect consequences on air safety are well worth the added effort of such considerations.

Factors influencing scheduling include economic, statutory, political, operational, labor-management agreement, and some nonverbalized variables. For example, economic factors are brought to bear because of the high cost of equipment and fuel. Further, competition among carriers in an era of deregulation is intense, both domestically and internationally. Statutory factors include the federal regulations which prescribe not-to-be-exceeded flight and duty times. National, state and local laws may be in effect which ban takeoffs or landings during certain clock hours at various airports. Noise restrictions which require power limitations or unusual maneuvers on takeoff additionally stress pilots and may compromise flight safety. It is important to know also that federal regulations on duty and flight times were written several decades ago for propellor-driven aircraft! Political factors include the restraints on route structures, landing times, and other influences not necessarily based on objective criteria. Operational factors are those imposed by aircraft range, load capabilities, etc. Working agreements between aircrew representative organizations and carriers are the current means of adjusting the needs of the carriers to provide fast efficient service, which gets passengers where they want to go when they want to get there, to the capabilities of pilots to perform effectively to meet the industry needs. The agreements must take into account the seniority of individual pilots in establishing schedules, and has resulted in complicated bidding systems. Pilots, depending on their seniority, bid a flying schedule monthly, and the bids of the many pilots are matched and collated by computer. The result, while usually equitable, may and often does have pilots working variable shift schedules from day to day, trip to trip, etc. Nonverbal factors are the tacit willingness and desire of pilots to "get the job done", unseen pressure from supervisory personnel to urge an extra effort from aircrew, and the interpersonal dynamics of pairs or small groups as pilots function in the cockpit.

Generally, we think of airline operations as composed of long-haul operations, short-haul operations, and combinations thereof. In long-haul operations, the peak workloads at takeoff, climb, or letdown, and approach and landing are broken up by relatively long periods of light workload in cruise, where the function of the crew is largely that of monitoring. Transmeridian flight operations, long duty hours and disruption of biologic rhythms are our principal areas of concern, particularly as these relate to the cost to the pilot in terms of his health and longevity. In short-haul operations, the time zone issue is, generally, minimal. Duty times are characteristically long, with multiple short segments, many takeoffs and landings, high workload (frequent communications) in crowded airspace, congested airfields and delays which can demolish a schedule.

For the air line pilot, as mentioned earlier, work-sleep cycles are typified by constant change and associated problems. The average professional pilot works fifteen to eighteen days per month, which requires approximately 240 hours away from home. Food service and lodging inadequacies and variability are a constant source of irritation. Physically, the work is usually not hard, but the demands are highly tiring in terms of attention required and periods of high mental workload. The domestic pilot may shift up to three time zones per day; but, the international pilot may shift five to eight time zones per day. Duty periods consist of two day to five day rotations with ten to twelve hours off for rest in a 24 hour period. The pilots suffer diurnal shifts, as many flights operate during night and early morning hours. They also may not be operating at maximal efficiency when required to perform the most critical functions. Approximately 20 per cent of pilots work on "reserve" or "on call". These pilots must be available on short notice to function as aircrew members any time within a given reserve period. A day on call may climax at 9:00 pm with a call to report for work at midnight, completing work at 8:00 am.

With these brief descriptive remarks in mind, we ask for expert guidance on how airline pilots prepare themselves mentally, physically and nutritionally for almost constant shift in work schedules, biologic rhythms, sleep schedules and meal schedules.

We hope your present and future deliberations will take into account the airline pilot, who is a shift worker with randomized or near-randomized rotational schedules.

Thank you for the opportunity to participate in this vital conference.

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ON VARYING WORK/SLEEP SCHEDULES:
ISSUES AND PERSPECTIVES AS SEEN BY A SLEEP RESEARCHER

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The published works of many of you attending this symposium indicate that the major issue for most workers with varied work/sleep schedules is sleep. Your subjects have complained about both the quantity and the quality of their sleep. In a paper on shift work and sleep, Foret and Benoit (1977) state, "As far as we know, no survey has ever found day sleep duration as long as night sleep duration." Foret and Lantin (1972), by use of both questionnaires and electroencephalogram (EEG) recordings, have documented the reduced sleep of shift workers. Their data show that train drivers sleep an average of 6 hours 22 minutes on working days and 7 hours 59 minutes on rest days. Foret and Lantin also found that these workers tended to make up their reduced sleep with naps during the day and prolonged night sleep on rest days, and wondered whether this variable kind of sleep was equivalent to regular and unbroken sleep. That is still an unanswered question.

In addition to the social factors that reduce sleep (e.g., meals with the family and leisure-time activities), noise is also a problem for the day sleeper. Sixty-three percent of 171 oil refinery shift workers reported noise as a sleep problem (Koller, Kundi, & Cervinka, 1978). Rutenfranz and Knauth (1970) have also emphasized the importance of noise in complaints about sleep, reporting that 78% of those sleeping during the day were bothered by noise. Along with the complaint of inadequate sleep is the feeling of fatigue. Kogi (1971), in a questionnaire study of oil refinery shift workers, found that 32% stated that they suffered from lack of sleep, 58% said they felt very tired, and 37% rather tired after a night shift.

Numerous published articles detail the problems of sleep and fatigue, and, in several review articles, Rutenfranz and his colleagues have summarized the sleep problems of shift- and night-workers (Rutenfranz, Knauth, & Colquhoun, 1976; Rutenfranz, Colquhoun, Knauth, & Ghata, 1977). Noting the consensus that night work usually results in sleep less than 7 hours and in some groups as low as 2.5 hours, they comment, "It is, therefore, understandable, that sleep disturbances are the principal symptom amongst the complaints of night-workers, and that the quality of sleep is one of the deciding factors, whether a worker can or cannot adapt to night- and shift-work" (Rutenfranz et al., 1976,p.335).

For sleep researchers, then, the issue is inadequate sleep, poor sleep quality, and fatigue. In this session, we are charged not only with stating the issues but also with discussing perspective. One definition of perspective is "the true relationship of objects or events to another." This definition is quite appropriate, for the question yet to be answered is: What is the relationship of sleep <u>per se</u> to the complaints of shift workers? Is the reduced amount of sleep they obtain the cause of their fatigue; is the quality of their sleep inferior; is there a chronic sleep deficit? Is sleep the focus of general dissatisfaction with the work schedule and, as Dr. Wedderburn would remind us, interacting with social factors? While I have referred to shift workers, the flight schedules of aircrew members not only cause sleep reversals but they also involve travel across several time zones. The presence of a representative from the Air Line Pilots Association at this symposium, Dr. Masters, attests to the concern of aircrew members. Dr. Endo has previously presented quantitative data on the effects of eastbound and westbound flights on sleep (Endo, Yamamoto, & Sasaki, 1978), and will be discussing his work on Saturday.

Later in our program, there will be reports of new sleep research pertinent to the issues of sleep quality, quantity, and fatigue. I would like, in this presentation, to briefly summarize previous work, with the goal of trying to narrow the number of questions I have posed. I will explore the research concerned with sleep quality, sleep quantity, and the fragmentation of sleep, to see if these factors could account for shift workers' sleep complaints and feelings of fatigue.

Research Issues

Sleep Quality

A primary goal of sleep research has been to determine what is good sleep and to obtain an objective measure of sleep quality. Perhaps because of the initial enthusiasm and excitement of our ability to chart a night of sleep by use of the EEG and to divide the EEG waves into sleep stages, much work has been oriented toward sleep stages as an index of sleep quality.

The EEG studies of sleep have added to our knowledge of the changes in sleep structure with variations in work/sleep schedules. We now know what happens to rapid eye movement (REM) latency, whether percent Stage REM increases or decreases, and what happens to slow wave sleep (SWS). While early laboratory studies varied sleep schedules of non-shift workers, recent work has focused on the recording of shift workers and the changes in EEG sleep measures of aircrew members following flights across several time zones. Though the search has been both extensive and intensive, the early expectations that sleep stages were the key to the mysteries of sleep have not been supported. The amount of REM sleep one gets is not the key to emotional well-being and time in SWS is not the crucial factor for "knitting up the raveled sleeve of care." In the past few years, most sleep researchers who previously suffered from REM tunnel vision or slow wave myopia (the former could only see REM during a night of sleep and the latter could not see beyond the first third of the night) have had their visual problems partially alleviated by overwhelming negative data (Johnson, Naitoh, Lubin, & Moses, 1972). I think that it is time to stop wondering whether REM latency is 60 or 90 minutes, or whether we have 30 or 40 minutes of SWS or a decrease or increase in REM sleep. In the evaluation of hypnotic drugs, perhaps a reflection of the failure of EEG sleep stages to quantify drug effectiveness and the finding that most hypnotics reduce either Stage REM or SWS, there is renewed interest in subjective estimates of sleep quality. More attention also is now being given to the effect of hypnotic drugs on daytime performance. It is unfortunate that those earlier studies concerned with alterations in sleep schedules did not ask their subjects how they felt after the shift in their sleep times. While there are numerous tables and figures on sleep stage amounts, percents, latencies, eye movements and REM periods, most researchers did not ask "How was your sleep?" If they did ask, they did not report the answer. There are also little performance data in the early shift-work studies.

I don't expect the sleep researchers to abandon their EEG machines--nor should they. As with many physiological measures, such as heart rate for example, extreme deviations from the norm, either in rate or rhythm, deserve further study and evaluation. Heart rate, like REM or SWS percent, however, can vary from person to person and within a single subject depending on the circumstances with minimal relation to performance or feeling of well-being. But I don't believe we will find the relationship of sleep to shift-work complaints by scoring EEG sleep stages alone. Although I am not impressed with stages of sleep as a measure of sleep quality, for those who do not agree with me and to summarize the major findings, I will briefly review the most consistent findings.

As is often the case, our Keynote Speaker has had a major impact, both in terms of quantity and quality of work, on research in the areas of altered sleep schedules and sleep structure (Webb & Agnew, 1971; Webb, Agnew, & Williams, 1971; Webb & Agnew, 1977). Webb and his associates believe that three variables are associated with the EEG sleep measure in split periods and altered sleep regimes: (1) the time interval between sleep periods, (2) the sidereal time of sleep onset, and (3) the length of the periods. The most consistent finding by Webb, and by others, has been the direct relationship of time between sleep periods and the amount of Stage 4 occurring in each sleep period. The longer the time awake, the greater the increase in SWS. There have also been consistent results with respect to time-of-day effects on sleep latency and length. As illustrated in Figure 1, Foret and Lantin (1972) found that, as the time of sleep onset was delayed after midnight, the total sleep duration decreased. The authors thus summarize their finding, "the duration of unbroken sleep periods...is an inverse function of bedtime, and an almost linear one at that" (p. 278).

In our nap studies (Moses, Hord, Lubin, Johnson, & Naitoh, 1975; Moses, Lubin, Naitoh, & Johnson, 1978), we have found more rapid sleep onset and more total sleep time (TST) when the time for a 1-hour nap fell in the last third of the night when body temperature was low (Figure 2). Webb also believes that there is a clear circadian effect in sleep stages since the displacement of the sleep period shows a tendency to reduce the amount of Stage 4 and increase the amount of REM. Morning sleep onset is usually associated with a shorter REM latency.

In contrast to the general support of the relationship between sleep loss and an increase in Stage 4, the association of REM sleep with time of day is less clear. Several have reported REM onset in morning sleepers (Decoster & Foret, 1979), but sleep-onset REM has been found in both morning and afternoon naps (Weitzman, Nogeire, Perlow, Fukushima, Sassin, McGregor, Gallagher, & Hellman, 1974; Carskadon & Dement, 1975; Moses et al., 1975). Instead of time of day or the awake time since last sleep, we believe REM latency is related to amount of total sleep since last REM onset, regardless of how fragmented the sleep; i.e., the REM cycle is a sleep-dependent rhythm while Stage 4 may be more wake-dependent (Moses, Lubin, Johnson, & Naitoh, 1977; Moses, Naitoh, & Johnson, 1978).

The duration of the sleep period is, of course, directly related to amount of time spent in each stage. In Figure 2, the amounts of Stage 2, Stage 4, and REM increase with TST in the 1-hour nap which, as we have seen, is in-

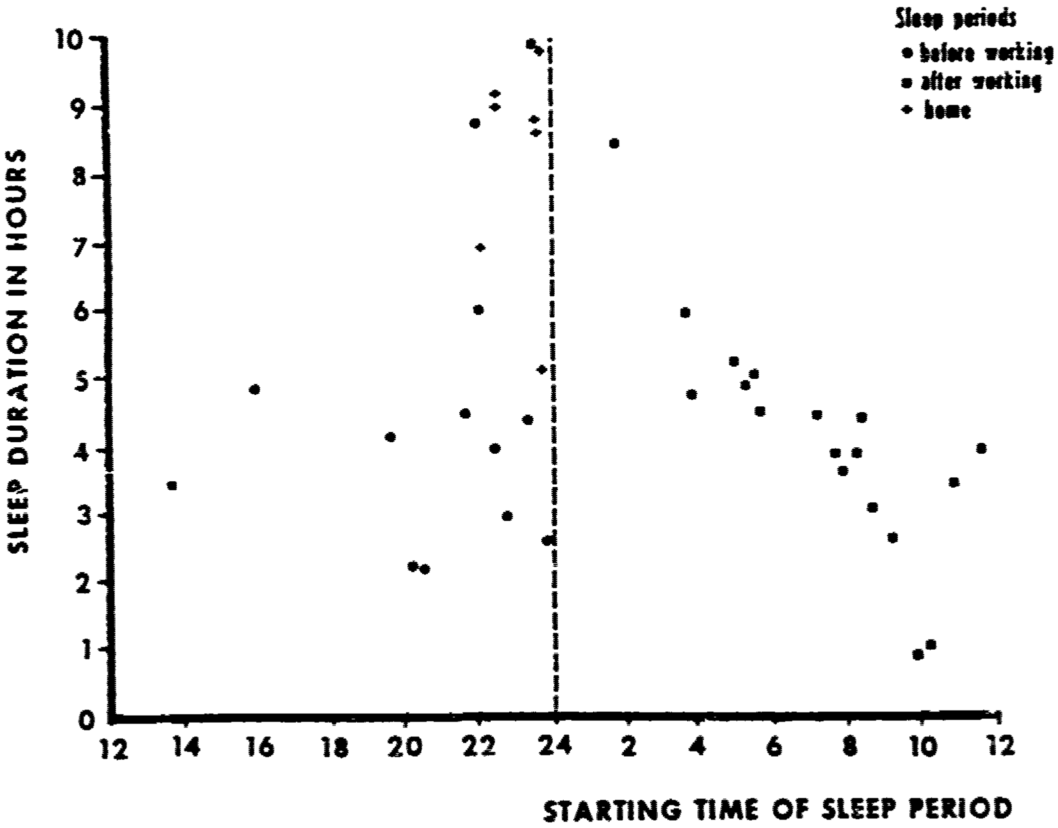

Figure 1. Relation of recorded sleep duration to the starting hour of sleep [from Foret & Lantin (1972), with permission].

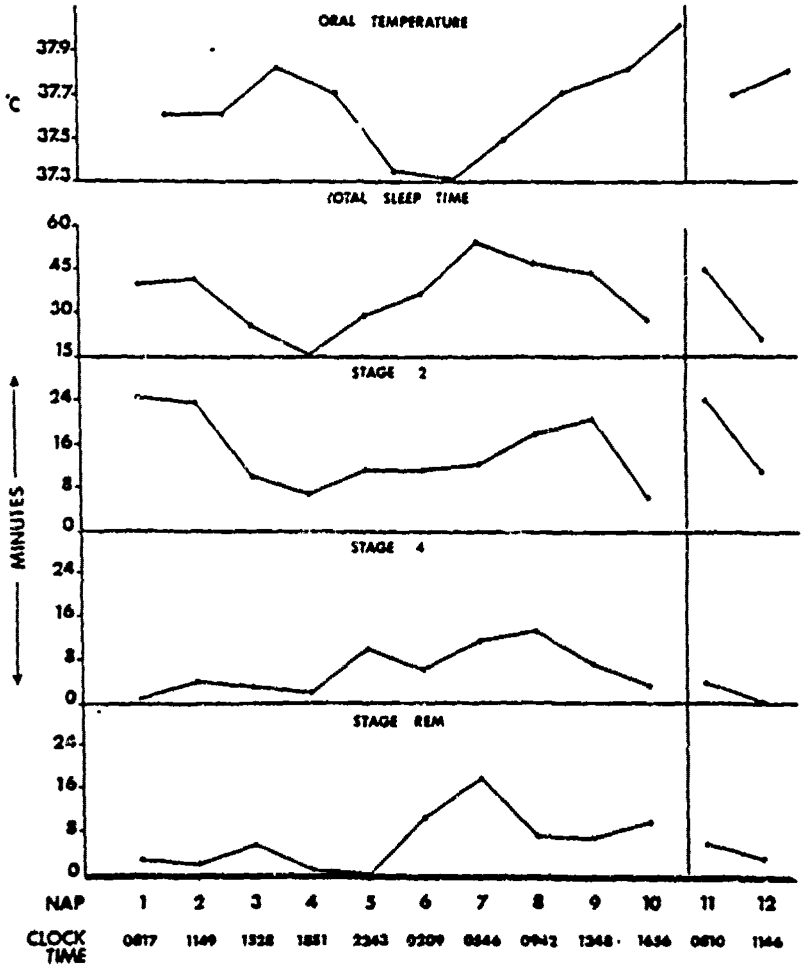

Figure 2. Distribution of sleep, sleep stages, and oral temperature during naps (N = 8) [from Moses et al., (1975), with permission].

versely related to body temperature. Regardless of the length of the nap, however, when sleep in each nap is averaged over a 24-hour period, all stages of sleep are present.

To illustrate the similarity of the structure of sleep in various sleep regimens, in Table 1 are data comparing the sleep measures for our nap sleepers and our gradual sleep reduction subjects. The baseline sleep for both groups was very comparable, even though the nap subjects were 8 male sailors and the gradual sleep reduction subjects were 3 male and 3 female graduate students. The 366 minutes of TST for the nap subjects were obtained in 10 naps over a 40-hour period, while the 346 minutes of TST for the sleep reduction subjects were obtained during a single uninterrupted sleep period. There was less stage REM in the nap sleepers, but the similarities in sleep stages were more striking than the differences. Note, however, the marked differences in total wake time and percent Stage 1. The nap sleep was clearly less efficient, with a 61% TST, than that of the gradual sleep reduction subjects whose percent sleep time was 96%.

Table 1

Sleep Measures for Nap Sleepers (N = 8) and
Gradual Sleep Reduction Subjects (N = 6)

	Nap Sleepers	Gradual Sleep Reouction Subjects
Measure	Naps 1-10	6-Hour Phase
Total bed time (minutes)	600	360
Total sleep time (minutes)	366	346
Percent total sleep time	61	96
Percent wake time	38	3
Percent Stage 1	20	4
Percent Stage 2	39	38
Percent Stage 3	7	10
Percent Stage 4	17	15
Percent Stage REM	17	25

Sleep Efficiency

If the stages of sleep do not relate to sleep quality, were there any findings from the sleep studies that do relate to sleep quality? Yes. In both the altered sleep schedules and in the nap studies, as seen in Table 1, there was more awake time and more Stage 1, the transition period between awake and sleep (Stage 2). In a study of the acute reversal of the sleep-waking cycle, (Weitzman, Kripke, Goldmacher, McGregor, & Nogeire, 1970) noted a significant increase in waking immediately after reversal; the awake time, though decreased, was still higher than baseline, 2 weeks after reversal. Before reversal, Stage W occurred predominantly in the first hour of sleep. After reversal, the amount of Stage W decreased significantly in the first hour and increased significantly in the last 3 hours. After reversal, their subjects fell asleep more quickly, but tended to awaken intermittently in the latter half of their daytime sleep period. Stage 1 followed a similar pattern. Matsumoto (1978) found a similar increase in number of awakenings and in Stage 1, in hospital nurses during day sleep. He also found an increase in Stage 1 in the third period of sleep.

In a discussion of the motivation of day sleepers, Foret and Benoit (1977), noting Weitzman et al.'s (1970) finding of increased waking in the latter part of the sleep period, wondered if "the sleeper is likely to think that he is wasting his time (psychosociological pressure) and feels that he is too much aroused (physiological pressure) to sleep. So he makes the choice of getting up" (pp. 83-84).

A series of shorter sleep, or naps, does not appear to be the answer. As noted earlier, the efficiency of a nap depends upon its time of occurrence, but, over the 24-hour period, nap sleep is not as efficient as a single period of nocturnal sleep. As in our nap study (Moses et al., 1975), Weitzman et al. (1974) reported low sleep efficiency; 56% sleep time during 3-hour sleep-wake schedules over ten 24-hour periods. In the 90-minute day--30 minutes sleep/60 minutes awake, which lasted 5 days--Carskadon and Dement (1975) reported 62.1% TST.

Thus, the answer to Foret and Benoit's question as to whether fragmented sleep is equivalent to unbroken sleep is "No" -- if we use percent time asleep as our measure.

Reduced Sleep

The question of whether there is a change in sleep quality is still unanswered, but reversed and fragmented sleep are less efficient resulting in decreased TST. Reduced sleep, thus, is present in both field and laboratory studies of altered sleep. Is the reduced amount of sleep the explanation for the sleep complaints and feelings of fatigue? It probably contributes but very likely is not the only cause. The average TST of shift workers appears to be between 6 and 7 hours. This is below the average day sleeper's 7.5-8.5 hours, but 30-40% of the 20-40 year olds sleep 7 hours or less with no complaints. There are about 1-2% who sleep less than 5 hours. You are quite correct if you are thinking: Yes, the amount of sleep a person needs varies, but shift work brings about sleep reduction. Abrupt and gradual sleep reduction studies have been done. Again, Dr. Webb and his associates were among the first to report quantitative sleep reduction data. In one study, they abruptly reduced sleep from 7.5-8 hours to 5.5 hours for 60 days (Webb & Agnew, 1974). Using tests sensitive to sleep loss, they found no performance decrement over the 60 days. There were also no significant changes in mood or affect during the study.

In gradual sleep reduction studies (Johnson & MacLeod, 1973; Friedmann, Globus, Huntley, Mullaney, Naitoh, & Johnson, 1977), subjects reduced their sleep by 30 minutes every 2-4 weeks until their sleep was reduced from 1-4 hours. A follow-up one year later indicated the subjects were still sleeping 1-2.5 hours less than before the study began. There were no significant performance decrements in school work or on tests sensitive to sleep loss. However, as indicated in Table 1, as sleep was reduced, the sleep time was used more efficiently; awakenings and Stage 1 were decreased. The subjects ended their sleep reduction due to feelings of fatigue and sleepiness. But, as shown in Figure 3, the sharp increase in fatigue did not appear until TST was 5.5 hours and sleepiness started to increase more rapidly after a TST of less than 6.5 hours. Sleep reduction of 1 to 2 hours thus occurred with no marked changes in performance or mood.

Many night sleepers obtain less sleep than shift workers, and greater sleep reduction than that experienced by most shift workers does not lead to major behavioral changes. These data suggest that reduction in sleep quantity per se should not be the major factor in sleep complaints by shift workers. Pollak, McGregor, and Weitzman (1975) came to the same conclusion after using Dalmane to decrease the awakenings and thus increase TST in day sleepers. Though TST was increased, Pollak et al. noted there was no decrease in complaints in the drug takers, suggesting that the timing of sleep may be as important as its quantity.

The findings of Pollak et al.'s study were confounded by possible drug hangover effects, but support for their conclusion comes from studies by Åkerstedt (1976), Taub and Berger (1974.1976), and from our laboratory. In a questionnaire study, Åkerstedt compared the well-being of 3-shift, 2-shift, and day workers. As indicated in Figure 4, the TST followed a pattern similar to that of the complaint scores. The afternoon shift for both second- and third-shift workers had the longest sleep and fewer complaints, but the sleep on the morning shift did not exceed that on the night shift. In spite of the similar quantity of sleep for the morning and night shifts, Åkerstedt found that complaints by the morning shift workers were significantly higher. For Åkerstedt, this suggested that factors other than quantity of sleep may be important in determining good sleep.

Taub and Berger (1974,1976) have investigated the effects of shifts in the sleep-wakefulness cycle in a series of laboratory studies. They investigated the effects of shortening or lengthening habitual sleep and by displacing the sleep time. These studies have involved subjects whose usual sleep times varied from 7-10.5 hours. Taub and Berger reported both sleep data as well as mood and performance data. Based upon the results of their studies, they concluded that acute disruption of the 24-hour sleep-wakefulness cycle produces degradations in performance, largely independent of TST. Taub and Berger found no relationship between sleep stage amounts and mood and performance.

Changing the time of sleep thus appears to be more important than the type or quantity of sleep. It is, thus, not surprising that night work produces the largest number of sleep complaints. These workers usually sleep in the morning after work. For these night workers, morning sleep, regardless of quantity, does not appear to provide the same benefits as night sleep. Dr. Naitoh, in his presentation, will discuss work from our laboratory that documents the ineffectiveness of an early morning 2-hour nap, 0400 to 0600, in overcoming sleep loss. In contrast, a 2-hour nap from 1200 to 1400 was more effective.

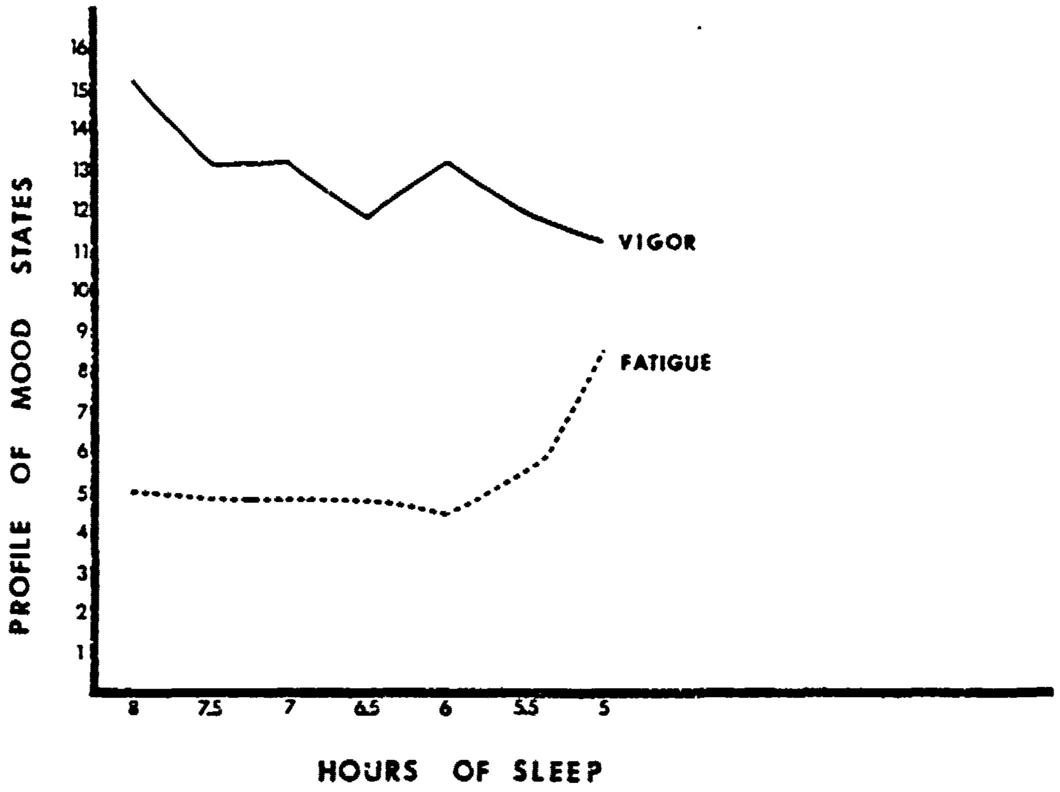

Figure 3. Effect of gradual sleep reduction on feelings of vigor and fatigue.

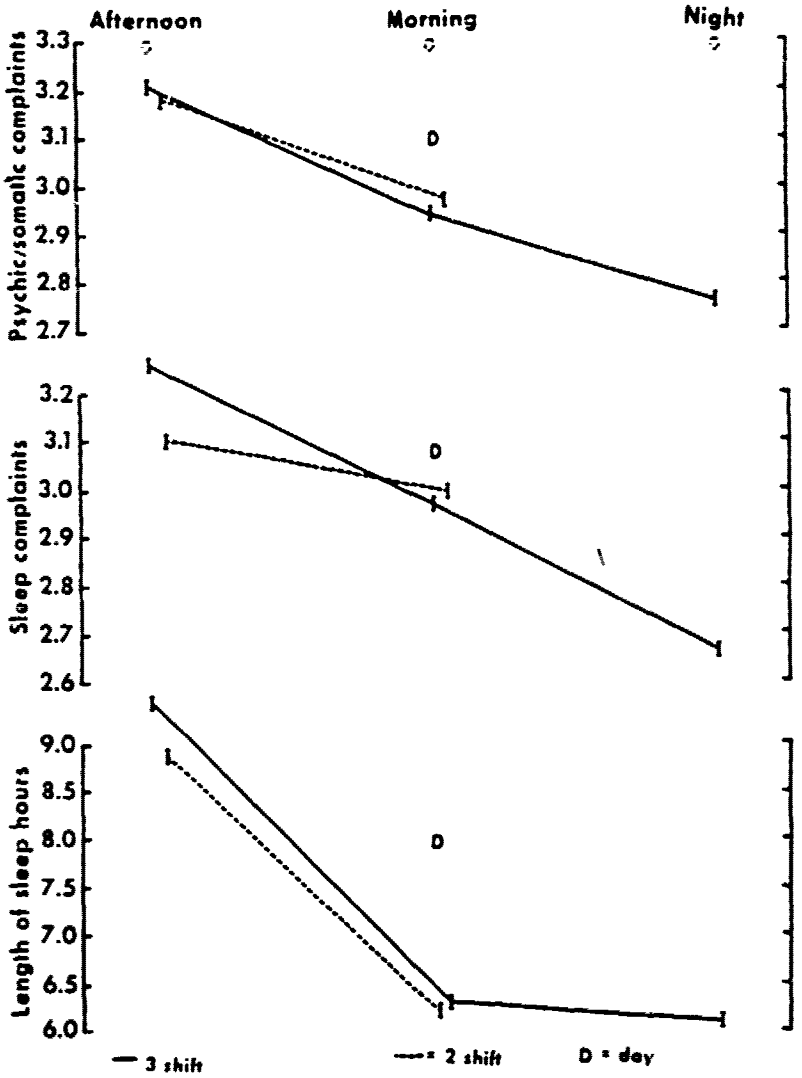

Figure 4. Means and standard errors for complaints and sleep length for each shift of 3-shift workers, 2-shift workers, and day workers. High scores = less complaints [from Åkerstedt (1976), with permission].

One final observation regarding the complaint that noise is a major problem for day sleepers. In 1971, we studied the arousal threshold from sleep of 35 hospital corpsmen who worked nights and slept days, and compared their arousal threshold from sleep with the arousal threshold of night sleepers (Keefe, Johnson, & Hunter, 1971). As shown in Figure 5, the dB level of a 1000 Hz, 5-second tone was significantly higher for the reversed sleepers than for the night sleepers. Our day sleepers were not light sleepers.

We recently further explored the relationship between the arousal threshold and subjective estimates of depth and quality of sleep in good and poor sleepers who slept in our laboratory for at least 7 nights (Bonnet & Johnson, 1978). First, we found no significant relationship between magnitude of arousal threshold and amounts of the various sleep stages. Also, there was no difference in threshold between those subjects who classified themselves as chronic poor sleepers, who reported they were easily awakened by noise, and good sleepers who "slept soundly." Subjective estimate of depth of sleep was not related to the dB arousal threshold.

Examination of individual subject data over nights indicated that, while most subjects had little fluctuation in arousal threshold from night to night, 12 of the 26 showed fluctuations of 10 dB or greater. On low threshold nights, there was significantly more awake time, and subjects reported worse sleep quality and more restlessness. Subjective estimates of depth of sleep also were significantly related to the amount of EEG defined wakefulness and Stage 1. Light sleep was sleep with more awakenings than deep sleep. These awakenings were not noise related.

It was apparent from our results that the relationship of arousal threshold and sleep quality was not determined on the basis of individual knowledge of actual arousal threshold when asleep. They judged their depth of sleep on the basis of how much time they spent awake or drifting in and out of sleep during the night. Remembering that day sleepers had more awake time and increased Stage 1, perhaps their subjective evaluation of their sleep as light sleep and their complaints of noise-disturbed sleep are a reflection of their state of consciousness, i.e., waking or Stage 1. These reversed sleepers may be aware of the noise as they awaken and drift back to sleep and assume the noise is what awakened them.

Conclusions

What are my conclusions--Are the sleep complaints valid? Yes, the sleep complaints should be taken seriously. As with the insomniac who complains of getting little sleep but is found to get 7 to 8 hours of sleep in the laboratory, the sleep complaint of shift workers may reflect problems and discontent. The major cause of this discontent may not be inadequate sleep, however. A decrease in sleep quantity does not appear to be sufficient to cause the extreme feelings of fatigue or the reason for the sleep complaints. The time in the 24-hour cycle that the sleep is obtained appears to be paramount in determining the effectiveness of sleep. There is undoubtedly an interaction between sleep reduction and phase shifts, but how the amount of sleep loss influences the magnitude of the interaction is yet to be determined. We need more studies of the relationship between sleep length at various times over 24 hours and mood and performance. If morning sleep, as it appears, is

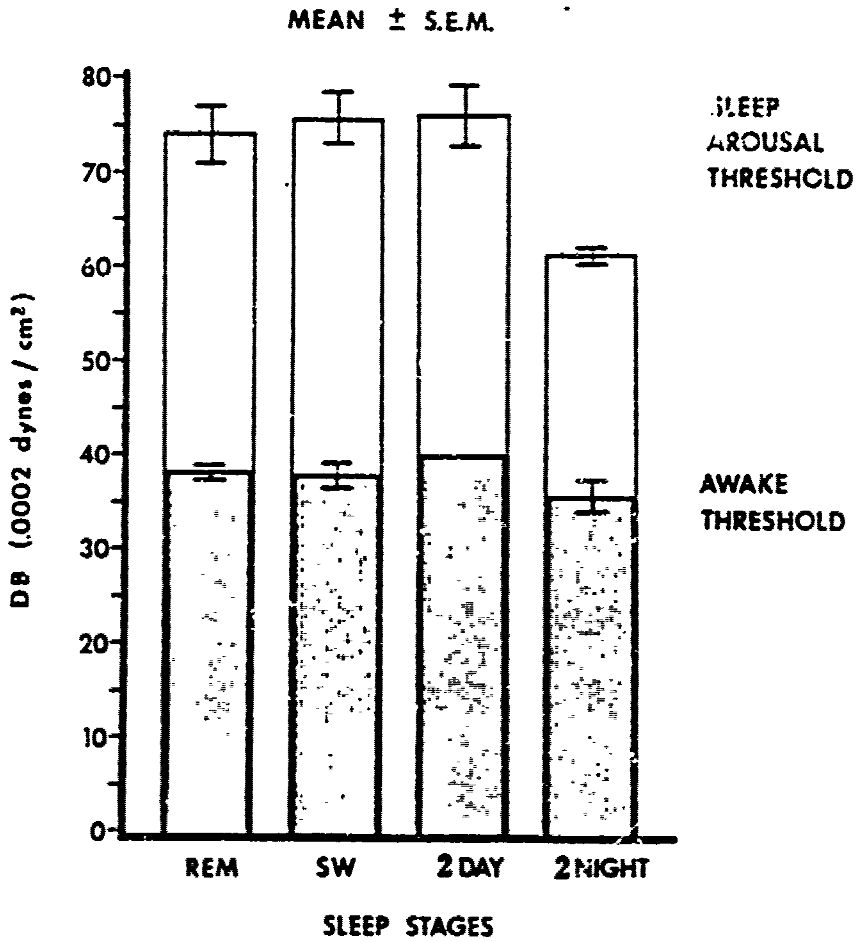

Figure 5. Mean auditory thresholds--awake and arousal from sleep--for the experimental groups. S.E.M. = standard error of the mean [from Keefe et al. (1971), with permission].

less effective than sleep at other times, what would be the consequence if night workers delayed their sleep until after lunch. This schedule would be similar to day workers where leisure follows work, then sleep followed by work; i.e., leisure, sleep, work, instead of the work, sleep, leisure pattern of most night workers.

It is doubtful that this afternoon sleep would be as efficient as night sleep. The importance of sleep at night was further confirmed by the late Dr. Mills and his co-workers, Drs. Minors and Waterhouse (1978), who found that 4 hours of sleep at night were sufficient to stabilize the circadian rhythms regardless of the number of sleep episodes during the day. In the nap studies reported above, some sleep occurred at night, which may be why there was minimal effect on rhythms, mood, and behavior. The suggestion to delay sleep until afternoon or early evening will undoubtedly cause new and perhaps additional social conflicts, but I will leave those problems to Dr. Wedderburn.

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COMPREHENSIVE STUDY OF THE SLEEP OF SHIFT WORKERS

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Although a significant portion of the American work force is involved in shift work, there has been little in the way of a systematic approach to the study of real-world shift workers in this country (Tasto & Colligan, 1977). In general, the data available to date are from studies in which a single method of data collection is employed, and many methodological approaches have not as yet been used (Tepas, 1976). The Work-Sleep Study, initially conducted in St. Louis and now in Chicago, is approaching shift workers using three methodological tactics: A brief survey; intensive laboratory study; and, extended interviews. This study is a comprehensive examination of shift workers in the sense that it includes three methodological tactics. It is also a comprehensive study in another sense. The study is designed to collect redundant information in an attempt to insure a reliable understanding of the data.

The methods used in the Work-Sleep Study have been described previously in detail (Gordon, Tepas, Stock, & Walsh,1979; Walsh, Gordon, Maltese, McGill, & Tepas, 1979). In essence, the study sequentially samples active shift workers with the three methodological tactics or approaches. Access to these shift workers is gained through their labor unions with participation always being confidential and voluntary. The brief survey, titled the Work-Sleep Survey, gathers information on type of work, hours of work, hours of sleep, health, drug use and related matters. Work-Sleep Survey respondents provide a pool of potential participants in subsequent parts of the study as well as demographic estimates of the population sampled.

This paper focuses on selected dimensions of the Work-Sleep Survey from our final St. Louis sample. The importance of a comprehensive approach will be demonstrated through comparison of survey data to similar data collected from the same workers in the laboratory and field interview parts of the study. More detailed reports of data from samples of the laboratory and field interview parts of the study will be found in subsequent papers in this volume (Walsh, Tepas, & Moss; Gordon, McGill, & Maltese). These three papers together provide an initial view of the findings of this comprehensive study.

Work-Sleep Survey Sample

A total of 1442 surveys were collected from the members of 35 St. Louis area locals and lodges belonging to 17 international unions. Of these surveys, 76% were collected by the study staff at union meetings. The remaining surveys were gathered by union officers or through a variety of mailing methods. The mean age of the workers sampled was 39.4 years. Within the sample, 78.3% were males, 73.6% were married, and 75.2% were at least high school graduates. Those working at least seven consecutive hours between 0600 and 1600 hrs were classified "Day" workers and made up 62% of the sample. Those working at least seven consecutive hours between 1500 and 0100 hrs were classified "Afternoon/Evening" workers and made up 10.9% of the sample. Those working at least seven consecutive hours between 2200 and 0700 hrs were classified "Night" workers and made up 9.5% of the sample. Workers on two or more shifts were classified as "Rotators" and made up 17.6% of the sample.

As a rule, the workers surveyed had significant experience with their specific shift schedule. Figure 1 shows the percentage of workers responding to each of five categories when asked how long they had worked these hours. In this sample 79.6% of the workers had been on their shift schedule for one year or more at the time the survey was completed. Rate of shift change for Rotators is shown in Figure 2. Fifty percent of the Rotators changed shifts once per week, whereas only 2.9% changed shifts at a more frequent rate.

In the results presented in the following sections, statistically significant differences are indicated only when they achieved the .05 level or higher. Chi Square and t-tests were used for the categorical and continuous variables, respectively.

Sleep Length

Workers were asked when during the work week they usually go to sleep and get up. Rotators were asked to provide this information for each shift they worked. Mean sleep length in hours is graphed in Figure 3 with the data from the steady permanent shift workers indicated by bracket A and the data from the Rotators indicated by bracket C. The other brackets in this figure contain similar data from two current independent studies. Bracket B contains data from steady permanent shift workers in a NIOSH sponsored study (Tasto, Colligan, Skjei, & Polly, 1978). The data from 1941 food processors and nurses have been combined for this figure. The data used corrects an error in the original report (Colligan, 1979). Bracket D contains data from a national sample comprised of 15% of the total membership of a small union of government workers (Armstrong & Tepas, 1979).

For all four samples shown in Figure 3, Afternoon/Evening shift work is accompanied by the statistically significant longest sleep length whereas Night work is accompanied by the statistically shortest sleep length. It should be noted that the differences in sleep length associated with the three permanent shifts are mirrored in the data from the Rotating shift workers. For the St. Louis data, the sleep length of the Rotating workers on a Day work shift is significantly shorter than that of a permanent Day worker, and the sleep length of the Rotating worker on Night work shift is significantly shorter than that of a permanent Night worker. Afternoon/Evening shift differences of this sort are not statistically significant.

Perhaps the only other comparable data from American shift workers is that reported by Mott, Mann, McLoughlin, and Warwick (1965) almost 15 years ago. Although not statistically significant in all cases, nearly identical trends are evident in this older data. Sleep chart data from European workers reported by Östberg (1973) give much the same picture.

Difficulty Sleeping

A question on the survey asks: Do you often have difficulty in falling asleep or staying asleep? Data from respondents was sorted on the basis of the yes-no response to this question. Figure 4 presents the mean sleep lengths obtained. The bars bracketed as ALL are the data from permanent shift workers and Rotators before the sort on this question. For Rotators the average sleep length for the three shifts is graphed. Bracket DS contains the

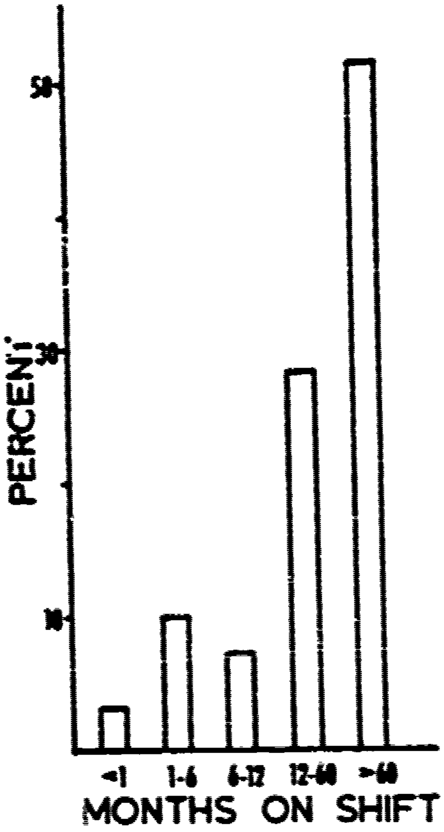

Figure 1. Worker experience on shift schedules for total sample of 1442 respondents.

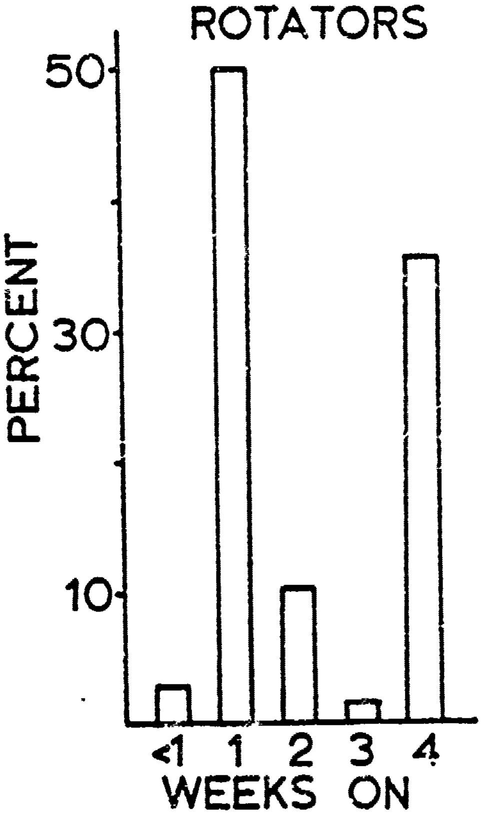

Figure 2. Rate of shift change for workers on Rotating shift schedules.

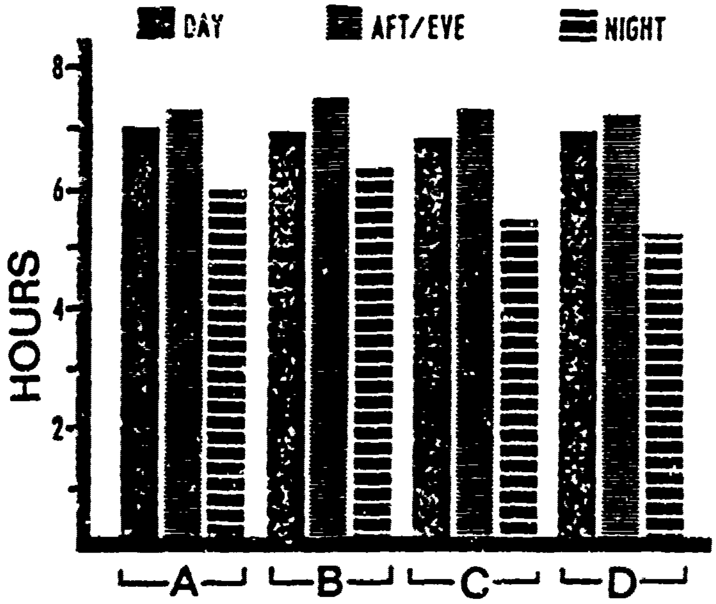

Figure 3. Mean sleep length in hours for Steady and Permanent, and Rotating shift workers. (A = St. Louis sample of Permanent shift workers; B = NIOSH sample of Permanent shift workers; C = St. Louis sample of Rotating shift workers; D = National sample of Rotating shift workers).

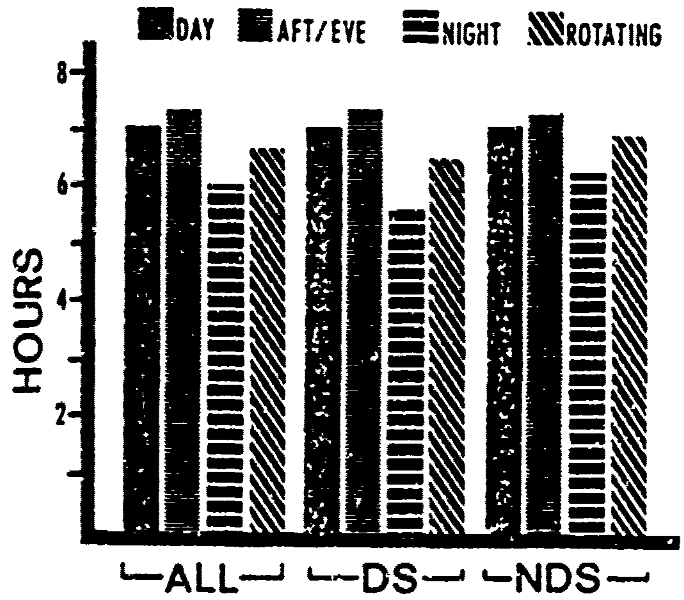

Figure 4. Mean sleep length in hours. (All = All workers responding in St. Louis sample; DS = St. Louis workers who report difficulty in falling or staying asleep; NDS = St.Louis workers who did not report difficulty in falling or staying asleep).

data from those answering "yes" to this question and NDS (No Difficulty Sleeping) brackets the data from those answering "no". There are no significant differences in sleep length between DS and NDS workers on permanent day or Afternoon/Evening shifts. For permanent Night shift, DS workers report significantly shorter sleep times than NDS workers. Also, DS Rotators have reported shorter sleep times than NDS Rotators. Overall, for Rotators the average sleep length is significantly shorter than that of either Day or Afternoon/Evening shift workers, but longer than the reported sleep length of Night workers. These differences are also evident in both the DS and NDS sorts. Thus, the average sleep of Rotators falls short of the reported sleep of either Day or Afternoon/Evening workers, and subjective reports of difficulty sleeping or staying asleep appear to interact with sleep length among both Night and Rotating workers.

Napping and Difficulty Sleeping

A question on the survey asks: Do you often take naps during the work week? Data from respondents was sorted on the basis of the yes-no response to this question. Figure 5 shows the percent responding "yes" to this napping question for each of the four shift groups as well as the percent responding "yes" to the difficulty sleeping (DS) question. For both the napping and DS variables, the Night and Rotating workers respond "yes" at a significantly higher rate than Day workers. In both cases, there are no significant differences in percentage responding "yes" between Day and Afternoon/Evening workers or between Night and Rotating workers.

In Figure 6, the percent responding "yes" to the napping question stated above is graphed for both NDS and DS groups. As we have already pointed out, overall the percent responding "yes" to the napping question is greater for both Night and Rotating workers. Among Night shift workers, DS workers report frequent napping more often than NDS workers. Similarly among Rotating workers, DS workers report frequent napping more often than NDS workers. With regard to nap length, there are no statistical differences between DS and NDS for any of the shift groups. With regard to sleep length, Night shift DS workers sleep less than NDS workers. This significant difference also holds for Rotators, but does not hold for Day and Afternoon/Evening workers. Thus, DS Night workers and Rotators appear to be short sleepers who take frequent average-length naps.

Work/Sleep Phase Type

In addition to being asked when during the work week they usually go to sleep and get up, workers were also asked when they went to work and when they ended work. Again, Rotators were asked to provide this information for each shift they worked. Those reporting sleep periods just prior to work were classified as having a Sleep/Work Phase Type, and those reporting sleep periods just after work were classified as having a Work/Sleep Phase Type. When this classification was not clear, workers were assigned to a number of other categories, but this was not a problem for most workers.

Figure 7 provides a schematic representation for the results of this analysis. In general, Day workers have Sleep/Work Phase Types with 99.4% of the Permanent (P) Day and 100% of the Rotating (R) respondents following this

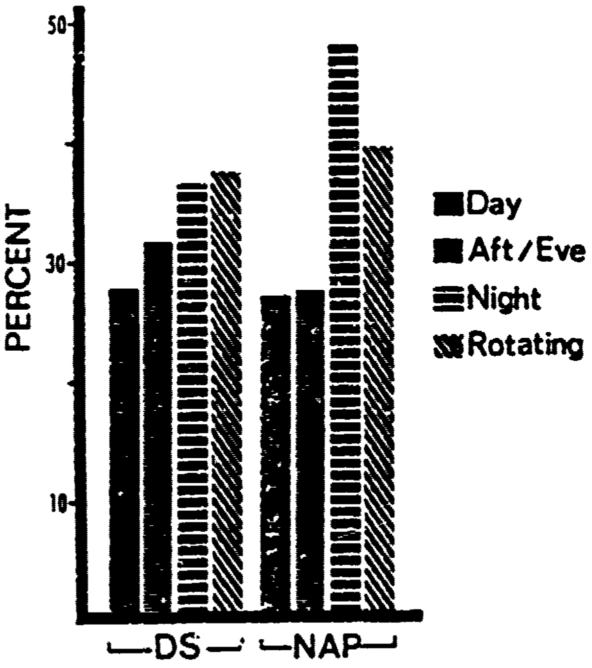

Figure 5. Percent workers responding yes. (DS = Have difficulty falling or staying asleep; NAP = Often take naps during the work week).

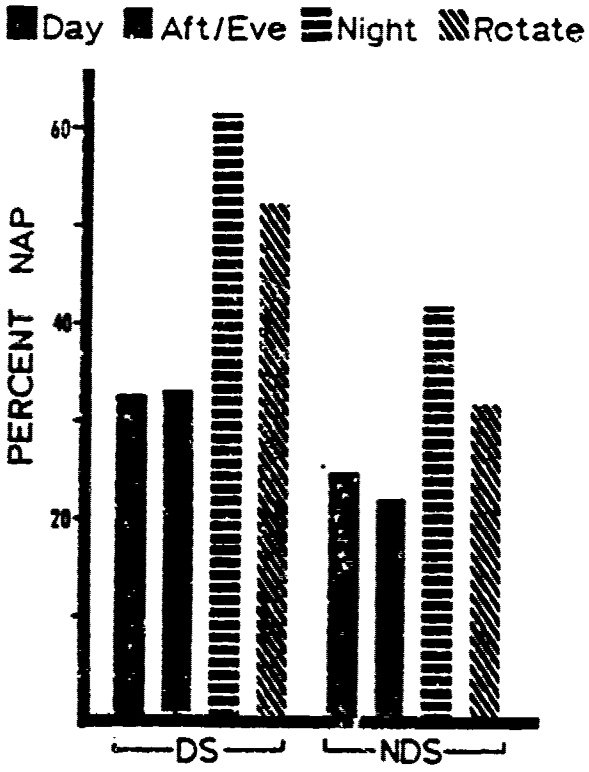

Figure 6. Percentages of workers who responded "yes" to the napping question. (DS = those who have difficulty falling or staying asleep; NDS = those who do not).

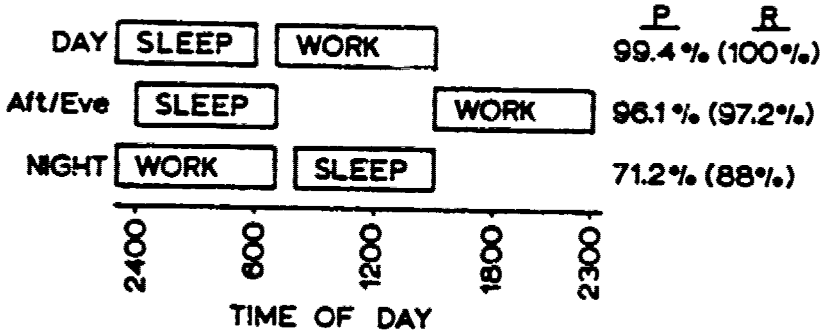

Figure 7. Schematic representation of typical Work/Sleep Phase Types. Percentages are shown for the percent of Permanent (P) and Rotating (R) shift workers conforming to this model.

model. Afternoon/Evening workers and Night workers, on the other hand in general sleep after work rather than before. For Afternoon/Evening work, 96.1% of the Permanent workers and 97.2% of the Rotating workers have Work/Sleep Phase Types. Night work for 71.2% of the Permanent workers and 88% of the Rotators yields times classified as Work/Sleep Phase Type. As one might expect from the napping data, classification of workers into phase types was most difficult for the Night workers. Thus, just as the sleep lengths of the three Permanent shifts are mirrored in the data from the Rotating shift workers, the Sleep Phase Type analysis also yields parallel results for Permanent and Rotating workers.

Correlation Between Sleep Length Estimates

As noted in our introduction, the sequential nature of our design requires that all participants in the intensive laboratory study first complete the Work-Sleep Survey. In addition, many participants in the laboratory study also participate in the extended field interviews. Using the 30 workers from the polysomnographic analysis (Walsh et al.) as our base and interview data when available (Gordon et al.), a correlation matrix was computed using the six sleep length estimates collected in the various parts of the overall study. The results of this analysis are presented in Table 1.

Table 1

Intercorrelations of Various Measures Used to Estimate Sleep Length

		S	I	TIB	TST	PSR
Survey	(S)					
Inventory	(I)	.28				
LAB TIB	(TIB)	.81	.40			
EEG TST	(TST)	.83	.31	.91		
LAB PSR	(PSR)	.73	.28	.86	.84	
Field Inter.	(F)	.80	-.20	.83	.83	.77

S=Work-Sleep Survey;
I=Sleep Inventory;
TIB=Time in bed;
TST=Total sleep time;
PSR=Personal sleep report;
F=Interview sleep estimate.

The six sleep length estimates included in Table 1 are as follows. Survey (S) sleep length estimates are the Work-Sleep Survey data gathered by asking the workers when they usually go to bed and get up during the work week. Inventory (I) sleep length estimates were obtained, on the average for this sample, 117 days after the administration of the Work-Sleep Survey in the course of the laboratory Orientation Session. In this case, workers were asked, on a questionnaire titled the Sleep Inventory: Excluding naps, how long are you asleep every 24 hours? Lab TIB (TIB) is the mean time in bed observed during the last three sleep sessions in the laboratory. EEG TST (TST) is the mean standard polysomnographic measure of total sleep time for the last three sleep sessions in the laboratory (Rechtschaffen & Kales, 1968).

Lab PSR (PSR) sleep length estimates are mean subjective estimates made by workers during the last three sleep sessions in the laboratory while electrodes for the polysomnographic recordings were removed after sleep. In this case, workers were asked, on a questionnaire titled the Personal Sleep Recorder: How long did you just sleep? The laboratory sleep length estimates were obtained, on the average for this sample, 182 days after adminstration of the Work-Sleep Survey. Field interview (F) sleep estimates were gleaned by staff from the extended interview data with the staff blind as to other length estimates (Gordon et al., this volume).

For the correlation coefficients shown in Table 1, an r value of .40 or greater is significant at the .05 level or better. In general, it seems reasonable to conclude that with the exception of Sleep Inventory data, sleep length estimates in the various parts of the study are highly correlated. We suspect that the insignificant Sleep Inventory correlations would be significant with larger samples. Two studies using larger samples from the Work-Sleep Study have reported statistically significant but modest correlations between the Work-Sleep Survey estimates of sleep length and those obtained with the Sleep Inventory (Maltese, 1979; Stock, 1979). Thus, it seems reasonable to suggest that Work-Sleep Survey sleep length estimates provide a reasonable index of other sleep length estimates collected in the laboratory or via interview methods. It should also be noted that these various estimates were distributed over a six month period on the average. This can be interpreted as suggesting that the workers studied have relatively stable and consistent sleep length characteristics.

Discussion

The Work-Sleep Study is aimed primarily at the study of real-world experienced shift workers while they continue to work on their usual job and shift. This is being achieved, but a clear explanation of the findings to date is difficult. By design, our laboratory study to date has been aimed at only Day, Night, and Rotating shift workers. Yet, it may be that the Work-Sleep Survey data collected by hap from Afternoon/Evening shift workers produces the most significant clues of all at this point in our study.

Afternoon/Evening shift workers sleep, in general, longer than workers on any of the other shift groups observed in our study. Since most Day workers sleep before work and most Afternoon/Evening workers sleep after work, this means that in practice the temporal placement of sleep for Day and Afternoon/Evening workers overlaps to a considerable degree. This prohibits a strict circadian/physiological explanation for the increased sleep of Afternoon/Evening workers. One might propose that the sleep length of Afternoon/Evening workers is extended due to increased fatigue produced by not sleeping just prior to work. This suggestion is clearly not totally satisfactory since Night workers also sleep after work rather than just before their work, and their sleep is shorter not longer than that of Day workers.

What remains as feasible major sources of variance are two rather complex groups of social factors. First, following the suggestion of Webb and Agnew (1975) it is reasonable to suggest that the hourly Day workers in our study are free to choose when they wish to go to sleep but must get up to go to work at a specific time in order to keep their jobs. Thus, one can argue that our

Day workers do not get as much sleep as they require due to the demands of their shift schedule. Second, it is also reasonable to suggest that the Afternoon/Evening workers can in practice extend their sleep to a reasonable degree without having this significantly interfere with their social obligations and opportunities immediately after awakening. Thus, one can argue that the Afternoon/Evening workers are the only ones to get as much sleep as they require.

The average sleep for all workers in the St. Louis Work-Sleep Survey sample is 6.96 hours. Obviously, this number has no absolute value since our sampling methods made overt efforts to include a large number of shift workers in the group. The proportioning of various shift groups in the total sample would, of course, influence the relative value of the total sample mean sleep length. However, it is certainly proper to note that the average sleep length observed is a long way from the traditional eight hours frequently touted in popular culture! Mott et al. (1965) provides us with the only comparable sleep length data from American shift workers which was collected some years in the past. Their sleep lengths are longer than our comparable ones and the comparable ones from the contemporary NIOSH study (Tasto et al., 1978). Perhaps these findings are in keeping with Webb's suggestion that sleep lengths have shortened in recent years (Webb, 1969). It is also interesting to contrast and compare our sleep data with that reported by Webb and Agnew (1978) for rotating laboratory shift conditions in which social pressures are minimal.

With regard to both sleep length and Sleep Phase Type, it is very clear from our data that Rotating workers in general change their behaviors as they change shifts so that they pretty much mirror the behaviors of Permanent workers on the same shifts. Thus, it would be quite difficult to argue that the Rotating workers we sampled have developed any unique way of adjusting to the rigors of their shift schedule. In fact, given the percentages of Rotators reporting difficulty sleeping or napping, together with their average sleep times, one is hard pressed to at all suggest on the basis of survey data that our Rotators tolerate well their changing shift schedules.

Night workers tend to nap longer than Day or Afternoon/Evening workers. Assuming that napping is a method used by workers to compensate for reduced sleep periods, we have calculated a variety of adjusted total sleep time estimates based on nap length and sleep extension estimates reported on our Work-Sleep Survey. To date, we have not been able to derive any way of adjusting times so that the total sleep time estimates for each of the three shifts is about the same. For example, when we adjust reported sleep by adding the appropriate mean nap or sleep extension times proportional to their incidence, the adjusted total sleep time estimates per 24 hours for Day, Afternoon/Evening, Night, and Rotating workers are 7.53, 7.86, 7.66, and 7.14 hours, respectively. This analysis does little to change our basic findings in terms of the sleep habits of shift workers.

Stock (1979) completed a detailed analysis of the sleep-related habits and subjective sleep perceptions as reported on the Sleep Inventory for a matched sample of workers in the DS and NDS Work-Sleep Survey response groups defined earlier. This analysis included the data from 134 workers in our sample. Among other things, the DS workers reported longer sleep latencies, more monthly incidents of trouble falling asleep, more problems with awakenings, and rated themselves as lighter sleepers more easily awakened by noise. They reported being more tense at bedtime and being more tired upon awakening on workdays. They did not differ from the NDS group in estimates of sleep duration, dreaming or napping habits. This analysis makes it quite clear that our DS shift workers do experience a variety of sleep complaints.

The decreased sleep length estimates obtained for Night shift work is particularly meaningful in light of the significant positive correlations with our polysomnographic measures. Maltese (1979) completed analysis of long and short sleepers in groups of workers from our shift worker sample. This analysis defined long and short sleepers using a statistical criteria, based on the total Work-Sleep Survey sample. Long and short sleepers were defined as the top and bottom quartiles of reported sleep length. For Work-Sleep Survey based criteria, short sleepers were those who slept less than 6.5 hours per night. Among other things, short sleepers were more manic, desired and felt they needed less sleep, and reported they were less sleepy after awakening. With a mean sleep length of 6.05 hrs for Permanent and 5.53 hrs for Rotating Night work, one might view Night work as a "producer" of short sleepers or appropriate for short sleepers. In general, the characteristics of a short sleeper are positive ones and therefore one might view Night work as a quite acceptable work alternative. On the other hand, if mortality rate (Kripke, Simons, Garfinkel, & Hammond, 1979) should be higher in short sleepers, Night work might prove to be an insidious silent killer.

As experiment-in-progress, the Work-Sleep Study should provide more light on the problems of shift work as data collection and analysis continue. However, it should be recognized that shift work issues are complex ones, subject to a host of variables. We are only beginning to explore these variables in this country. Although the Work-Sleep Study is a comprehensive approach, comprehensive findings should not be expected. It will be years before we arrive at that point.

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HOME AND COMMUNITY LIFE OF A SAMPLE OF SHIFT WORKERS

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When shift workers are asked to evaluate their job schedules, effects on family and social life are reported as major concerns. Difficulty and dissatisfaction with roles and activities at home and in the community are reported in a number of studies and reviews by European and American investigators (Carpentier & Cazamian, 1977; Lein, 1974; Maurice, 1975; Mott, Mann, McLoughlin, & Warwick, 1965; Tasto, Colligan, Skjei, & Polly, 1978; Wedderburn, 1975; Young & Willmott, 1973).

Workers' own assessments of the impact of shift work on their lives are especially relevant since there is a significant association between the degree of shift satisfaction and the ability to adapt to a particular shift (Tasto et al., 1978).

Less is known about the relationship between shift work and home life or psychosocial life than about the physiological consequences of unusual work-sleep schedules. In this respect shift work partakes of a more general problem, namely the lack of sufficient research into the many occupational factors that can affect the quality and quantity of a worker's involvement in life away from work. An extensive review of the literature on the relation between work and family in the United States shows that the intersections between most aspects of work and family well-being have been relatively ignored (Kanter, 1977).

Method

This study constituted a component part of a work-sleep s[illegible]ucted in St. Louis to examine relationships among job shift hours, sleep and off-the-job life variables. The full work-sleep study consisted of three sequential methodologies: a brief Work-Sleep Survey, administered to a broad sample of labor union members; a laboratory study of sleep, performance, and mood, carried out with selected volunteers from the survey sample; and a field interview concerning life away from the job, administered to both laboratory participants and additional volunteers from the survey sample. The study was carried out with the cooperation of 17 national labor unions in the St. Louis area. The full methodology is described elsewhere (Gordon, Tepas, Stock, & Walsh, 1979; Walsh, Gordon, Maltese, McGill, & Tepas, 1979).

The present paper reports only on the interview study. It was descriptive and exploratory in nature and was designed to obtain psychosocial data on the lives of workers and their families as a function of shift. Two types of data were sought: subjective responses indicating the levels of worker satisfaction/dissatisfaction with the shift, other dimensions of the job, and life away from work; and reports of the type and frequency of leisure, family, social, and organizational activity occurring during the 12 months prior to the study. A primary intent of the study was to provide workers with an opportunity to describe freely their feelings and experiences both on and off the job.

Three shifts were included in the study: day shift (starting time from 0600 to 0900); night shift (starting time from 2300 to 0100); and rotating shift, including workers who changed either between two or among three different shifts. The two-shift rotators oscillated between day and afternoon/evening shift (starting time 1500 to 1700) the three-shift rotators changed among day, afternoon/evening, and night shifts. Steady afternoon/evening shift workers were not included.

Respondents

Interviews were conducted with 71 volunteer respondents, whose distribution by shift and sex is shown in Table 1. Sixty percent of the rotators changed among three shifts and the remainder between two shifts. The size of the groups reflects the availability of volunteers in the sample surveyed. The intention to interview equal numbers of female and male workers was not realized, particularly in the rotator group.

Table 1

Number of Interview Respondents by Sex and Shift

Shift	Sex		Total
	Males	Females	
Day	16	13	29
Night	12	11	23
Rotating	12	7	19
Total	40(56%)	31(44%)	71(100%)

The majority of respondents were employed by manufacturing, transportation, and utility companies; the remainder were employed by government. Most of the workers were of three types: blue-collar craft and kindred workers, blue-collar machine operators, and white-collar clerical workers. The interview sample was drawn from the membership of 12 different national labor unions.

The 71 interview respondents were selected from the pool of surveyed workers who volunteered for further participation in the study. Of the 71, 38 also slept in the laboratory and 33 did not. Those who slept in the laboratory had been selected by the investigators in the laboratory phase of the full study on the basis of certain criteria: work schedule, absence of serious medical, psychological, and sleep problems; limited use of drugs, including alcohol, caffein, and medications; and limited off-the-job exercise. The 33 additional respondents were selected on the basis of similar criteria. It was recognized that the respondent selection process would yield a healthier-than-average sample and might tend to reduce the size of any differences among shift groups that would emerge in the findings.

Procedure

The content and methodology of the field interview have been described previously (Walsh et al., 1979). Briefly, the interview lasted about 2.5 hours and included the following content areas: job, shift, health, leisure, home and family life, social life, and participation in organizations. The interview was composed of two formats: a nonstandardized, semi-structured conversation focusing on the worker's attitudes, feelings, and opinions; and a verbally-administered, structured questionnaire requesting specific descriptive information. Two of the present authors (Gordon & McGill) developed the interview methodology and conducted all interviews. The development period included 30 preliminary interviews.

In all aspects the interview was aimed at maximizing rapport and facilitating conversation. The majority of interviews took place at respondents' homes. Married workers were encourage to invite spouses to join the interview session. All interviews were tape recorded with the permission of the respondent.

By incorporating the semi-structured conversation and the structured questionnaire into a single interview, it was possible to obtain two qualitatively different types of information: reports of worker and family satisfaction with the shift and off-the-job life; and description of worker and family activity, plus demographic and other concrete information.

Scoring of semi-structured conversation. Tape recordings of the semi-structured conversations were scored directly, without being transcribed, by an aural method of content analysis developed for this study. Scoring was carried out by two raters after the entire set of interviews was completed. A sub-sample of 33 respondents, 11 in each shift group, was chosen for the content analysis. Tapes were randomly selected to yield 6 male and 5 female respondents per shift. As the raters listened to each taped interview, they completed a scoring booklet in which they wrote or tabulated each specific comment within the content areas of the interview. Comments were identified and designated as follows:

1. Positive evaluations. For example, "I like the hours I work because they let me do things when I want."
2. Negative evaluations/complaints. For example, "I never get to see my children when I work the evening shift."
3. Coping strategies for shift-related problems. For example, "I've bought thicker shades so the light doesn't disturb my sleep."
4. Signs of support or assistance from the worker's family or others that facilitate his/her adjustment to the shift. For example, "My wife gets up extra early to make dinner for me when I get home in the morning."

From the collection of positive evaluations, complaints, coping strategies, and supports within a given content area, the rater made judgments of the level of satisfaction-dissatisfaction. Three judgments of the satisfied, tolerant, and dissatisfied.

A rating of "satisfied" was given when the worker voiced a preponderance of positive evaluations with few or no complaints. A rating of "tolerant" was made where the worker expressed both positive and negative comments that appeared to be of about equal significance in the worker's life. A rating of "dissatisfied" was assigned when the worker voiced a preponderance of negative evaluations with few or no positive comments. The final rating for a given area was subject to the rater's assessment of the affective import of the feelings expressed, as shown by the respondent's tone of voice and degree of emphasis.

Initially each taped interview was scored and evaluated by both judges. When ratings (satisfied, tolerant, or dissatisfied) across all content areas reached an interrater agreement rate of 85%, subsequent tapes were scored by only one of the two judges.

Results

Results based on the semi-structured conversation and questionnaire are presented under four headings: demography, job, and shift tenure; levels of satisfaction; interview impressions; and frequency of activity.

Demography, Job, and Shift Tenure

The sample of respondents consisted largely of mature, experienced employees. The mean ages across shift groups were similar; 42.5 years (day shift); 39.1 years (nightshift); and 41.4 years (rotators). Other demographic variables are shown in Table 2. All but four of the males were married, while only half of the females were married. The higher percentage of high school graduates on the rotator group was reflected in their higher job income ranges. The median job income range for the day and night shift groups was $16,000 to $18,000 per year, and the median job income range for the rotators was $18,000 to $20,000 per year.

Table 2

Percentage of Respondents in Each Shift Group by Selected Demography Variables

	Day	Night	Rotating
Marital status: Single	7	13	16
Married	72	74	68
Divorced	21	13	16
Households with children at home	65	47	47
Single-parent respondents	14	13	16
Ethnic background: White	79	78	95
Black	21	22	5
High school graduates	69	71	94

The mean number of years with the same employer showed the rotating group with the longest tenure and the night shift group with the shortest: 15.9 years (day shift); 12.4 years (night shift); and 18.0 years (rotators). The mean number of years on the shift varied in a similar pattern across the three groups: 7.8 years (day shift); 6.6 years (night shift); and 11.8 years (rotators).

Levels of Satisfaction

Levels of satisfaction were obtained in five areas of life, based upon ratings of the semi-structured, taped conversations with the sub-sample of 33 respondents. Figure 1 shows the percent of respondents in each shift group who were rated as "satisfied" (see Method) for each of the following content areas: shift hours, job, sleep, family life, and leisure-social life.

As determined by a content analysis of the taped semi-structured interviews, all of the 11 day shift workers were judged to be satisfied with their shift, while 55% of the workers on night shift and only 18% of the rotators were rated as satisfied with their shift. Responses to a questionnaire item by the 71 respondents of the full sample were consistent with the above trend. When asked, "If you had a choice, what exact hours would you like to start and end work?" 91% of the day workers stated a preference for the day shift, 43% of the night workers preferred night shift, while none of the rotators stated that they would choose a rotating shift if they had a choice.

Both the questionnaire item concerning shift preference and the ratings of shift satisfaction based upon the taped interviews thus showed a similar pattern: nearly all of the day workers appeared to be satisfied with their shift but only half of the night workers and relatively few of the rotators expressed satisfaction with their shift hours.

In contrast, the judges' ratings of worker satisfaction with the job itself, excluding the shift, showed job satisfaction to follow a different pattern that varied less across shifts. Rotators appeared most satisfied with the job itself (64%), followed by day worker (55%), and finally by the night workers (45%).

Satisfaction ratings in the three main areas of life-sleep, family life, and leisure-social life (combined), are also shown in Figure 1. In all three areas significantly fewer of the shift workers than the day workers were judged to be satisfied. The pattern of satisfaction by shift for sleep and leisure-social life parallels closely the trend noted for shift satisfaction. With respect to the percent satisfied with family life, the rotators were judged to be relatively more satisfied than in the other areas of life.

Interviewer Impressions

During the course of conducting 100 semi-structured conversations, including 30 in the preliminary stage, the interviewers developed impressions as to the effects of working hours on the respondents' lives. These inpressions were formed around two major questions: first, what is the balance of hazards and benefits experienced by workers on the different shifts? second, what kinds of coping strategies or accommodations do shift workers and their families develop?

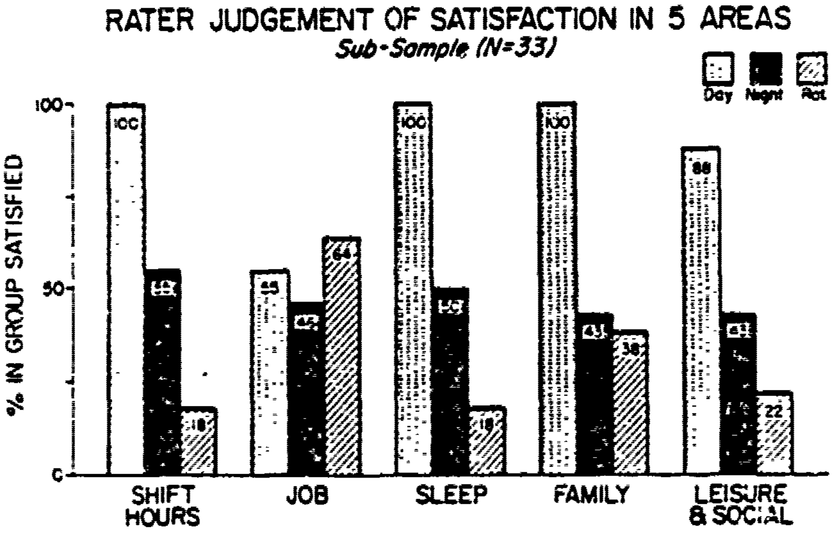

Figure 1. Percent of each shift group rated as "satisfied" on the basis of content analysis of tape-recorded semi-structured conversation.

Findings on levels of satisfaction for the random sub-sample of 33 respondents (Figure 1) corroborate the impressions that the interviewers developed during the data-collection process. Obvious qualitative differences were recognized between interviews where the respondents verbalized complaints and dissatisfactions relating to the shift and those where neutral and positive conversation was prevalent. With few exceptions, it was clear during the course of the interview which of these two general categories it represented. Interviews with day shift workers were almost always in the second category, although some day-shift respondents evidenced considerable dissatisfaction. Roughly half of the night-shift workers viewed themselves as "night people" and spoke in a generally positive vein. The other half of the nightshift group and most of the rotators described many physiological and psychosocial problems. For some, the shift hours appeared to have an all-but-overwhelming impact on their lives. The dissatisfied night and rotating shift workers sometimes expressed the opinion that they were an unattended, unappreciated, oppressed sector of the work force.

Regarding the second question about coping strategies by workers and their families, the interviewers noted a variety of styles that were not readily categorized. Two key variables were apparent: first, the extent to which the shift worker made accommodations or compromises with the "normal" schedule of his/her family and the surrounding world; second, the extent to which the worker's marital partner and children made accommodations or compromises to the working hours of their family shift worker. Family adjustments were intended to provide direct support to the shift worker or to bolster the well-being of the family as a unit. The intersection of the worker and family styles resulted in cases at one extreme where the worker and family tended to ignore each other's schedules, and the other extreme where there was considerable cooperation and often sacrifice. One pattern that emerged more clearly than others was the presence of considerable support and accommodation by the wives of male rotators.

Reported Frequency of Activity

In the questionnaire respondents were asked how frequently they had engaged in a given activity during the previous year, i.e., the 12 months just prior to the interview. Responses were obtained initially in terms of four frequency categories: not at all, less than once a month, at least once a month but less than once a week, and once a week or more. In the following data, two categories of once a month and once a week are collapsed into the single category of once a month or more (12+times) to indicate activities that occurred with some regularity.

Leisure activity. Frequency of leisure activity was partially assessed with the question, "Would you tell me three of your favorite ways to spend time--ways that you particularly enjoy?" Respondents also indicated how frequently they had engaged in each activity in the past 12 months. Figure 2 shows that fewer night shift workers than day or rotating shift workers reported regular involvement in their favorite activities.

Level of leisure acitvity was also assessed with a list of 12 pre-selected leisure activites. Frequency of engaging in thses activities at least once a month is shown in Table 3. For certain of these activities fewer mem-

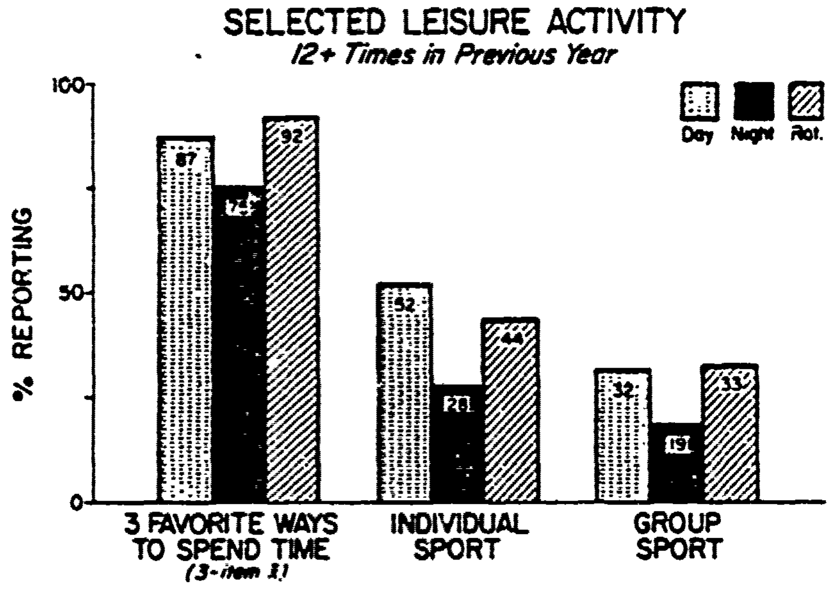

Figure 2. Percentage of each shift group reporting that they carried out specified leisure activity once a month or more in the previous year.

bers of the night shift group reported as much activity as the day or rotating shift workers: group sport, individual sport, and spectator sport. For other acitivities, fewer members of the day shift group were involved at least monthly: dancing, napping, window shopping, and attendance at movies, concerts, and theaters. The rotators emerged as least active of the shift groups in attending courses.

Table 3

Leisure Activity: Percentage of Respondents Reporting Activity Once a Month or More in the Previous Year

Activity	Shift Group Day Shift n=29	 Night Shift n=23	 Rotating Shift n=19
Group sport	32	19	33
Individual sport	52	28	44
Dancing	4	24	19
Reading	100	95	100
Relaxing yard or house work	74	62	67
Class, course	35	32	12
Watch TV	100	95	100
Nap	61	81	81
Resting	77	80	82
Spectator sport	31	19	27
Window shopping	48	62	69
Movies, concerts, theater	22	50	44

<u>Family life</u>. The level of the worker's involvement with the family was determined for interactions with spouse (partner role) and with children (parent role). Five questionnaire items related to each role (Table 4). A trend is evident for a lower percentage of night workers than day and rotating workers to engage in individual partner and parent role items at least once a month.

The five-item sets of activity pertaining to partner role and parent role were combined (Figure 3) to provide a more general comparison among the three shifts of the involvement in family roles. Fewer night shift workers evidenced regular involvement with spouse and children. Rotators appeared similar to the day shift group in level of parent-role activity and exceeded the day workers in level of partner-role activity.

As an additional measure of worker-partner interaction, respondents were asked how many waking hours were usually spent in the same location as their spouse, regardless of whether there was any interaction between them. For workdays, the day-shift group reported an average of 5-6 hours of worker-

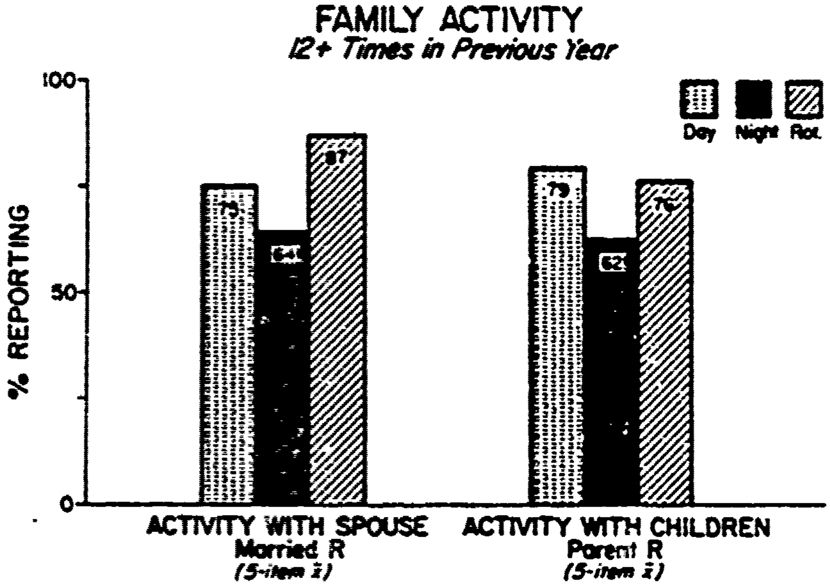

Figure 3. Percentage of married respondents and parent respondents reporting that they engaged in activity with spouse and with children once a month or more in the previous year.

partner co-presence, while the night and rotating shift groups reported an average of only 3-4 hours of co-presence. Thus, the day shift group averaged 25-30 hours of co-presence in a five day work week, while the night and rotating groups averaged ten hours less, or 15-20 hours of co-presence.

Table 4

Selected Items From Questionnaire: Percentage of Respondents Reporting Activity Once a Month or More in the Previous Year

Partner-role item	Day	Night	Rotating
Discuss family and personal problems	83	60	100
Work together around the house	76	67	91
Entertain relatives or friends at home	53	40	64
Relax together at home	88	80	100
Go out together for dinner, movies, or other recreation	72	73	81
Parent-role items			
Talk with children about their problems or things that interest them	100	89	100
Relax together with children by watching TV or working on a project	92	89	100
Attend PTA meetings, scout groups, ball games, school programs	64	11	28
Do something together as a family at home	69	44	88
Do something together as a family away from home	69	78	62
Contact with relatives and friends (flexible)			
Spend time with relatives	88	67	69
Talk with relatives on the phone	80	75	62
Spend time with friends from work	65	40	77
Spend time with other friends	60	55	69
Talk with friends on the phone	68	73	56
Social occasions (scheduled)			
Attend special occasions such as wedding, birthday, or holiday get-together	35	18	12
Visit other people at their home	64	27	56
Have other people over to your home	48	46	50
Go out with others for entertainment or any kind of outing	32	32	69

On days off, the reported co-presence increased for all three shift groups, with rotators showing a larger increase than either of the other shifts. Rotators reported six additional hours of co-presence, while the day and night workers each showed four additional hours of co-presence.

Informal social activity. Frequency of informal social activity (distinguished from participation in formal community organizations) was obtained for two types of activity that differ in the amount of scheduling flexibility they permit: activities with flexible starting and ending times; and activities with scheduled starting or ending times. The flexible activities included five items related to in-person and telephone contact with relatives and friends. The scheduled items related to four kinds of social occasions (see Table 4). The items pertaining to frequency of flexible social contact show a higher percentage of regular activity and smaller differences between shift groups than the items pertaining to scheduled social occasions. The most inflexible item of social activity (wedding, birthday, holiday) shows the night and rotating shift groups at a relatively low level of participation.

The two sets of items pertaining to contact with relatives and friends (flexible) and social occasions (scheduled) were combined (Figure 4) to provide an overall comparison of participation in informal social activity by the three shift groups.

As shown in Figure 4, regular activity was more prevalent and differed less between shifts for the flexible than for the scheduled activities. The night shift workers had a lower level of participation in the four types of scheduled occasions, averaged together.

Participation in organizations. Participation in three kinds of organized activity is shown in Figure 5: church service, labor union meeting, and class or workshop sessions. A lower percentage of both night and rotating workers attended church and union meetings as often as once a month or more, in comparison to the day workers. Attendance in class sessions was similar for day and night workers and considerably lower for rotators.

Since all respondents were union members, details were requested on their level of participation in the union. Asked whether they currently held a position in the union as an officer, shop steward, or committee member, more day workers responded affirmatively (56%) than night workers (14%) and rotators (24%), indicating relatively less union leadership by night and rotating workers than the day workers. Likewise, more day shift workers (60%) had filed grievances in the previous five-year period than night (45%) or rotating (50%) workers.

These data on level of union participation indicate a lower level of union involvement by shift workers than day workers, relatively speaking. At the same time they show that all three shift groups in the study sample represent an unusually active and involved portion of the work force.

Discussion

The discussion will relate to four topics: the problem of extrapolating these findings to the general population of workers; the predictive value of

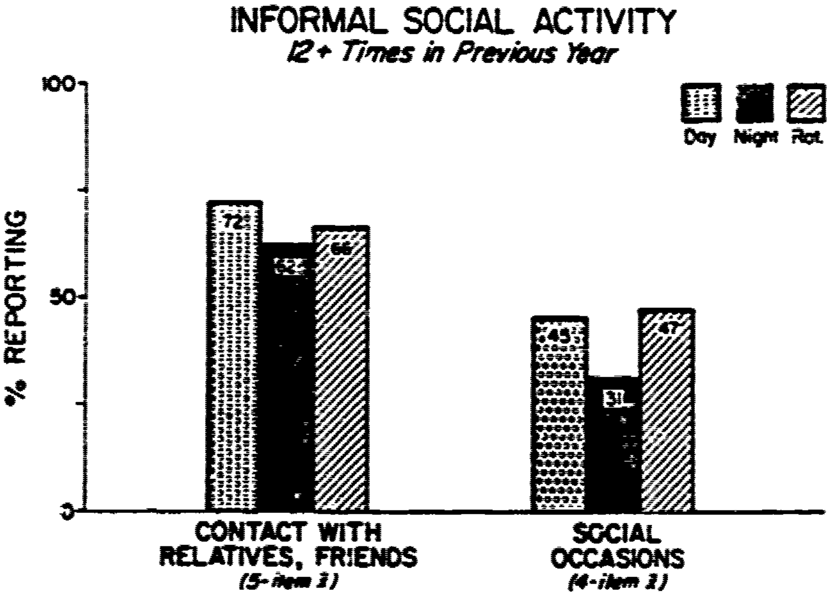

Figure 4. Percentage of respondents reporting that they engaged in two types of social activity once a month or more in the previous year.

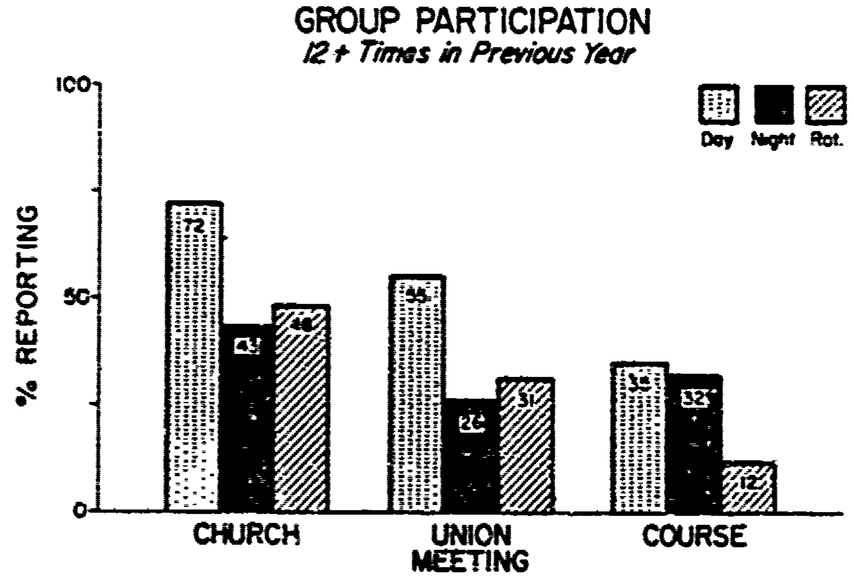

Figure 5. Percentage of respondents reporting that they participated in types of organized activity once a month or more in the previous year.

shift satisfaction for off-the-job areas of life satisfaction; the relationship between shift satisfaction and level of activity in home and community life; and the need for further interview study of shift workers, with an emphasis on females.

In interpreting the results, the nature of the study sample should be kept in mind. All respondents were union members, while only about one-quarter of the U.S. work force belongs to unions. The volunteers were selected to eliminate obvious health or sleep problems. The interview respondents were found to be more active than average in union participation and leadership. In addition, it is likely that workers with high stress levels in their lives did not volunteer for the study. Since this particular sample of workers appears to occupy a relatively advantaged position in comparison with the broad population of hourly employees, the differences between shifts found in this sample may well be an underestimation of the differences to be seen in the wider population.

An interesting finding from the semi-structured conversations (Figure 1) was that satisfaction with shift hours is more closely related than job satisfaction to the way shift workers feel about certain aspects of their lives off-the-job. The importance of shift satisfaction as a predictor of life satisfaction is easily seen in the case of the rotators. This group contained more craft workers than the other shift groups and earned a higher median job income, both of which probably contributed to the higher level of job satisfaction they reported. Yet the rotators' dissatisfaction with the changing shift hours was more predictive of their satisfaction with key elements of life away from work than was their job satisfaction.

Levels of shift satisfaction proved to have a complex relationship to levels of activity in home and community life, as seen in the questionnaire responses. It had been expected that both night and rotating shift groups would evidence more dissatisfaction with their job hours and less activity in home and community life than the day shift group. Instead, it was found that the two factors of shift satisfaction and activity level were positively associated for the night shift group and negatively associated in many measures for the rotating shift group.

A complex example can be found in the questionnaire findings about workers' favorite ways to spend time. In addition to asking respondents to indicate the frequency of engaging in their three favorite activities, they were also asked to indicate how satisfied they were with the amount of time they had during the prior 12 months to carry out each of the three favorite activities. Responses were made on a 7-point scale ranging from very satisfied to very dissatisfied. Although the night shift group reported the lowest frequency of activity, they also reported significantly more satisfaction than the other two shifts on the 7-point scale.

What interpretation can be made of the differences in activity level between the shift groups? The chronic incompatibility of the night shift worker's schedule with the "normal" day-time world would seem to explain the differences in activity levels between night and day shift groups. The rotators, on the other hand, can adopt a strategy of doing the activities that are most compatible with each shift as they change from one shift to the next.

For example, they can use their time on day shift to "make up" for what they could not do at other times. This might allow their activity level in flexible areas of family and social life to approximate that of the day worker.

As stated, half of the night shift group preferred night hours and half were dissatisfied with the hours. Why were more rotators dissatisfied with their shift hours than the night shift group, given the higher levels of activity they reported? Several suggestions can be made: the rotators may view themselves as part of the "day" world, and find it frustrating to carry on in spite of the periods of time on different shifts; the higher economic level of the rotators in this sample may have been associated with higher expectations for their quality of life than can be realized while working on a rotating shift; and in many places of employment the rotating shift schedule has the additional element of unpredictability, which creates an added burden for rotators and their families.

As a final point, it is hoped that further interviews with semi-structured components will be carried out with shift workers. In particular, special efforts will be needed to reach a sizeable sample of female shift workers. In the present study, for example, working women with families tended to be much less available for participation than working men with families. The problems of all shift workers, including females, merit further study.

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THE EEG SLEEP OF NIGHT AND ROTATING SHIFT WORKERS

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In the past ten years several studies have examined EEG sleep patterns during sleep-wake variations of the type imposed by short-term exposure to shiftwork. For example, Weitzman, Kripke, Goldmacher, McGregor, and Nogeire (1970), Webb, Agnew, and Williams (1971), and Rutenfranz and Knauth (1970) studied regular nocturnal sleepers during daytime sleep. Kripke, Cook, and Lewis (1971) reported on the day sleep of corpsmen assigned to the night shift for a median duration of 4 weeks. The results of these short-term sleep schedule inversion studies are rather consistent. Rapid eye movement (REM) sleep tended to occur earlier in daytime sleep periods. Total sleep time (TST) is reduced in daytime sleep. Percentages of sleep stages remain constant, or nearly so, with the exception that Stage 1 and waking may be higher for day sleep. Sleep latency does not seem to differ substantially.

Other studies have compared the diurnal and nocturnal sleep of persons on rotating shifts. Bryden and Holdstock (1973) reported on nursing students who changed from night to day sleep every two months. Diurnal sleep was characterized by a higher percentage of Stage 1, a lesser percentage of slow-wave sleep (SWS) and more awakenings in the last third of the sleep period than night sleep. Decreased TST and earlier REM onset were also observed in daytime sleep. Matsumoto (1978) has recently reported similar findings in a study of nurses who rotated on a three shift system although no evidence for reduced SWS percentage was noted. Unfortunately, the latter two studies do not specify how long their subjects had been assigned to rotating shift schedules. Webb and Agnew (1978) placed individuals on a rapidly rotating three-shift schedule for two rotations. Their data indicate no sleep stage percentage differences, but variations in the absolute amounts of REM and Stage 2. REM latency tended to be shorter for diurnal sleep and sleep latencies were shortest for sleep following the night shift.

Foret and colleagues have examined the diurnal and nocturnal sleep of train drivers who work exceptionally irregular rotating shifts. These reports are of special interest because the subjects had worked "months or years in this type of job" (Foret & Lantin, 1972) or, in the case of Foret and Benoit (1974), between 2 and 20 years on this type of shift schedule. The primary findings of these studies are shorter TST, earlier REM onset, and an increase in REM amount early in the sleep period during daytime sleep. Smaller absolute amounts of Stages 1 and 2 during daytime sleep were also reported. Wedderburn (1975) has also reported decreased REM latencies for two long term rotating workers.

With the exception of the reports of Foret's group, one might interpret most of the aforementioned results to suggest that these shift schedule variations result in insomnia-like sleep patterns. That is less TST, more waking and Stage 1 sleep and perhaps less SWS are consistent with a sleep "disturbance" interpretation. The fact that Foret's train drivers are the only group that does not display most of these characteristics and have relatively long exposure to altered shift schedules might suggest that they have partially adapted to their schedule.

From this review one can see that although some consistencies exist, the results of these studies are difficult to integrate and interpret. First, many of the studies consider only short-term effects of shift schedule variations and, therefore, are of indetermined value in the assessment of chronic shiftwork influences upon sleep and any possible adaptation. Second, studies dealing with rotating sleep-wake schedules typically compare diurnal and nocturnal sleeping patterns for the same individuals. It is possible that changes in EEG sleep patterns associated with long term totating schedules may occur for both the day and night sleep periods of individual workers. Therefore, some sleep structure alternations might not be apparent from intra-group comparisons. Finally, most studies have examined the effects of some form of rotating shift schedule. Little attention has been directed toward the effect of steady night work upon sleep. The present study is an attempt to extend our knowledge of shiftwork-sleep interactions by comparing the sleep of day, night and rotating workers who have been on their specific shift schedule for at least one year prior to study.

Method

The general design and methods of this study have been presented elsewhere (Gordon, Tepas, Stock, & Walsh, 1979; Walsh, Gordon, Maltese, McGill, & Tepas, 1979). The data reported here are the result of an analysis from a subsample of the study. Briefly, the participants were recruited through labor unions and selected for laboratory study on the basis of their work schedule. Only workers in good health who reported limited drug use and off-the-job exercise were chosen for laboratory study. All participants were volunteers who were paid $100 upon completion of the laboratory sessions.

The data of ten workers in each of three shift groups will be presented: day shift, night shift, and rotating shifts. All workers slept in the laboratory for four consecutive sleep periods during a typical work week. During this time the workers performed their regular job duties and otherwise led as normal a life as possible. Laboratory sleep times were selected by the individual worker and were usually identical to that individual's normal sleep times. In no case did laboratory sleep times vary by more than 30 minutes from a worker's typical sleep time. Given the individual sleep times of each worker, a general idea of temporal sleep placement can be given. Day workers slept sometime between 21:45 and 6:30. Night workers' sleep periods fell sometime between the hours of 9:00 and 21:30. Rotating workers were studied while working either day or afternoon shift and slept between 21:45 and 11:30. Figure 1 displays the actual sleep times for all 30 participants. The mean ages of the day, night and rotating workers were 37.1 (27-57), 33.5 (19-60), and 36.8 (23-53) years respectively and did not differ significantly. Four night workers were females as were two day and two rotating workers. All participants had worked for at least one year on the shift they maintained during the laboratory sessions.

Standard polysomnographic recordings were performed and scored following the methods and criteria of Rechtschaffen and Kales (1968). All recordings were made while the worker slept in a sound attenuated, electrically shielded chamber.

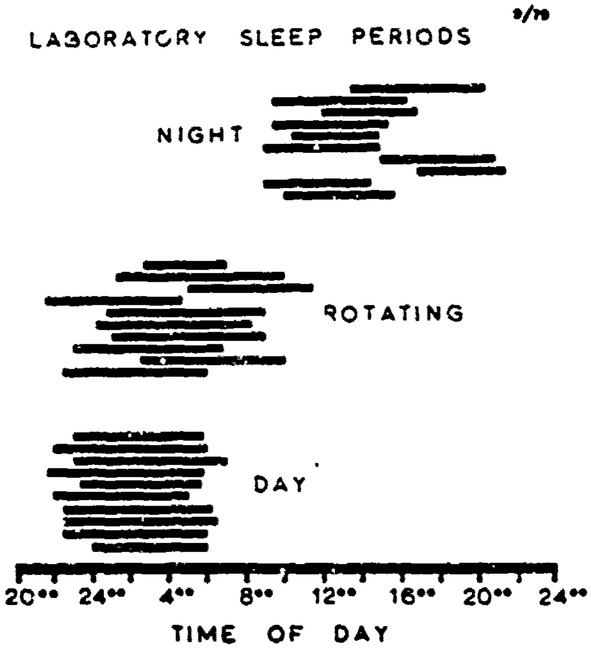

Figure 1. Laboratory sleep periods for the night, rotating, and day shift groups. Each bar represents the sleep period for one worker.

Data Analysis

The first sleep session for each worker was considered an adaptation session and is not included in this analysis. Mean values of 24 standard EEG sleep measures were computed for each subject from the data of the remaining Three sleep sessions. A one way analysis of variance (ANOVA) was performed for each of the 24 measures across shift groups. When the overall F was significant, individual means were compared using the Newman-Keuls technique. Mean hour by hour distributions of each sleep stage were compiled and examined among groups. Statistical comparisons were made as above with ANOVA and Newman-Keuls.

Results

Table 1 displays the mean values for each shift group for each of the 24 EEG sleep measures and the results of the ANOVAs. No differences were obtained between the day shift and rotating shift worker groups. The night shift group differed from both the day shift and rotating shift on several dimensions.

Table 1

Mean Sleep Characteristics for Three Shift Groups

Sleep characteristic	Day	Rotating	Night	F
Minutes of wakefulness	30.69	20.87	34.37	.60
Minutes of movement	7.15	9.61	4.13	2.42
Minutes of Stage 1	47.70	49.69	26.20	5.45*
Minutes of Stage 2	204.08	196.64	152.32	3.16
Mintues of Stage 3	36.09	38.51	35.12	.17
Mintues of Stage 4	12.49	22.15	22.13	1.04
Mintues of REM	94.61	95.89	65.72	5.88**
Mintues of SWS	48.58	60.65	57.25	.92
Movement %	1.66	2.31	1.33	1.76
Stage 1 %	11.92	12.32	8.87	1.52
Stage 2 %	51.00	46.94	49.19	.42
Stage 3 %	9.02	9.65	12.03	1.20
Stage 4 %	2.89	4.99	7.19	2.92
REM %	23.43	27.80	21.40	.41
SWS %	11.91	14.64	19.22	4.38*
Number of awakenings	8.20	7.55	5.45	.88
Number of stage changes	105.55	108.80	74.67	4.21*
Stage 1 latency	12.20	11.29	8.38	.80
Stage 2 latency	18.36	18.35	14.24	.98
Total sleep time	400.81	411.49	305.58	10.62**
Sleep efficiency (TST/TIB)	.93	.95	.91	1.23
REM latency	99.81	91.61	54.32	9.13**
REM cycle duration	89.70	91.99	98.46	1.57
Number of REM periods	4.13	4.25	3.07	7.58*

* p<.05; ** p<.01

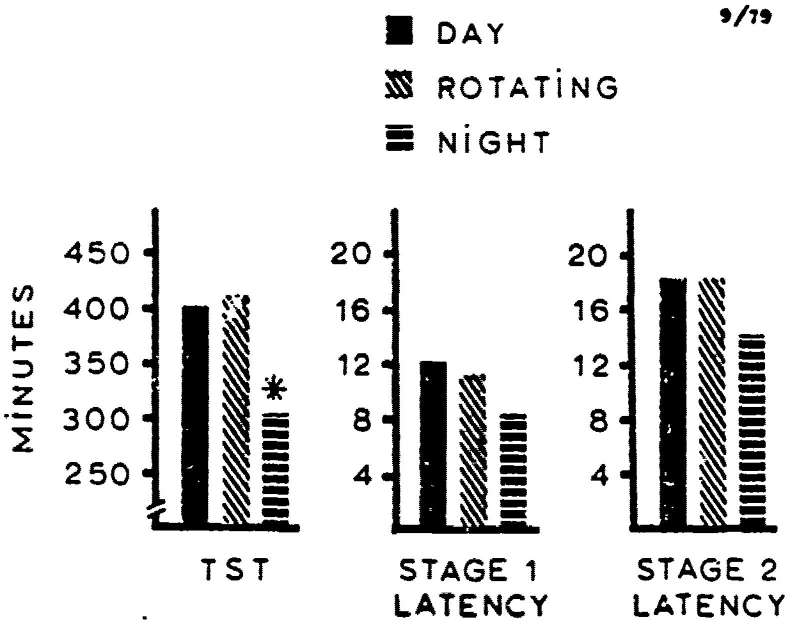

Figure 2. Left graph: Mean total sleep time (TST) for each shift group. Center Graph: Mean Stage 1 latency for each shift group. Right graph: Mean Stage 2 latency for each shift group. Asterisk indicates that TST for the night shift group was statistically different from both other shift groups ($p < .01$).

Figure 2 shows that they had a much lower TST, but latency to Stages 1 or 2 did not differ among shift groups.

Figure 3 displays EEG sleep stages as a percentage of TST. Night workers spent a greater percent of TST in SWS than did day or rotating shift workers. No other comparisons differed significantly. In absolute amounts, the night shift group had less Stage 1 and REM as shown in Figure 4. There was also a trend for night workers to spend fewer minutes in Stage 2.

Figure 5 shows that the night workers differed on two REM related measures. Night workers had a shorter mean REM latency and fewer REM periods during a sleep period. No difference in mean REM cycle duration was found. The average number of sleep stage transitions was also lower for night workers. However, the rate of stage transitions did not differ among groups (.263, .264 and .244 stage transitions per minute for day, rotating, and night shifts, respectively).

The mean hour by hour distribution of sleep stages for each shift group were also examined. Once again no differences were observed between the rotators and the day shift group. The night shift did have a significantly higher mean percentage of REM in the first hour of sleep than the other groups ($\underline{F} = 6.01$, df-2.27; $p < .01$); the mean values were 13.8%, 0%, and 1.4% for the night, day, and rotating shifts, respectively. The schematic polysomnograms displayed in Figure 6 were derived from the mean hour by hour sleep stage distributions. These polysomnograms illustrate the temporal distribution of the sleep stages for each shift group.

Two phenomena which are atypical of normal nocturnal sleep did appear in the EEG recordings of certain night workers. The first was the occurrence of REM within 10 minutes of sleep onset in the records of two night workers. In the six sessions of these participants,three sleep onset REM periods (SOREMPs) occurred. Neither worker reported or displayed any manifestation of narcolepsy, a disorder characterized by SOREMPs. The second atypical observation was the frequent alternation between REM and Stage 2 in the records of two night workers. At times these alternations were so rapid that scoring became difficult.

Discussion

The EEG sleep characteristics of the day shift group are similar to the norms for adult sleep presented by Williams, Karacan, and Hursch (1974). The lone exception is the somewhat shorter TST of our day shift workers (400.8 min vs. 423.6 min).

The finding that rotating shift workers' sleep does not differ on any dimension from that of day workers could be interpreted as being inconsistent with subjective reports. Rotating workers report having difficulty falling asleep or staying asleep more often than do day workers (Tasto, Colligan, Skjei, & Polly, 1978;Tepas, Walsh, & Armstrong, this volume). It should be noted that the rotators in the present study participated in laboratory sessions while working either day or afternoon shift. Thus, their sleep had approximately the same circadian placement as did the sleep of the day workers. It is possible that the sleep of rotators differs from the normal nocturnal pat-

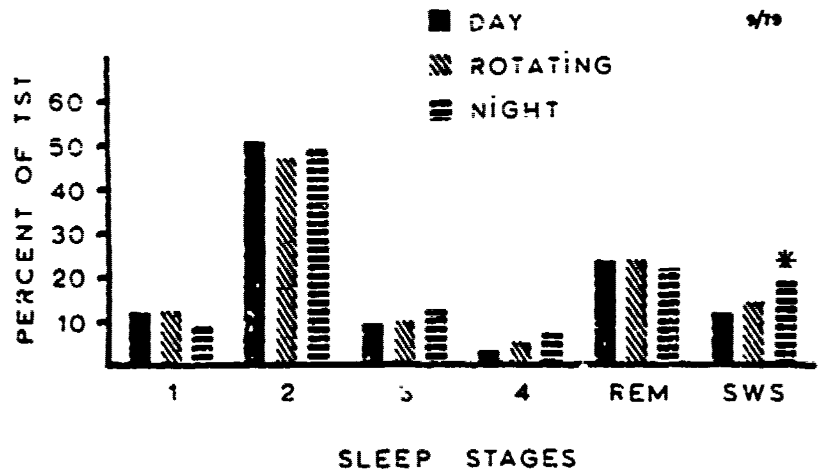

Figure 3. Sleep stages expressed as a percentage of TST for all three shift groups. Asterisk indicates that the night shift group had a significantly greater percentage of slow wave sleep (SWS) than did the day or rotating shift groups (p <.05).

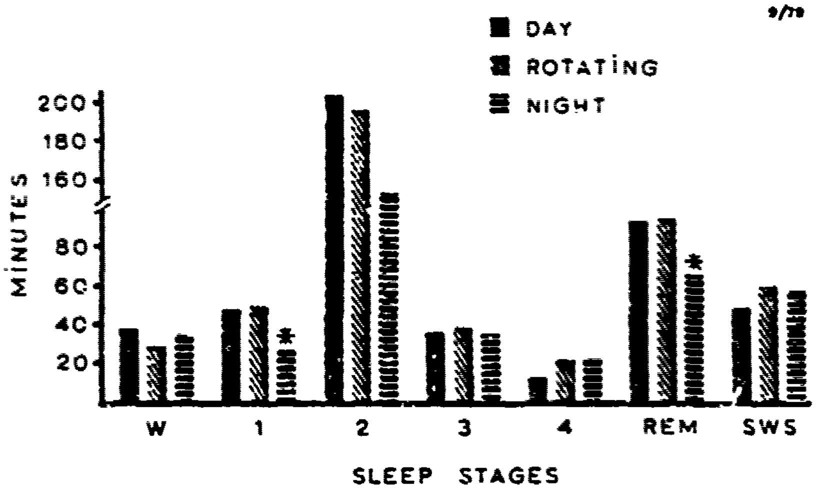

Figure 4. Mean number of minutes of each sleep stage for all three shift groups. Asterisks indicate that night workers had fewer minutes of both Stage 1 ($p < .05$) and REM ($p < .01$) than either the day or rotating shift groups.

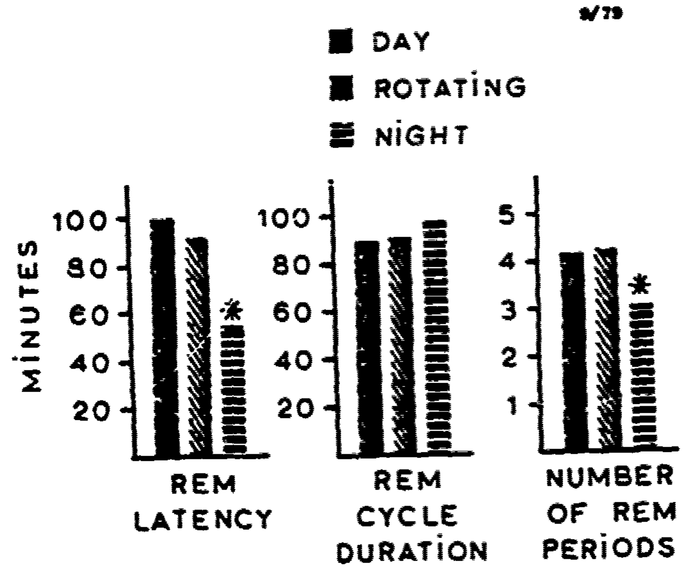

Figure 5. Mean REM characteristics for each of the shift groups. Asterisks indicate that night worker had a shorter REM latency (p <.01) and fewer REM periods (p <.05) than day or rotating shift workers. REM cycle durations did not differ statistically.

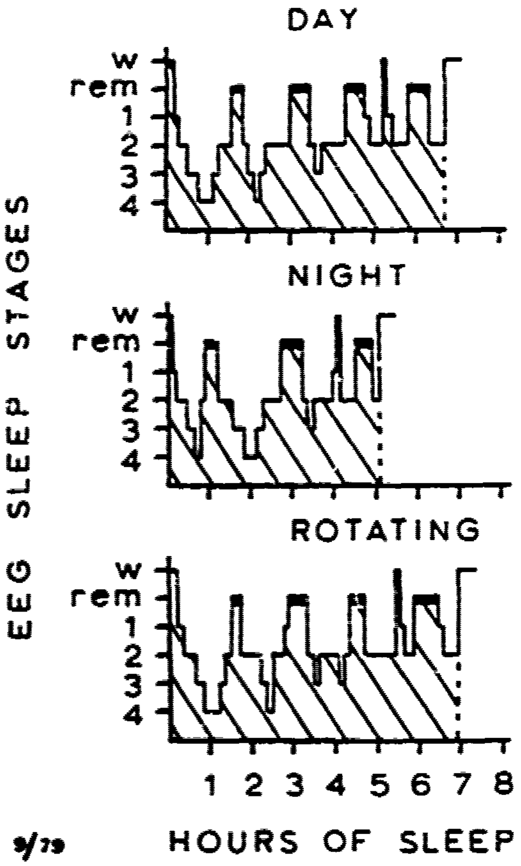

Figure 6. Schematic polysomnograms constructed from mean hour by hour distributions of sleep stages for each shift group.

terns only when they sleep during the day. Differences between the diurnal and nocturnal sleep structure of rotators reported in the literature might be attributable to the propensity for REM to occur in the early morning hours (Webb, 1971), the need or desire to participate in social activities during the daytime or a member of other factors. It is possible that rotators working on the night shift would increase their TST if social pressure to get up was removed (Webb & Agnew, 1975; Webb & Agnew, 1978). If this proposal is accurate, most reported differences between the diurnal and nocturnal sleep of rotators might be explained in a fairly direct manner. Reductions in TST may be a function of the need or choice to participate in social or family activities. REM latency decreases may result from having sleep onset occur in the morning when REM is most likely. Possible reductions in SWS or Stage 2 are the result of being displaced by REM early in the sleep period in conjunction with a shortened TST which prevents their total occurrence later in the sleep period. The subjective report that rotators have more difficulty sleeping may only be relevant to their sleep while on the night shift. Wyatt and Marriot (1953) for example, report that 83% of rotating workers feel most tired while on the night shift, and Östberg (1973) concluded that adjustment to the night shift was the most difficult for workers.

An alternative explanation for the similarity of sleep patterns for day and rotating workers in the present study is that the chronic nature of their shift history has resulted in an adaptation of sleep process while on the night shift, However, given the findings of Foret and Benoit (1974) reported above and the lack of evidence that our chronic night workers' sleep adapted in any major way, the former explanation seems more likely.

The sleep pattern of the night workers differed substantially from both day and rotating workers. The mean TST of just over 5 hours is remarkable especially considering the fact that only four of the ten night workers reported napping often. During the forty days of laboratory study of these night workers only five naps were reported and only one of these was more than one hour in length. Seven of ten night workers did not nap during the laboratory study. This low TST is fairly consistent, however, with reported sleep lengths of night workers (Tepas et al., this volume; Wyatt & Marriot, 1953) and EEG studies of worker's day sleep (Kripke et al., 1971; Rutengranz & Knauth, 1970).

Figure 6 displays schematic representations of average sleep periods for each of the three shift groups. In addition, to the obvious difference in TST, several sleep structure differences exist for night workers. The latency to the first REM period is reduced as is the average number of REM periods. Decreased REM latency may be related to early morning sleep onset, although one night worker in the present study who slept from 17:00 to 21:30 had a rather short average REM latency of 50 minutes. The decreased number of REM periods is probably a direct result of the shortened TST. Therefore, the differences in REM characteristics may be substantially attributable to the circadian placement of the sleep period and shortened TST.

The rapid alternation between Stage 2 and REM found for two of our night workers was reported for all 10 rotators examined by Kripke et al., (1971). Since most of the workers in that study were on night shift for a short period of time, this phenomena may be more prominent in the sleep structure of relatively inexperienced night workers. It should be noted, however, that both workers displaying Stage 2-REM alternations in this study had been on the night shift for between 1 and 2 years.

Previous studies of day sleep agree with the present data that TST and REM latency are reduced (Kripke et al., 1971; Rutenfranz & Knauth, 1970; Webb et al., 1971; Weitzman et al., 1970). However, these studies do not report greater SWS percentages. Furthermore, they suggest that Stage 1 amount may increase, whereas it decreased in the present study. It is difficult to explain these differences, however, they may be related to the difference in shift schedule duration. Certainly, a pattern of insomnia-like sleep is not present for either the night or rotating shift workers in this study.

In many ways, our night workers' sleep resembles that of persons undergoing partial sleep deprivation. Increased SWS percent, decreased REM latency, fewer minutes of REM and occasional SOREMPs have all been reported to be associated with chronic limitations of sleep length (Mullaney, Johnson, Naitoh, Friedman, & Globus, 1977; Webb & Agnew, 1974). Additionally, trends towards less time in Stages 1 and 2 are evident in both types of study. Perhaps chronic assignment to night shift results in a state of sleep deprivation. It is difficult to determine if the sleep structure differences observed in the present study are attributable to sleep deprivation, circadian effects, a combination of the two or some unknown factor(s).

A few methodological issues deserve mention in relation to the results presented. In most instances this study was conducted in a manner which maximized similarity between the participants' typical life and the laboratory schedule. All workers maintained their scheduled work hours and selected their sleep hours just as they would during home sleep. In this way the temporal relation of regular work, sleep, and leisure time activities was simulated quite accurately. Since small shifts in sleep-wake schedules may result in changes in sleep structure (Taub & Berger, 1973a) and performance and mood (Taub & Berger, 1973b) the maintanence of regular schedules is crucial in the assessment of shiftwork affects upon such variables.

The participants in the present study were workers reporting low drug use, infrequent off-the-job exercise and little difficulty sleeping. An examination of workers who do report sleep difficulty, a high level of drug usage or other extreme behaviors may result in different findings. Likewise, the use of sound attenuated sleeping rooms may have influenced our results. Shiftworkers commonly report being disturbed by noise when they sleep (Rutenfranz & Knauth, 1970) and noise levels were minimal during the laboratory sessions. Home sleep periods for our participants might be distrubed by noise although individuals seem to adapt to noise during sleep (Griefahn, 1977).

Concluding Remarks

It should be emphasized that our data do not suggest that rotating shifts are preferred to night shift. The lack of major sleep structure differences, as compared to day workers, may only reflect the fact that the present sample or rotating workers were assigned to day or afternoon shift while the laboratory sessions were conducted. An entirely different conclusion might be reached if chronic rotating workers were studied while working nights. For example, survey data indicate that rotating workers' sleep length varies depending upon the shift being worked (Tepas et al., this volume). To emphasize this point further, consider the actual sleep-wake behavior of our night workers. Most report that they revert to a nocturnal sleeping pattern on non-work days. In fact, most night workers do not have totally or chronically inverted sleep-wake patterns. Their work shift may be steady nights but their "sleep shift" is usually a rotating one--day sleep on workdays and night sleep on non-workdays.

In general, our results concur with the proposal that sleep stage characteristics are, to a large degree, determined by TST (Lubin, Moses, & Naitoh, 1977; Mullaney et al.,1977) and circadian placement of the sleep period (Webb, 1971). Previous research suggests that TST is a more important factor than individual sleep stages in the recovery or maintenance of waking performance (Johnson, Naitoh, Moses, & Lubin, 1974; Lubin, Moses, Johnson, & Naitoh,1974). Therefore, with regard to the differences in sleep structure reported here, it seems most appropriate to emphasize the greatly reduced TST of night workers.

The behavioral, physiological, and psychological consequences of years of limited sleep are unknown. Previous studies of performance and mood during and after weeks of partial sleep deprivation suggest no major decrements (Friedmann, Globus, Huntley, Mullaney, Naitoh, & Johnson, 1977; Webb & Agnew, 1974). Nevertheless, several reports have emphasized the low level of psychosocial and physical well-being of night workers (Åkerstedt & Torsvall, 1978; Koller, Kundi, & Cervinka, 1978), and at least one study implicates short sleep length as a consideration in mortality rate (Kripke, Simons, Garfinkel, & Hammond, 1979). Whether these factors are related to sleep restriction per se or other variables is yet to be determined.

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HYPNOTICS AND SHIFT WORK

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Sleep disturbance associated with working irregular hours has been studied by several authors (Tune, 1969; Kripke, Cook, & Lewis, 1971; Foret & Lantin, 1972; Ehrenstein & Muller-Limroth, 1975; Knauth & Rutenfranz, 1975; Knauth & Ilmarinen, 1975; and Masterton, 1965), while the effects of working in unusual environments have been investigated in polar explorers (Lewis, 1961; Natani, Shurley, Pierce, & Brooks, 1970), in man in the arctic (Semagin, 1961; Weitzman, deGraff, Sassin, Hansen, Gotlibsen, Perlow, & Hellmann, 1975), antarctic (Patterson, 1975) and in solitude underground (Mills, 1964), and in submariners (Kleitmen, 1949) and astronauts (Adey, Kado, & Walter, 1967; Kelloway, 1966). Aircrew involved in world-wide operations also work at unusual times and have to cope with time zone changes (Klein, Bruner, & Ruff, 1966; Nicholson, 1970). In each case a satisfactory sleep pattern is important in maintaining well-being and operational efficiency, and careful planning of work schedules is usually the most important approach to the problem.

Studies on the work-rest patterns of aircrew operating world-wide (Figures 1 & 2) suggest that in carefully controlled schedules sleep disturbance rather than sleep loss is the problem. Modification of the sleep pattern within rest periods plays a particularly important role (Figure 3), but, nevertheless, the irregular nature of their work and rest causes difficulties even though the time available for sleep usually appears to be of sufficient duration. It may be difficult to cope with some reduction in sleep when this is superimposed on an irregular pattern of rest. For this reason hypnotics have been used. However, the drug must not only be effective at times of the day when the period for rest may not coincide with the circadian desire for sleep, but must also be free of residual effects on performance. It is these aspects of the use of hypnotics in the management of disturbed rest which have been of particular interest to our group, and studies have led to advice on the use of hypnotics by aircrew in the United Kingdom. Though this work has been directed toward aircrew, it is equally relevant to other shift workers involved in skilled activity.

Performance Studies

Residual impairments of performance with the overnight ingestion of hypnotics have been clearly established over the past few years, but it is now clear that residual sequelae are not an inevitable concomitant of a useful hypnotic. It is true that many of the commonly used hypnotics have residual effects on performance in doses within their normally accepted therapeutic range, but hypnotics free of residual sequelae are now available. Several centres have been involved with the problem of residual effects, and a variety of tasks have been used to detect impaired performance the next day. Our work has been concerned mainly with visuo-motor coordination (Borland & Nicholson, 1974) and the residual and immediate effects related to dose and time have been investigated. The results are broadly similar between the various groups involved.

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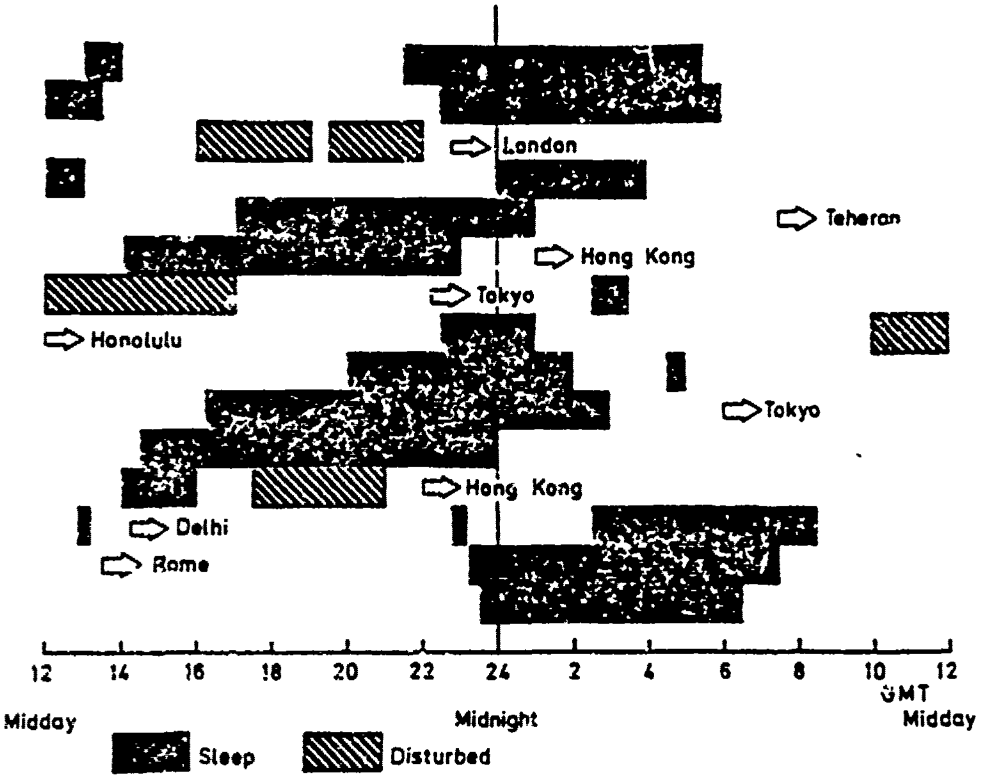

Figure 1. Sleep pattern during an eastward flight from London to Honolulu and return. The flight was via Rome, Delhi, Hong Kong, and Teheran. The illustration is read from the bottom line up. The pilot slept from 2300 to 0630 hours GMT London preceding the flight to Rome. Periods of sleep which were considered by the pilot to be satisfactory are in black rectangles, and disturbed sleep is hatched.

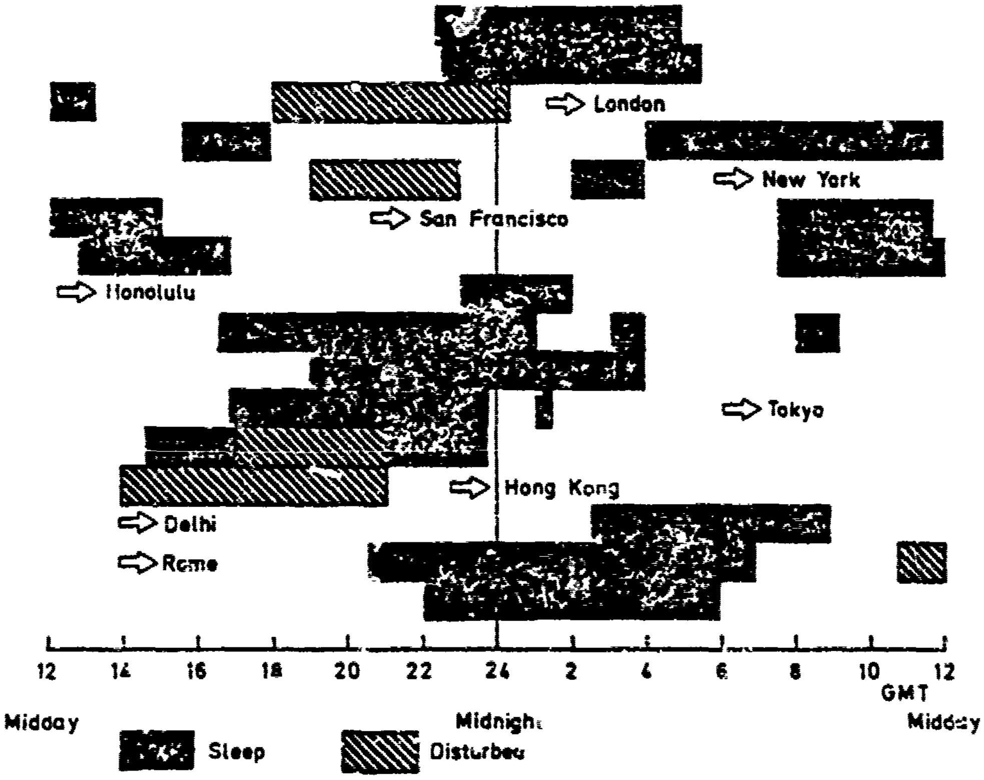

Figure 2. Sleep pattern during an eastward round-the-world flight via Tokyo. The illustration is read from the bottom line up. The pilot slept from 2200 to 0600 hours GMT London preceding the flight to Rome.

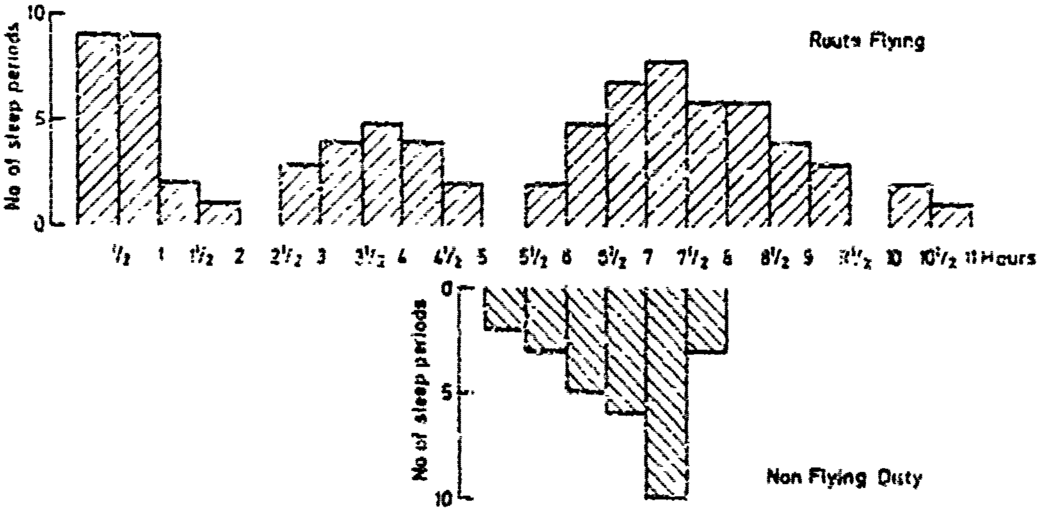

Figure 3. Histogram of duration of individual sleep periods during non-flying duty and during route flying. The data cover one month. It can be seen that the sleep periods include naps of approximately 1/2-1 hour duration, short periods of sleep of around 3 1/2-4 hours and periods of sleep of normal length.

The task requires the subject to position a spot inside a randomly moving circle displayed on an oscilloscope. The movement of the spot is controlled by a hand-held stick, and an error signal, proportional to the distance between the spot and the centre of the circle, controls the difficulty of the task by modulating the mean amplitude of the movement of the circle. The technique provides the adaptive component which maintains optimum performance by the operator. At the start of each experiment the circle is stationary. The subject positions the spot inside the circle, and with a negative error signal the circle moves away from the spot. When the spot can no longer be maintained inside the target circle due to the increasing difficulty of the task, the task becomes less demanding. At zero error the task requires about 25 s to reach maximum difficulty, whereas a constant displacement between the spot and the centre of the circle of 4 cm reduces the task to zero difficulty within 6 seconds. Subjects are aware of the penalty of error signals, and so they try to avoid all errors, though the task does not permit the maximum performance level to be reached.

Experiments were carried out in sound-attenuated and air-conditioned rooms. The subjects were required to attain a steady performance level before drug studies were carried out. In those familiar with the technique, steady performance was reached within about 5 days' practice, but novices usually required at least 2-3 weeks practice to achieve this level. Each assessment lasted 10 mins and trained subjects attained their plateau of performance within the first 100 s of the run. The mean amplitude of the task over the final 500 s was computed, and this was the performance measure. The subjects were informed at this time when the period of time commenced. Healthy male volunteers (age range 21-45 years), who were not involved in any form of therapy acted as subjects. Instructions were given to avoid alcohol but there were no restrictions on the consumption of non-alcoholic beverages.

Barbiturates

Initial studies were carried out with heptabarbitone and pentobarbitone sodium. With heptabarbitone decrements in performance were observed 10 h after 200 mg, 10 & 13 h after 300 mg and 10, 13, 16 & 19 h after 400 mg (Borland & Nicholson, 1974), and with pentobarbitone sodium the residual sequelae during the day after overnight ingestion of 200 mg were very similar to those observed with heptabarbitone 400 mg (Borland & Nicholson, 1975a). The residual effects on visuo-motor coordination were related to dose both in their persistence and in the decrement at a given time interval (Figure 4), and in this way the studies supported previous investigations (Von Felsinger, Lasagna & Beechler, 1953; Malpas, Rowan, Joyce & Scott, 1970; Bond & Lader, 1972) and showed, as did Kornetsky, Vates and Kessler (1959), that impaired performance may be more severe and may persist longer with higher doses which are still, nevertheless, within the usually accepted therapeutic range.

1,4-Benzodiazepines

Preliminary studies with barbiturates had established the sensitivity of a tracking task to the residual sequelae of drugs both in relation to time and to dose, and so the technique was used in the investigation of the benzodiazepines (Borland & Nicholson, 1975b). It was found that, although performance was impaired 16 h after flurazepam hydrochloride (30 mg) and to, at least, 19

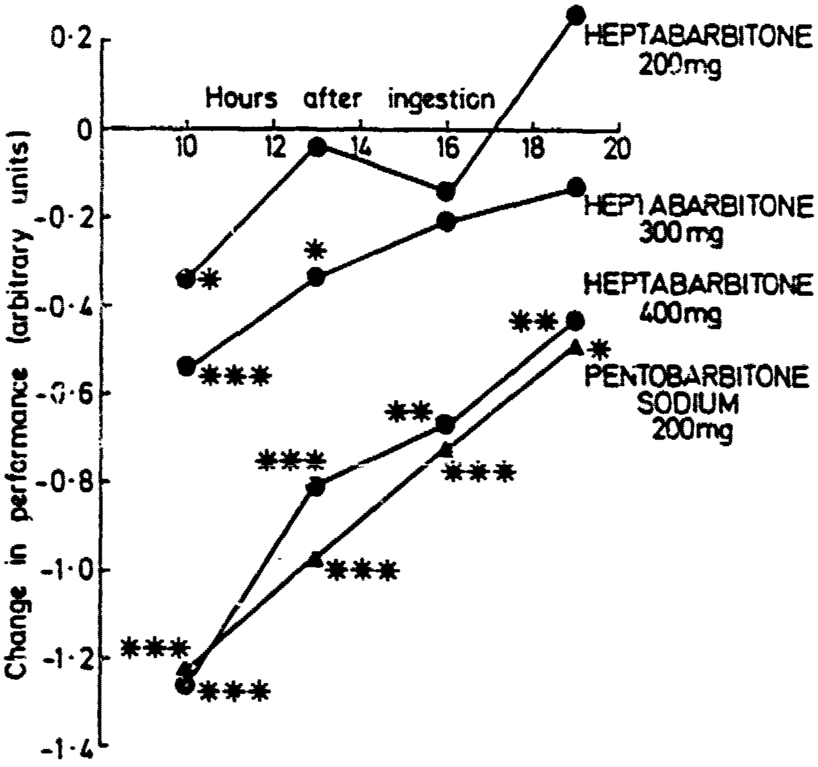

Figure 4. Effect of 200, 300, & 400 mg heptabarbitone and 200 mg pentobarbitone sodium on visuo-motor coordination (arbitrary units). Significance levels: * p <.05; ** p <.01; *** p <.001.

h after nitrazepam (10 mg), the effects with diazepam (10 mg) were more limited (Figure 5). Studies on the immediate effects of diazepam (10 mg) showed that performance decrements were limited to a few hours after ingestion and that there was little likelihood of residual impairment with overnight ingestion as long as the dose did not exceed 10 mg (Borland & Nicholson, 1977).

A detailed analysis of the effects of diazepam and its metabolites, 3-hydroxydiazepam (temazepam) and 3-hydroxy, N-desmethyldiazepam (oxazepam) (Clarke & Nicholson, 1978) was then carried out. Performance was observed from 10-16 h after overnight ingestion of diazepam (5 & 10 mg), temazepam (10, 20 & 30 mg) and oxazepam (15, 30 & 45 mg) and from 0.5-6.5 h after morning ingestion of diazepam (10 mg), temazepam (20 mg) and oxazepam (30 mg). Coordination was not altered with the overnight ingestion of diazepam (5 & 10 mg) (Figure 6), temazepam (10,20 & 30 mg)(Figure 7) or oxazepam (15 & 30 mg) (Figure 8). However, with 30 mg temazepam there was a trend toward impaired performance and with 45 mg oxazepam there was a decrement in performance 10 h after ingestion. With morning ingestion visuo-motor coordination was impaired at 0.5 & 2.5 h after 10 mg diazepam, at 0.5 h after 20 mg temazepam, and at 2.5 & 4.5 h after 30 mg oxazepam (Figure 9).

These observations were in broad agreement with other studies. Similar results with diazepam were reported by Seppala, Kortilla, Hakkinens, and Linnoila (1976) with coordination skills and visual functions related to driving. Recovery within a few hours after ingestion of diazepam has been observed by Hart, Hill, Bye, Wilkinson, and Peck (1976) with performance at a variety of tasks including auditory vigilance, reaction time, short term memory and digit symbol substitution. With temazepam our results were comparable with those of Hindmarch (1975), and suggested a residual effect with the 30 mg dose. Other workers have observed the slow onset of impaired performance with oxazepam, and Molander and Duvhok (1976) have recorded maximum depression of critical flicker fusion frequency 3.0 h after ingestion of 20 & 40 mg oxazepam and impaired coordination with 40 mg oxazepam.

It is clear that diazepam and its hydroxylated metabolites may be free of residual sequelae within certain dose ranges. However, there are certain points to be taken in to consideration when using these drugs. With diazepam 10 mg daily, accumulation of its long-acting metabolite, nordiazepam, is likely, and so diazepam is for occasional use as an hypnotic. Temazepam and oxazepam have the advantage over diazepam that their metabolism is not complicated by a long-acting metabolite, and daily ingestion of these drugs would therefore not be contraindicated, though the relatively slow absorption of oxazepam indicated by the delayed appearance of performance decrements could reduce its usefulness as an hypnotic.

More recently, flunitrazepam has been introduced. A dose of 1-2 mg taken at night leads to impaired performance the next day (Bond & Lader, 1975) and has adverse effects on sleep with unpleasant and emotional dreams (Monti & Altier, 1973; Jovanovic, 1977; Gaillard & Phellipeau, 1977). However, smaller doses may be more useful, and in this context recent studies using visuo-motor coordination (Nicholson & Stone, 1980) have shown that with 0.25 mg performance is impaired for only 2.0 h after ingestion, and that with doses up to 0.50 mg overnight there are no residual effects (Figure 10).

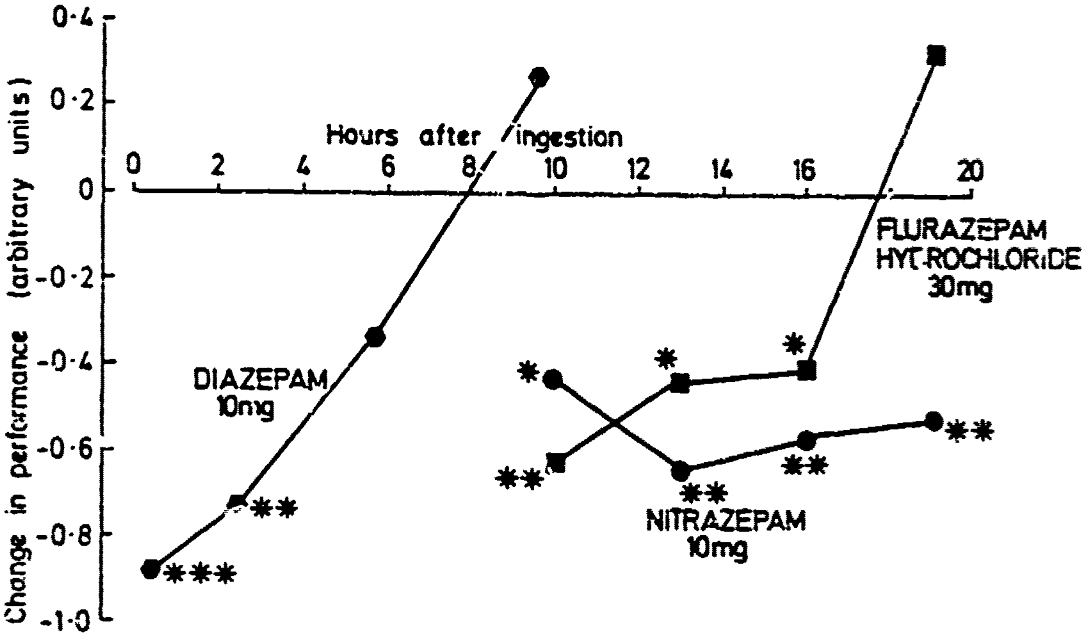

Figure 5. Effect of 10 mg diazepam ingested in the morning, and 10 mg nitrazepam and 30 mg flurazepam hydrochloride ingested overnight on visuomotor coordination (arbitrary units). Significance levels: * P <.05; ** p < .01; *** p <.001.

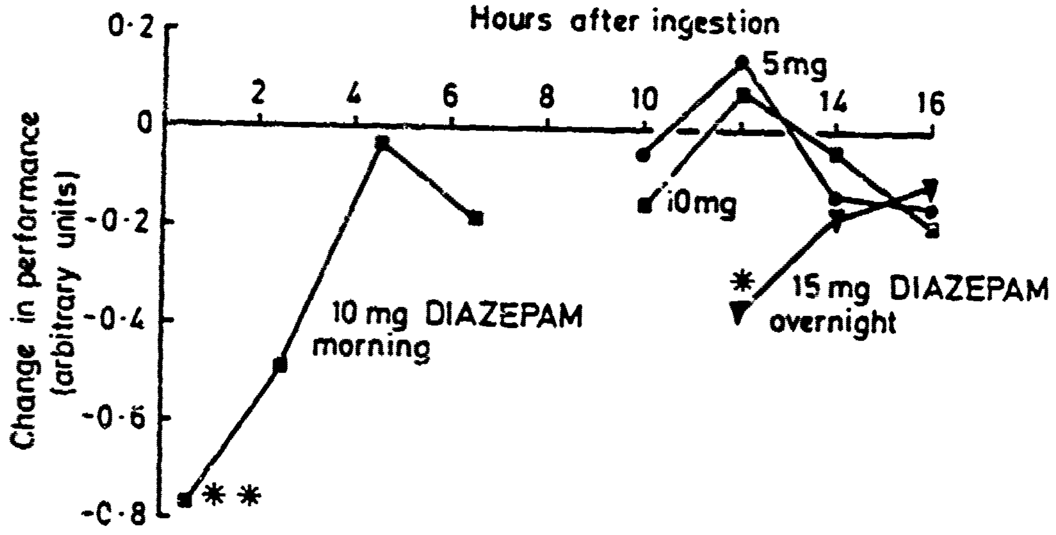

Figure 6. Effect of 10 mg diazepam ingested in the morning, and 5, 10, & 15 mg diazepam ingested overnight on visuo-motor coordination (arbitrary units). Significance levels: * p <.05; ** p <.01; *** p <.001.

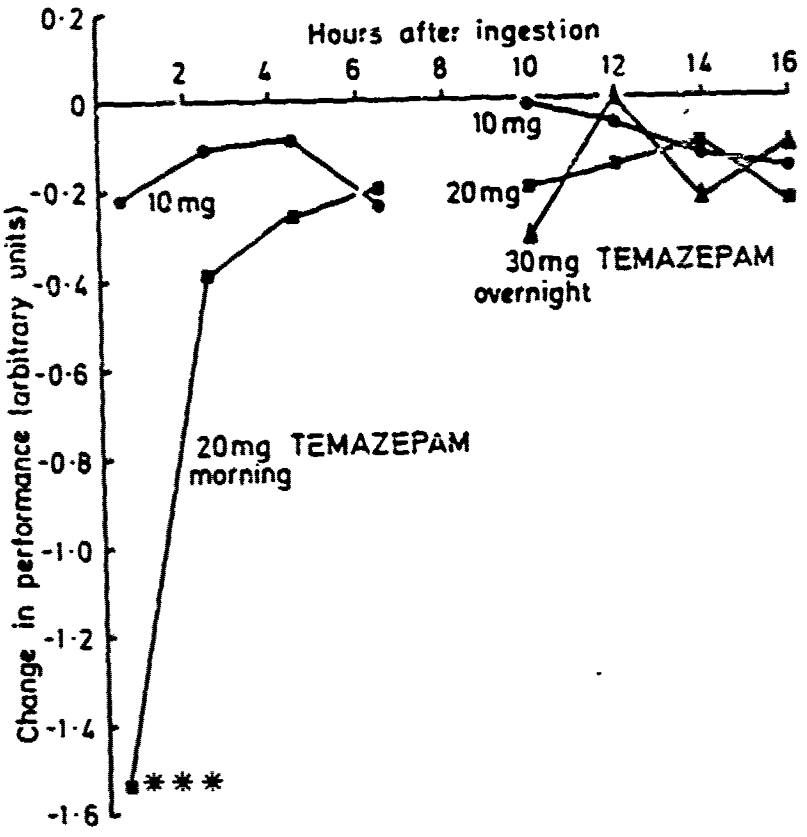

Figure 7. Effect of 10 & 20 mg temazepam ingested in the morning, and 10, 20, & 30 mg temazepam ingested overnight on visuo-motor coordination (arbitrary units). Significance level: *** p <.001.

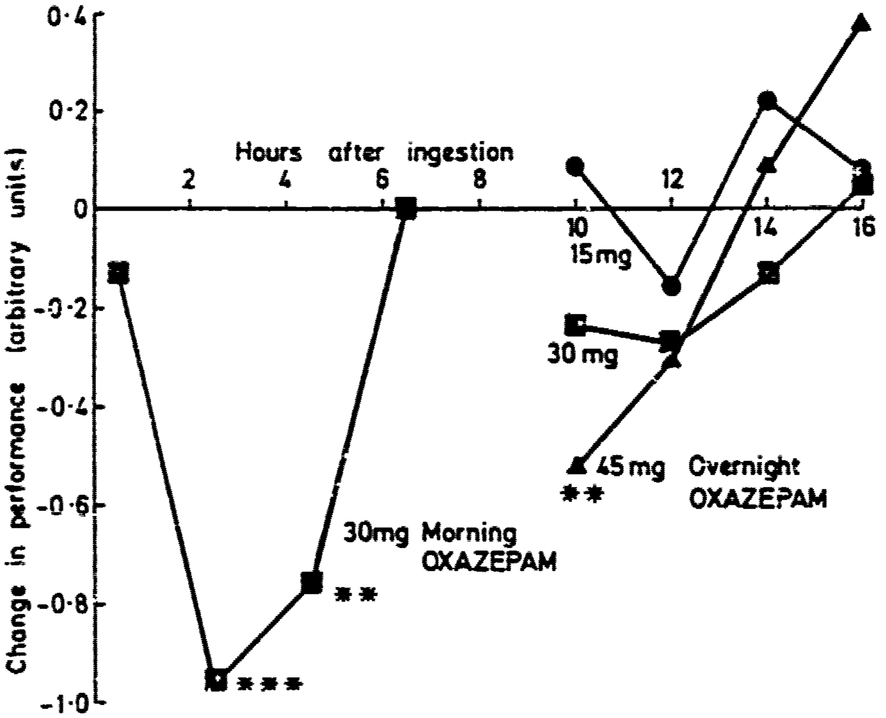

Figure 8. Effect of 30 mg oxazepam ingested in the morning, and 15, 30, & 45 mg oxazepam ingested overnight on visuo-motor coordination (arbitrary units). Significance levels: ** p <.01: *** p <.001.

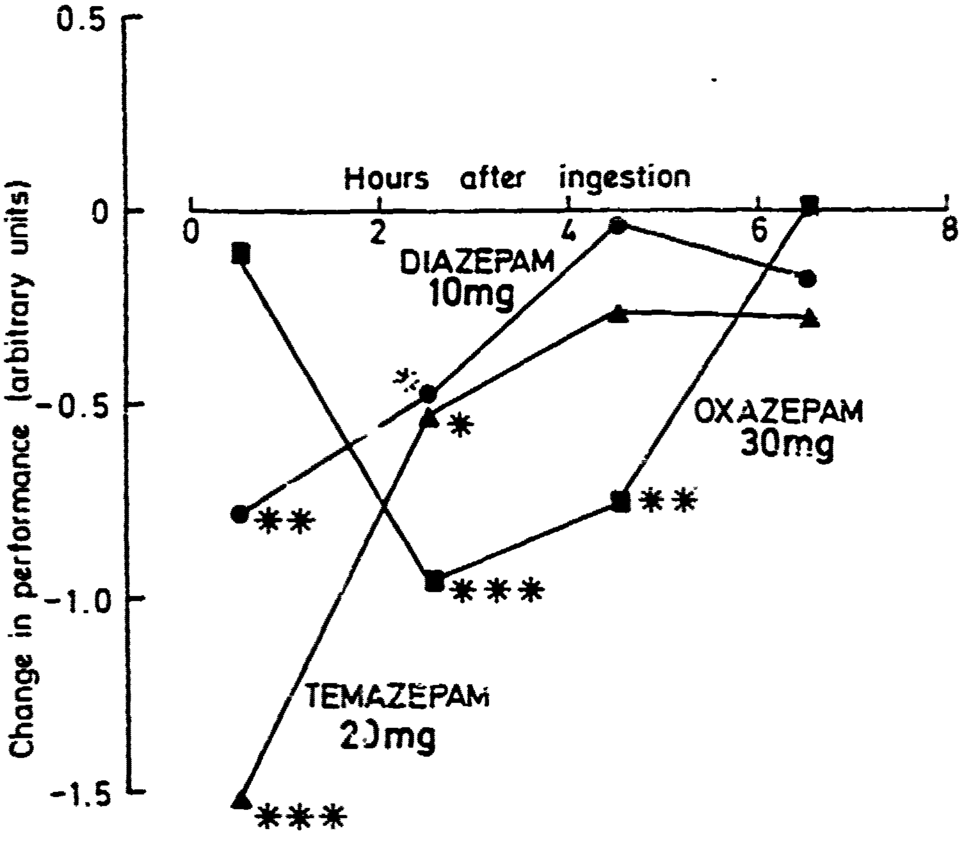

Figure 9. Effect of 10 mg diazepam, 20 mg temazepam, and 30 mg oxazepam ingested in the morning on visuo-motor coordination (arbitrary units). Significance levels: * p <.05; ** p <.01; *** p <.001.

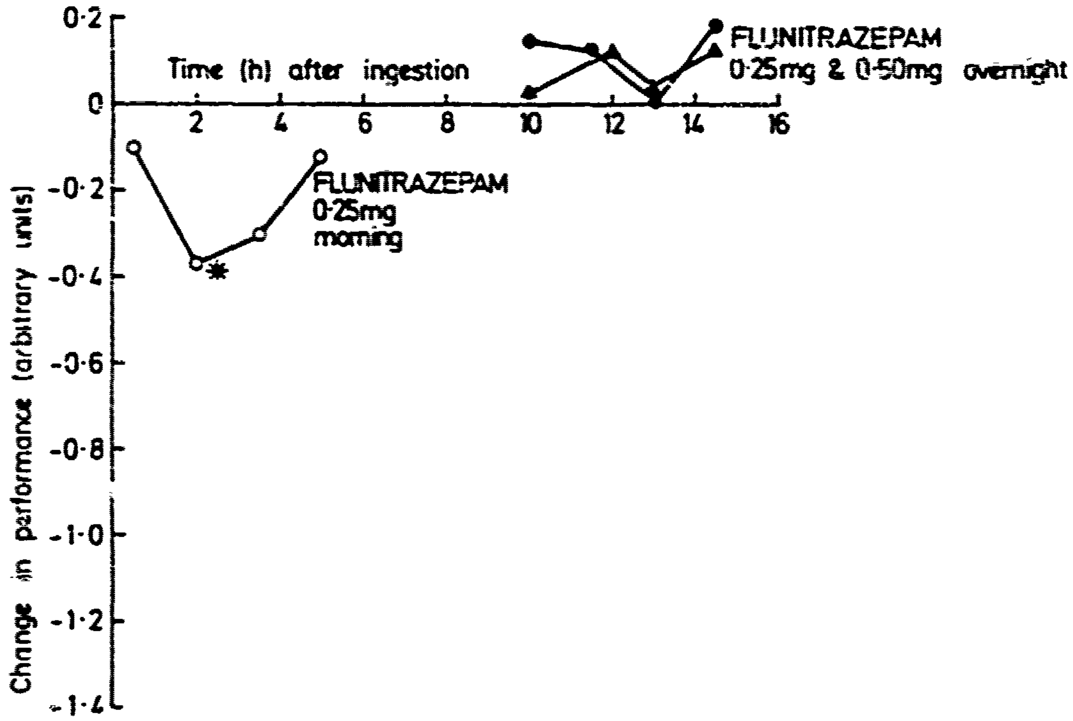

Figure 10. Effect of 0.25 mg flunitrazepam ingested in the morning, and 0.25 & 0.50 mg flunitrazepam ingested overnight on visuo-motor coordination. Significance level: * $p < .05$.

Triazolo-Benzodiazepines

A disadvantage of the use of diazepam is its long-acting metabolite, nordiazepam, and to avoid this pathway heterocyclic ring structures have been added across the 1- and 2-positions. Triazolam, which is an example of a triazolo-benzodiazepine with an ortho chlorophenyl group (Rudzik, Hester, Tang, Straw, & Friis, 1973), has relatively short half life (Eberts, Ko, & Thomas, 1978). However, triazolam around 1 mg has residual effects on performance (Veldkamp, Straw, Metzler, & Demissianos, 1974) and smaller doses may be more appropriate. Studies using visuo-motor coordination (Nicholson & Stone, 1980) have shown that with 0.25 mg triazolam performance is impaired for about 5.0 h after ingestion, but there are no residual effects with overnight ingestion. With 0.50 mg triazolam there are residual effects but these have disappeared within 11.5 h of ingestion (Figure 11).

Sleep Studies

Diazepam and its hydroxylated metabolites, as well as flunitrazepam and triazolam, may be appropriate hypnotics for persons involved in skilled activity, and so we have examined their effects on sleep. With diazepam and its metabolites the investigations have included observations in young adulthood (Nicholson & Stone, 1976, 1978) and in middle age (Nicholson & Stone, 1979a) and on their effectiveness for inducing sleep during the day (Nicholson & Stone, 1979b), which may be relevant to the management of sleep disturbance associated with irregular work. Studies with flunitrazepam and triazolam are less well advanced, but their effectiveness for sleep in young adults in doses free of residual effects has been studied (Nicholson & Stone, 1980).

The subjects were healthy male volunteers familiar with the labratory and with the techniques used in sleep recording. They were required to refrain from napping and undue exercise, and to abstain from caffeine and alcohol after mid-day on the days with overnight sleep recordings and during the whole day for day-time recordings. The laboratory was sound attenuated and temperature and humidity were controlled. Recordings were made with silver-silver chloride electrodes placed according to the 10:20 system. Electroencephalographic activity was recorded from the F_1-F_7 or C_4-A_1, P_1-T_5 and O_2P_z-O_3 positions. The electromyogram was recorded from the right eye-mastoid or nasion and the left eye-mastoid or nasion. Each sleep record was scored in 30 s epochs according to the scheme of Rechtschaffen and Kales (1968) and each night's sleep was then analysed for various measures.

The subjects completed assessments of sleep and well-being related to a 100 mm analogue scale 0.5 h after awakening. The assessments and the extremes of the scales were, I slept, <u>Very poorly</u> - <u>Very well</u>, Now I feel, <u>Very sleepy</u> - <u>Wide awake</u>, I fell asleep, <u>Never</u> - <u>Immediately</u> and After I fell asleep, I slept, <u>Very badly</u> - <u>Very well</u>.

Studies in Young Adulthood
(Figure 12)

Investigations with diazepam (5 & 10 mg), temazepam (10 & 20 mg) and oxazepam (15, 30 & 45 mg) were each carried out in six males aged between 19 & 43 years (Nicholson & Stone, 1976, 1978). Total sleep time was increased with 10

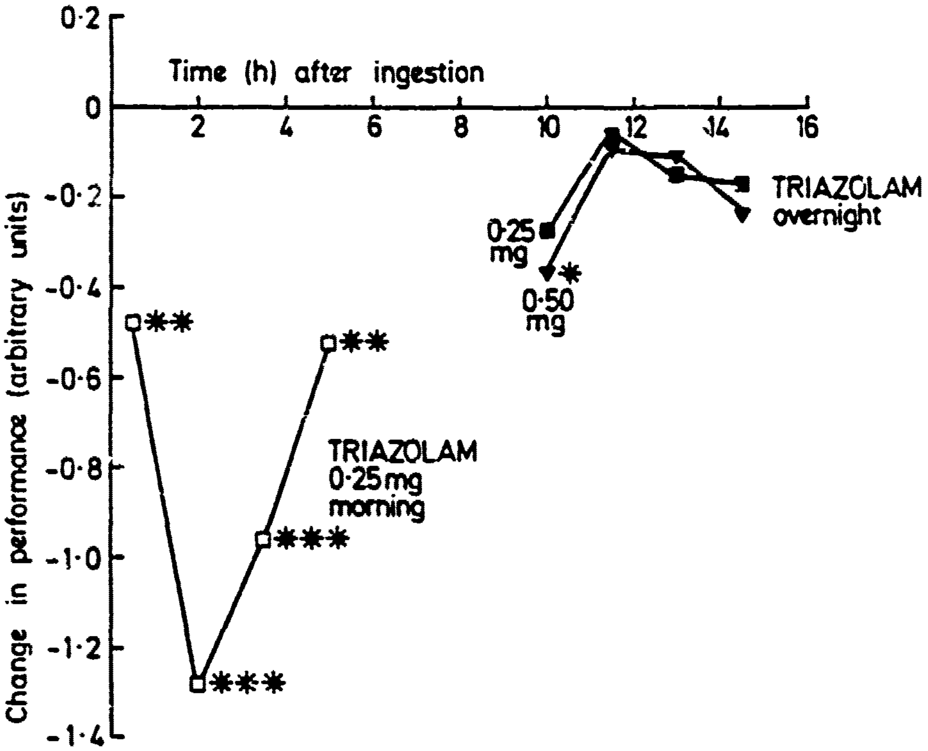

Figure 11. Effect of 0.25 mg triazolam ingested in the morning and 0.25 & 0.50 mg triazolam ingested overnight on visuo-motor coordination. Significance levels: * p <.05; ** p <.01; *** p <.001.

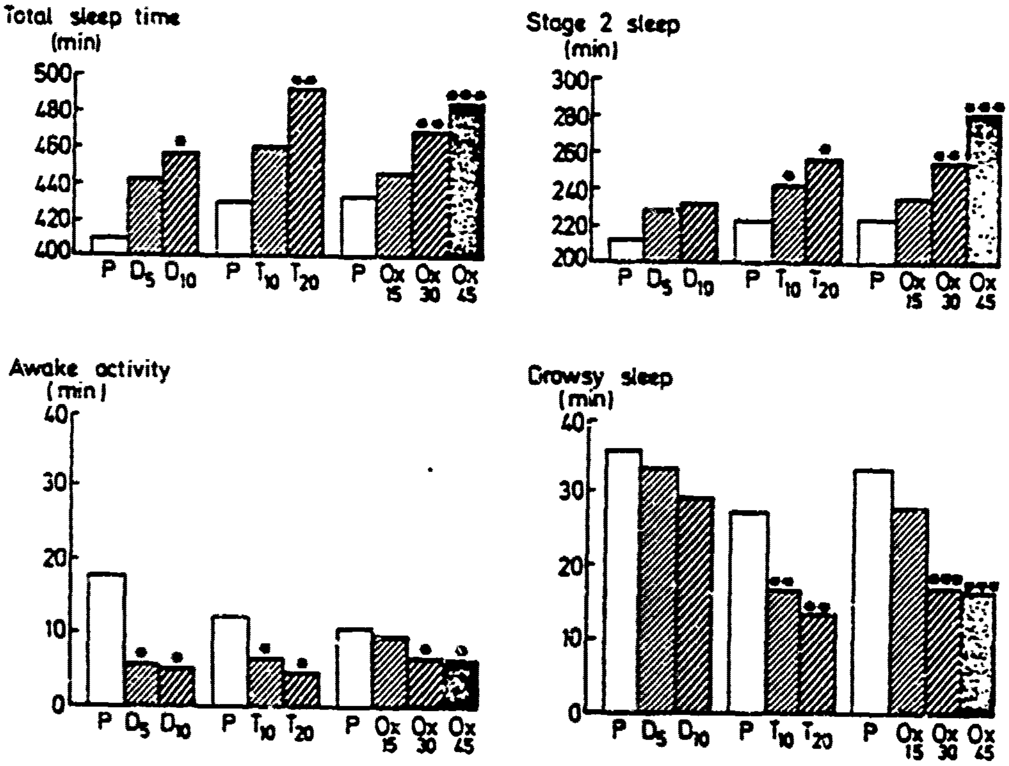

Figure 12. Some effects of diazepam (5 & 10 mg), temazepam (10 & 20 mg) and oxazepam (15, 30, & 45 mg) on night-time sleep in young adults compared with placebo. P - placebo, D - diazepam, T - temazepam, and Ox - oxazepam. Significance levels: * p <.05; ** p <.01; *** p <.001.

mg diazepam, and sleep onset latencies were shortened and awakenings were reduced. With 10 mg temazepam there was no change in total sleep time, though with 20 mg total sleep time was increased. Temazepam shortened sleep onset latencies, and reduced awake activity and drowsy sleep, and the effect on drowsy sleep was seen during each two hourly interval of the sleep period. The subjects reported improved sleep with temazepam, but subjective assessments of well-being were not altered. Oxazepam (30 & 45 mg) increased total sleep time and reduced awake activity and drowsy sleep, but it was not possible to establish an effect on sleep onset latencies. The subjects did not report changes in their quality of sleep or well-being with 15 & 30 mg oxazepam, but reported impaired wakefulness after the overnight ingestion of 45 mg. With these drugs no changes were observed in stages 3, 4 or REM sleep, except that the first REM period was delayed with 20 mg temazepam.

The potential for flunitrazepam is uncertain. With 0.25 mg there is little, if any, effect, though the higher dose (0.50 mg) may be useful when residual sequelae are to be avoided. With the higher dose total sleep time is increased and awake activity and drowsy sleep decreased without any adverse effects on the sleep process (Figure 13). With 0.25 & 0.50 mg triazolam total sleep time is increased and awake activity and drowsy sleep decreased (Figure 13). There are no changes in slow wave sleep, though the first period of rapid eye movement sleep is delayed with the higher dose. However, though triazolam reduces the duration and percentage of REM sleep during the early part of the night, REM sleep over the whole night is not changed. There is no clear evidence of a greater hypnotic effect in the healthy individual with the higher dose of triazolam.

Studies in Middle Age
(Figure 14)

The effect of diazepam (5 & 10 mg) and temazepam (10, 20 & 30 mg) were examined in six healthy middle aged (45-55 years) males. The sleep of the group was also compared with that of young adults (20-29 years) (Nicholson & Stone, 1979a). Control studies showed that there was a marked reduction in total sleep time, an increase in latency to Stage 3 and an increase in percentage of drowsy and Stage 2 sleep in the older group, but there were no changes in REM sleep. Diazepam and temazepam did not increase total sleep time. Sleep onset latencies were shortened by diazepam, but were unchanged with temazepam, and awake activity was reduced by both drugs. The subjects assessed their sleep as improved with both drugs without residual effects on well-being.

Studies on Day-Time Sleep
(Figure 15)

An investigation of the effects of diazepam (5, 10 & 15 mg), temazepam (10 & 20 mg) and oxazepam (15, 30 & 45 mg) on day-time sleep was carried out in six healthy males aged 19-28 years. The subjects slept normally the preceding night, and were required to sleep for a 6 h period beginning at 1400 h the next day (Nicholson & Stone, 1979b). Total sleep time was increased by 10 & 15 mg diazepam and by 30 & 45 mg oxazepam, but it was not possible to establish an increase in total sleep time with temazepam. Sleep onset latencies were decreased by diazepam, though such an effect was not observed with tema-

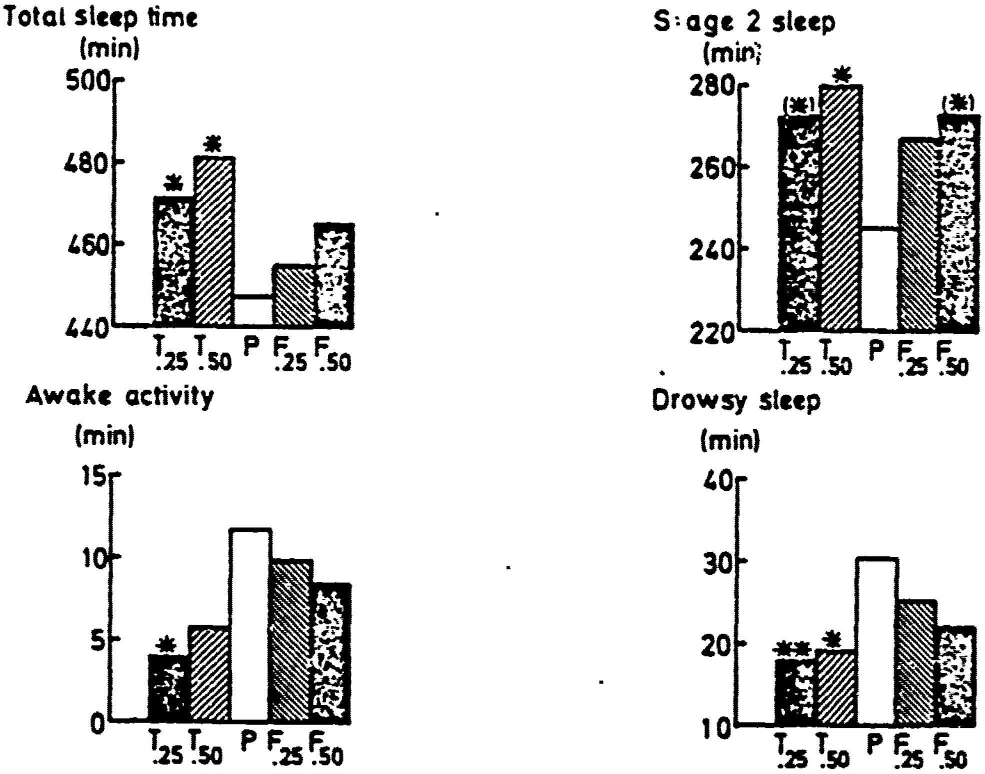

Figure 13. Some effects of triazolam (0.25 & 0.50 mg) and flunitrazepam (0.25 & 0.50 mg) on night-time sleep in young adults compared with placebo. P - placebo, T - triazolam, and F - flunitrazepam. Significance levels: * p <.05; ** p <.01.

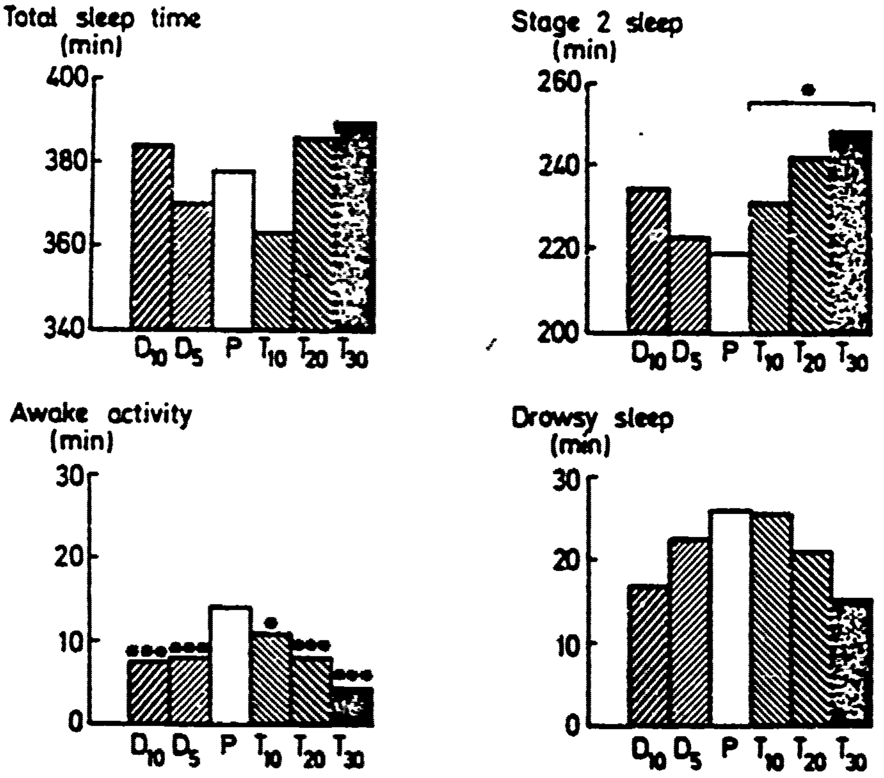

Figure 14. Some effects of diazepam (5 & 10 mg) and temazepam (10, 20, & 30 mg) on night-time sleep in middle age compared with placebo. D - diazepam and T - temazepam. Significance levels: * $p < .05$; *** $p < .001$.

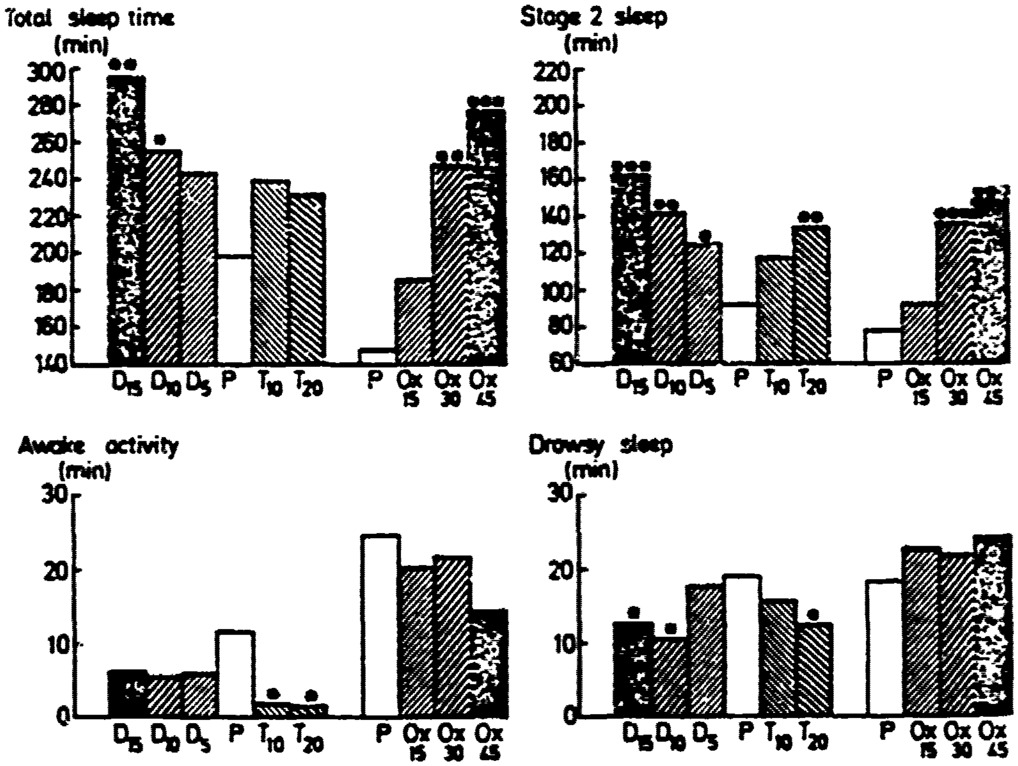

Figure 15. Some effects of diazepam (5, 10, & 15 mg), temazepam (10 & 20 mg), and oxazepam (15, 30, & 45 mg) on day-time sleep in young adults compared with placebo. P - placebo, D - diazepam, T - temazepam, O - oxazepam. Significance levels: * p <.05; ** p <.01; *** P <.001.

zepam or oxazepam. Awake activity was reduced by 10 & 20 mg temazepam. Drowsy sleep was decreased by 10 & 15 mg diazepam, and by 20 mg temazepam, but was not altered by oxazepam.

These results on three closely related benzodiazepines showed that very similar drugs may have different effects on sleep. In young adults, diazepam and temazepam reduced sleep onset latencies and awake activity and increased total sleep time, though temazepam also reduced drowsy sleep. The activity of oxazepam was similar to that of temazepam, although it has no effect on sleep onset latencies. In middle age, the effects of diazepam and temazepam were much less pronounced than would be expected from studies in the younger group. There was no increase in the total sleep time of middle age, even though both drugs increased the much longer sleep of young adults, and, though sleep onset latencies were similar between the two groups, it was only possible to establish an effect with diazepam, though temazepam shortens sleep onset latencies in early adulthood. Essentially, the effect of diazepam and temazepam in middle age was to reduce awake activity only.

The effects of these drugs on sleep during the day were unrelated to their relative effects on sleep during the night. Diazepam increased total sleep time during the day and reduced drowsy sleep, but temazepam and oxazepam had less activity during the day than would be expected from night-time studies. With temazepam there was no increase in total sleep time, though there was reduced awake activity and drowsy sleep, and with oxazepam total sleep time was increased.

Recommendations

It is considered that these findings provide a basis for the management of sleep disturbance in persons involved in skilled activity. The residual effects of nitrazepam (10 mg) and flurazepam hydrochloride (30 mg) within the currently accepted therapeutic dose ranges preclude their use in those involved in skilled activity the next day. However, diazepam (5-10 mg) is useful for both night-time and day-time sleep, though daily ingestion could lead to an accumulation of its long-acting metabolite with persistent behavioural effects. It may be wise to restrict the ingestion of diazepam to intervals not less than 48 hours and perhaps to not more than twice in a 7-day period. On the other hand, such restrictions are unlikely to be necessary with temazepam (10-20 mg) and oxazepam (15-30 mg). Temazepam (20 mg) may not be so effective for sleep as diazepam (10 mg) at times which do not coincide with the normal circadian desire to sleep and may be of less usefulness in shift workers, while oxazepam, at least in its present formulation, is unlikely to hasten sleep onset. Triazolam (0.125-0.25 mg) and flunitrazepam (0.50 mg) are without residual effects on performance and have useful hypnotic activity, but further experience with these drugs is required before any decision can be made as to their suitability in the present context.

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ANCHOR SLEEP AS A SYNCHRONIZER OF RHYTHMS ON ABNORMAL ROUTINES

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Recent reviews of shift work (Knauth & Rutenfranz, 1976; Rutenfranz & Knauth, 1976; Rutenfranz, Colquhoun, Knauth, & Ghata, 1977; Winget, Hughes, & LaDou, 1978) have emphasized the disadvantages associated with it, whether these are performance decrement, ill-health, job dissatisfaction, increased accidents or social inconvenience. At least in part, these problems seem to arise because the shift worker is required to work, to take his leisure and to sleep at unusual hours. As a result his endogenous circadian rhythms are at variance with the schedule of sleep and wakefulness. With successive days on the same shift these rhythms progressively adapt so that they become more appropriately phased to the cycle of work and sleep, but there is doubt if adaptation is ever complete unless the same shift is worked for a long period of time (Conroy, Elliott, & Mills, 1970; Lobban,1963). Thus it has been shown (Knauth & Rutenfranz, 1976; Knauth, Rutenfranz, Herrmann, & Poeppl, 1978) that rhythms are often flatter when on shift-work than when they are measured in the same subjects on the conventional pattern of diurnal work and nocturnal sleep. The problem is exacerbated by the observation that the rhythms rapidly regain their normal phasing when the worker, generally for reasons of social expedience, reverts to a normal routine during his days off (Åkerstedt & Fröberg, 1975). To avoid this problem of continual adaptation, loss of adaptation and readaptation, rapidly rotating shift systems have been advocated (Knauth & Rutenfranz, 1976; Rutenfranz & Knauth, 1976; Rutenfranz et al., 1977). On such systems, large day-by-day changes of rhythms are not seen but it is possible that in the absence of regular habits the rhythms might free-run with a period in excess of 24 hours and so it would be only by chance that the rhythms of the worker would be appropriate to his schedule, whether this be one of work or leisure.

Clearly it would be an advantage if rhythms could in some way be stabilized to a particular shift, so that after the occasional day off with its associated change in routine the rhythms would still be adapted to the work shift when it was resumed.

There is evidence that sleep directly affects circadian rhythms (Mills, Minors & Waterhouse, 1978a), one result of which is that rhythms are more closely related to midsleep than to clock time (Halberg, Reinhardt, Bartter, Delsea, Gordon, Reinberg, Ghata, Halhuber, Hoffman, Gunther, Knapp, Pena, & Garcia Sainz, 1969; Mills & Waterhouse, 1973). Therefore a series of experiments has been performed in which an attempt has been made to stabilize the rhythms of subjects by making them take part of their sleep at a regular time each day even though the rest of their sleep-wakefulness routine was irregular. Preliminary accounts of these experiments have appeared (Mills, Minors, & Waterhouse, 1977a; Minors & Waterhouse, 1979).

Methods

The subjects were healthy students aged 18-21. Details are shown in Table 1. The subjects were studied in groups of 2 to 5 in an Isolation Unit,

Table 1

Details of Subjects and Experimental Protocols

Group	Sex	Ages	Length of daily sleep periods during experimental phase (h)	Time of anchor sleep
A	M	19, 20, 18, 18	8	None
B	F	18, 18, 20, 19, 18	2 x 4	None
C	F	18, 21, 20, 18	2 x 4	0000-0400
D	M	19, 20	2 x 4	0000-0400
E	F	19, 19	2 x 4*	0000-0400
F	F	18, 18, 19, 18	2 x 4	0400-0800
G	M	20, 19, 21, 19	2 x 4	0800-1200
H	M	19, 20	2 x 4	1200-1600

* Sequence of irregular sleeps the reverse of groups C, D and F-H.

the ambient air temperature and humidity of which were maintained constant. Further details of this unit have been described elsewhere (Elliott, Mills, Minors, & Waterhouse, 1972). Initially, subjects were studied for a 5-day control period living on a customary nychthemeral routine. During this they slept between midnight and 0800 and ate meals at their customary times. After this control phase subjects were then asked to sleep at irregular times--the experimental phase--according to one of six designs, even though they continued to eat at times as nearly as possible the same as those during the control phase. Lighting was under the control of the subjects; they were instructed to take all sleep periods in the dark.

The different experimental designs are shown in Figures 1 and 2. In the first design, Figure 1A, 4 male subjects (Group A) took a single 8-hour sleep per day, but at a different time each day. The ordering of these times was randomized. In the second experimental design, Figure 1B, 5 female subjects (Group B) took their sleep in two 4-hour periods per day. The time of one of these, labelled with an X in the figure, was such that its mid-point was at the same time as that of the 8-hour sleep on the corresponding day in subjects of Group A. The other 4-hour sleep was always begun 12 hours earlier.

In the remaining experimental designs, Figure 2, the customary 8 hours of sleep per day were again divided into two 4-hour periods. By contrast, how-

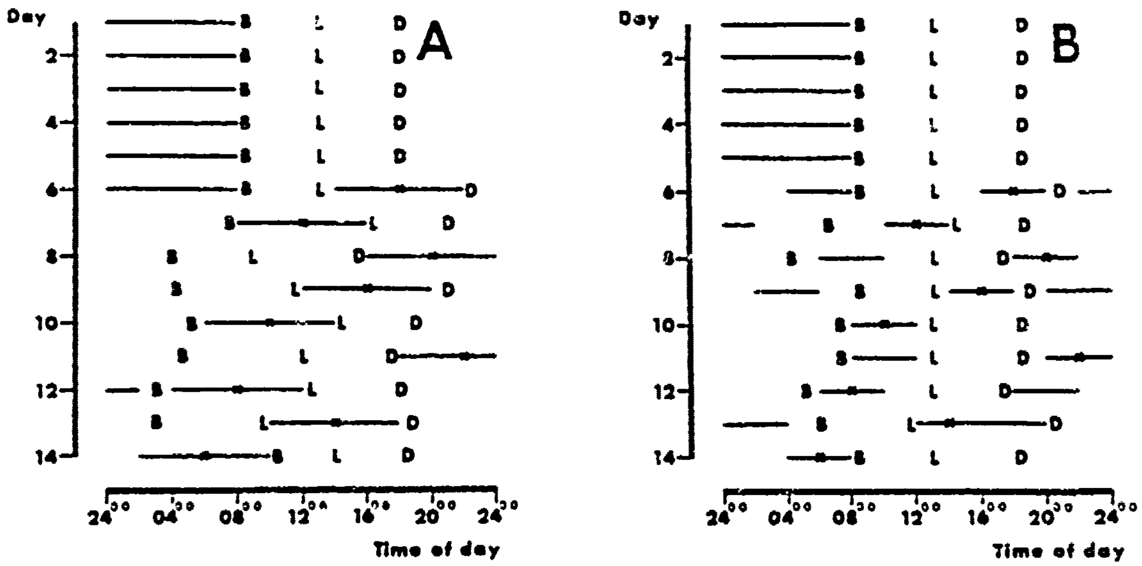

Figure 1. A (left): Experimental protocol for Group A. B (right): Experimental protocol for Group B. Successive days in Isolation Unit from above downwards. Mealtimes indicated as B (breakfast), L (lunch), or D (dinner). Horizontal bars represent times the subjects were in bed. Mid-points of irregularly-timed sleep periods indicated by X.

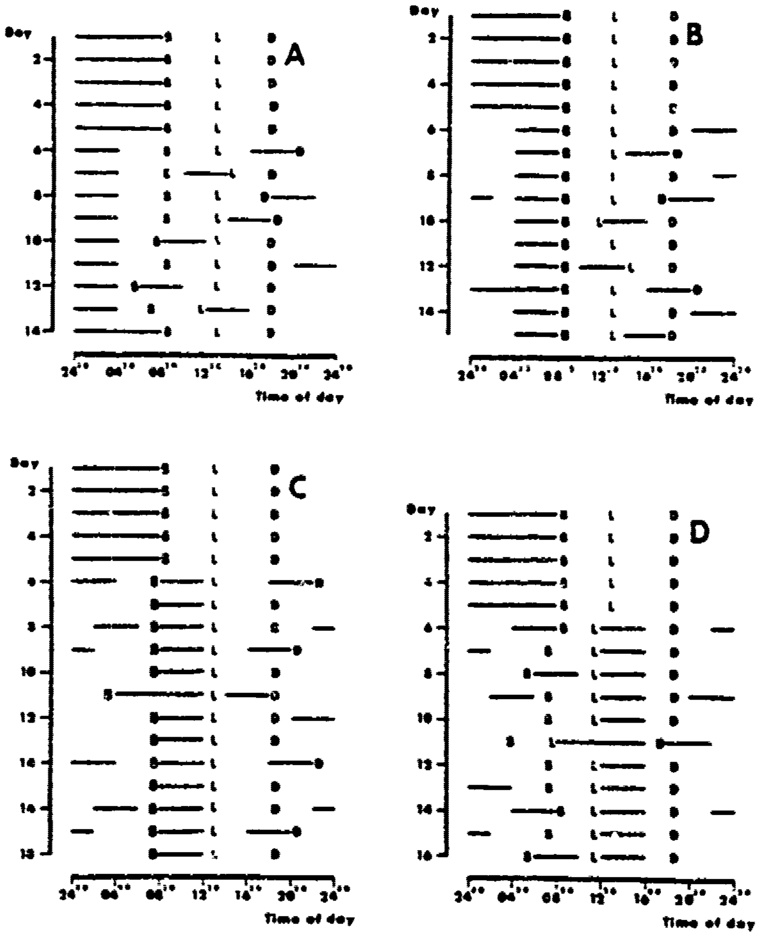

Figure 2. A: Experimental protocol for Groups C and D. B: Experimental protocol for Group F. C: Experimental protocol for Group G. D: Experimental protocol for Group H. Other details as Figure 1.

ever, one of these was taken at a constant time on each day. This constant 4-hour sleep period is referred to by us as 'anchor sleep' and was taken over one of 4 intervals: 0000-0400, Figure 2A; 0400-0800, Figure 2B; 0800-1200, Figure 2C; 1200-1600, Figure 2D. Details of subjects participating in these designs are given in Table 1. The second 4-hour sleep taken in these experiments was at a different time on each successive day. For subjects of Groups C and D, whose anchor sleep was 0000-0400 (Figure 2A) the irregularly-taken 4-hour sleep was at the same time as that taken on the corresponding day by Group B and labelled with an X in Figure 1B. For the other three designs these irregularly-taken sleep periods were 4 hours (anchor sleep 0400-0800, Group F), 8 hours (anchor sleep 0800-1200, Group G) or 12 hours (anchor sleep 1200-1600, Group H) later than on the corresponding day for 0000-0400 anchor sleep experiment. To minimize the effects of sleep deprivation when the anchor sleep was taken at 0800-1200 or at 1200-1600, the irregularly-taken sleep was advanced by one day and so was placed before the anchor sleep rather than after (compare Figures 2B and 2C).

A final group of subjects (Group E) was studied. This group also took an anchor sleep from 0000-0400 but differed from Groups C and D in that it underwent the reverse sequence of irregularly-taken 4-hour sleeps.

Throughout all experiments, subjects micturated on rising from bed and every 2 hours thereafter whilst awake. The volume of all urine passed for each collection period was noted and an aliquot refrigerated for subsequent analysis. Rectal temperature was also measured using a thermistor probe placed 10 cm beyond the anal sphincter. During the hours of wakefulness this temperature was measured by the subjects every hour and during sleep it was telemetered hourly. All urine samples were analyzed by an AutoAnalyzer II, the analyses performed being for sodium, potassium, chloride, creatinine, inorganic phosphate, calcium, and urate. No calcium analysis was performed on the samples produced by Group C due to a technical failure. For each period of collection of urine the flow rate and excretion rates of each of the constituents in urine were determined.

Circadian rhythms were sought by the fitting of cosine curves to the data. For the temperature data the single cosinor method (Halberg, Johnson, Nelson, Runge, & Sothern, 1972) was used and for the urinary data the method of Fort and Mills (1970). For rhythm analyses, experiments were divided into two phases: the control phase, during which the subjects slept at their habitual times; and the experimental phase, during which the schedule of sleeping had been changed as already described. To each phase a spectrum of cosine curves with periods from 22 hours in increments of 0.1 hour to 27 hours were fitted to each variable. The most appropriate period for the rhythm of each variable was assessed as that of the fitted cosine curves which minimized the residual error. The data from the experimental phase were also analyzed by a pergressive serial section analysis (Halberg & Katinas, 1973) in which cosine curves with a period of 24 hours were fitted to 72-hour intervals of data progressively incremented by 24 hours. Other statistical analyses will be described as they arise in the following section.

Results

Sleep Taken at Irregular Times (Groups A and B)

Examples of the behaviour of the acrohpases of 24-hour cosine curves fitted pergressively to data from subjects of Groups A and B are shown in Figures 3 and 4. In both cases it can be seen that during the experimental phase, when the subjects slept at irregular times, the acrophase was initially similar to that determined by fitting a 24-hour cosine curve to the entire control phase. Thereafter the acrophase became progressively later, a finding in accord with the view that the rhythm was free-running with a period of greater than 24 hours. This conclusion has been confirmed for the group as a whole by determining the mean period of rhythms (derived from all variables and all subjects) during both the control and the experimental phases. For Group A the mean period of rhythms during the control phase was 24.160 ± 0.103 hours and for Group B the corresponding mean was 24.195 ± 0.106 hours; in neither case was this significantly different from 24 hours at the 5% level. By contrast, the mean period of rhythms for both these groups during the experimental phase was significantly ($p < .05$) greater than 24 hours (24.515 ± 0.191 hours, Group A; 24.683 ± 0.159 hours, Group B). Further, in both groups, paired t-tests showed that the period determined during the experimental phase was significantly greater ($p < .05$ by one-tailed test) than that determined during the control phase (mean difference: 0.360 ± 0.205 hours, Group A; 0.486 ± 0.198 hours, Group B).

It, thus, appeared in both these groups that, despite the fact that meals were taken at regular times throughout, stable 24-hour rhythms were not obtained; rather, rhythms appeared to free-run with a period greater than 24-hours.

Anchor Sleep 0000-0400 (Groups C, D, and E)

Pergressive serial section analysis of the data from Groups C and D showed that the acrophases of the cosine curves fitted to the experimental phase remained at a fairly constant time throughout. An example is shown in Figure 5. It can be seen in this Figure that the acrophase occurs at a time which is also similar to that determined during the control phase. It, thus, appears that rhythms retained a 24-hour period and a phase similar to that determined whilst subjects lived on their customary nychthemeral routine. The results from subjects of Group E, for whom the ordering of the irregularly taken sleeps over successive days was the reverse of that for Groups C and D, were very similar. An example is shown in Figure 6. Therefore, for statistical analysis, the three groups have been considered together.

In these groups, then, it appears that taking a 4-hour sleep at a regular time was associated with stable 24-hour rhythms. This has been confirmed by fitting a spectrum of cosine curves, as described previously, and by determining the period of the rhythms during all but the first 4 days of the experimental phase. [The reason for omitting the first 4 days of the experimental phase was to remove the effects of any transient changes which might occur immediately after subjects started sleeping at irregular times—for further comments, see later.] The mean period of all rhythms from subjects of Groups C-E was not significantly different from 24 hours as shown in Table 2, column A.

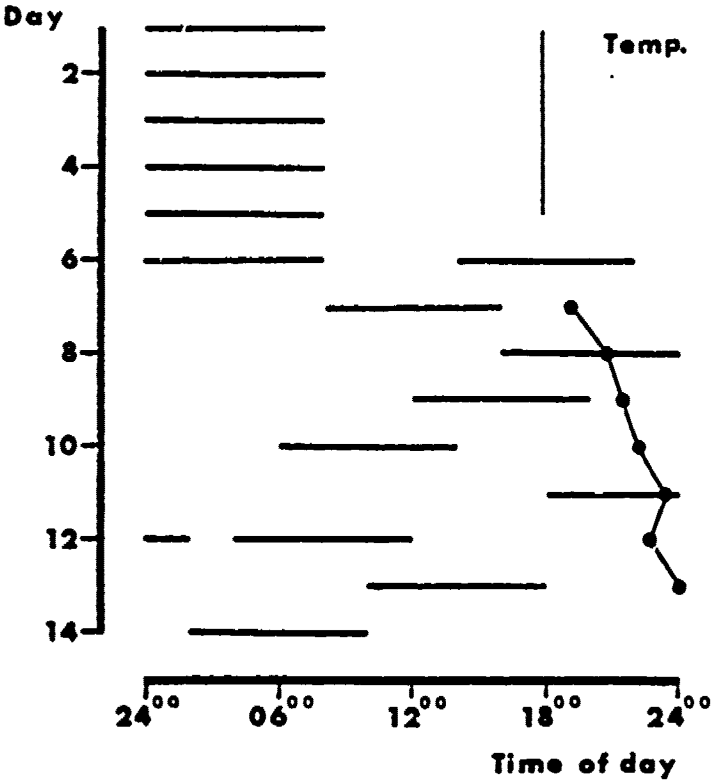

Figure 3. Rectal temperature rhythm in a subject of Group A. Acrophases of 24-h cosine curves fitted to 72 hours of data pergressively incremented by 24 hours. Acrophase of 24-h cosine curve fitted to all control phase as shown in vertical line.

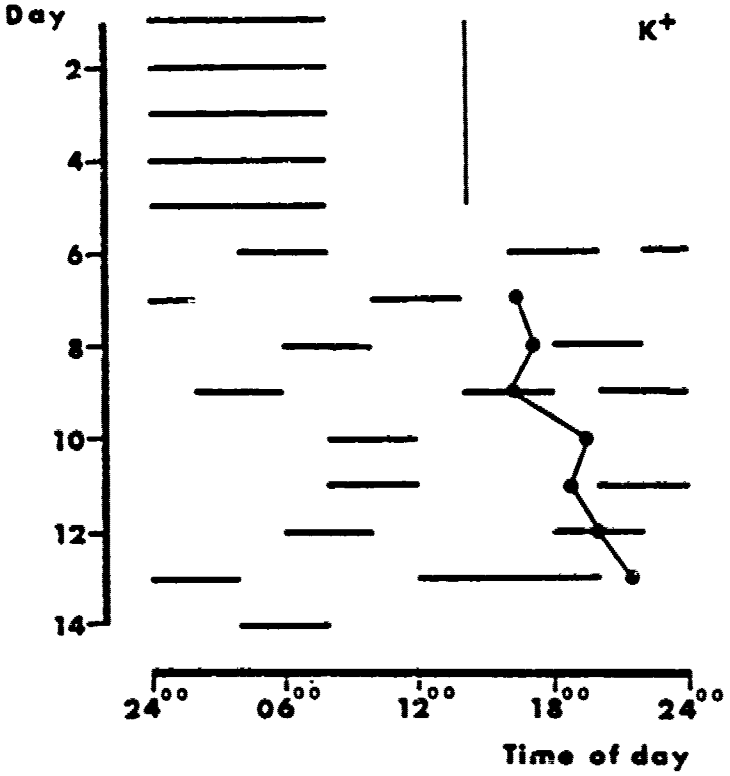

Figure 4. Urinary potassium rhythm in a subject of Group B. Data plotted as in Figure 3.

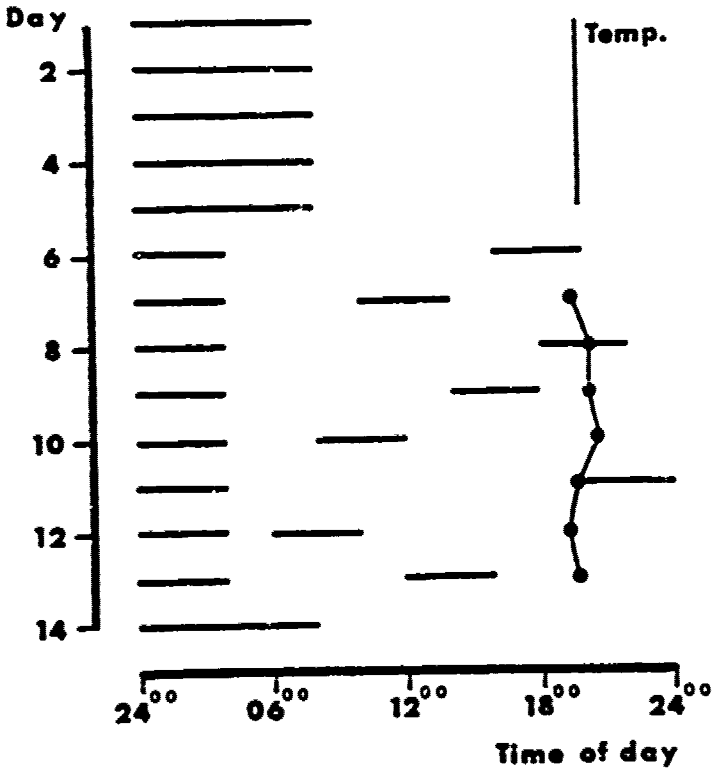

Figure 5. Rectal temperature rhythm in a subject of Group D. Data plotted as in Figure 3.

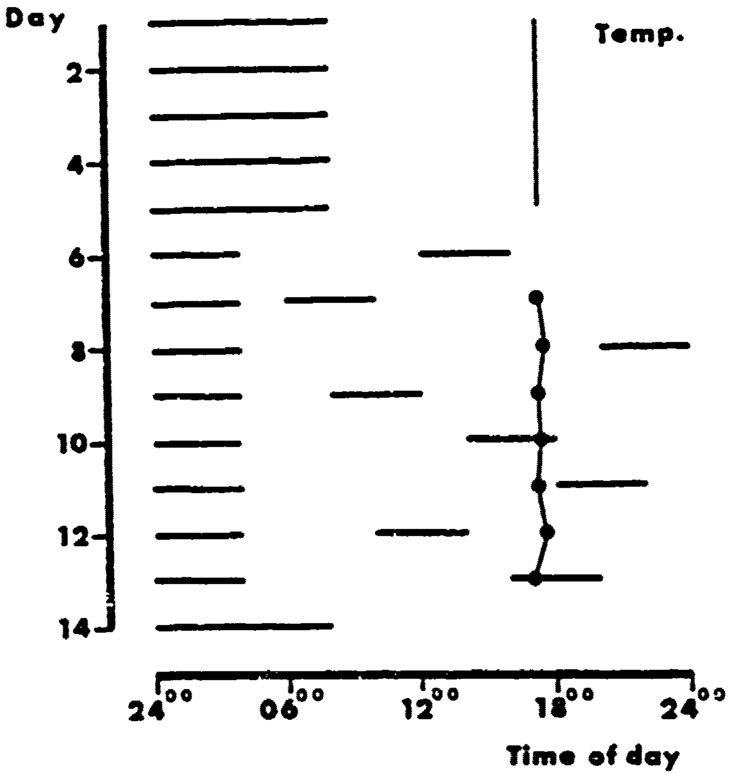

Figure 6. Rectal temperature rhythm in a subject of Group E. Data plotted as in Figure 3.

Anchor Sleep at Other Times (Groups F, G, and H)

The results from the previous section lead one to speculate if taking an anchor sleep at times other than 0000-0400 would also result in stable 24-hour rhythms. An example of the behaviour of the acrophases of cosine curves progressively fitted to the data of Group F, whose anchor sleep was 0400-0800, is shown in Figure 7. As for Groups C, D, and E the acrophases were stable during the experimental phase. However, as the example shows, the acrophase was sometimes a few hours later during the experimental phase than in the control phase, though in other cases its timing in the two phases was indistinguishable. As previously, the mean period of the rhythms for all variables was determined over all but the first 4 days of the experimental phase and is shown in Table 2, column A. This mean was not significantly different from 24 hours.

Table 2

Mean Periods of Rhythms During the Experimental Phase for the Different Groups

	A		B	
	Period during experimental phase. Mean ± 1 S.E. (hours)	p*	Difference in period between initial and later part of experimental phase. Mean ± 1 S.E. (hours)	p**
Groups C, D, and E	24.166 ± 0.164 (n=47)	ns	-0.295 ± 0.227 (n=38)	ns
Group F	24.191 ± 0.137 (n=34)	ns	+0.303 ± 0.175 (n=29)	ns
Group G	23.977 ± 0.081 (n=35)	ns	+0.667 ± 0.150 (n=33)	0.001
Group H	24.213 ± 0.168 (n=15)	ns	+0.686 ± 0.264 (n=14)	0.021

Column A: Mean period derived from all but the first 4 days (Group H, 6 days) of the experimental phase.

Column B: Mean difference in period of rhythms between the initial 4 days (Group H, 6 days) of the experimental phase and the remainder of the experimental phase (+ indicates period longer during the initial days).

p* probability that the difference is significantly different from 24 (unpaired t-test, two-tailed).

p** probability that difference is significantly different from zero (paired t-test, two-tailed).

ns $p > .05$.

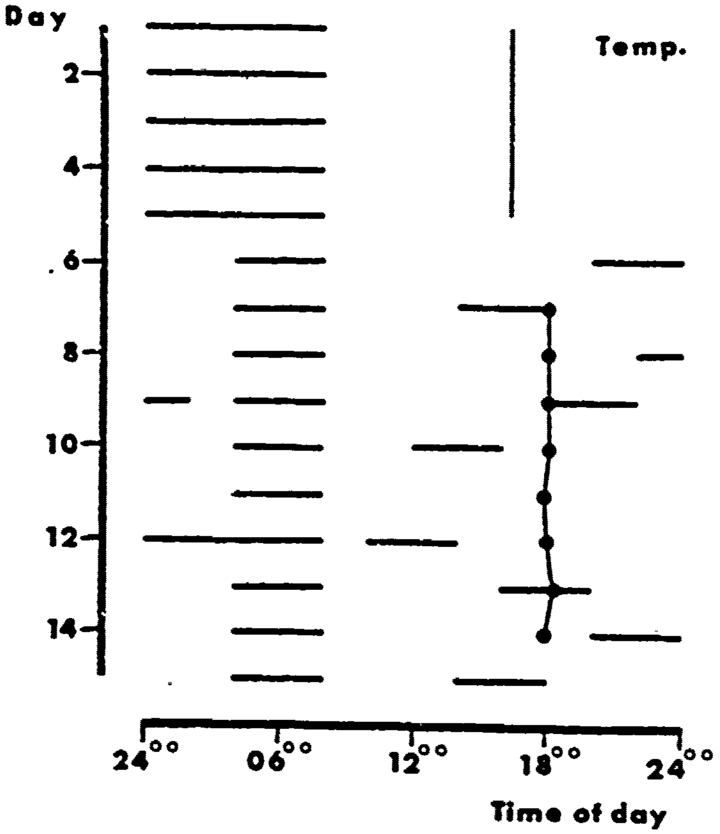

Figure 7. Rectal temperature rhythm in a subject of Group F. Data plotted as in Figure 3.

The results from Groups G and H differed slightly from those of other groups. Figures 8 and 9 show examples of the behaviour of the acrophases derived from cosine curves fitted pergressively to data from these two groups. In both cases it can be seen that, during the latter part of the experimental phase, the acrophase was constant but that this stability was not gained immediately. In the initial part of the experimental phase the acrophase became progressively later such that, once stability was attained, the acrophase of the rhythm was later than that determined during the initial control phase. In addition, the time required to attain stability was different in the two groups; inspection of all the data indicate it took about 4 days in Group G but about 6 days in Group H (see examples in Figures 8 and 9). Therefore, to confirm stability during the latter part of the experimental phase, the mean periods of rhythms of all variables have been determined as previously but for Group H the first 6, rather than 4, days have been omitted. The mean periods so determined are shown in Table 2, column A; in neither case was this mean significantly different from 24 hours.

How Was Stability Attained?

From the preceding sections it is evident that in all groups who took an anchor sleep, stable 24-hour rhythms were obtained at least towards the end of the experimental phase. For Groups C, D, E, and F (Figures 5, 6, and 7) this stability appeared almost immediately, whilst for Groups G and H stable 24-hour rhythms appeared only after an initial period during which the acrophase of the rhythms became progressively later. It, thus, appears that for these last two groups the period of rhythms initially changed during the experimental phase; during the early stages of the experimental phase the period was greater than that during the remainder of the experiment. Evidence in favour of this has been obtained in two ways.

Firstly, by fitting a spectrum of cosine curves we have compared, by paired t-test, the period of the rhythm during the initial 4 days of the experimental phase (for Group H the initial 6 days) with the period determined during the remainder of the experimental phase; the mean differences for all variables for the different groups are shown in Table 2, column B. For Groups C, D, E, and F the mean difference was not significantly different from zero indicating that the period did not change significantly during the two parts of the experimental phase. By contrast, for Groups G and H, the period of rhythms was longer in the initial phase of the experiment and this difference was statistically significant.

The second way in which a change in period of rhythms has been confirmed is by a pergressive serial section analysis in which, for each variable, a spectrum of cosine curves with different periods has been fitted to sections of data from the experimental phase. The sections chosen were the first 24 hours of the experimental phase and then sections obtained by progressively incrementing by 24 hours the amount of data analyzed until the entire experimental phase was covered. This analysis was continued by progressively decrementing the data to which the spectrum of cosine curves was fitted by omitting the first 24 hours of data, then the second 24 hours and so on, until only the last day's data were included. In all cases the best fit period was that of the cosine curve which minimized the residual error. Such an analysis would indicate whether the dominant periodicity changed during the course of a

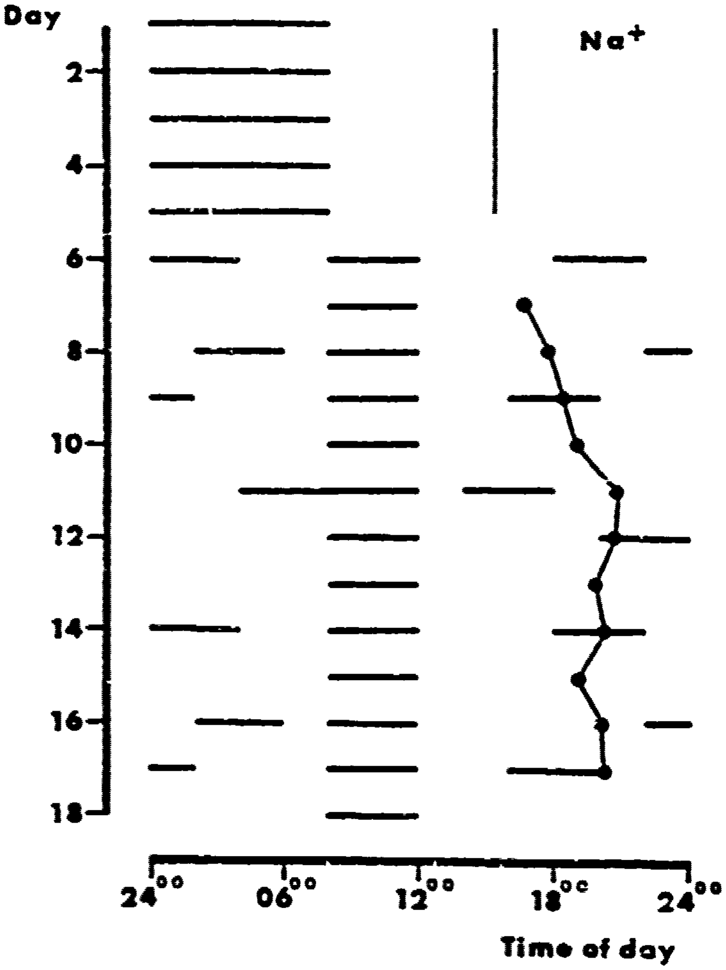

Figure 8. Urinary sodium rhythm in a subject of Group G. Data plotted as in Figure 3.

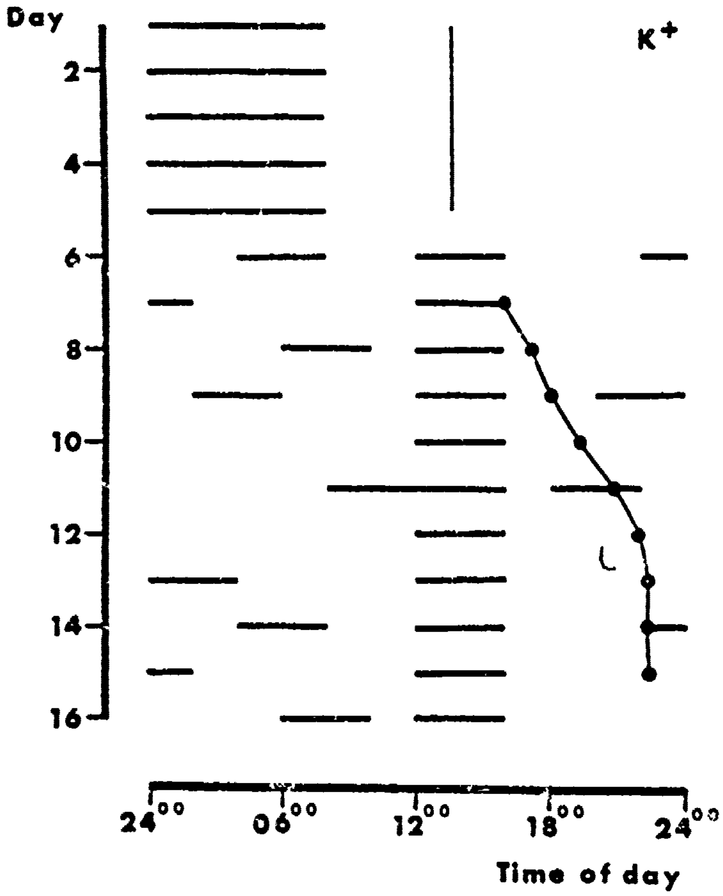

Figure 9. Urinary potassium rhythm in a subject of Group H. Data plotted as in Figure 3.

long stretch of data. For example, if the period changed from a longer to a shorter value, the period of the best-fitting cosine curves should be longer during the initial sections (when the amount of data was being increased) than during the later sections (when the amount of data was being decreased). Examples of this analysis applied to the potassium excretory data for subjects from the different groups are shown in Figure 10. For subjects of Groups G and H the period was initially in excess of 24 hours but by the latter stages, during which data from the latter days only was being considered, the period was close to 24 hours. For the subjects of Group G this 24-hour period was attained sooner than for the subjects of Group H whose rhythm showed a 24-hour rhythm only by the end of the experiment. By contrast, for the subjects of Group B the period remained fairly constant and greater than 24 hours throughout, confirming our earlier conclusion that the rhythm was free-running. Finally, the subjects representative of Groups C and F also showed a constant period throughout, but, in both cases the period was very close to 24 hours. With temperature, chloride, and sodium, similar conclusions could be drawn; with the other urinary constituents the rather greater amount of noise associated with the data precluded such firm inferences.

In conclusion, these analyses suggest that when the anchor sleep was either 0000-0400 or 0400-0800, stable 24-hour rhythms were rapidly obtained and maintained thereafter. When the anchor sleep was taken from 0800-1200 or 1200-1600, however, rhythms oscillated initially with a period greater than 24 hours, as might occur if they were free-running, but then were stabilized to a 24-hour period.

Sleep or Meals Producing Stability?

In all the experimental designs, meals were eaten at times as near as possible to those during the control phase. The possibility exists, therefore, that the regular mealtimes were responsible for the stable 24-hour rhythms in Groups C-H. There is evidence against such a view. First, stable 24-hour rhythms were not obtained in subjects of Groups A and B who also ate meals at the same time as during the control phase. Second, the acrophase of the 24-hour rhythms should not have been different from that determined during the initial control days if mealtimes were a controlling influence. However, when the difference in acrophase between the control phase and the latter part of the experimental phase was calculated, a large difference was found for Groups G and H. The mean difference in acrophase is shown for three variables in Figure 11. The upper, middle, and lower dashed lines in this Figure represent the changes in the times of retiring, mid-sleep, and rising respectively for the different anchor sleep times. It can be seen that, for each anchor sleep time, the change of acrophase from that during the control phase was closely parallel to the changes in sleep time, though it is not possible to ascribe this change to any particular aspect of sleep. Certainly the observed changes do not follow the horizontal full lines as would be the case if mealtimes rather than sleep were and important determinant of phase. Similar results were obtained with the other urinary constituents, but, for calcium, phosphate, and creatinine there was considerable variation.

In conclusion, the phase of the stable 24-hour rhythms obtained during our anchor sleep experiments depends on the time of the anchor sleep, the phase-shift being approximately equal to the time by which the mid-sleep is shifted.

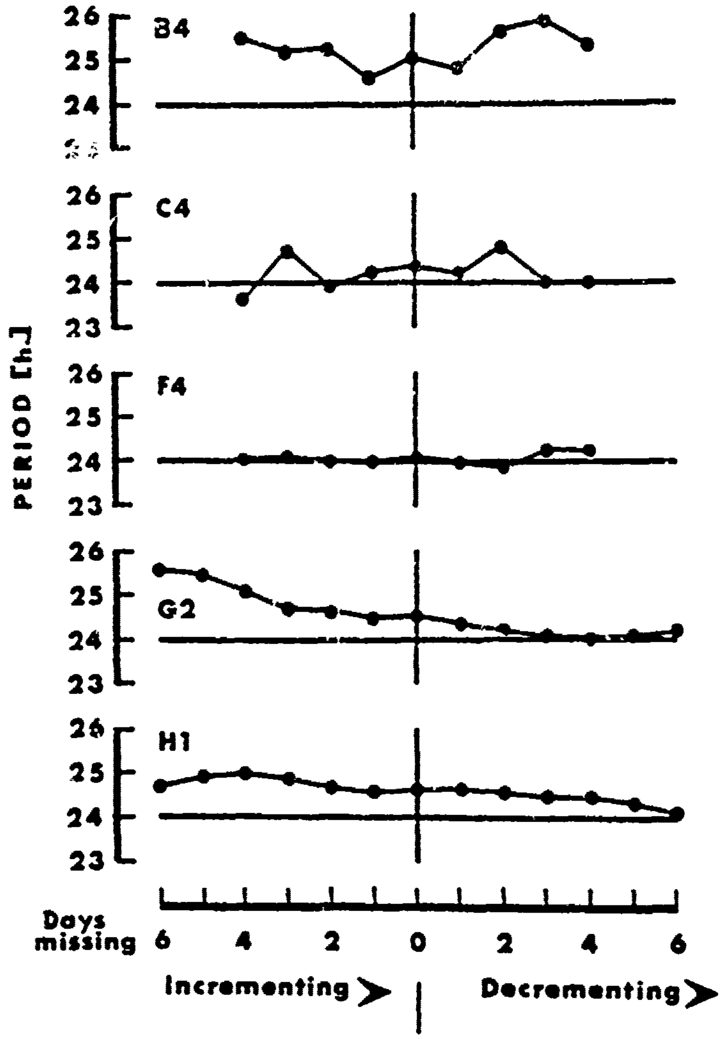

Figure 10. Urinary potassium rhythm, selected subjects from different groups as labelled. Period of best-fitting cosine curve applied to different amounts of data from experimental phase. Vertical line indicated the section when all data were considered. For other details, see text.

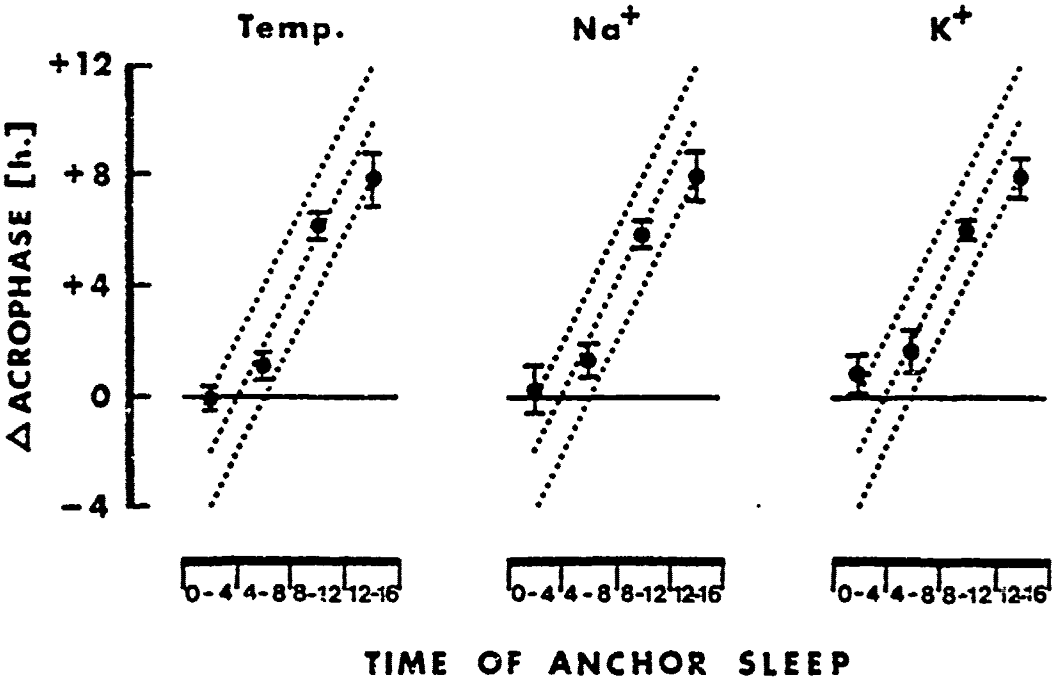

Figure 11. Change in acrophase, as compared with control phase value, when anchor sleep taken at different times for rectal temperature, sodium and potassium. + indicates phase delay. Dotted lines indicate result predicted if change in acrophase due solely to time of retiring (top), mid-sleep (middle), or time of rising (bottom). Horizontal unbroken line indicates result predicted if change in acrophase due solely to mealtimes. Results expressed as mean ± 1 S.E.

Discussion

Our results indicate that the rhythms of subjects undergoing irregular routines free-run but that, in the presence of an anchor sleep, the rhythms are stabilized with a period indistinguishable from 24 hours (see Table 2).

That people on irregular routines have free-running rhythms has been found occasionally by others, for example by Colquhoun and his colleagues in their experiments upon submariner watchkeepers (1978, 1979). Studies performed upon workers involving rapidly-rotating shift systems have been interpreted to show an absence of marked changes in rhythms on different days (Rutenfranz et al., 1977). However, these data have not been analyzed in a way that would enable a decision to be made as to whether or not the rhythms were free-running in these circumstances. In previous work, we have found rhythms with a period in excess of 24 hours in a single subject who underwent a series of simulated time-zone transitions (Mills et al., 1978c) and similarities would seem to exist between changes in routine associated with continual time-zone displacement and the effect of rapidly-rotating shifts.

Free-running rhythms are also found when subjects are isolated from external time clues, whether they are placed in a bunker (Wever, 1975a), an Isolation Unit (Mills et al., 1974), or a cave (Mills, 1964). What all these people might have in common, together with our Groups A and B, are external conditions that fail to provide sufficient temporal stability so that the endogenous rhythms cannot be synchronized to the external environment and so they free-run.

There does not seem to be much precedent for our demonstration that an anchor sleep can stabilize rhythms in subjects on an otherwise irregular routine. Colquhoun et al. (1978) have pointed out that there seemed to be a greater stability of temperature rhythm in submariner watchkeepers who took sleep at as regular hours as their shift system would allow.

The implication of our finding is that the rhythms of shift-workers might be stabilized if they took at least some of their sleep during their days off at the same time as when working. For this reason, our anchor sleep at 0800-1200 (Group G) is particularly significant since this is at a time that is both appropriate for workers after a night shift and socially acceptable during days off.

That the stability we have observed is not a spurious result due to some unknown influence of the irregular components of the routine can be inferred from two sources. First, Group B underwent the same pattern of irregular 4 hour sleeps as Groups C-H but, in the absence of the anchor sleep, showed rhythms with a period in excess of 24 hours. Second, Group E, in whom the sequence of irregular sleeps was reversed in comparison with Groups C and D but who like them had an anchor sleep from 0000-0400, gave results indistinguishable from these two groups.

Even though mealtimes do have some effect upon certain human rhythms (Goetz, Bishop, Halberg, Sothern, Brunning, Senske, Greenberg, Minors, Stoney, Smith, Rosen, Cressley, Haus, & Apfelbaum, 1976), our observation that regular mealtimes alone are not sufficient to stabilize rhythms (Groups A & B) argues that mealtimes are not a strong zeitgeber in man. In this, humans would seem to differ from monkeys (Sulzman, Fuller, & Moore Ede, 1977) and rats (Krieger & Hauser, 1978), in both of which species mealtimes have been found to act as zeitgeber.

The present observations (Groups C-H) stress the importance of some aspect of sleep as a stabilizing influence. But since sleep is associated with so many changes--in electrophysiology, posture, light, social interaction, etc.--and these cannot be dissociated in our experiments, we are not able to offer evidence for or against specific roles of social interaction (Aschoff, Fatranska, Gerecke, & Giedke, 1974; Wever, 1975b) or light (Mills & Waterhouse, 1973; Lobban, 1967; Miles, Raynal, & Wilson, 1977) as zeitgeber. Certainly our finding that sleep is in some way important accords with the practice of referring acrophases to mid-sleep rather than to clock-time (Halberg et al., 1969; Mills & Waterhouse, 1973).

Even though the different times of anchor sleep in different groups all resulted in stabilized rhythms, there was a shift in acrophase, especially in Groups G and H as shown in Figures 8, 9, and 11. The process by which this shift took place would seem to be similar to changes sometimes seen following time-zone transitions. Thus, a recent report (Aschoff, 1978) has indicated that, when humans undergo a real or simulated time-zone transition in an eastward direction, some subjects adapt to the new time-zones not by progressive advances in their rhythms (even if this would require a shift of acrophase by a smaller number of hours) but instead by delays. Such delays are seen more regularly and clearly when the masking influence of the external environment has been minimized by placing subjects on a 'constant routine' (Mills, Minors, & Waterhouse, 1978b).

In the present study, the rhythms appeared to free-run transiently with a period in excess of 24 hours until they stabilized at their new time, again bearing a relationship between acrophase and mid-sleep that was very similar to that found during the control phase. In Groups C-F, no such free-running phase was observed either because the shift involved was too small or because the rhythm was within the limits of entrainment of an endogenous oscillator by external influences or because the free-running phase was finished in less than 4 days.

Finally, it must be considered whether the observed stability is a true entrainment of the endogenous rhythms or rather the result produced by masking effects of the regular component of the daily routine (Mills et al., 1978a; Mills et al., 1978b). Figure 12 enables a comparison to be made between the daily effect of the random sleeps and the overall trend when data from the whole experimental phase are considered. The period of the cosine curve best fitting all the data was 24.4 hours. However, the decrease in urate excretion associated with sleeps caused the acrophase on successive days to zig-zag between them.

Such an effect will be more obvious in the case of variables with larger exogenous components (for example; urate, Figure 12) than in the case of variables with larger endogenous components (for example; temperature, Figure 3). It is likely that the larger exogenous components in urate, flow, phosphate, calcium, and creatinine rhythms (Mills, Minors, & Waterhouse, 1977b) coupled

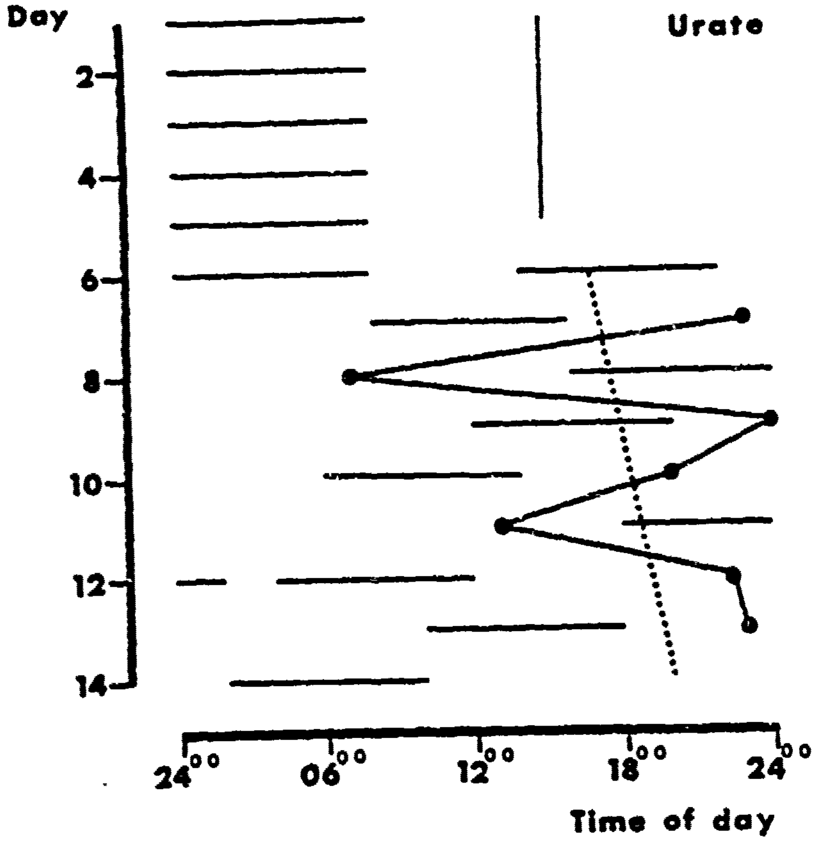

Figure 12. Urinary urate rhythm in a subject of Group A. Data plotted as in Figure 3. Dotted line indicated acrophase and period (24.4 h) of cosine curve best-fitting all data of experimental phase.

with the irregular sleep periods, accounts for the greater variation in these constituents. Further, the result that the stable acrophase bears a consistent relation with mid-sleep would fit with the view that only a direct effect of sleep is being measured. But against this view is the observation that the rhythms seem initially to free-run (Groups G & H). However, a clear distinction between these possibilities can be made only by investigating the rhythms in the absence of external rhythmic factors, that is by the use of a constant routine (Halberg, 1978); experiments to investigate this are being performed.

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EFFECTS OF TIME ZONE CHANGES ON SLEEP

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It is well known that, after rapid flight by a high speed jet-plane over a distance of more than 4 hour time difference, most of the passengers and jet crew suffer from so called "jet syndrome" or "jet lag". For example, if a passenger leaves Tokyo (TYO) at 1700 h, as shown in Figure 1, he arrives, after a 9 hour flight, at San Francisco (SFO) on the same date at 0900 h by the local time, that is, 0200 h by Japan time due to the time difference by 7 hours. In this case, he may stay awake and soon be busy with day-time activities, while he would still be asleep, if he were in Japan. If he goes to bed at 2300 h (at 1600 h by Japan time) in SFO on that day, his sleep, corresponds to a nap in the late afternoon continuing to evening sleep by his circadian rhythm, and consequently he may have a different type of sleep from his habitual nocturnal sleep. Seven O'clock in the morning in SFO corresponds to midnight in Japan, and the traveller is difficult to wake up, and even if he gets up, he may feel that his brain is muddled.

In this way, a rapid flight across many time zones produces desynchronization between the external or physical clock and the internal or biological clock. This desynchronization results in so called "jet syndrome", which was replaced in 1973 by "desynchronosis syndrome" (Beljan, Winget, & Rosenblatt, 1973). The desynchronosis syndrome includes:

(a) Fatigue and psychomotor performance degradation.
(b) Insomnia, and other sleep-wake disturbances.
(c) Gastrointestinal dysfunction in a wide variety of forms.
(d) Various psychosomatic manifestations in other organs.
(e) Other symptoms which have been variously reported included headache, ophthalmocopia, dyspea, diaphoresis, nightmare, anxiety, and menstral abnormality.

There are individual differences in susceptibility to the effects of rapid changing time zones, but all experience the above symptoms to some extent. For example, Lowell Thomas (Silverstein & Silverstein, 1974), a radio and television commentator and writer, made so many time zone transitions during a certain period of his life and worked under such a full schedule that he had no time to synchronize his biological rhythm with the local time of a new destination. In one period of about a year, he flew on a number of trips to various parts of the world crossing all twenty-four time zones at least twice. His schedule was so busy that he had very little time to rest between trips. After a while, he began to feel ill. Several times he had alarming blackouts, in which he actually lost consciousness for brief periods. Then one day, after a jet flight half way around the world, he had a frightening attack. His hands began to shake, and he found it difficult to speak and move. He was attacked by a sensation of depersonalization, feeling as if there were a thick sheet of glass separating him from the people around him. The above is an extreme case of desynchronosis syndrome.

The polygraphic study of effects of time zone transitions on sleep with civilian aircraft crews was initiated by the authors after a flight from Tokyo to San Francisco in 1967 (Endo, Sasaki, Negishi, & Suenaga, 1968). Years after, Evans, Christie, Lewis, Lewis, Daly,and Moore-Robinson (1972) reported a study on changes in sleep after flights between London and San Francisco with an 8 hour time difference. Here is an outline of the work by Evans et al. (1972).

They carried with them a portable EEG machine and flew together with the subjects to record all-night sleep EEG at the destination. On four carefully selected, healthy male subjects, all-night EEGs were recorded for seven nights in London as control nights. After trans-Atlantic flights, all-night sleep EEGs were recorded in San Francisco eight times during an eleven-day stay. After returning to London, home night recordings were again carried out on six consecutive nights.

On the first night after a London/San Francisco flight, Stage 4 sleep was enhanced, and REM sleep was decreased, although the distribution of both types of sleep during the night was not altered. Early morning awakening was a feature of the first five nights in the new time zone, particularily in the older subjects. Similar changes occurred after the return flight. There was no evidence of enhancement of REM sleep or the alteration in the distribution of REM sleep which has been noted in laboratory studies of sleep reversal. No definite evidence of circadian effects due to alteration in time zone were demonstrated.

Those who have experienced the syndrome complain that the most annoying factor is sleep disturbance, which takes place frequently, and which easily results in degradation of psychomotor performance and fatigue.

Studies on the effects of time zone changes on biological rhythms are indispensable not only for the solution of the problems in industrial hygiene, such as maintenance of health, prevention of accidents for aircraft occupants and shift workers, but also are important for the maintenance of health and the control of psychological and physical functions of diplomates and business executives who must perform important international tasks during a short stay, as well as sportsmen who participate in the Olympic games and scientists who attend international congresses. Therefore, the study on effects of time zone changes on biological rhythm will give a clue for the solution of still unsolved problems of desynchronosis syndrome caused by desynchronization between physical and biological clock from the chronobiological view point.

Procedures and Results

The First Experiment After Flight from West to East (TYO/SFO, 1967)
(Endo et al., 1968; Sasaki & Endo, 1977)

Subjects and procedure. The subjects were 6 male civilian aircraft crew members, aged 26-47 years. Three of them were chief pilots, two copilots, and one steward. The subjects left Tokyo at 2300 h on a non-stop flight and arrived at San Francisco at 1400 h by the local time. On that night, at a hotel in the city, all night polygraphic recordings were obtained from them by us, with an eight channel portable polygraph brought from Japan. EEG, EOG, EKG, resp. and noise were simultaneously recorded, and the results were analysed by the international classification system.

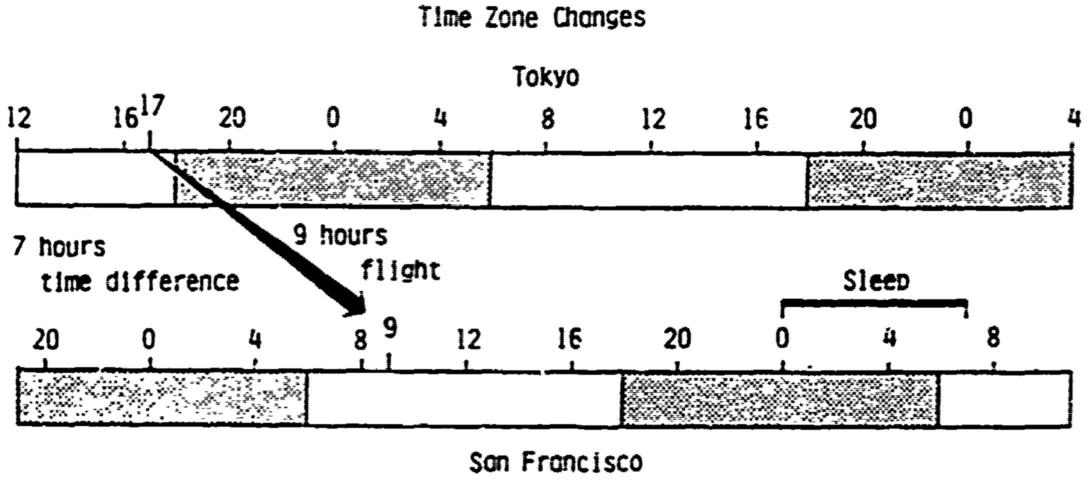

Figure 1. Changes of sleep-wake cycle due to time zone changes between TYO and SFO. If a passenger leaves TYO at 1700 h, he arrives, after a 9 hour flight, at SFO on the same day at 0900 h by local time, that is 0200 h by Japan time due to a time difference of 7 hours. In this case, he would still be asleep, if he were in Japan.

Results. Recordings were divided into three types according to the sleep time: 1) prolonged sleep time; 2) medium sleep time; and 3) shortened sleep time, which were observed in two of the subjects.

1) Cases of prolonged sleep lasted 11-12 hours until about noon of the next day. In this group, slow wave sleep (Stages 3 & 4) was enhanced, while REM sleep was depressed in the first half of sleep period, without any marked change in the percentage of Stage REM. There was a tendency toward increased awakenings in the first half of sleep. Pulse rate kept a high level during these sleep periods.

2) Cases of medium sleep lasted 8-9 hours with final awakening at 0700 h to 0900 h. They seemed to sleep according to the local time. The intrasleep cycles consisting of NREM and REM sleep were rather disturbed,NREM sleep being enhanced and REM sleep depressed in the first half of sleep period, with long latencies to REM sleep. A very impressive finding in one of these cases was a change in pulse rate. As shown in Figure 2, the pulse rate which was at a high level in the first half of the sleep period began to fall at about 0400 h by the local time. This means that the first half of the sleep period in San Francisco corresponds to the period from late afternoon to early evening in Tokyo. This is considered to be the result of the persistent home circadian rhythm of the pulse rate in Japan.

3) Cases of shortened sleep terminated after 2-3 hours of sleep, and thereafter remained awake. Their sleep seemed to correspond to an afternoon nap by Japan time. They tried to maintain stability by sleeping on their own "home time".

These changes in sleep and heart rate observed after time zone transition produced by a flight from West to East can be assumed to be the desynchronization between the home circadian rhythm and physical time in the new destination. This experiment, however, was insufficient and imperfect, since polygraphic recordings for baseline nights in Tokyo and after the return home were not performed.

The Second Experiment (Flight from West to East and from East to West, 1973) (Endo & Sasaki, 1975)

Subjects and procedure. The subjects were 4 healthy male physicians, aged 30 to 38. All-night sleep EEGs were recorded before the flight in TYO as control nights, twice in SFO, once in Honolulu (HNL) on the way home, and three to four times after returning home. The travel schedule is represented in Figure 3. The aircraft left TYO at 1700 h, arrived at SFO at 0900 h on the same date, due to the 9-hour flight and 7-hour time difference. The subjects went to bed in SFO at 2300 h, which corresponds to 1600 h in Japan. According to their circadian rhythms in "home time", this means that they began a nap, followed by evening sleep. Because there was one night's sleep deprivation due to the flight, one day was prolonged to 41 hours. To awaken at 0800 h in SFO corresponds to 0100 h in TYO.

When it is 2300 h in HNL (time to go to bed) during the return flight, it is 1800 h in TYO and 0100 h in SFO, since there is a 2-hour difference in time between SFO and HNL. When the subjects go to bed at 2300 h on returning to TYO, it is 0400 h in HNL and 0600 h in SFO.

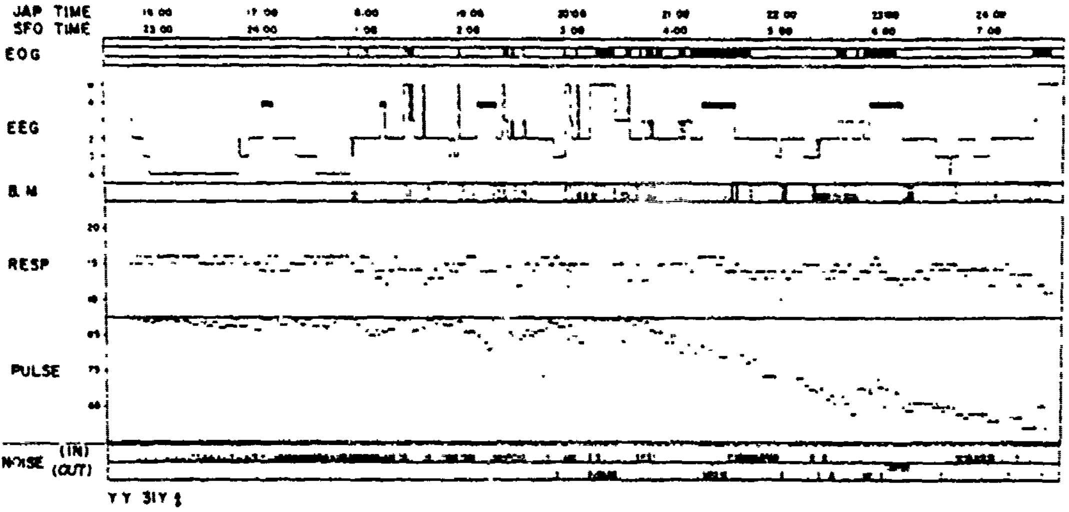

Figure 2. Polygraphic sleep diagram on the first night in SFO. A very impressive finging was the change in pulse rate. The pulse rate, which was at a high level in the first half of the sleep period, began to fall at about 0400h by local time. JAP. time: Japan time; SFO. time: San Francisco time; EOG: Electrooculogram; EEG: electroencephalographic sleep stage; RESP: Respiration. Black bar of EEG indicates REM sleep.

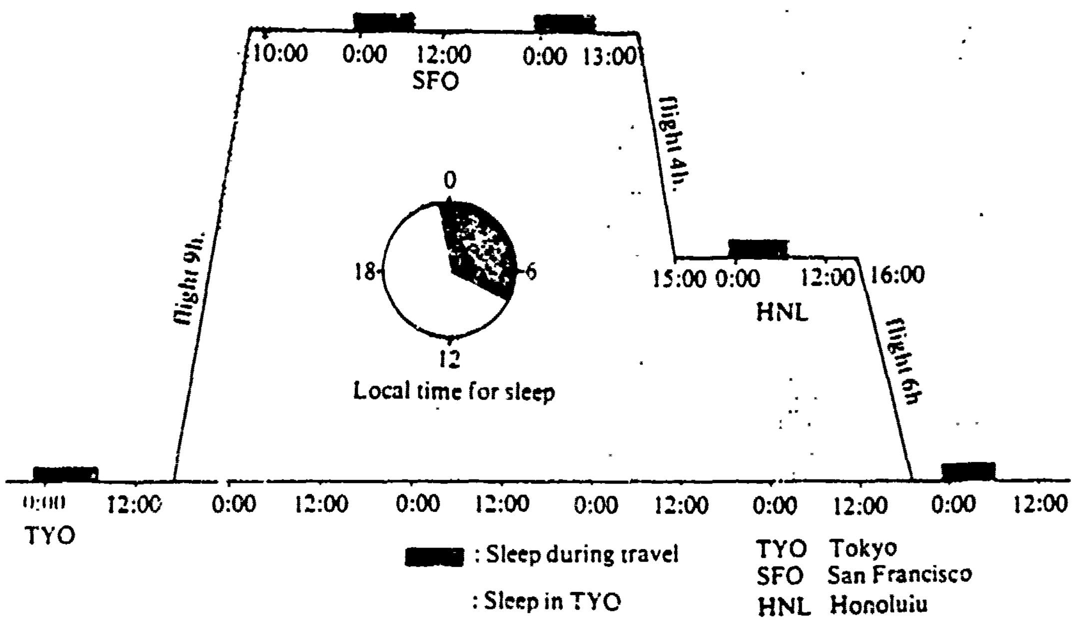

Figure 3. Flight schedule. The aircraft left TYO at 1700 h and arrived at SFO at 0900 h on the same date due to the 9-hour flight and 7-hour difference in time zone. 2300 h in SFO corresponds to 1600 h in TYO. 0800 h in SFO corresponds to 0100 h in TYO. Since there was one night's sleep deprivation due to TYO/SFO flight, one day was prolonged to 41 hours.

Results. Table 1 and Figure 4 represent sleep latency (S), REM sleep latency (R), percentage of REM sleep (%SREM) and percentage of slow wave sleep (%S3+S4). These are evidently altered by time zone transitions. Thus, sleep latency is rather short in SFO, and significantly reduced on returning home ($p < .01$). REM sleep latency becomes slightly shorter in SFO but not significantly. On returning home, however, it is reduced significantly ($p < .01$). It is also significantly shorter than in HNL and SFO ($p < .05$ and $p < .01$, respectively). Thus, REM sleep is shown to appear rapidly after falling asleep. The %S3+S4 was significantly increased in SFO ($p < .05$), while %SREM was significantly decreased in SFO ($p < .001$), and significantly enhanced on returning home ($p < .01$).

Table 1

Mean and Standard Deviation of Basic Data for Four Subjects Under Four Conditions

Conditions	TYO-C	SFO	HNL	TYO-H
Sleep latency (S)	8.00± 5.52	3.50± 4.95	3.25± 3.42	1.62± 1.39**
REM sleep latency (R)	111.44±52.13	105.13±39.78	104.25±38.62	*53.50±27.49** **
%S3+S4	17.61± 2.88	22.10± 3.23*	20.10± 2.26	19.73± 4.45
%SREM	23.72± 2.73	**16.48± 2.03***	21.49± 2.03	**28.66± 3.69** ***

TYO-C: Control nights in TYO
TYO-H: Home nights in TYO after return flight from SFO
* on the upper right side of the table denotes significant difference from TYO-C, on the left, that from SFO, and on the upper left, from HNL.
*** $p < .001$, ** $p < .01$, * $p < .05$.

Figure 5 represents the model of appearance of REM sleep in subject C.S. On the first night in SFO, there was not much change in periodic appearance of REM sleep as an intrasleep cycle, but its duration was shortened. This was especially marked in the first half of sleep. On the first night after returning home, a sleep onset REM period (SOREMP) was observed with marked increase of %SREM. The same tendency was likewise shown on the second night, and moreover REM sleep was increased in the first half of the sleep.

The %SREM and %S3+S4 are represented in Figure 6. Since all the subjects exhibited similar trends, the changes in case C.S. are described below. On the baseline nights before the start from Japan, he showed normal levels of %SREM and %S3+S4, which are considered to be 20-25% and 18-22%, respectively. In SFO, %SREM was decreased, while %S3+S4 was increased. On returning home, however, the former was conversely increased while the latter was decreased.

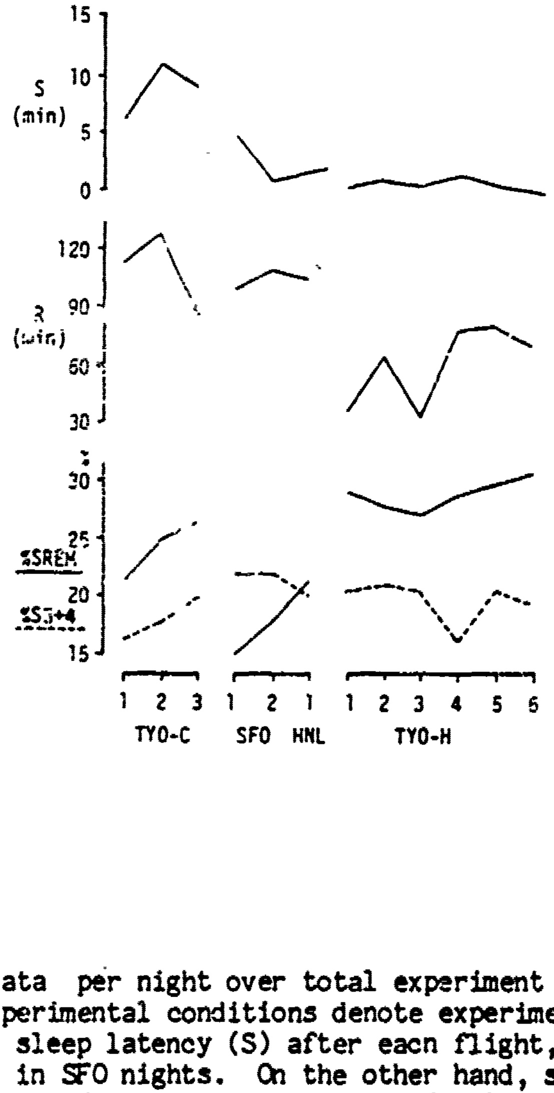

Figure 4. Mean data per night over total experiment for four subjects. Arabic numbers over experimental conditions denote experimental nights. Diagram shows shortened sleep latency (S) after each flight, decrease in %SREM and increase in %S3+4 in SFO nights. On the other hand, shortened REM sleep latency (R), increase of %SREM and decrease of %S3+4 are shown in TYO-Home nights. S: Sleep latency; R: REM sleep latency; %SREM: Percentage of stage REM in total time in bed; %S3+4: Percentage of Stage 3 and 4 in total time in bed.

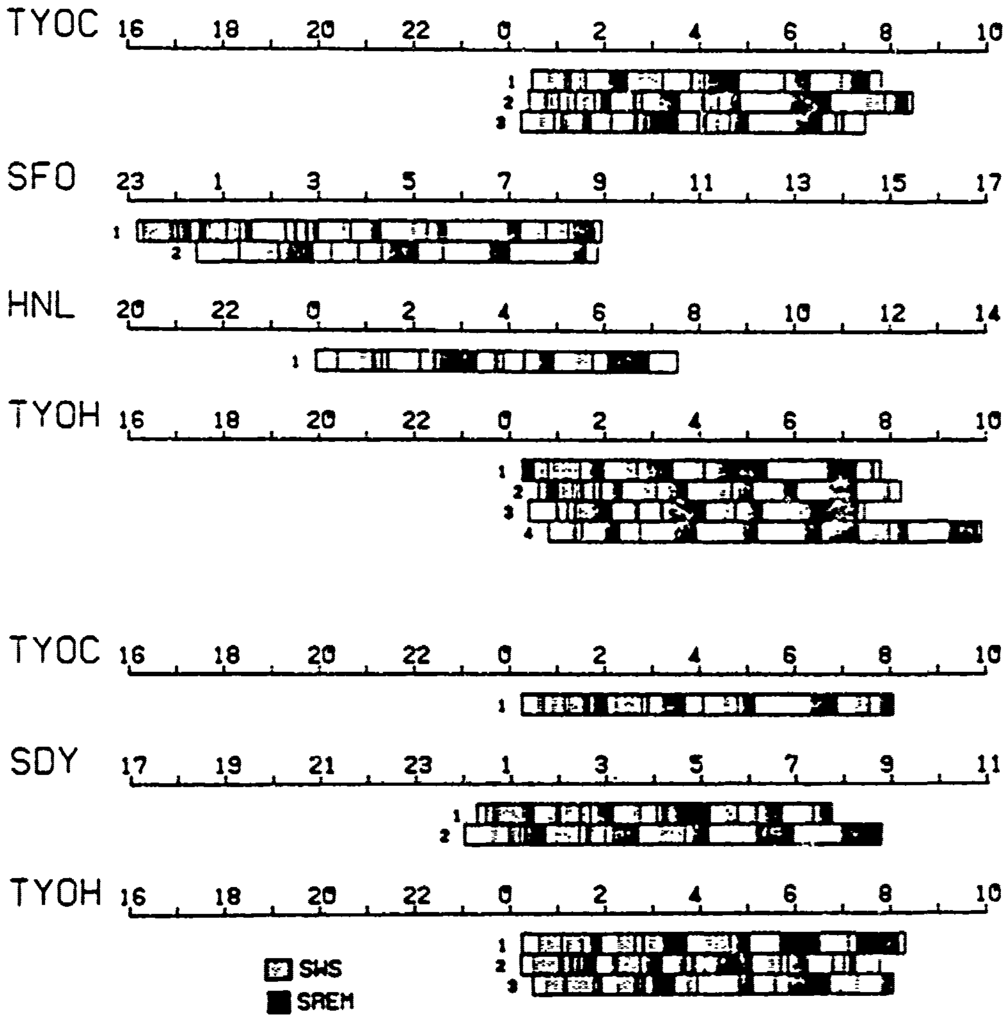

Figure 5. Distribution of REM sleep and slow wave sleep. On the first night in SFO, the durations of REM sleep periods were shortened especially in the first half of the sleep. On the first night after returning home, the sleep onset REM periods (SOREMPs) were observed with marked increase of %SREM. On the first night in SDY, scarcely any change was observed in the distributions of REM sleep periods, while SWS was increased.

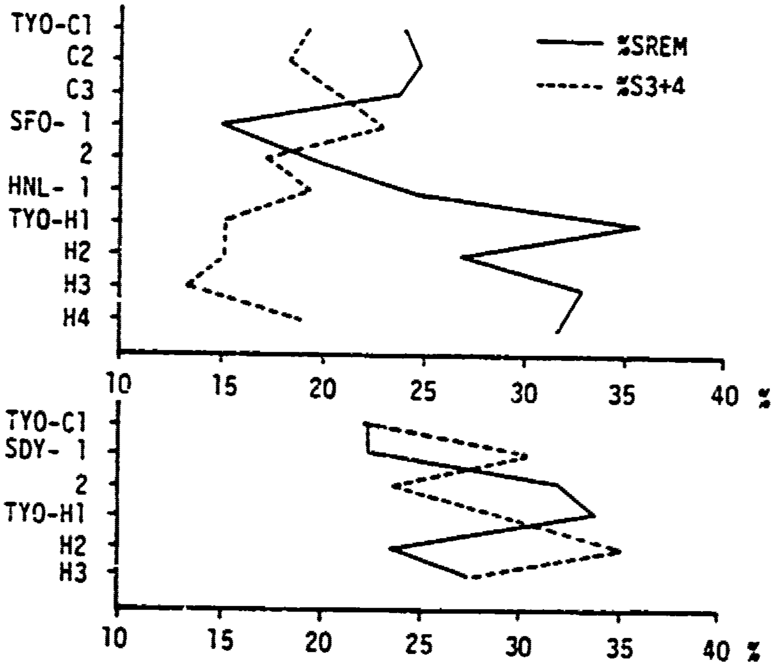

Figure 6. Percentage of Stage REM and Stage 3+4. REM sleep is markedly decreased and SWS (S3+4) increased in SFO, and vice versa on returning home. Southward and northward flight do not exhibit such phenomenon.

REM sleep, which has a circadian rhythm as later described, was investigated to determine whether the change was elicited in the first or last part of sleep. The proportion of REM and NREM sleep, especially S3+S4, are represented in Figure 7 for case C.S. In the first 120 min of sleep, NREM sleep, especially slow wave sleep, was increased and REM sleep decreased and the later was markedly increased in TYO-H. In the last 120 min., REM sleep was decreased and NREM sleep was increased in SFO; whereas, after returning home, REM sleep became less than in baseline nights in TYO and more than in SFO.

As for the change in the autonomic functions, an investigation was made on pulse rate as an example. As seen in Figure 8, the mean pulse rate was elevated on the first night in SFO, and the distribution curve of pulse became double peaked on the second night, indicating the coexistence of both Japan's and SFO's rhythm in one record. In HNL on the return trip, the pulse distribution curve exhibited three peaks. On home nights the pulse rate was elevated, but it failed to reach the level of the pulse rate during baseline nights even on the third home night.

The results mentioned above conspicuously demonstrate how sleep after time zone transitions is, in many respects, altered in comparison to usual nocturnal sleep. It is, however, necessary to eliminate effects of flight itself and sleep deprivation to confirm the effects of time displacement alone on sleep. So it is necessary for us to attempt a flight, which takes as long as that to SFO, with similar sleep deprivation, and without any time zone differences. Accordingly, the following experiment was undertaken.

The Third Experiment (Southward and Northward Flight 1974)
(Endo & Sasaki, 1975)

Subjects and procedure. On one of the subjects mentioned above, after baseline nights in Tokyo, all-night sleep EEGs were recorded in two consecutive nights in Sydney (SDY) and in three consecutive nights after returning to TYO. The aircraft started from TYO at 1800 h and via Manila arrived at SDY at 0800 h on the next day. Thus one day was prolonged to 49 hours for this subject because of the sleep deprivation of one night and a one hour time displacement. On the return flight, on day was prolonged to 47 hours.

Results. On the first night in SDY, scarcely any change was observed in the distributions of REM sleep periods (as on the lower part of Figure 5). On the second night, REM sleep was increased especially in the last half of sleep. On the first night after returning home, REM sleep was increased in the last half of sleep, but a sleep onset REM period as seen in the westward flight was not observed.

%SREM and %S3+S4 are presented in the lower part of Figure 6. On the first night in SDY, %SREM was scarcely changed, while %S3+S4 was increased. These were evidently different from the result on the first night in SFO. On the second night in SDY, %SREM was increased, while %S3+S4 was decreased from that on the first night.

The proportions of REM and NREM sleep in the first and the last part of sleep were presented in Figure 9. %SREM was not altered at all, while %S3+S4 was increased in the first half of sleep in SDY, and both %SREM and %S3+S4 re-

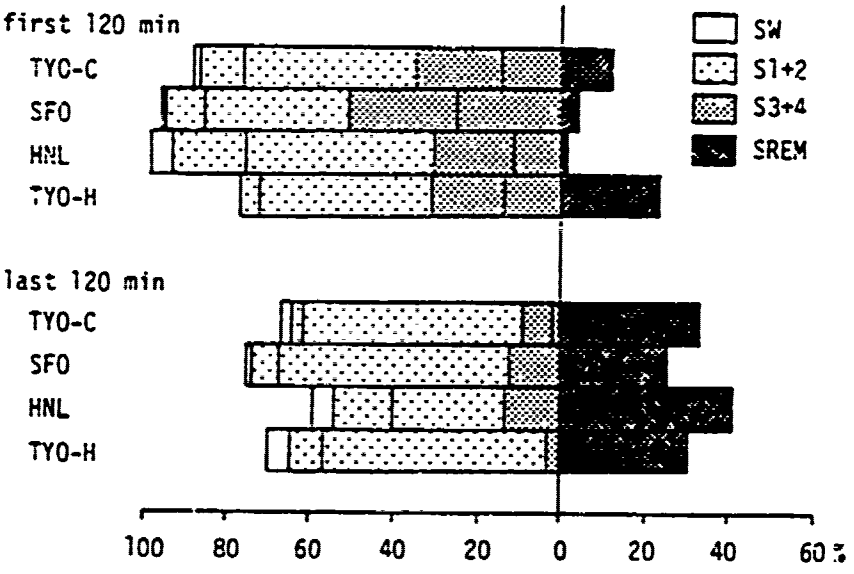

Figure 7. Percentage of sleep in each stage during the first and last 120 min. In the first 120 minutes of sleep SWS (S3+4) was increased and REM sleep decreased in SFO, whereas SWS was slightly decreased and REM sleep markedly increased in TYO-H. In the last part of sleep, REM sleep was decreased and SWS was slightly increased in SFO, whereas in TYO-H REM sleep became less than in TYO-C and more than in SFO.

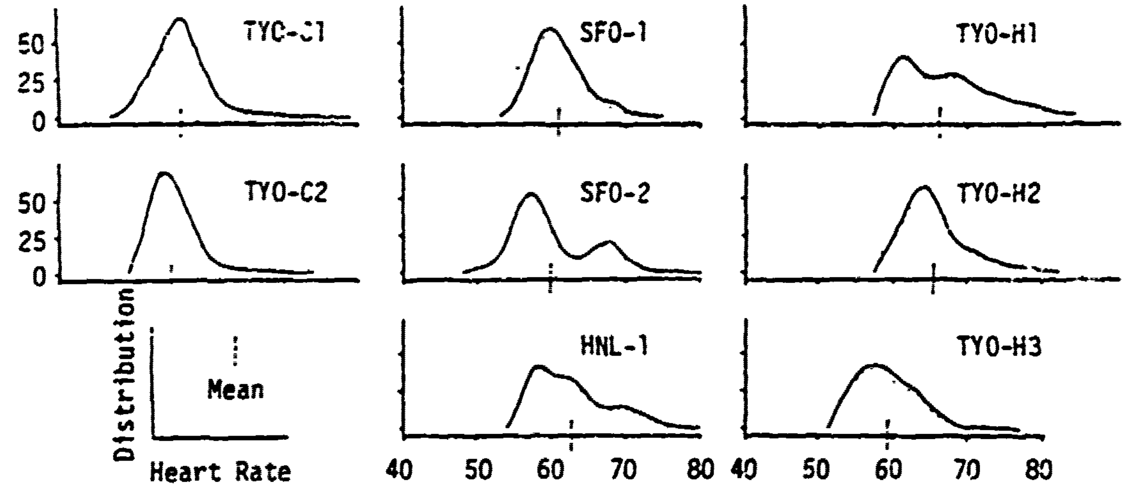

Figure 8. Distribution curve of heart rate during whole night of sleep. Heart rate rises on the first night in SFO, exhibits two peaks on the second night, and three peaks in HNL on the return trip. On the first night after returning home, it again rises exhibiting two peaks.

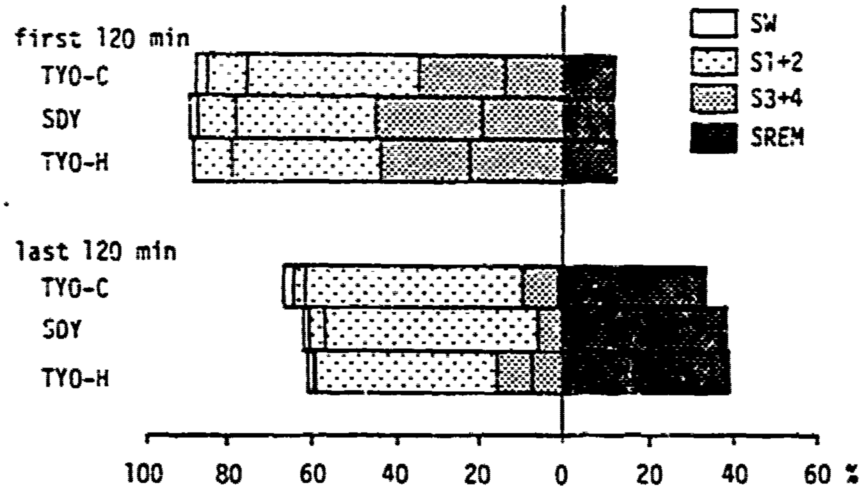

Figure 9. Percentage of sleep in each stage during the first and last 120 min of sleep after flights to and from SDY. In the first part of sleep %SRRM was not altered at all, while %SWS was increased in SDY and both %SREM and %SWS remained unaltered in TYO-H. In the last part of sleep %SWS was decreased while %SREM was increased in SDY.

mained unaltered after returning home. In the last part of sleep in SDY, however, %S3+S4 was decreased while %SREM was increased.

These changes mentioned above were evidently different from those after the flights from East to West and vice versa, which were accompanied by many time zone changes. The changes in sleep after southward and northward flights were similar to those after total sleep deprivation which are described later. One should refrain from drawing any definite conclusion from the above experiment performed on a single subject, and it is necessary to repeat this experiment to corroborate the above results.

It is, however, considered likely from the third experiment that changes in sleep in the first and second experiment may be caused by time zone changes. Therefore, the authors carried out the fourth experiment in order to investigate the length of time and physiological changes necessary for recovery from desynchronization of sleep with the local time.

The Fourth Experiment (Eastward and Westward Flights and Synchronization 1975) (Endo, Sasaki, Nishihara, Sekiguchi, Murasaki, Bono, & Suenaga, 1975)

Subjects and procedure. The subject was the same physician as in the third experiment. All-night sleep EEGs were recorded twice as baseline nights in TYO, 7 times during a 10-day stay in SFO and 5 times during an 8-day period following the return home.

Results. The appearance pattern of REM sleep in SFO coincided with that on baseline nights in TYO on about the 8th day. After returning home, the coincidence was also realized in the 8th day (Figure 10). It was evident from this figure that the REM sleep in SFO synchronized with the local time in about 8 days after the arrival, and that, on returning home, the sleep onset REM periods were again observed in spite of accomplishment of synchronization of sleep.

Figure 11 represents %SREM and %S3+S4 on baseline nights in TYO, on nights in SFO and on home nights in TYO. In SFO, lowered %SREM was gradually elevated with lapse of day until it returned to the level of %SREM on baseline nights in TYO in 7 to 8 days. On the other hand, increased %S3+S4 was gradually reduced to restore the baseline level again 7 to 8 days.

After the accomplishment of synchronization of sleep to the local time in SFO, enhancement of REM sleep did not take place on home nights. However, REM sleep latencies were much shortened, and it appeared without passing through Stages 3 and 4. It took 8 days for REM sleep to restore the usual pattern of its appearance.

In order to study the rhythmicity of REM sleep periods, a binary autocorrelation test by Globus was performed (Figure 12). Minimum agreement levels in baseline nights were at a lag time 45-50 minutes followed by peak agreement levels at 90 to 100 minutes. In SFO, the curve was flattened and minimum agreement occurred earlier with a peak agreement at around 50 minutes in 1 to 5 days, and the disturbances with a decreased peak agreement level was remaining as late as 7 to 10 days in spite of the peak agreement at 90-100 minutes. Tokyo home nights (home nights 5 to 8) showed a return to rhythmicity compati-

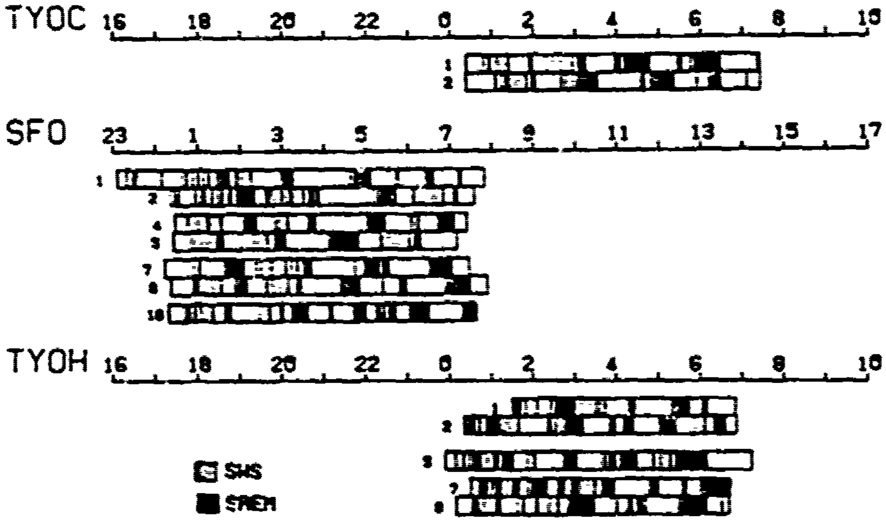

Figure 10. Appearance patterns of REM sleep and SWS before, during, and after 10-day stay in SFO. Synchronization of appearance patterns of REM sleep and SWS in SFO and TYOH with those in TYOC becomes clear in about 8 days both after arriving at SFO adn after returning home.

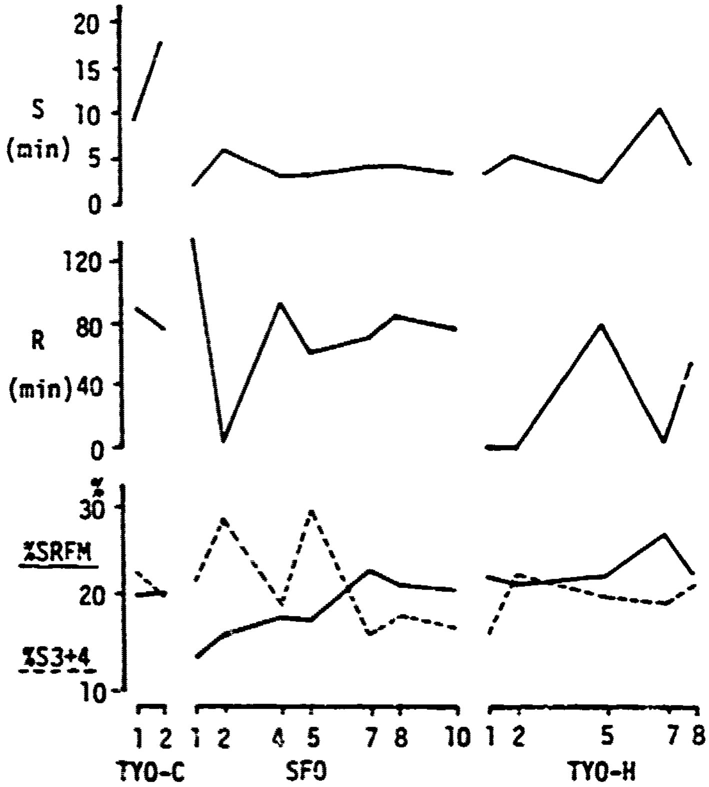

Figure 11. Sleep latency (S), REM sleep latency (R), %SREM, and %S3+4 before, during, and after 10-day stay in SFO.

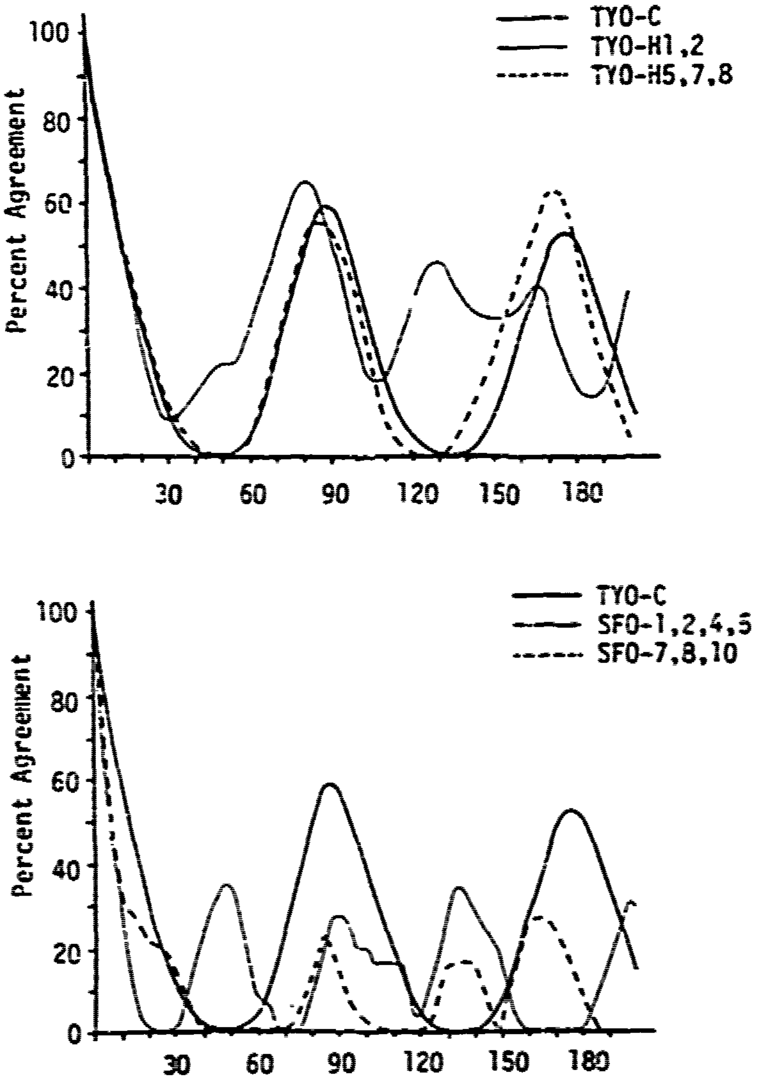

Figure 12. Results of binary autocorrelation test. Minimum agreement level in baseline nights was at a lag time 45-50 minutes followed by peak agreement level at 90 to 100 minutes. In SFO the curve was flattened and minimum agreement occurred earlier with a peak agreement at around 50 minutes in 1 to 5 days and disturbance was remaining as late as 7 to 10 days. TYO-home nights 5 to 8 showed a return to rhythmicity compatible with baseline nights in TYO.

ble with baseline nights in TYO. Though desynchronization in sleep is generally greater in the case of a flight from West to East, synchronization in sleep seems to occur approximately in 8 days as a whole.

Pulse rate, taken as an index of the autonomic functions, failed to recover synchronization over the 10 days after arrival in SFO as seen in Figure 13. Its restoration is aquired on the 5th day after returning home. Thus, there are differences in time needed for synchronization of physiological functions between eastward and westward flights.

The Fifth Experiment (Flight From East to West 1976)

Subjects and procedures. The same physician as in the fourth experiment served as the subject. After baseline nights in TYO, all-night sleep EEGs were recorded on four consecutive nights in London (LDN).

The aircraft left TYO at 2130 h and via Anchorage arrived at LDN at 0605 h on next day due to a 17-hour flight and the 8-hour difference in time zone. The subject went to bed in LDN at 2300 h, which corresponded to 0700 h in TYO. According to his circadian rhythm in "home time", this means that he began to take a morning nap followed by an afternoon nap. To wake up at 0700 h in LDN corresponds to 1500 h. As there was one night's sleep deprivation due to the flight and 8 hour difference in time zone, his one day was prolonged to 54 hours.

Results. The appearance pattern of REM sleep is represented in Figure 14. On the first night in LDN, increased numbers of REM sleep periods were noted. On the first and second nights in LDN, early appearances of REM sleep periods were observed with marked increase of REM sleep which was predominantly in the first part of the sleep period.

Sleep latencies and REM sleep latencies were reduced on the nights in LDN and gradually increased to those of baseline nights. %SREM was increased, while %S3+S4 was reduced on the nights in LDN (Figure 15). The findings mentioned above are similar to those on the home nights after returning from SFO.

The proportions of REM sleep and slow wave sleep (S3+S4) within 120 minutes of sleep onset (the first part) and within 120 minutes before waking up on the next morning are represented in Figure 16. In the first part, REM sleep was increased and gradually decreased, but by the fourth night in LDN did not return to the REM sleep levels on the baseline night. Slow wave sleep was markedly increased on the first night in LDN but was decreased from the second to fourth nights in LDN. In the last 120 minutes of sleep, REM sleep was also increased and slow wave sleep was decreased and on the fourth night in LDN these tendencies continued.

As for the change in autonomic function, examination of pulse rate data was taken as an example. As seen in Figure 17, the mean pulse rate was elevated by the third night in LDN and its restoration was aquired on the fourth night in LDN.

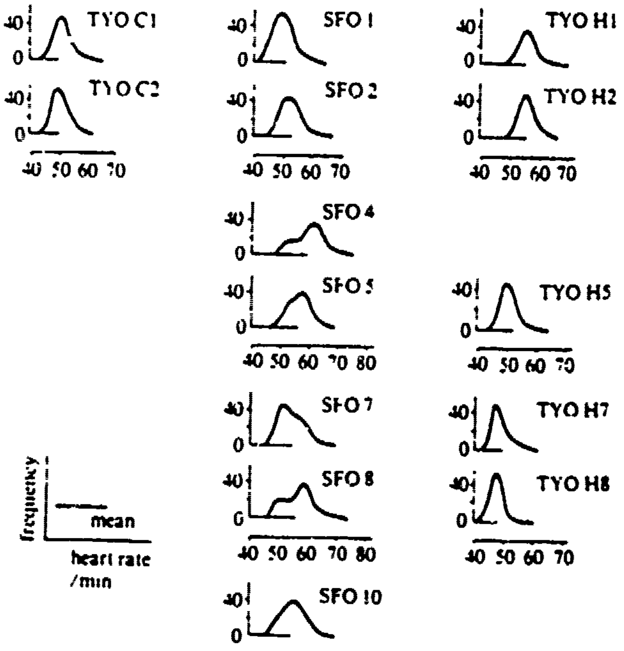

Figure 13. Frequency distribution of heart rate in nocturnal sleep before, during, and after 10-day stay in SFO. Heart rate failed to restore synchronization with that in baseline nights even on the 10th day after arrival at SFO and its restoration is acquired on the 5th day after returning home.

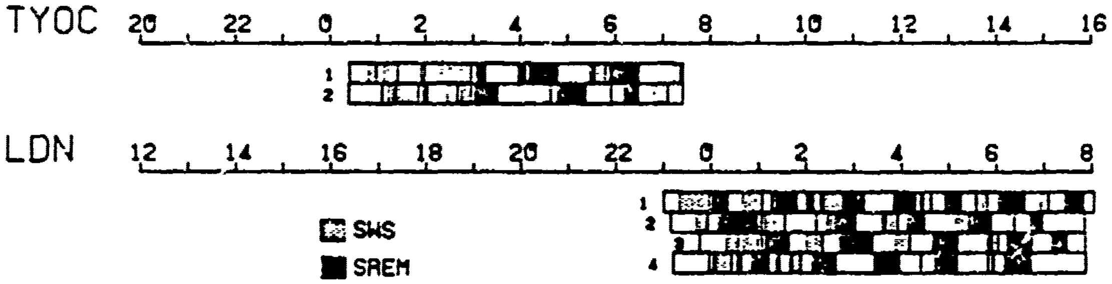

Figure 14. The appearance patterns of REM sleep and SWS in the nights in TYOC and LDN. The Figure shows increased numbers of REM sleep periods on the first night in LDN and early appearances of REM sleep periods on the first and second nights in LDN.

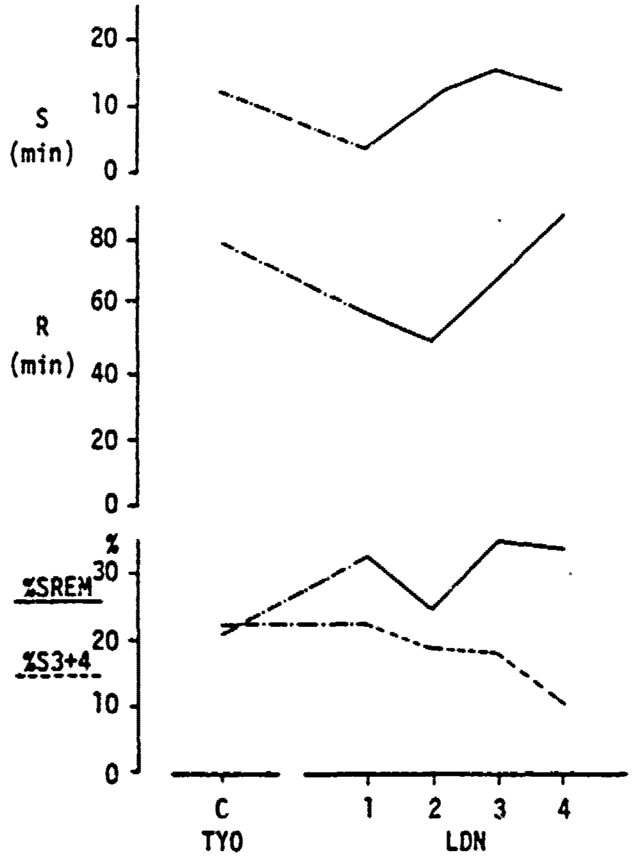

Figure 15. Sleep latency (S), REM sleep latency (R), %SREM and %S3+4 at nights in LDN. The Figure shows shortened sleep latency, shortened REM sleep latency, and increase in REM sleep after TYO/LDN flight.

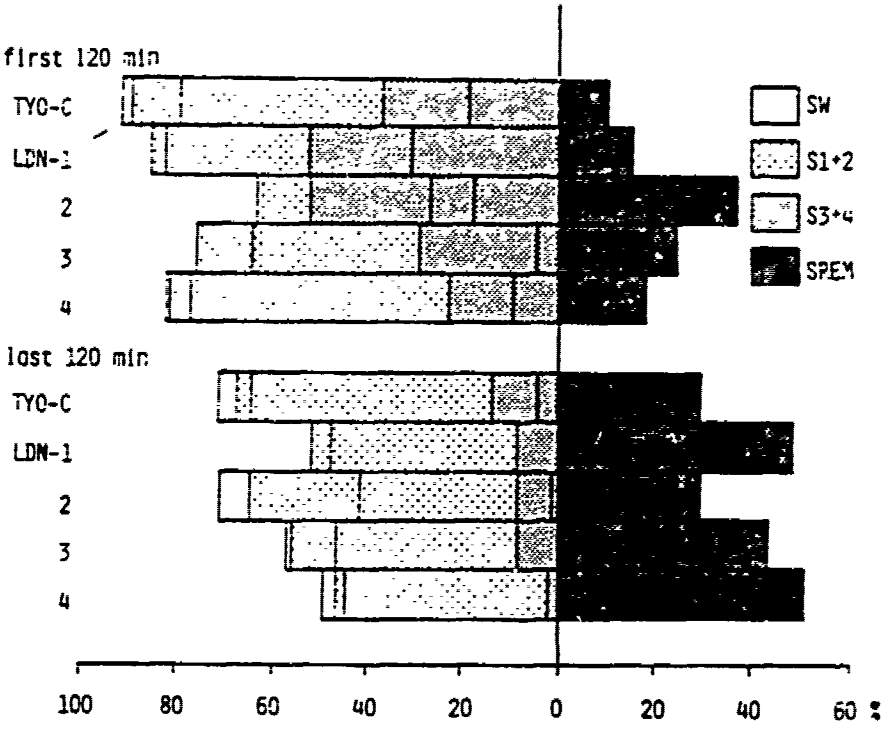

Figure 16. The proportions of REM sleep and slow wave sleep within the first and last 120 minutes of sleep. In the first part REM sleep and SWS were increased and gradually decreased at nights in LDN. In the last part REM sleep was increased and SWS was decreased at nights in LDN.

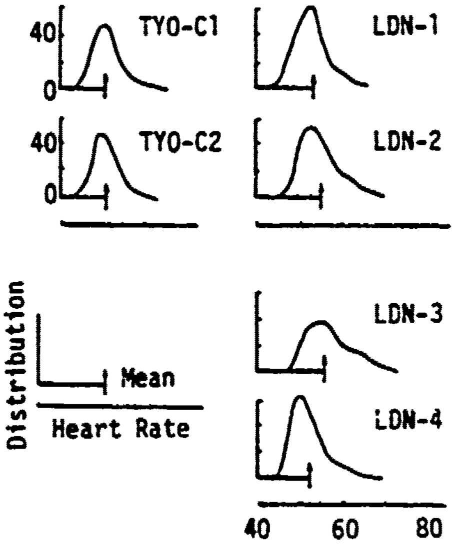

Figure 17. Frequency distribution of heart rate in nocturnal sleep on nights in LDN. The mean heart rate was elevated by the third night in LDN and its restoration was on the fourth night in LDN.

Discussion

The described changes in sleep after time zone changes are thought to be the result of a complicated summation of sleep deprivation, sleep reversal, naps, shifts in sleep onset time and changes in circadian rhythm. As mentioned before, Evans reported that no definite evidence of circadian effects due to alteration in time zone were demonstrated. According to the author's findings however, sleep as a circadian rhythm can not be free from the effect of time zone changes.

Changes in Sleep After Eastward Flight (Flight from TYO to SFO)

In SFO, as compared with baseline nights in TYO, both the amount and proportion of Stage REM (TSREM and %SREM) were decreased. NREM sleep, especially slow wave sleep, was increased in both amount and proportion. It is not considered unreasonable to assume that these changes in sleep may have resulted from the maintenance of the home circadian rhythm to a new destination. To go to bed at 2300 h in SFO, which corresponds to 1600 h in TYO, means that a traveller from TYO starts his sleep from evening nap in TYO if he was in TYO. In evening naps, NREM sleep is increased and REM sleep is decreased (Maron, Rechtschaffen, & Wolpert, 1964; Webb, Agnew, & Sternthal, 1966; Webb & Agnew, 1967; Webb, 1966). Endo, Nishihara, Aizawa, and Oda (1976) and Endo, Koga, and Fukuda (1978), who made detailed studies of naps, confirmed that in evening naps, REM sleep was decreased and slow wave sleep was increased as seen in Figure 18. In the flight from West ot East, however, the subjects experienced one night total sleep deprivation. Consequently, it is necessary to do research on naps after total sleep deprivation.

Changes of REM and NREM sleep after total sleep deprivation are represented in the lower part of Figure 18. REM sleep is clearly increased in the morning and decreased in the evening in spite of one night of total sleep deprivation. These findings indicate that the distribution of REM sleep is not affected by total sleep deprivation, but has a clear circadian rhythm, that is, clock dependency. By contrast, slow wave sleep is increased in the morning, afternoon, and evening naps after total sleep deprivation. Thus, slow wave sleep is more independent of circadian effects and responsive to the length of prior wakefulness.

From the findings mentioned above, it is assumed that the decrease of REM sleep and the increase of slow wave sleep in the first part of the sleep in SFO may be caused by effects of one night total sleep deprivation and circadian rhythm of REM Sleep. Seven o'clock in the morning in SFO, when the subjects wake up, corresponds 0000 h in TYO, when REM sleep is usually decreased and SWS increased (Taub & Berger, 1973). This may be the reason that in the last half of sleep on the first night in SFO, REM sleep was decreased.

The effects of one night total sleep deprivation during the flight from TYO to SFO must be taken into consideration. In the first recovery night after sleep deprivation, NREM sleep is markedly increased, while REM sleep remains unchanged (Berger & Oswald, 1962; Williams, Hammack, Daly, Dement, & Lubin, 1964). Therefore, a decrease in REM sleep on the first night in SFO can not be explained only by the effect of sleep deprivation. Globus (1966) and Globus, Gardner, and Williams (1969) stated that the occurrance of REM sleep is

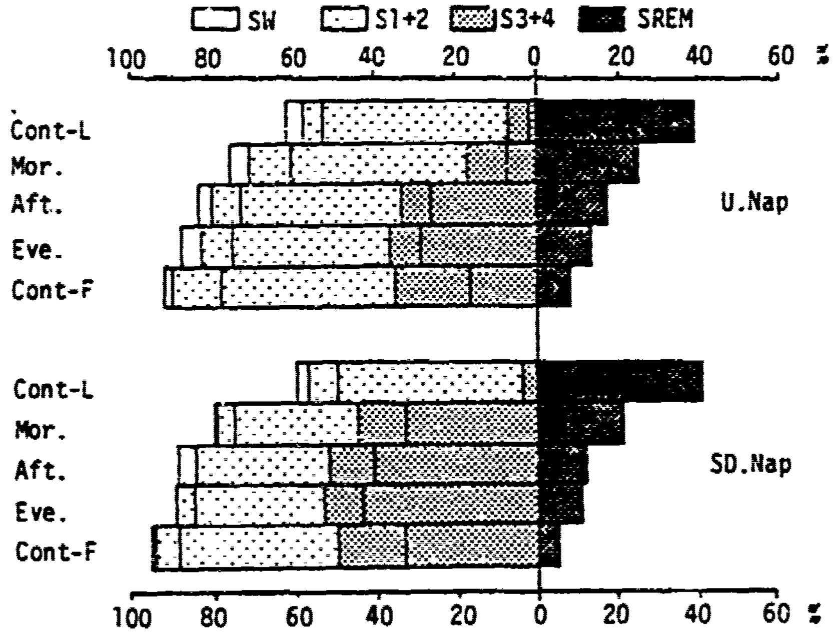

Figure 18. Percentage of sleep in each stage during 120 min after sleep onset in usual nap (U.Nap) and after one night total sleep deprivation (SD. Nap). Mor: morning nap; Aft: afternoon nap; Eve: evening nap; Cont-L: 120 min of sleep before awaking from nocturnal sleep; Cont-F: 120 min of sleep after falling asleep in nocturnal sleep.

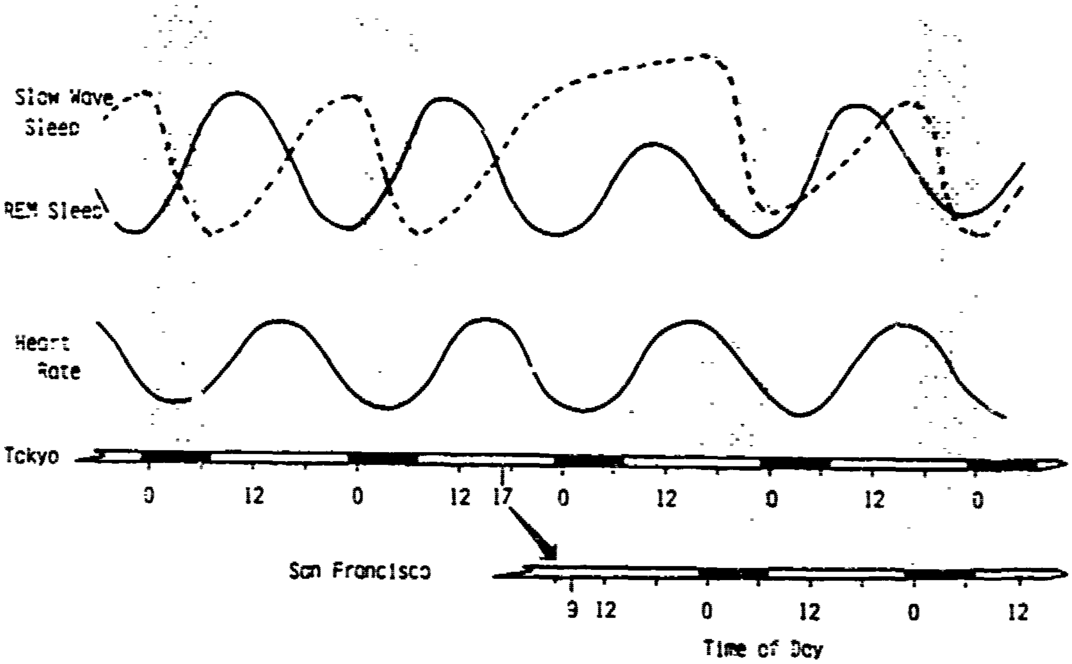

Figure 19. Schematic relationship between a shift of sleeping time and changes of biological rhythms after eastward flight.

a function of real time, occurring at the same time from day to day. Endo et al. (1976,1978) elucidated the circadian rhythm of REM sleep, that is, clock dependency of REM sleep. The changes of REM sleep in SFO mentioned above, are considered to be the result of having brought the circadian rhythm of REM sleep in TYO to SFO.

A schematic relationship between a shift of sleeping time due to time zone changes and changes of biological rhythms is represented in Figure 19. From the results of temporal distributions of REM sleep and changes of slow wave sleep based on the research of naps after usual nocturnal sleep and after one night total sleep deprivation, we can represent circadian rhythm of REM sleep and increase of slow wave sleep as the results of summation of prior wakefulness in the upper part ot this Figure. As the sleep in SFO corresponds to that in the late afternoon to the evening in TYO, the decrease of REM sleep in SFO is considered to be the result of having brought the home circadian rhythm of REM sleep into SFO. The increase of slow wave sleep appears to be the result of prior wakefulness due to one night sleep deprivation. The circadian rhythm of heart rate is represented in the middle of Figure 19. The increase of heart rate during nocturnal sleep in SFO may be caused by the persistence of the home circadian rhythm of the heart rate.

As the sleep onset time is almost the same in SDY as in TYO after a southward flight to SDY, only the effects of one night sleep deprivation were found on the first night in SDY. Thus, the first night sleep after arrival at SFO was evidently different from that in SDY.

Changes in Sleep After Westward Flight (Flights from SFO to TYO and from TYO to LDN)

The sleep after returning home was different from that in baseline nights in TYO, with decreased REM sleep latency, appearance of SOREMPs and increased REM sleep in the first part of sleep. The sleep after the flight from TYO to LDN was also different from that on baseline nights in TYO, with decreased REM sleep latency and increased REM sleep especially in the first part of the sleep.

Since the sleep after returning home and in LDN corresponds to that in the early morning to forenoon in the place before the flight, it is necessary to investigate the effect of sleep reversal and naps in daytime.

Weitzman, Kripke, Goldmacher, McGregor, and Nogeire (1970) and Jovanović (1971) reported that in sleep reversal, REM sleep was increased in the first half of sleep and REM sleep latency was reduced. Nakagawa and Nakagawa (1970) reported that in daytime naps REM sleep occurred without passing through Stage 3 or Stage 4. Endo et al. (1978) elucidated that in both usual naps and naps after one night total sleep deprivation, morning naps had shortened REM sleep latency, increased REM sleep and frequent SOREMPs.

From the findings mentioned above, it is suggested that the nocturnal sleep after returning home and in LDN may reflect the circadian rhythm of sleep in the place before the start of the flight. It is, however, impossible to give sufficient explanation as to why the increase of REM sleep in the fourth experiment was only vestigial, whereas that in the second experiment was marked. Elucidation of this point must wait future study.

Synchronization of sleep as a circadian rhythm to new time zone is attained nearly in 8 days either after eastward or westward flight. This seems to suggest that sleep, which to a certain degree is voluntarily changeable, may not be influenced by advanced shift or by delayed shift. By contrast, the circadian rhythm of autonomic functions such as pulse rate, which is involuntary, takes 10 days for synchronization after eastward flight, and only 5 days after westward flight. The findings mentioned above indicate that there may be varying synchronization in different physiological rhythms.

In the southward and northward flights, the changes in sleep mentioned above were unobservable except the effect of total sleep deprivation. It can therefore be assumed that the changes in sleep elicited by the transmeridian flights may chiefly be attributed to time zone changes.

Summary

Studies on alterations in circadian rhythms due to time zone changes were discussed with emphasis placed on sleep. On the basis of five experiments; 1) changes in sleep after TYO/SFO flight (Eastward flight), 2) changes in sleep after TYO/SFO and SFO/TYO flights (Eastward and Westward flights), 3) control study on changes in sleep after TYO/SDY and SDY/TYO flights (Southward and Northward flights), 4) synchronization of sleep with the local time after eastward and westward flights, and 5) changes in sleep after TYO/LDN (Westward Flight). Changes in sleep after time zone changes were summarized as follows:

1. Changes in sleep after eastward flight (from TYO to SFO). After TYO/SFO flight, the amount of SWS was significantly elevated and REM sleep was markedly depressed especially during the first and last parts of nocturnal sleep, although the distributuin of both types of sleep was not altered. The sleep latency was short and REM sleep latency did not change. The mean pulse rate was elevated. It took 8 days for the sleep rhythm to synchronize with the local time in SFO, and more than 10 days for pulse rate. Thus, there was a difference in synchronization between different physiological phenomena.

2. Changes in sleep after westward flight (from SFO to TYO and from TYO to LDN). After SFO/TYO flight, there was enhancement of REM sleep especially in the first part of the nocturnal sleep, but SWS did not change. Sleep latency and REM sleep latency were significantly abbreviated. Also there was clear evidence of alteration in the distribution of REM sleep with SOREMP on the nights after SFO/TYO flight. After TYO/LDN flight as the westward flight, sleep latency and REM sleep latency were also abbreviated and REM sleep was increased. It took 8 days for the sleep rhythm after SFO/TYO flight to synchronize with Japan time, and about 5 days for pulse rate. Thus, there was a difference in the number of days prior to synchronization for different physiological functions, and more days were needed for synchronization after the eastward than after the westward flight.

3. Changes in sleep after southward and northward flights. After the TYO/SDY flight without a time zone change, there was no change of REM sleep but marked enhancement of SWS on the first night in SDY. On the first night after the return flight SDY/TYO, there was enhancement of SWS

but no change of REM sleep. This supports the assumption that desynchronization syndrome including sleep disturbance may be attributable to time zone changes.

The utilization of time zone changes for the study of desynchronization of circadian rhythms and of the chronobiology of desynchronization is not only possible, but also contributes to the pathophysiological elucidation of sleep disturbance and to the study of shift workers.

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THE MILITARY PERFORMANCE OF SOLDIERS IN CONTINUOUS OPERATIONS: EXERCISES "EARLY CALL" I AND II

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There are frequently times in defensive encounters when there is little or no opportunity for sleep. Hence, the effects of sleep loss are the object of continuing study in military psychology.

Although many experiments have been carried out to determine the effects of sleep loss, most of these have been in a laboratory setting, and the few that have been carried out in the field have been mainly of relatively short duration (up to 5 days) and have not all aimed at being militarily realistic. There was a need, therefore, to carry out a field trial of longer duration, with as much realism as possible, and with sufficient numbers to preserve this realism.

Exercise Early Call I (Haslam, Allnutt, Worsley, Dunn, Abraham, Few, Labuc, & Lawrence, 1977) was designed to meet these aims, and it was decided that Infantrymen should adopt a defensive role against a small number of 'enemy' troops, and that the tactical situation should be maintained for 9 days.

Methods

Subjects. Three Platoons, consisting of 68 members of the Parachute Regiment were the trial subjects. Their age range was 17 to 38 years, with a mean of 21 years.

For purposes of testing, the three Platoons were each divided into 2 groups, called Alpha and Beta groups, both of which consisted of Platoon Commanders, Section Commanders, and rank and file. The Platoons were so divided because it was possible to process only 36 men a day, 12 from each Platoon, on the various military, psychological and physiological tests; these were the Alpha groups. The Beta groups remained in the defensive positions for the entire trial. Subjective assessments were carried out on both Alpha and Beta groups.

Trial design. The trial was divided into 5 exercises, during each of which a defensive position was prepared and occupied. Exercises 1 (2 days) and 5 (3 days) were the control periods with 6 hours sleep per night in the field, and Exercises 2, 3, and 4 (3 days each) were the experimental or sleep-deprivation periods. After the first control period, each Platoon was randomly assigned a sleep schedule, namely 3 hours continuous sleep, 1.5 hours continuous sleep, and 0 hours sleep in 24 hours. In addition to comparing the performance of the 3 groups, it was intended to find out for how many days the 0-hours sleep group could remain in the field. Three days of training and briefing on various aspects of the trial preceded Exercise 1. The 9-day sleep-deprivation period consisted of a 3-day sequence of events which was repeated 3 times in different locations (Exercises 2, 3, and 4); thus, a defensive position was prepared and occupied for 3 days before moving to a new one. Activities undertaken in each position, apart from digging and camouflaging, included wiring, mining, patrolling, ambushing, sentry duty, and radio operating. Exercise 2 was preceded by one day of rest and preparation, and Exercise 4 was followed by 3 days of rest and recovery.

Medical and psychiatric monitoring. Considerable effort went into the provision of a strong medical team, but no untoward reactions occurred. Before the exercise began, subjects and observers were briefed on signs of exposure and of fatigue. All trial troops had the right to withdraw themselves from the exercise at any time, and they were, of course, withdrawn if they were thought by those in charge to be unfit to continue. All observers were briefed by a psychiatrist before the exercise began on the possible psychological effects of continuous operations, and were instructed to report to him any incident which gave cause for concern. The defensive positions were visited daily by the psychiatrist as a matter of routine, and further visits were made if it was thought necessary. After withdrawal from the exercise and return to the medical centre in camp, subjects were again visited by a psychiatrist.

Environment. The trial was carried out in the north of England, on the Otterburn training area, which consists mostly of open heath and moorland, intersected by gullies and streams, and with a few scattered tree plantations. Although it was summer, the climate was cool and windy with periods of quite considerable rainfall, and with relatively little sunshine. Also, the night hours were usually associated with very high relative humidity, dew point being reached on several nights.

Objective measures. To assess shooting and weapon handling, cognitive functioning, and physical fitness, the test subjects were taken from the defensive positions to testing sites. For 3.5 hours at the same time every day, between 0930 and 1630, the subjects went to the range and adjacent test site and later to a tent for these tests. During Exercises 2, 3, and 4, cognitive testing took place between 0230 and 0700, but during the control and recovery exercises (1 and 5), this was the subjects' sleep period and testing was carried out during the day.

Subjective measures. Subjective assessments were made by military observers, the Company Commander, and the subjects themselves.

Observers. One hundred military observers, drawn from all Arms, were divided into 3 shifts of 30 to cover each 24 hours, and one group of 10 who were responsible for all work carried out at the shooting and weapon-handling range.

Military Tests

Vigilance shooting. A test which combines vigilance with shooting was developed in order to study shooting performance under conditions of sleep loss. The test was of 20 minutes duration, in which time 9 rounds were fired. Portable electric targets, which were at ranges of 100 m, 200 m, and 300 m from the firing point, were exposed for 5 seconds (including the upward movement) at time intervals varying between 10 seconds and 7 minutes. Targets appeared 3 times at each distance, and 3 men were tested together. The targets were set out in such a way as to give each man an arc of fire of approximately 622 mils. In order that subjects did not learn the sequence of time intervals and ranges, there were 3 versions of the test. The score recorded for each subject was the number of hits out of a total of 9. Subjects were told their scores.

Grouping capacity. Grouping capacity is the ability to fire 5 rounds so the shots fall in as small an area as possible. Statistical analysis of data from pilot trials indicated that if the best of 3 groups of fall of shot was taken as a subject's score, then the test had sufficient reliability to assess the effects (if any) of sleep loss. Three white cards, 295 mm X 210 mm, were placed on a board, one above the other. In the centre of the card was a black aiming mark, 25.4 mm square. Three subjects were tested together, and so there were 3 boards, which were at a distance of 25 m from the subjects. In their own time, subjects fired a group of 5 rounds at each card, starting with the one uppermost. Subjects were told their group sizes.

Weapon handling tests. The tests included filling the magazine by hand, loading rifle (standing position), unloading rifle (standing position), stripping rifle to firing pin, and assembling rifle. The tests were carried out according to the Infantry Training Manual and were scored for time and errors.

Cognitive tests. Six paper-and-pencil tests were selected, which were either meaningful to the subjects, or which examined a cognitive function of some importance. The tasks chosen for study were: encoding/decoding (Dudley, Huband, & Cox, 1972), map-plotting, short-term memory (digit span), logical reasoning (adapted from Baddeley, 1968), and the Stroop test (Jensen & Rohwer, 1966). The tests were carried out in a tent adjacent to, but out of sight of the defensive positions. The tent contained 12 booths for the subjects. Testing of the 3 Platoons during Exercises 2 to 4 was at 0200 hours (no-sleep group), 0400 and 0530 hours respectively for the 1.5 and 3 hour sleep groups, 30 minutes after being wakened from sleep.

Electroencephalography. The role of EEG recording in this study of performance during continuous operations was to provide objective physiological evidence of the amount and quality of sleep obtained and of subjects' level of awareness at particular times throughout the exercise. EEG recordings were made from 6 randomly selected subjects--as many as resources would permit. One pair was drawn from each of the 3 Platoons having 0, 1.5, and 3 hours of scheduled sleep. The recordings were made with Medilog tape recorders, running for 24 hours at a time, carried by one member of each pair on alternate days.

Visual Acuity Tests

Binocular near acuity. Binocular near acuity was measured by means of a reduced Snellen chart held by the experimenter at a distance of 37.5 cm from the subject's eyes. In order to avoid learning, there were several versions of the chart. the subject was asked to read out as many lines as he was able.

Binocular far acuity. Binocular far acuity was measured by means of a standard Snellen chart at a distance of 6 m. The illumination on the chart was 140 lux. Again, there were several versions of the chart to avoid learning, and the subject was asked to read out as many lines as he was able.

Physiological and Biochemical Measures

The physiological measures were intended in the main as background to the performance tests. Body weight and skinfold thickness were measured by regularly calibrated balance and Harpenden calipers in the standard manner. Aerobic capacity (VO_2 max) was estimated from a 6 min single-load submaximal bicycle ergometer test, using the age-corrected Astrand-Ryhming nomogram (Astrand & Ryhming, 1970). Isometric muscle strength was measured by the method of Hermansen (1974) for back flexion, back extension, left forearm flexion and extension, right forearm flexion and extension, leg extension, and hand grip.

Temperature and heart rate circadian rhythms were observed before and after the field phase by the simplest possible methods, compatible with the realism of the exercise. In addition, assessments were made of urine and blood biochemistry.

Subjective measures. As indicated earlier, subjective measures included both self-rated and observer-rated assessments. They were concerned with mood, alertness, effort, morale, effectiveness, and sleepiness.

Results

In general, the results of this trial are most easily assimilated in graphical form and they will be presented in this way in the following pages. Some specific comments will be made here as a preface.

Withdrawal from the exercise. All of the 0-hours sleep Platoon had withdrawal from the Exercise by Day 4, i.e., after 4 nights without sleep (one subject withdrew on Day 3); 39% of the 1.5 hours sleep group had left by Day 5; 48% of the latter Platoon and 91% of the 3 hours sleep Platoon completed the Exercise (Figure 1).

Although the trial was carried out in the summer, the weather was, for the most part, cold, wet, and windy. Undoubtedly the heavy rain which fell on Day 4 interacted with sleep loss, hastening the departure of the 0 hours sleep Platoon. The suddenness of this departure was probably also brought about by the early retirement of the Platoon Commander (thus saving the others from loss of face), inexperienced observers who wished to err on the side of caution, and the fact that the soldiers calculated that they had just beaten the 100 hours deprivation point, which they felt to be a significant landmark. Against all this must be set the opinion of the military observers that this Platoon had ceased to be effective by Day 3.

Military Tasks

Vigilance shooting. The average number of hits can be seen in Figure 2. Analysis of variance indicated:

(1) that for all 3 Platoons, performance on the experimental days was significantly worse than on the control days ($p < .01$ for 0 hours sleep group; $p < .001$ for the other 2 groups);
(2) there was a significant deterioration over the sleep deprivation

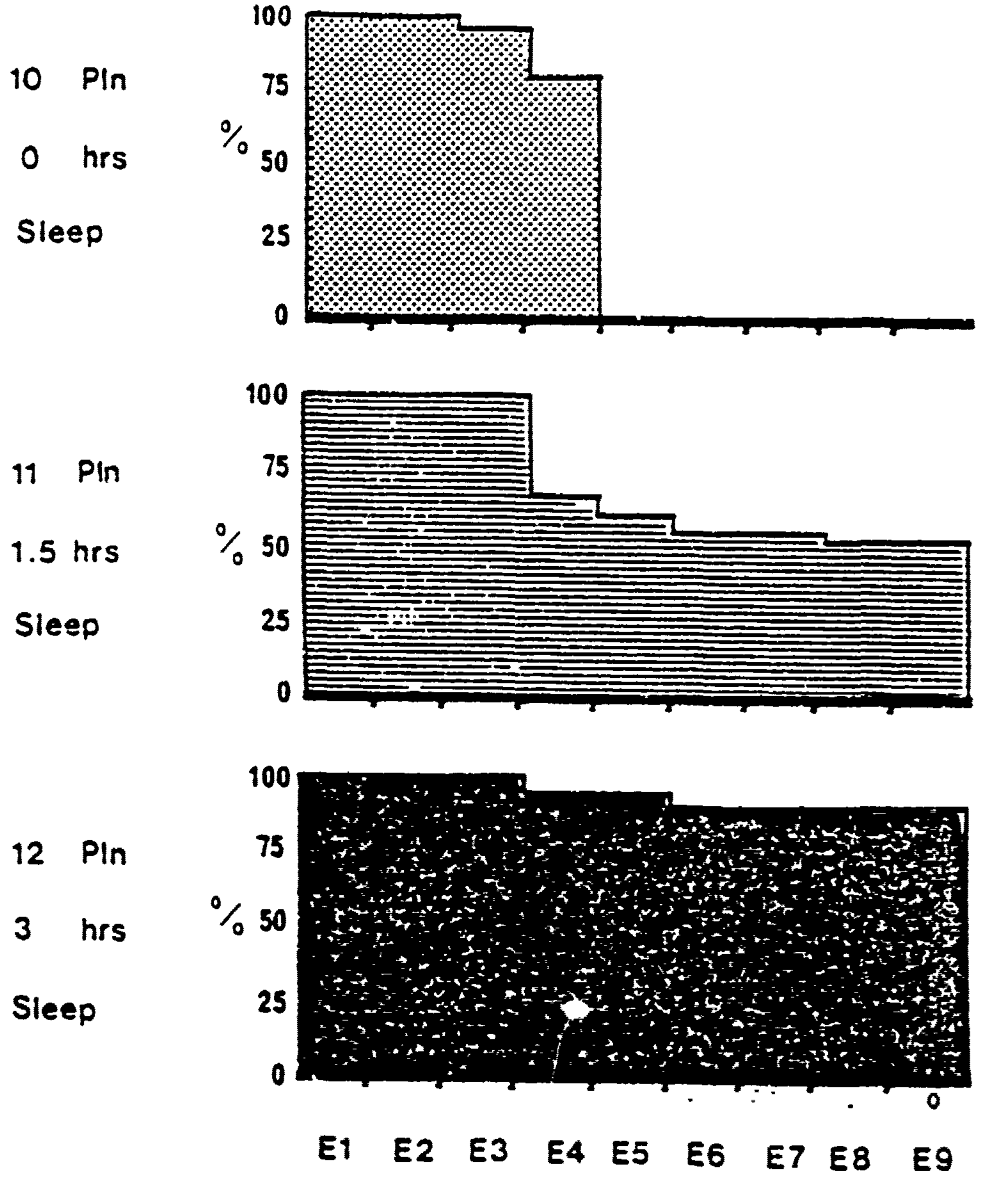

Figure 1. Percentage of soldiers in the 3 Platoons remaining in the field over experimental Days 1-9.

period for the 1.5 hours and 3 hours sleep groups ($p < .01$ in both cases);

(3) for the 0 hours sleep group, performance on Day 2 was significantly worse than on Day 1 ($p < .05$).

Grouping capacity. The average size of the best group for the 3 Platoons over the course of the trial can be seen in Figure 3. As this figure shows, there was no overall deterioration with sleep loss, and means varied between 2.00 and 2.75 inches for the entire trial.

Weapon handling tests. There was no significant difference between experimental and control days for any group. With regard to the more difficult tasks of stripping and assembling the rifle, there were larger fluctuations than in a simple task like loading the rifle. In stripping and assembling, the performance of the no sleep group was significantly worse than the other 2 groups on deprivation Days 2 and 3 ($p < .05$ and .001, respectively); but it was also significantly worse on the first post-deprivation day ($p < .05$ and .001 for stripping and assembling, respectively). There appeared to be a practice effect (C3-C5 compared with C1-C2 was significant at the .01 level) for the 3 hours group in stripping and assembling, and at the same level for the 1.5 hours group in assembling which obviously would have had most impact on the performance of the 3 hours sleep group (91% of whom remained in the field) and on half of the 1.5 group. Figures 4 and 5, which give mean times for assembling the rifle and for loading it, illustrate the above points.

Cognitive Tests

In Figure 6 can be seen the results for encoding. This figure will serve to illustrate the general pattern of performance in the cognitive tests. For the majority of these tests, there was a rapid deterioration in performance over the first 4 days of sleep loss, with an upturn on Day 5 for those subjects remaining after the night in base camp. [Because of the heavy rain which fell continuously for 24 hours, the subjects were taken into camp for a change of clothing and general drying out. The sleep regimes were adhered to.] Thereafter, there was a further decline, followed in most instances by improved performance on Day 9, the last deprivation day.

In most tests, for all 3 Platoons performance on the experimental days was significantly worse than on the control days (p varies from $< .05$ to .001), and there was a significant deterioration over the sleep deprivation days. Although in the encoding test, the performance of the no sleep group was significantly worse than the other 2 groups on Day 3 ($p < .01$), this was not the general finding. That is, the cognitive tests did not distinguish between the 3 sleep groups; in fact, in most instances, there was a non-significant trend for the performance of the 1.5 hours group to be better than that of the 3 hours group.

Electroencephalography

The proportion of reliable data recovered was gratifyingly high. Obviously there were gaps in the data from individuals on the alternate days. A more serious restriction of the amount of information obtained resulted from the fact that by Day 5 both of the 0 hours scheduled sleep pair and one each of

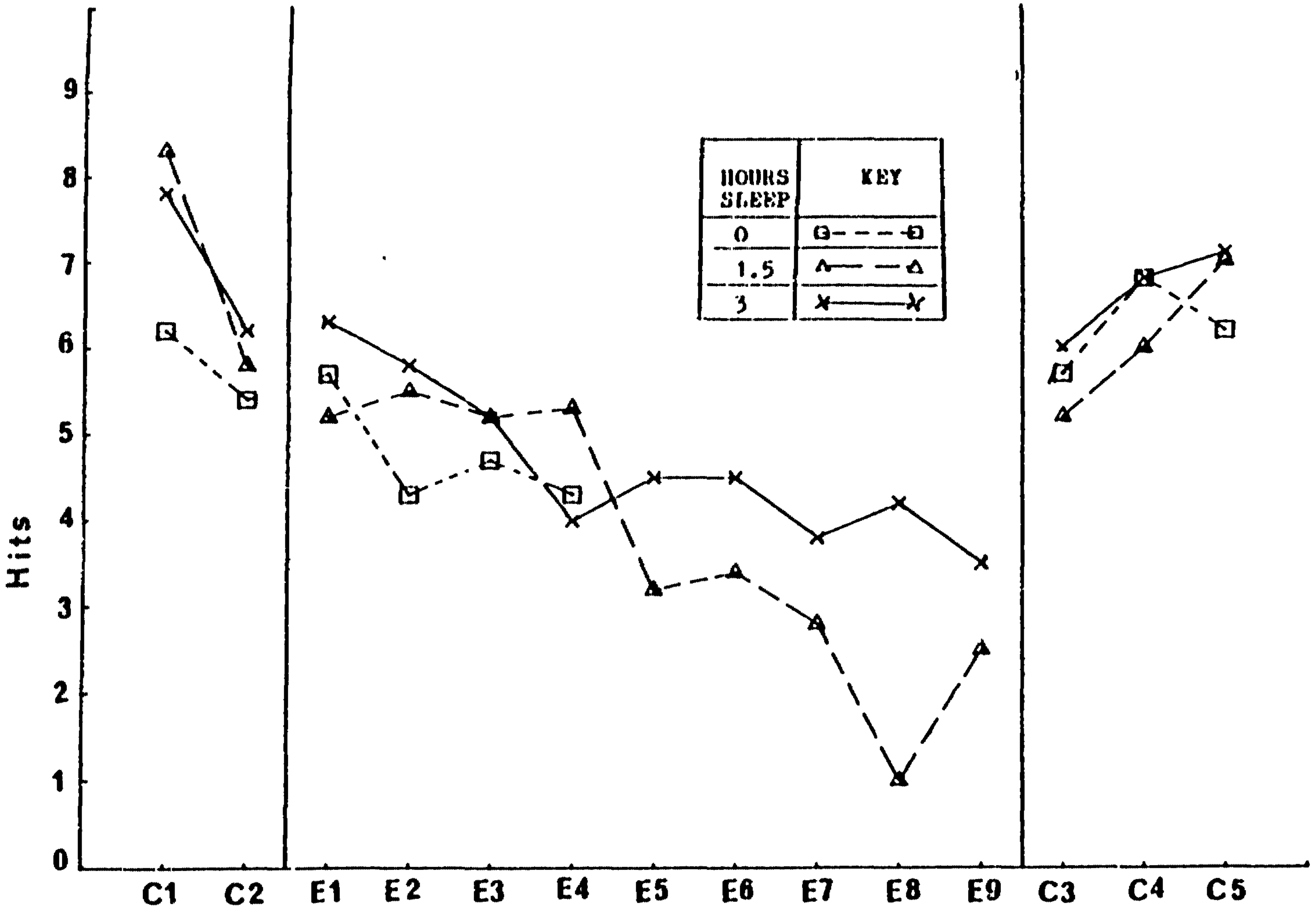

Figure 2. Vigilance Shooting. Average number of hits for the 3 Platoons.

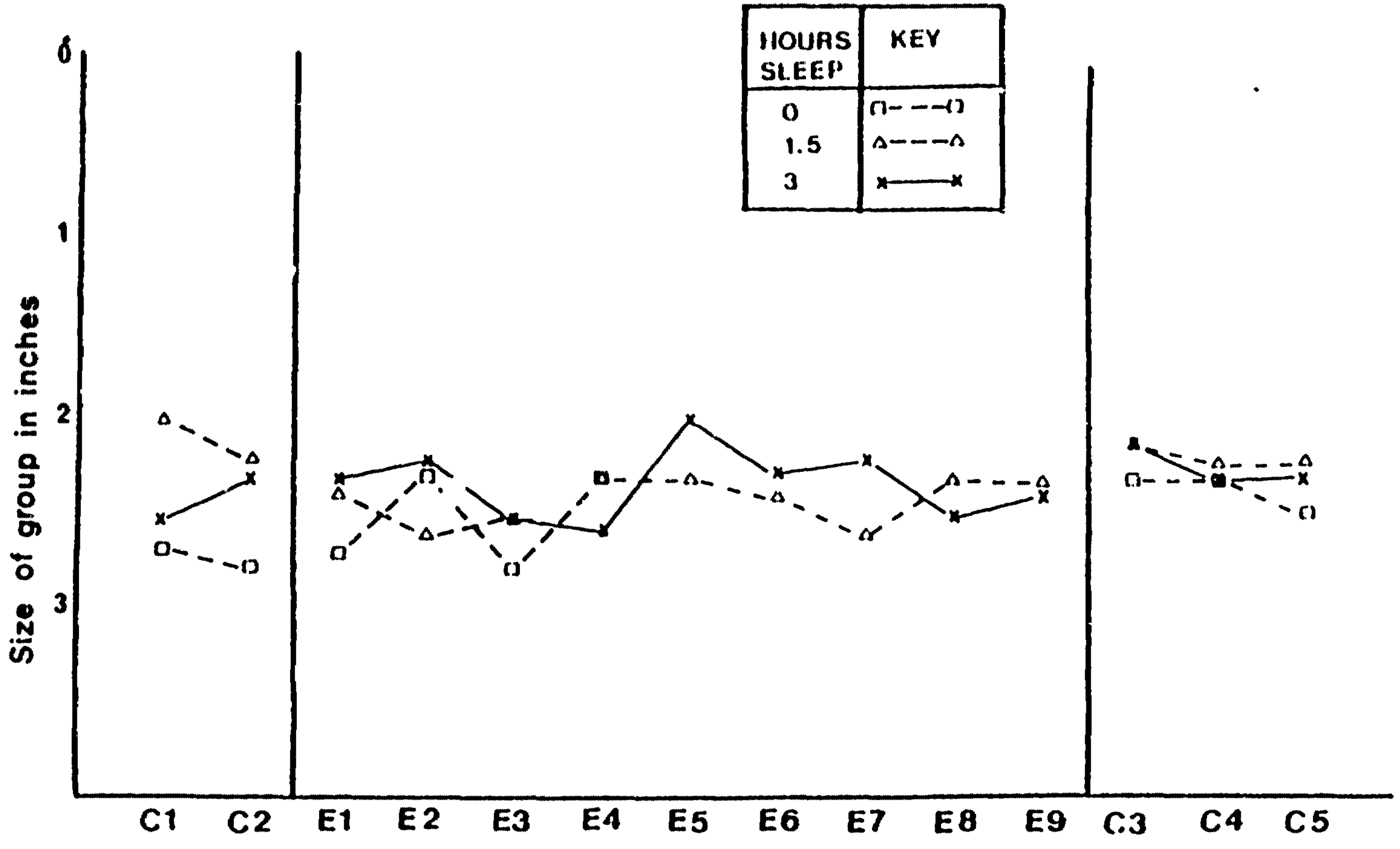

Figure 3. Grouping Capacity. Average size of best of 3 groups for the 3 Platoons.

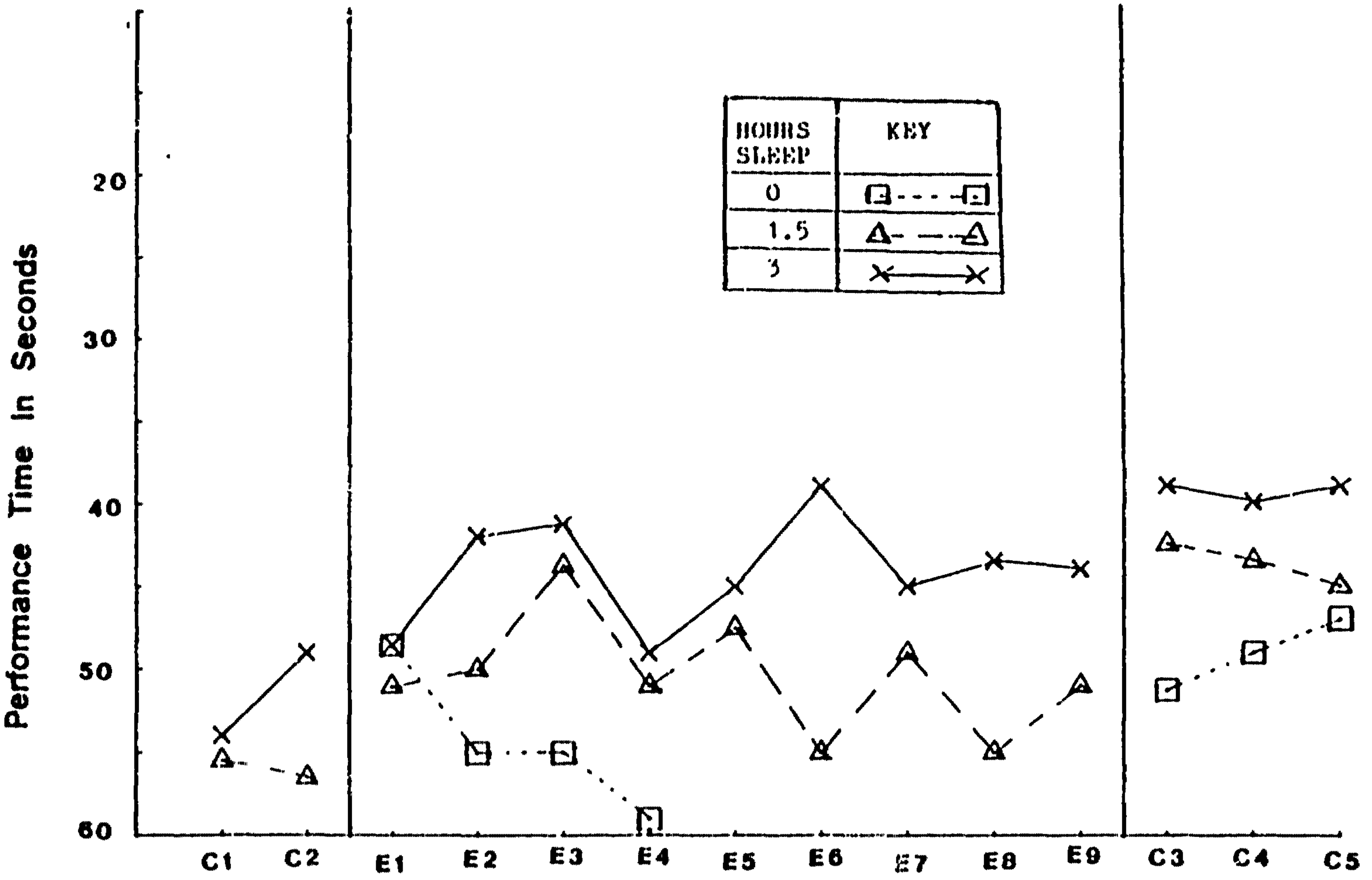

Figure 4. Assembling rifle. Average time taken by the 3 Platoons.

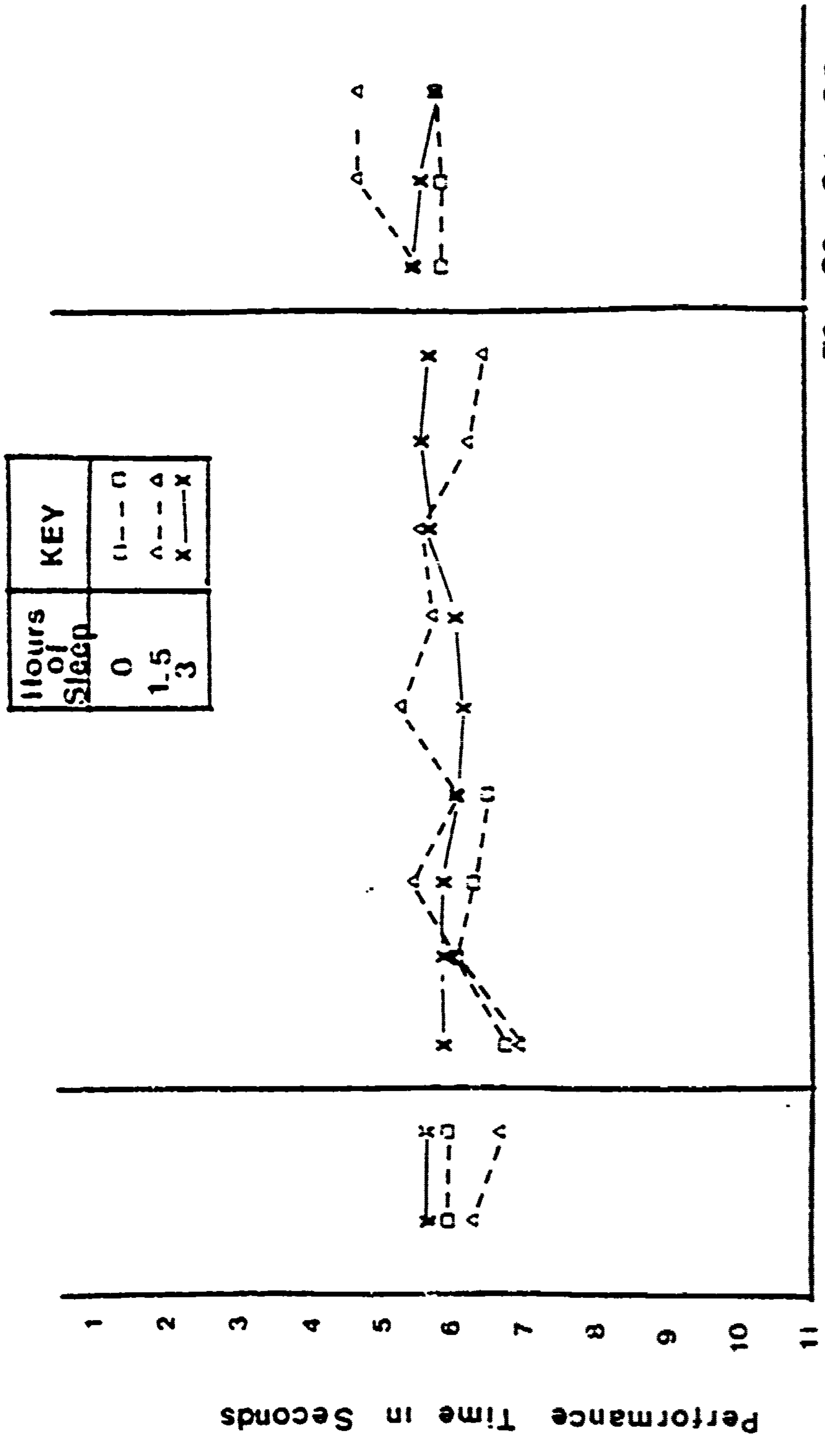

Figure 5. Loading rifle. Average time taken by the 3 Platoons.

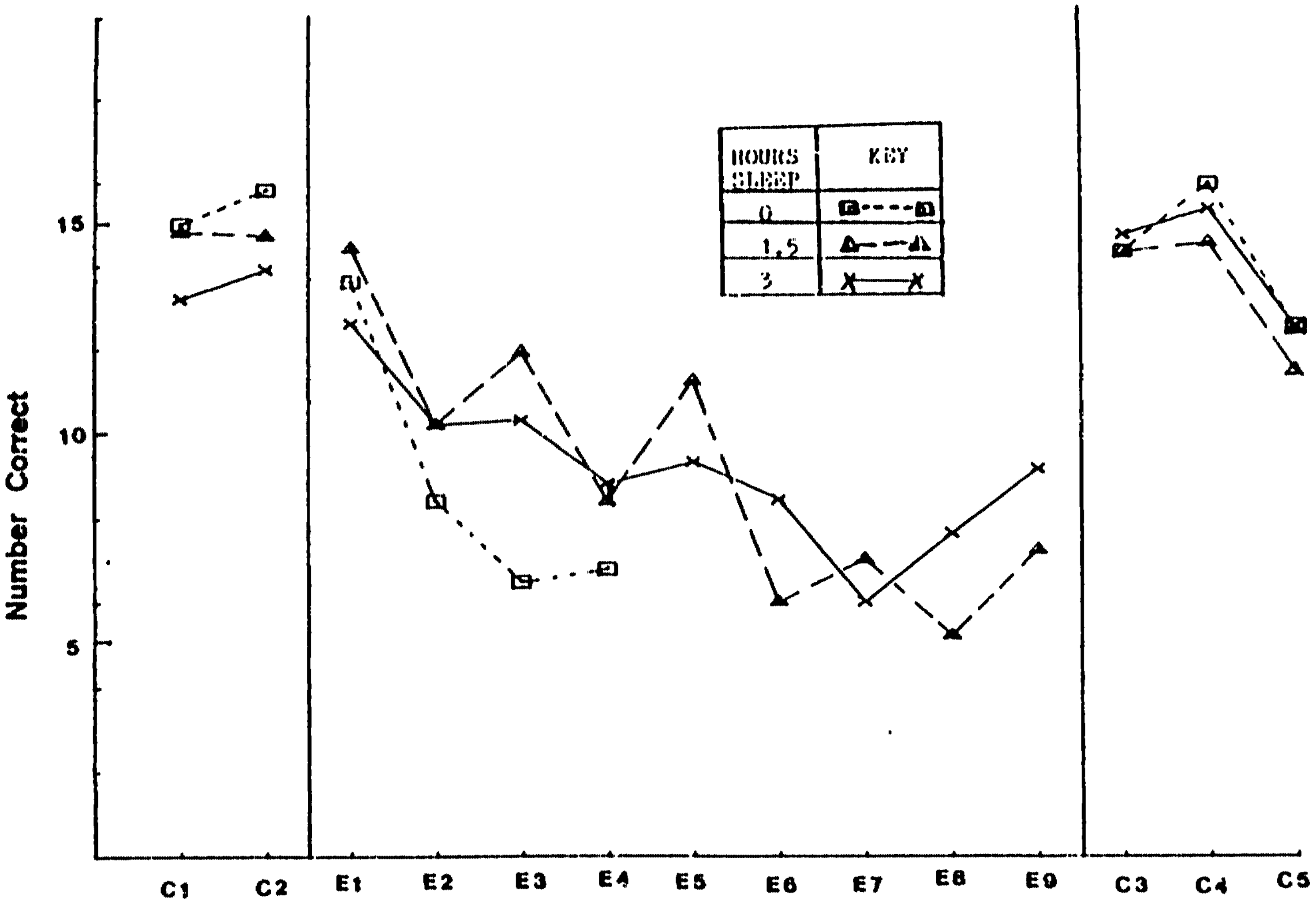

Figure 6. Encoding. Average number correct for the 3 Platoons.

the 1.5 hours and 3 hours sleep pairs had withdrawn or been withdrawn. Nevertheless, it was possible to build up a picture of the changing pattern of consciousness. The picture that emerges is as follows:

(1) Despite the efforts of the observers, there was unscheduled sleep, which increased progressively both in terms of depth and duration, over the sleep deprivation period;
(2) The unscheduled sleep was principally in the form of light sleep, the major part of which was Stage 2 sleep;
(3) During the sleep deprivation period, there was an increase in activity that was mainly alpha, without eye movement, and with reduced muscle tonus.

During the post-deprivation phase, EEG records for 2 subjects, one from the 1.5 hours and the other from the 3 hours sleep group, both of whom had completed the 9 days, suggested that after only one recovery day, the sleep pattern on the second night was little different from their baseline pattern. The amount of "recovery" sleep on the first day was 17.47 and 12.44 hours, respectively.

Visual Acuity

There was no deterioration in near and far acuity; it is unlikely, therefore, that these aspects of visual functioning contributed to the observed decrement in cognitive tasks and vigilance shooting.

Physiological and Biochemical Measures

The results indicated that the subjects' survival times were not determined by physiological factors.

While many measures did not reveal anything of physiological significance, there were 2 exceptions, namely, back extensor muscle strength and circadian rhythms. There was a deterioration of the former, significant only for the 1.5 hour sleep groups, and a flattening of the latter, especially body temperature, roughly proportional to the 3 sleep schedules.

Subjective Measures

As expected, sleepiness increased, alertness decreased, and there was a deterioration in mood and effort. Figure 7 shows mean scores for the 3 groups on a 5-point scale of alertness, rated by the military observers. This will serve to give the general picture of subjective measures, except for group morale which remained high. At the de-brief session, several non-commissioned officers reported that they had found a more relaxed style of leadership to be apposite and, particularly in the later stages of the exercise, exhortation to be better than order.

Discussion

Military Tasks

Vigilance shooting and grouping capacity. These 2 sets of results confirm

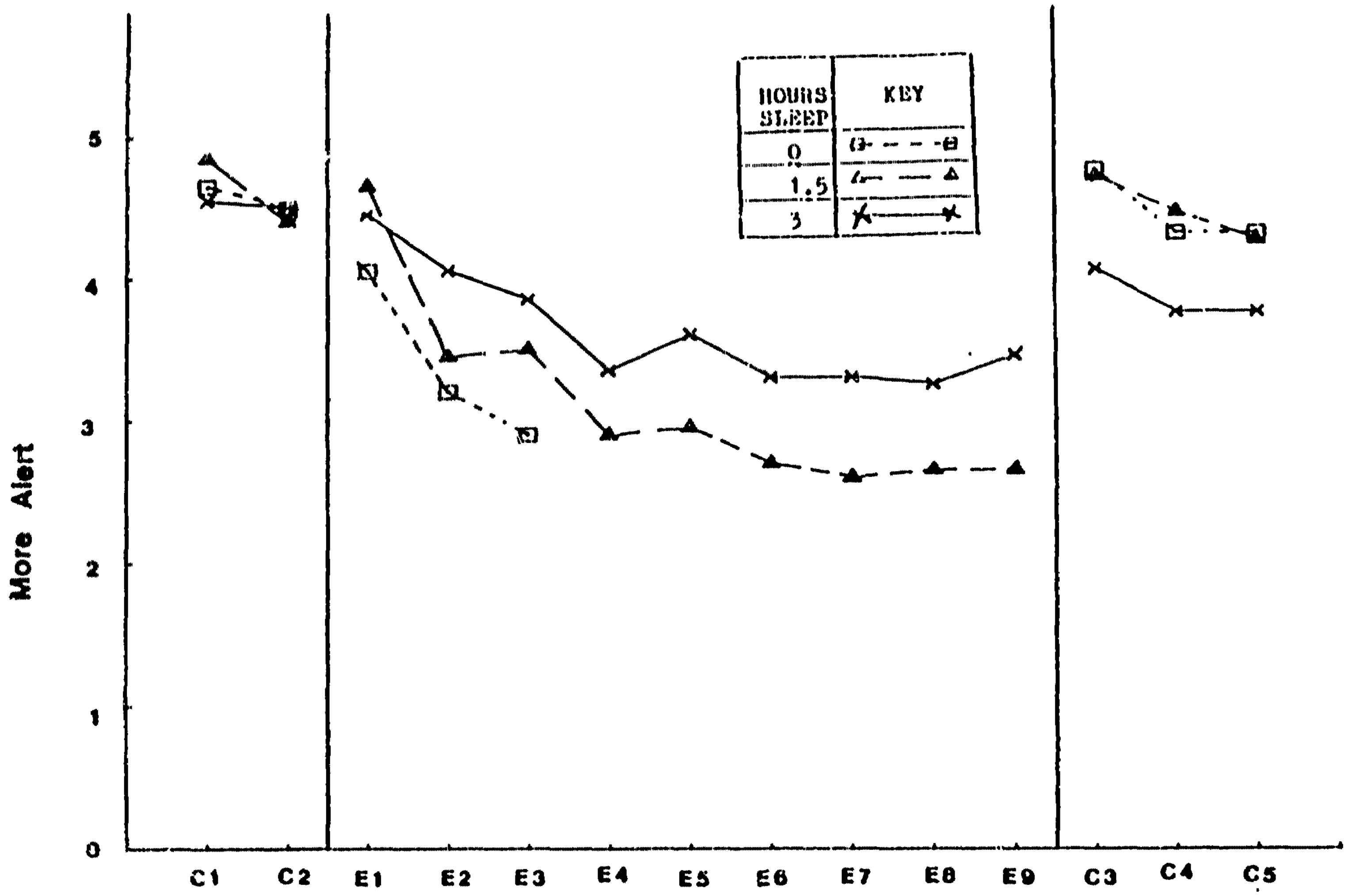

Figure 7. Average level of alertness for the 3 Platoons.

other sleep loss results in that grouping is a self-paced task and is therefore less likely to deteriorate than an experimenter-paced task with a high vigilance component (Johnson & Naitoh, 1974). Vigilance, of course, is extremely sensitive to sleep loss (Wilkinson, 1964). Also, grouping is a well-learned task and thus resistant to sleep loss effects (Johnson & Naitoh, 1974). These 2 sets of results together indicate that shooting skill per se does not deteriorate but that attention does. This was confirmed in a de-brief session when subjects said that their eyes had wandered from the target locations. In the event of war, motivation to see and kill the enemy will be high, but, nonetheless, vigilance in any situation, and especially under conditions of sleep loss, will almost certainly deteriorate over time.

Weapon handling tests. The observed practice effect, which only became manifest when subjects were less tired, presumably nullified any effect of sleep deprivation over the experimental days. However, weapon handling is, of course, a well-practised skill, and in this respect should be resistant to sleep loss effects. Nevertheless, stripping and assembling the rifle are somewhat "fiddling" tasks (especially assembling), and might be expected to show some effect (Johnson & Naitoh, 1974); to the extent that these tests differentiated between the Platoons, this expectation was borne out.

Cognitive Tests

There are several indications from the results of these tests that amount of sleep loss was not the only influence upon performance, and that morale and motivation played their part. One indication is the improved performance after the night in base camp, when the sleep regimes were adhered to but the subjects were warm and dry; a second indication is the upswing in performance on the last day of sleep deprivation, and the third is the overall performance of the 1.5 hours Platoon. Throughout the exercise, it appeared that this Platoon was very highly motivated, perhaps because they had the greatest challenge. Clearly, the Platoon with no scheduled sleep could not keep going for the 9-day period of the exercise, and for the 3 hours group, the challenge was not prodigious.

Electroencephalography

It has been shown that monitoring of brain activity by continuous tape recording is feasible under the conditions of a military exercise. Such recordings give the best available objective indication of a subject's state of alertness at any given time, and provide the only complete information concerning the duration and depth of sleep acquired each day. Processing the information is, however, likely to remain a tedious task until the advent of reliable computer methods.

Physiological and Biochemical Measures

It has been accepted from the outset that the study of physiological aspects would be subsidiary to the main aims of the trial, and that the test programme would, of necessity, proceed under a certain number of constraints lest it exert undue influence on the performance of the subjects by the very nature of the tests employed. Also, it was important that the Alpha Groups should not be placed at a disadvantage as compared with the Beta Groups.

Back extensor muscle strength. A reduction in back muscle strength is cited by Simonson (1972) as a result of sleep deprivation. In the present trial, sleep deprivation was associated with maintenance of the erect posture, with consequent demands upon the back extensors. The observed deterioration was thought unlikely to be of military significance, however.

Circadian rhythms. The military significance of the observed changes in circadian rhythms is debatable; previous British Army studies (Adam, Brown, Colquhoun, Hamilton, Orsborn, Thomas, & Worsley, 1972) produced inconclusive results, although here the disturbances were induced by time-zone transition. More recent analysis of the data (Colquhoun, 1976) demonstrates relationships between the degree of circadian rhythm disturbance and performance in psychological tests, coupled with personality characteristics. The link between these observations and combat effectiveness will depend in part upon studies involving the military 'decision makers', but could also be usefully examined in studies involving the rifleman to find out the length of time, coupled with degree of sleep loss, in continuous operations before circadian rhythms are disturbed.

Subjective Measures

Mood and behavioural changes can appear after one night of sleep loss, and are present, to some degree, in all subjects following 2 nights without sleep (Johnson & Naitoh, 1974). The results of the Exercise reported here support these general observations. However, the morale of the Company remained good, and this was probably attributable to the fact that they were a well-integrated group. Another factor was that the Company knew the scheduled end of the exercise, and the survivors were able to gear themselves to the known time limit. Particularly for the 3 hours sleep Platoon, this is manifest in the end-of-trial spurt in performance on some tests.

Conclusions

Thus, to sum up, it can be said that even small amounts of scheduled sleep are beneficial; compared with a survival time of 4 days for the 0 hours sleep Platoon, 48% of the 1.5 hours sleep Platoon and 91% of the 3 hours sleep Platoon survived for the full 9 days. Tasks with a mainly physical content suffered least, and those with a cognitive and vigilance component suffered most, deteriorating to about 50% of control values over the first 4 days of sleep loss. Experienced military observers considered that physical tasks were carried out at an acceptable level by the 0 hours sleep Platoon for 3 days, by the 1.5 hours sleep Platoon for 6 days, and by the 3 hours sleep Platoon for 9 days.

Exercise Early Call II

A militarily realistic regime, but one previously unstudied in the field, is one which demands, without remission, several days of continuous activity, followed by a period of less intense activity, during which short periods of rest are possible. With this in mind, and based on the results for Early Call I, the design of Early Call II (Haslam, 1978) was for 3.75 days of continuous activity followed by 6 days when there was limited opportunity for sleep.

With regard to recovery, it was found in Early Call I that after 3 days rest in camp following the 9-day sleep deprivation period, performance was restored to its initial level. As stated earlier, during the recovery period, EEG records for 2 subjects suggested that after only one day, the sleep patterns on the second night were little different from base line patterns. This raised the question as to whether 2 days, or even one, would be sufficient to restore efficiency to its initial level. It was decided, therefore, in Early Call II to examine the effect of 1.25 days of rest following the 9-day exercise.

Methods

Subjects. Ten members of the APRE Trials Team, formed into a Rifle Section of 2 non-commissioned officers and 8 other ranks, were the trial subjects. They were all trained Infantrymen, with an average age of 23.9 years, range 21-26.

Subject briefing. Before the trial began, the subjects were briefed about the sleep regimes and the duration of the trial; they were also briefed on the nature of the medical and physiological activities in the Exercise period. All were required to declare any current illness, disability or medication. At that time, all were fit. In addition to the above, subjects were briefed on signs of hypothermia. Further, they were told that they would be withdrawn from the trial by the Senior Medical Officer-in-Charge if he thought they were unfit to continue.

Trial design. During the first 90 hours of the trial (Exercise 1) there was no scheduled sleep, after which there was a schedule of 4 hours block sleep in every 24 hours for the following 6 days (Exercise 2). This 9-day period was preceded and followed by a 2-day control period when 6 hours block sleep per 24 hours was allowed; the first of the control periods was preceded by one day of training, and the second by 30 hours of rest. Twenty four hour medical coverage was provided during all phases.

Military aspects of the trial. The trial took the form of a tactical exercise, and a full Section defensive position was dug, camouflaged and occupied. Surprise attacks by "enemy" troops were countered and other activities included, for example, mine-laying, mine-clearing, First Aid, and "casualty" evacuation. In order to prevent sleep occurring, there were many other activities throughout each 24 hours; tests and assessments took up much of the day and night.

Environment. The trial took place in the south of England, during winter months. Basic meteorological data were collected; these included rainfall, air temperature, and windspeed.

Objective measures. In order to assess shooting, cognitive functioning, and physical fitness, subjects were taken daily to various ranges and test sites. This entailed traveling 26 miles per day in a 4-ton vehicle.

Subjective measures. In addition to the above objective measures, subjective assessments were made by military observers of the subjects' military effectiveness or "fitness to fight" and also of their morale; the subjects assessed their own mood daily by means of a questionnaire.

Observers. Throughout the trial, military and civilian staff observed the subjects for 24 hours a day. In addition to assessing the various activities carried out during their shift, their duty was to ensure that subjects had no unscheduled sleep, for example, while in the defensive position or traveling to and from the ranges.

Military Tests

Vigilance shooting. The same test was used as in Early Call I, but it was carried out on an electronic target range (ETR), and all 10 subjects were tested together.

Grouping capacity. Although in Early Call I no overall deterioration was found, it was decided that, while using grouping for zeroing purposes, a measurement would be made of the group. This assessment, therefore, had less reliability than the earlier test.

One group of 5 rounds was fired at a range of 100 m and measurements were made to the nearest quarter-inch. Greater variation would, of course, be expected than in Early Call I because of the shorter range in that trial.

Cognitive Tests

The 2 most sensitive tests used in Early Call I were selected and lengthened: a 20-minute Logical Reasoning Test modified from Baddeley (1968) and a 10-minute decoding test (Dudley et al., 1972). On the experimental days, test sessions were at 1300 hours, 0100 hours, and 0545 hours. During the control days there was only one session daily at 1300 hours because subjects slept from 0045-0700 hours. Due to a circadian effect, performance would be expected to be better at 1300 hours than at the other 2 times of testing. During Exercise 2, performance on awakening was assessed.

Electroencephalography

During this trial, the EEG activity of all 10 subjects was continuously monitored for the 15 days of the trial, again using Medilog recorders.

Physiological and Biochemical Measures

The aim of these assessments was to detect and measure any change in physiological state during the exercise, with particular reference to physical fitness. The following methods were used:

(1) Anthropometry: Height, weight, and skinfold thickness at 4 sites;
(2) Electrocardiography: 12 leads (resting; supine);
(3) Blood pressure measurement: 3 automatic reading at 120 second intervals after a period of rest (supine) during electrocardiography;
(4) Pulmonary assessment: Total expired volume and forced expiratory volume 1 second (Vitalograph);
(5) Isometric muscle strength (static);
(6) Estimated maximum oxygen uptake: 12-minute, 4-load sub-maximal bi-

cycle ergometer test;

(7) Haematological and biochemical assessment of venous blood on 8 control and exercise days;

(8) Six-hourly urine collections;

(9) Rectal temperatures for 24 hours with leads connected at 15-minute intervals during 2 control days, the first during the week preceding the exercise, and the second during the Recovery Day.

Assessments (1)-(6) were made between 2000 and 2330 daily. Each subject was involved in testing for approximately one hour. Subjects were put through the assessment battery in pairs in the same order each night; the requirement to combine physiological assessment with 2 other activities sharing the same block of time precluded random processing.

The order of testing, with the exception of 2 interchangeable parallel blocks of activity, was constant. This was determined by the need to achieve the maximum relaxation for electrocardiography and blood pressure measurement and to retain bicycle ergometry and venepuncture as the last activity.

Subjective Measures

In order to assess mood, subjects completed daily at 1230 hours the 'Profile of Mood States' (McNair, Lorr, & Droppleman, 1971). This questionnaire includes the factors of tension, depression, anger, confusion, fatigue and vigour; these can be summed, with vigour weighted negatively, to give a Total Mood Disturbance score. In addition, and as stated above, the military observers assessed the subjects' overall effectiveness and morale.

Results

Subjects. In spite of a few minor complaints such as colds and headaches, all 10 subjects completed the trial in good order. Three factors probably contributed to this:

(1) each evening they spent 3 hours in a warm building for physical fitness tests and servicing of EEG recorders;

(2) the amount of physical exercise was moderate, especially after the initial digging-in period;

(3) they were protected from wind and rain by rainproof overgarments.

Weather. The weather was typical for the time of year. During the sleep deprivation days, maximum and minimum temperatures ranged from 10.7°C to -3.2°C. On 5 of these days, there was rainfall, the amount ranging from 0.71 mm to 24.79 mm.

Military Tasks

Vigilance shooting. As can be seen in Figure 8, the general trend of performance was U-shaped. The visit of a VIP to the range on the third day of sleep loss may have affected alertness, leading to the observed upswing in scores on that day. Overall, performance deteriorated 20% from a mean control value of 68% of targets being hit. Recovery to this value had occurred by Day 6 (i.e., after 3 nights with 4 hours block sleep per night).

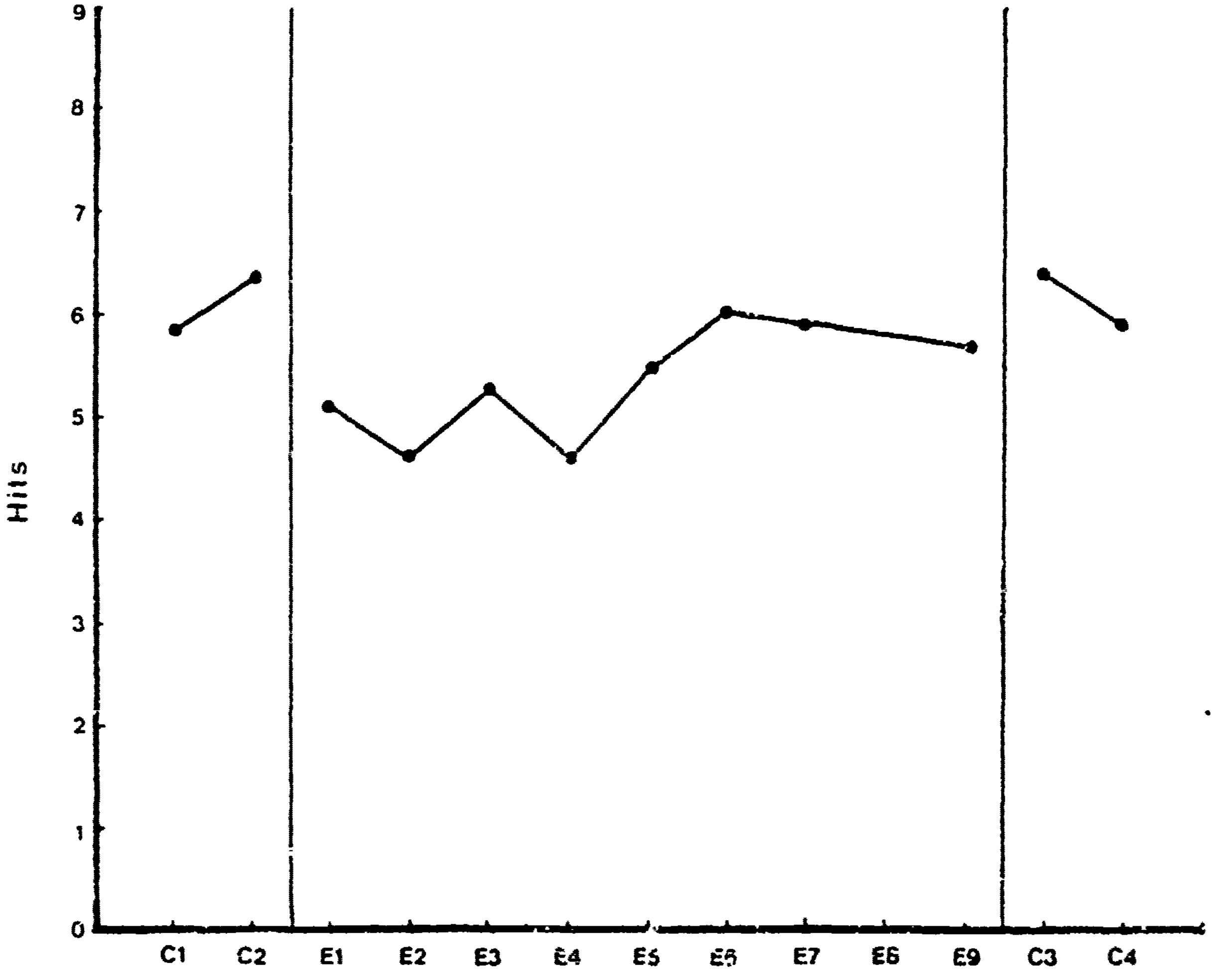

Figure 8. Vigilance Shooting. Average number of hits.

Analysis of variance indicated that scores on sleep deprivation days 1-3 and also on 4-6 were significantly worse than on control days ($p < .01$ and .05, respectively). However, performance on Day 7 and Day 9 was not significantly different from that on control days.

Grouping capacity. In spite of only one group being fired, the basic stability of the measure is indicated by mean scores for the control days which varied little. As can be seen in Figure 9, there was a small amount of variation in average performance over the sleep deprivation days, and an increase in group size of 4.3 inches on Day 5 compared with Day 4. Analysis of variance with selected contrasts indicated that performance on Days 4-6 was significantly worse than on Days 7 and 9 ($p < .05$) and also than on the control days ($p < .001$); it was not, however, significantly different from Days 1-3.

Cognitive Tests

Logical reasoning. During the 0545 hours test sessions in Exercise II i.e., Days 4-9), it was apparent that most of the subjects were unable to start the Logical Reasoning test within 5 minutes of awakening. Scores, therefore, were derived from a 15-minute test, and in order that all sessions should yield scores from tests of comparable length, the first 5 minutes were excluded from the statistical analysis for the other 2 sessions. The mean number of correct responses per page of the test for the 3 sessions can be seen in Figure 10.

By the third day without scheduled sleep, the average score of the 3 sessions (1300, 0100 and 0545 hours) was approximately 35% of the control value. With 4 hours scheduled sleep per night, performance during 1300 hours and 0100 hours sessions showed an overall improvement to a mean value of approximately 80% of the control value on Day 6; 60% of the control value was reached on Day 4, i.e., after 4 hours sleep. On Days 7-9 performance evened out at approximately 83%. However, at 0545 hours it remained at an average level of approximately 35% of the control value for the remainder of the exercise. Part (about 5-10%) of this decrement was presumably due to a circadian effect and a further part to an awakening effect. An unexpected finding was that performance at 0100 hours was better than at 1300 hours. [It should be remembered that on Day 4 at 0100 hours, subjects had not had their 4 hours scheduled sleep.]

Decoding. Figure 12 gives mean scores for the 3 sessions. By Day 3, the average score for the 3 sessions was approximately 50% of the control value. By Day 6, the mean performance level of the 1300 and 0100 hours sessions had recovered to approximately 85% of the control value; after only 4 hours sleep it had recovered to 80%. On Days 7-9, performance leveled out at approximately 90%. At 0545 hours, however, the average level was approximately 65% for the remainder of the trial.

Electroencephalography

At the time of writing, the EEG analysis is incomplete, and covers the second control day, the first 4 days of sleep loss, and also the last day of the deprivation phase. So far as they go, the results support those of Early Call I in as much as there were increasing amounts of unscheduled sleep over

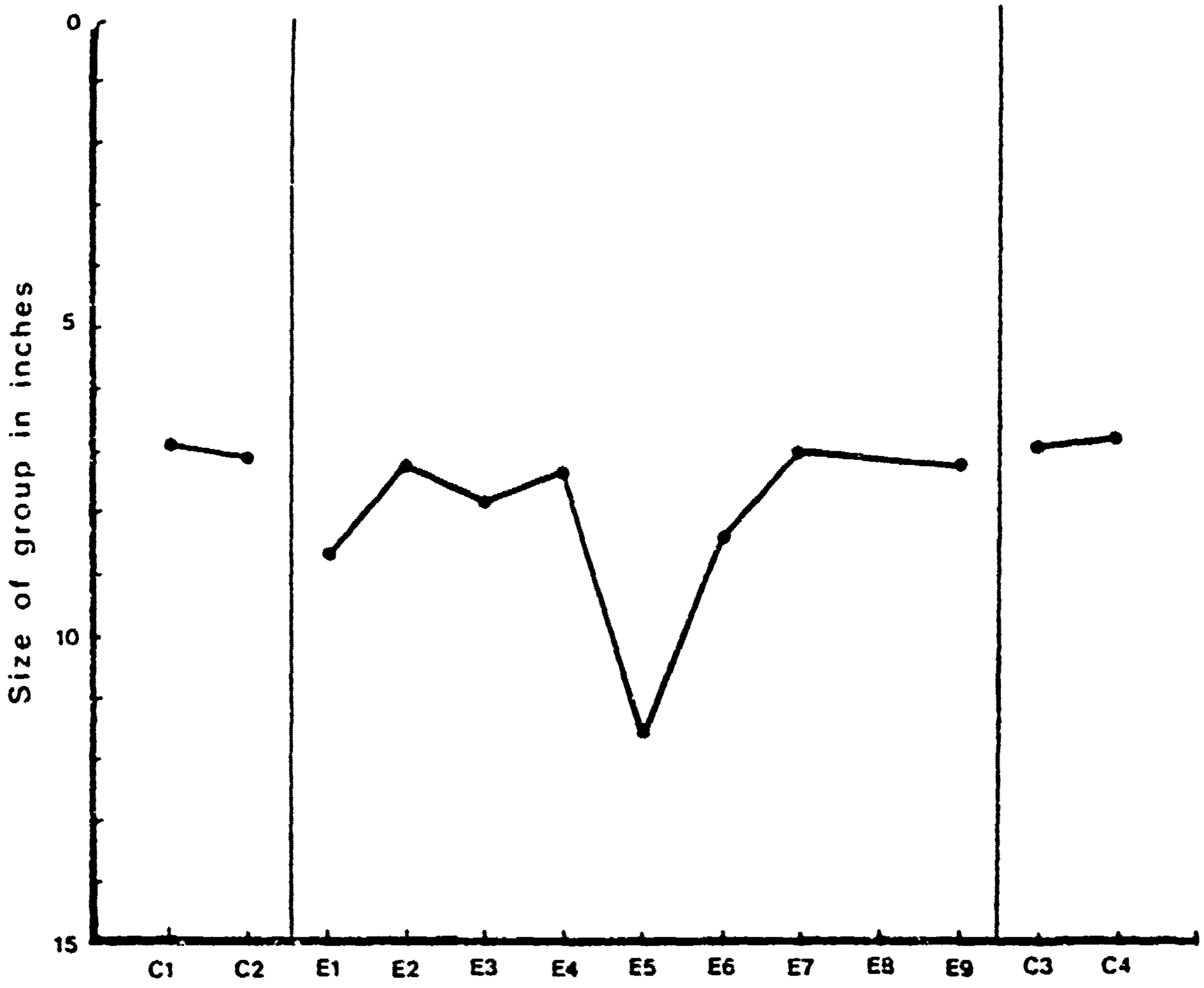

Figure 9. Grouping Capacity. Average size of group in inches.

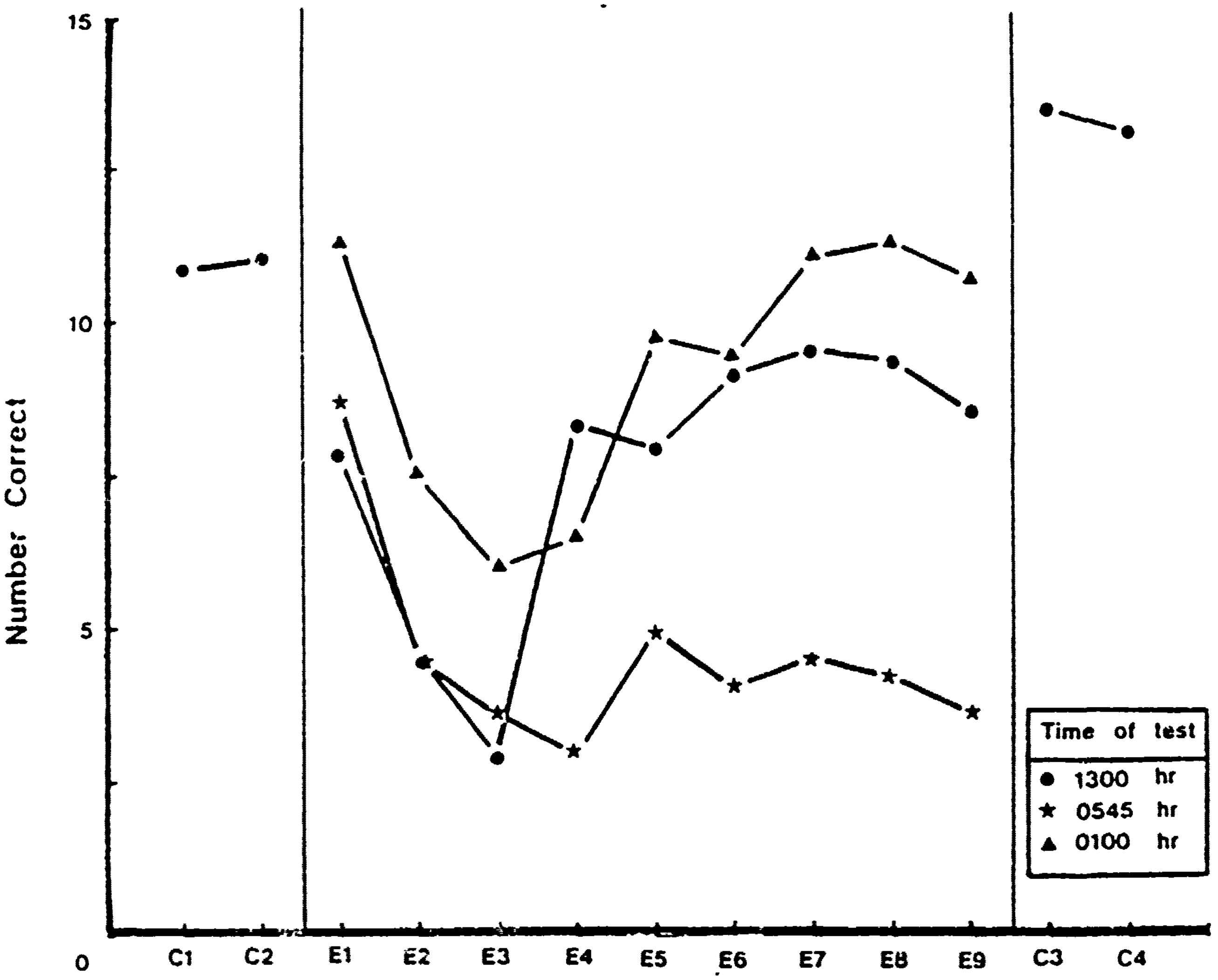

Figure 10. Logical Reasoning. Average number correct per page at different times of day.

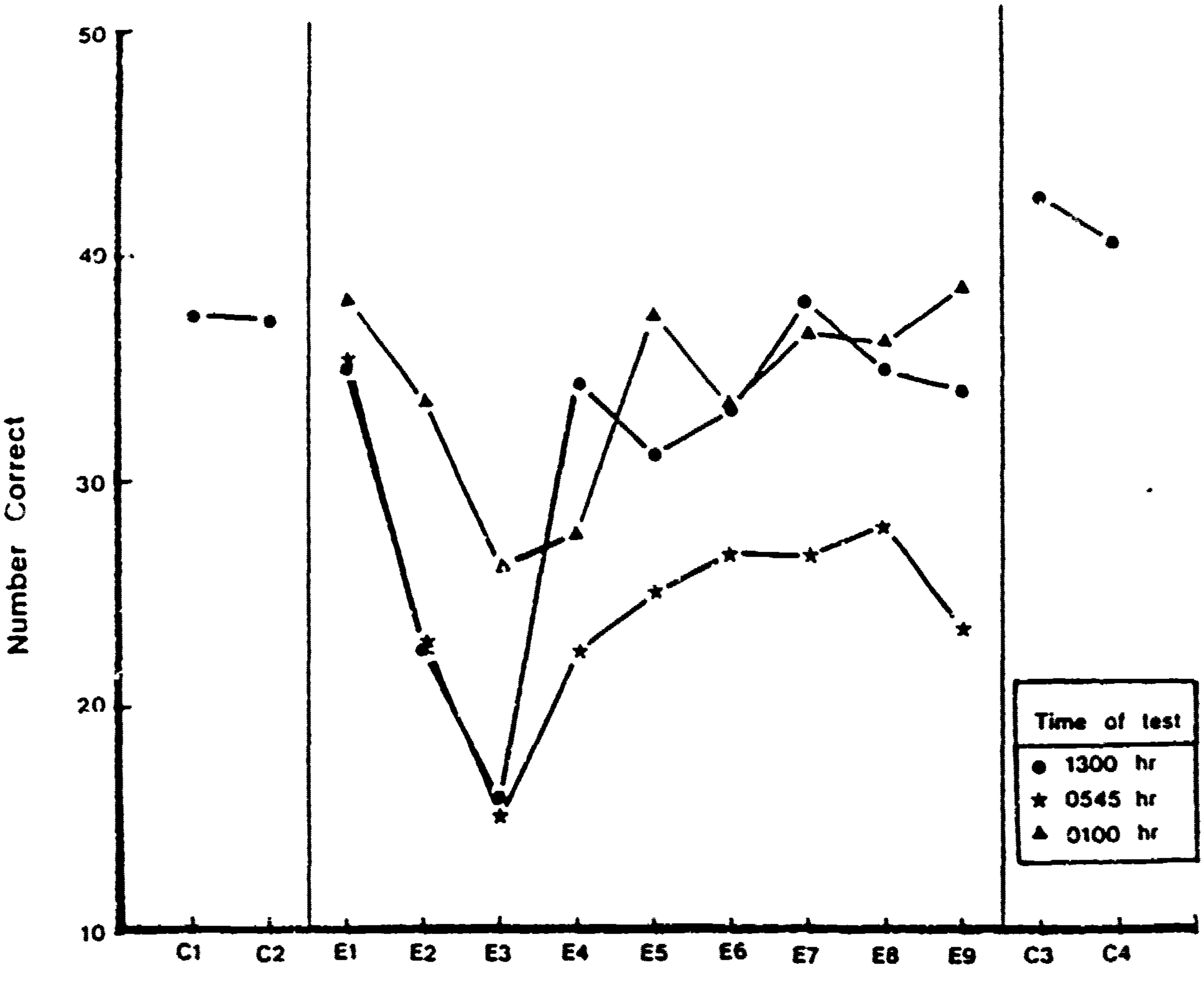

Figure 11. Decoding. Average number correct at different times of day.

Day 1 to Day 3, that is, until the first period of 4 hour scheduled sleep, and there were also increasing amounts of alpha activity. The average amount of unscheduled sleep during the whole of this period was approximately one hour.

It is of interest that one period of 4 hours sleep was enough to reverse the trend of increasing unscheduled sleep and increasing amounts of alpha activity although not enough to abolish them altogether.

Physiological and Biochemical Measures

No change in physiological status or physical fitness, defined here as strength and stamina, was observed, except that which lies within the limits of experimental error. No trend within the limits of experimental error was demonstrated.

With regard to rectal temperatures, the lack of change in the circadian pattern in the 2 control periods does not exclude the possibility of a shift having occurred at some point during the 10 intervening days with complete subsequent reversion to the former pattern. In addition, no adverse effects to the imposed regime were detected by the simple biochemical methods used.

Subjective Measures

Profile of mood states. Analysis of variance indicated that for all measures scores were significantly worse on the experimental days than on the control days ($p < .01$ or .001 in all cases). With the exception of fatigue, all scores were lowest on Day 5 (after 2 nights with 4 hours sleep), with gradual partial recovery to Day 8 or 9. Figures 12 and 13 show mean scores for Total Mood Disturbance and Fatigue. As can be seen in these figures, mood did not fully recover to pre-deprivation levels until after the Recovery Day, during which an approximate average amount of 19.5 hours (range 17-22) sleep was taken.

Military effectiveness. By Day 2, the subjects' movements, reactions, and speech were becoming slower. Four hours sleep, however, had a marked effect in that on Day 4, subjects were much more alert.

In response to simulated attacks by the "enemy" in the early hours of the morning, weapon handling deteriorated over the sleep deprivation days. It was not possible to observe the soldiers' defensive tactics on the nights of Day 4 to Day 9 because on these nights they slept from 0145-0545 hours. As in Early Call I, morale remained high (except for Day 5), and a relaxed leadership style was found to be effective when dealing with tired soldiers.

Discussion

Military Tasks

Vigilance shooting. Although with no scheduled sleep, performance decrement was only 20% compared with control values, this test was an indicator first of the effect of total sleep deprivation, and then of the effect of 4 hours sleep per 24 hours. The recovery which had occurred by Day 6 was maintained to Day 9.

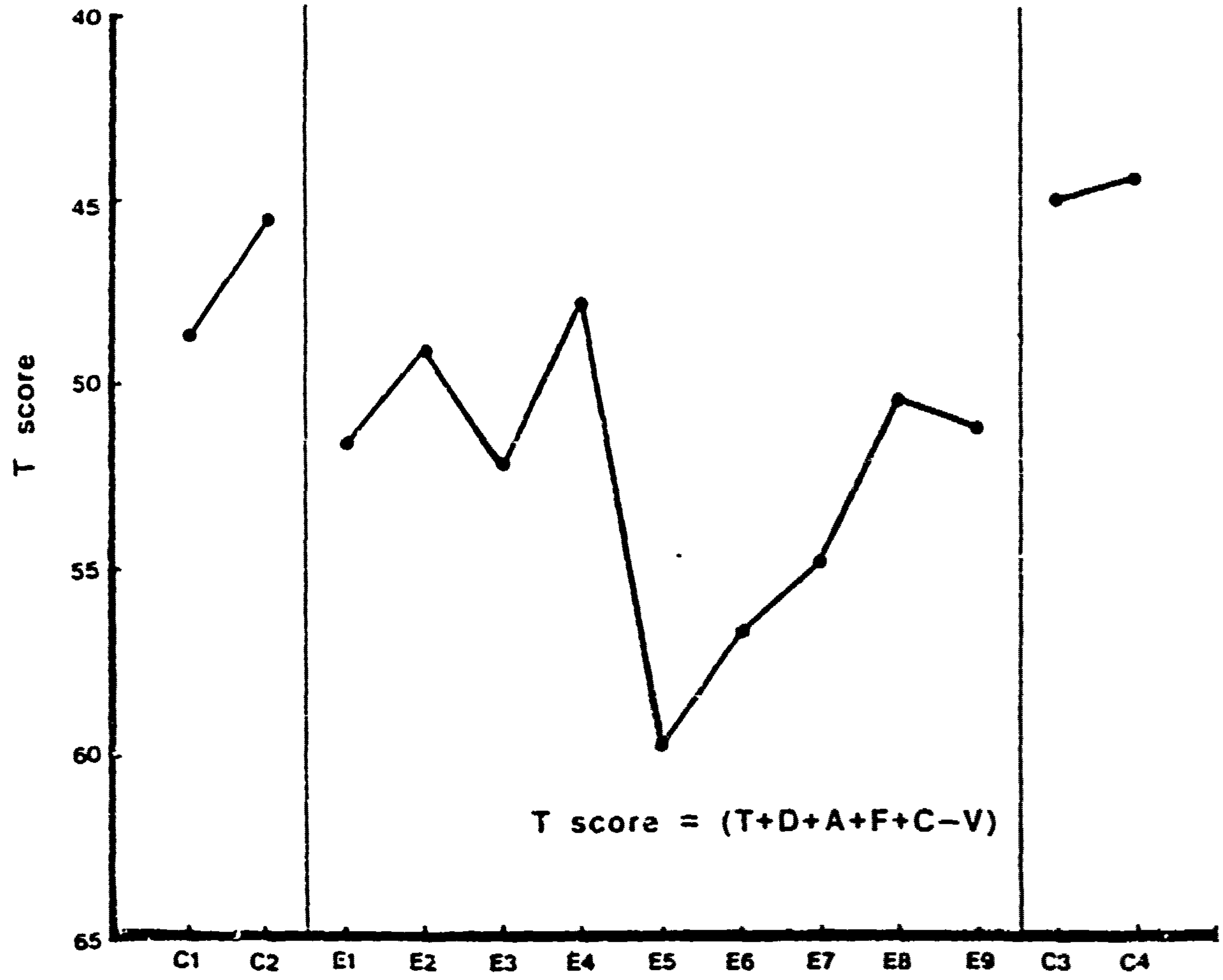

Figure 12. Profile of Mood States: Total Mood Disturbance average score.

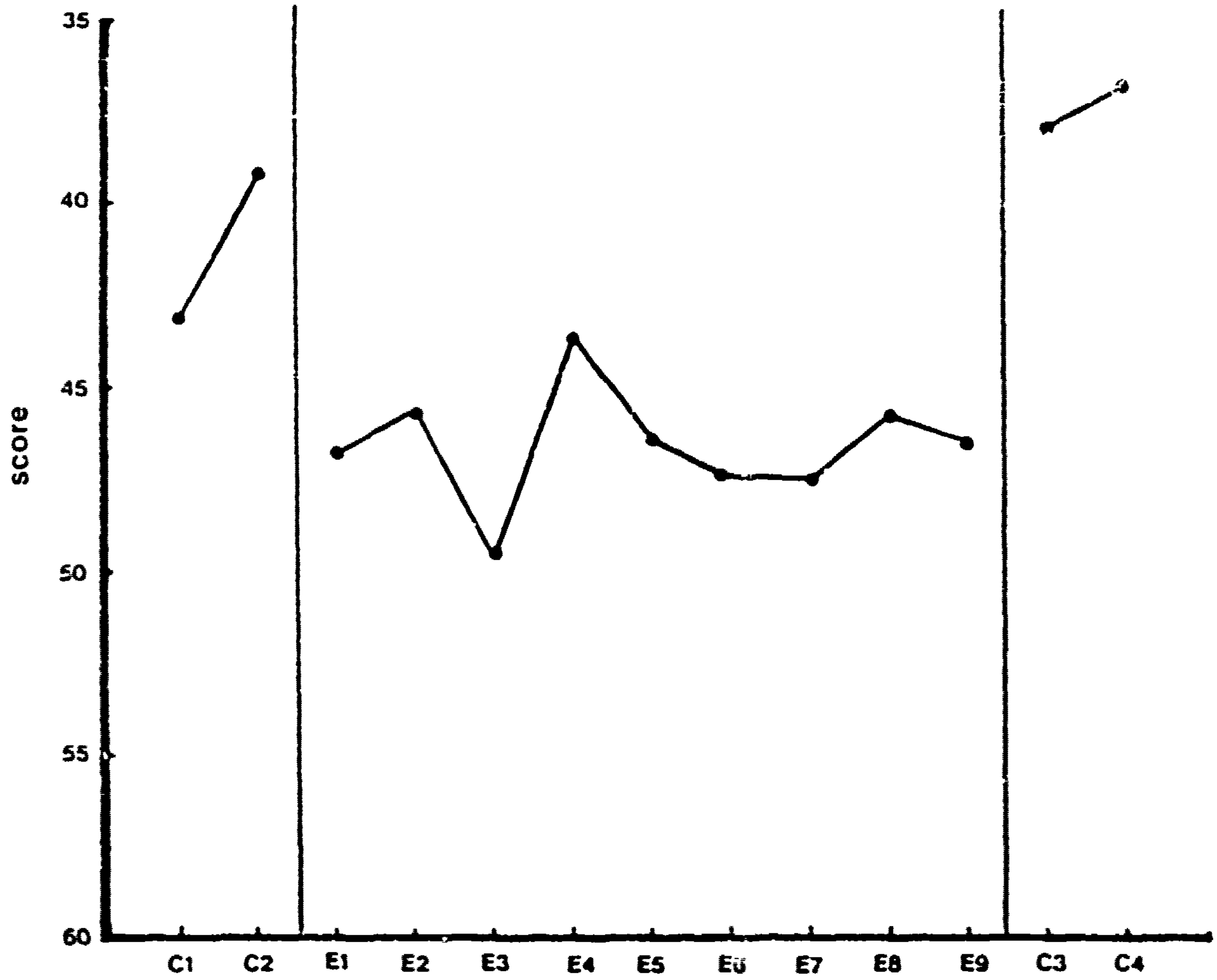

Figure 13. Profile of Mood States: Fatigue average score.

When the present results are compared with those for Early Call I, it can be seen that approximately the same percentage decrement was observed for the Platoon who had no scheduled sleep for 3 days. For the other 2 Platoons, one of which had 3 hours and the other 1.5 hours scheduled sleep in 24 hours, performance on the ninth day of sleep deprivation had deteriorated to the level where 37% and 28%, respectively, of the targets were hit.

Over the 9-day sleep deprivation period, the 1.5 hours sleep Platoon had a total of 13.5 hours scheduled sleep and the 3 hours sleep Platoon had a total of 27 hours scheduled sleep; these amounts span the Early Call II quota when subjects had a total of 24 hours scheduled sleep in 9 days.

Although it is interesting to make these comparisons, no further comment is justified because of the different conditions of the 2 trials.

In any event, 4 hours block sleep was found to have recuperative value for vigilance shooting performance, following a decrement when there was no scheduled sleep.

Grouping capacity. The drop in performance on some tasks on Day 5 was probably due less to sleep loss than to weather conditions, because a cold wind blowing in the subjects' faces that morning. The biggest fall in mood was also on Day 5. On that day, there was a change for the worse in the washing facilities and the subjects were told about this at midday by the military advisor to the trial. Grouping was carried out at 0900 hours; poor performance on Day 5 cannot, therefore, be attributed to the above. Apart from this drop, there was no statistically significant variation over the trial, and in this way the results are similar to those for Early Call I.

The results confirmed expectations that no overall deterioration would be found in grouping, a self-paced, well-learned task which was carried out under as controlled conditions as possible.

Cognitive Tests

Logical reasoning and decoding. The unexpected finding that performance in the Logical Reasoning test, and on Days 1-3 in the Decoding test also, was better at 0100 hours than at 1300 hours is probably attributable to the fact that subjects had recently been in a warm, dry building for 3 to 4 hours while carrying out the Physical Fitness tests. [It will be remembered that in Early Call I there was a marked improvement in nearly all tests after one night in camp, which subjects left immediately prior to their cognitive test session.]

The results indicate a drop in Logical Reasoning performance after one night without sleep, and in Decoding, a more mechanical task, after 2 nights without sleep. As little as 4 hours sleep clearly had a marked beneficial effect, except for Logical Reasoning at 0545 hours. This is the time of day when performance is usually at its worst (Colquhoun, Blake, & Edwards, 1968), and also when there is maximum interaction between sleep loss and circadian effects (Johnson & Naitoh, 1974). However, in this trial, there was an added effect, attributable to awakening. This effect has been shown to impair performance, with drowsiness persisting for at least 15 minutes in non-sleep-deprived subjects (Wilkinson & Stretton, 1971). For subjects suffering from loss of sleep, the effect may well last longer than this, and in this case would account for the less marked improvement at 0545 hours in the Decoding test compared with performance at the other two times of testing.

When considering these results, it should be remembered that in this trial there was no real spur to awakening, such as a threatening or demanding situation, to provide an arousing stimulus.

To sum up, it can be said that cognitive functioning began to deteriorate following one night without sleep, and on the third day of sleep loss was considerably impaired.

Four hours sleep per 24 hours had a beneficial effect which was less marked at 0545 hours than at 1300 and 0100 hours.

Electroencephalography

Physical activity. Quantifiable changes in physical activity, indicated by eye movements, movement artifact, and muscle activity, were recorded by the EEG, although no change in physical fitness was detected by a battery of 8 other physiological assessments. The EEG changes were in accordance with the qualitative observations made by directing staff, and corresponded closely with self-rated fluctuations in fatigue and vigour.

Sleep. One of the difficulties encountered in an exercise of this kind is that of ensuring that the amounts of sleep obtained coincide with the amounts planned and observed. In Early Call II, the tape recorders showed that:

(1) in the day in which 90 hours without sleep was reached, the average amount of unscheduled sleep was only 47 minutes;
(2) in the day following the first 4 hour sleep period, this amount was reduced to 17 minutes;
(3) the amounts of unscheduled sleep recorded agreed closely with those noted by observers.

Alpha Activity. In Early Call I, alpha activity was most prominent in the subjects on the "no sleep" schedule, and increased as sleeplessness accumulated in parallel with unscheduled sleep. This pattern was confirmed in Early Call II in a larger and more completely recorded group.

The general trend was for amounts of alpha activity to increase with sleeplessness and amounts of adventitious sleep in the group. To this extent, alpha activity could be regarded as akin to sleep, perhaps a half-awake state. Although some of the alpha activity was indeed "paradoxical alpha", i.e., alpha occurring in response to stimulation in a drowsy or lightly asleep subject, the greater part of it was not.

To sum up, it can be said that:

(1) There was a clearly demonstrable and quantifiable impairment of cerebral function as well as military performance in the absence of sleep for more than 48 hours;

(2) The effect could be offset to a limited but useful extent by as little as 4 hours sleep per day;
(3) It is felt, for various reasons that cannot be discussed here in the interests of brevity, that the stimulus of battle is unlikely to be sufficient to offset the impairment adequately.

Physiological and Biochemical Measures

The results show no change in physical fitness or in any other aspect of physiological status of any statistical significance or military importance. However, there remain a number of factors relating to experimental method and the nature of the trial which must be discussed before any predictions concerning operational performance can be considered valid.

The subjects were assessed in dry, well-lit and relatively warm conditions; this may have affected their physical status and performance to such a degree that the results may not reflect their condition as it was during the same period in the field. This hypothesis would, however, require a systematic difference in results between those who were consistently assessed at the beginning of the 3-hour period and those who consistently entered the physiological battery at the end of the 3-hour block. There was no such difference.

The lack of change in physical fitness, as measured, must be interpreted within the pattern of work rate demanded by trial tasks. With the exception of the early stages of establishing the defensive position and some of the military tasks, the trial was not physically demanding. It cannot be assumed that stability of stamina and strength would have been sustained had a greater level of physical demand been imposed within the same type of continuous operations scenario.

With regard to the absence of adverse biochemical findings, the psychological concomitants of an emergency cannot be reproduced during a controlled exercise, and it is emergency or threatening situations that are likely to induce biochemical changes.

Subjective Measures

Profile of mood states. The biggest fall was also on Day 5. On that day, there was a change for the worse in the washing facilities, and the subjects were told about this at midday [Grouping was carried out at 0900 hours; poor performance on Day 5 cannot, therefore, be attributed to the above.] by the military advisor to the trial. It is worth noting that the withdrawal of a privilege from tired soldiers can result in a deterioration in mood far greater than that induced by sleep-loss itself.

On the first control day following the rest day, subjects reported that they felt completely recovered. This was supported by the observers' accounts of boisterous and cheerful behaviour, and was reflected in the Mood Profile scores.

Military effectiveness. These results for weapon-handling can be compared with those for Early Call I when little deterioration was observed in the formal weapon-handling tests. Probable reasons for this discrepancy are that in Early Call I, the tests were carried out during the day in a situation in which there was no other activity whereas, in Early Call II, weapons were handled in the early hours of the morning in a tactical situation which, judging by their reactions, the subjects found stressful.

Thus, even well-learned skills have been found to break down in sleep-deprived subjects under stress at a time of day when performance has been shown to be at its worst (Colquhoun et al., 1968).

Conclusions

In summary, it can be said that cognitive and vigilance tasks began to deteriorate after one night without sleep, and, after 3 nights without sleep, performance on these tasks was considerably impaired. The introduction of 4 hours block sleep following 90 hours in which there was no scheduled sleep (and very little unscheduled sleep) had a marked beneficial effect upon performance and mood, and an average amount of 19.5 hours sleep at the end of the 9-day trial eliminated any remaining decrement.

Throughout the exercise, in which the amount of physical activity was moderate, there was no physiological evidence of deterioration in physical fitness; there was EEG evidence of alterations in cerebral function.

General Conslusions

To summarize, in exercises without combat stress,

(1) the effects of sleep loss are psychological rather than physiological;
(2) even small amounts of sleep are beneficial;
(3) with increasing sleep deprivation, there is an increasing likelihood of physiological sleep patterns developing in the brain;
(4) a hostile climate interacts with sleep loss and influences "survival" times.

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ARTILLERY TEAMS IN SIMULATED SUSTAINED COMBAT: PERFORMANCE AND OTHER MEASURES

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Scientific and Military Rationale

In modern war, military units are likely to be engaged in intense sustained operations which permit at best only brief, fragmented sleep. Army ground combat depends heavily on team functions which involve complex interactions of individual performance capability (both mental and physical), psychosocial behavior, biological responses to stress and fatigue, and system (team task) organization. Command/control and communications elements may be especially vulnerable to performance degradation, since their roles often keep them continuously occupied, while their critical tasks are ones especially sensitive to sleep loss and the physiological consequences of the battlefield environment (Johnson & Naitoh, 1974; Woodward & Nelson, 1974).

In evaluating the impact of such conditions upon one's ability to perform, the scientific literature (Johnson & Naiton, 1974; Woodward & Nelson, 1974; Davis & Behan, 1962; Horrocks & Gayer, 1959; Glanzer) indicates the importance of task, personnel, and organizational variables. These include: task complexity, feedback pacing, level of training, intrinsic interest in the task, prior experience, motivation, and social factors. Such variables are considered critical determinants of performance capability under a variety of conditions. Furthermore, in both modern Industrial Society and in the Armed Forces, tasks are increasingly organized around teams rather than individuals. In the military community, concerns are often expressed as to the generality and predictive validity of past studies which have not included such variables inherent in many military tasks. To address these issues and provide a framework for communicating research results to the military community the Field Artillery Fire Direction Center (FDC) was selected by the US Army Research Institute of Environmental Medicine (USARIEM) as a "model" team for study. It was postulated that such complex issues could be studies in a laboratory simulation which would use actual Army teams performing their normal functions, yet permit control and replication of environmental and situational conditions and measurement and correlation of mission effectiveness, behavior and biological process (Davis & Behan, 1962; Glanzer, Finan, 1962). This approach capitalizes on preexisting training, professional pride, social support and military task organization. Such factors are critical in the study of group military task performance, contribution of individual performance to system (team) output (Davis & Benan, 1962; Finan, 1962), and physiological as well as psychological responses to stress (Bourne; Mason, 1968).

The FDC team seemed well suited for scientific study and laboratory simulation since 1) FDCs are common and critical to successful ground combat operations, 2) FDC teams are located immediately behind the front lines and are exposed to most extent stresses, 3) FDC include tasks common to other command/control and communication elements, 4) Detailed scenarios can be developed to provide content validity and calibrated performance demands, 5) The task output provides quantifiable measures of both individual and team performance, 6) The compactness of FDCs allows collection of a wide range of biomedical and psychosocial data, 7) Many variables which influence performance capability are inherent in FDCs, and 8) The FDC provides a performance paradigm with operational criteria, recognized by the military community, with which various data arrays can be correlated.

FDC Tasks and Organization

In the Field Artillery, the FDC is a service center which receives requests from various individuals and agencies who require artillery shells to hit target areas. These targets are typically kilometers away and out of sight of the guns. In the US Army (at the Artillery battery level) 5 to 7 individuals work together as a team to process these requests. Manual FDCs have exhisted since World War I and have evolved to minimize errors and to insure that performance is extremely robust under a variety of adverse conditions. Roles, tasks, communication sequences and content, error detection and resolution capabilities, information readback procedures, etc. are well specified and practiced. Given this high degree of task and organizational specification, at both the individual and system levels, deviations from these guidelines can be used as another means for assessing operational efficiency. In order to understand variations in system output, individual team member task contributions and interactions can be isolated and analyzed.

A variety of tasks and functions are assumed by various FDC members (see Table I). These include: sending and receiving information with various radio sets, encoding and decoding numerical/cipher codes, maintaining current information on unit position and movement, plotting target coordinates on grid sheets and maps, measuring target distances and directions from the firing battery, determining ballistic factors with nomograms and slide rules, selecting correct courses of action according to prescribed standing operating procedures (SOP), detecting and correcting discrepant or erroneous information, and communicating relevant information to the firing battery. Many of these tasks are similar to classical laboratory tests of performance. In the FDC these tasks are sometimes embedded in contexts where conflicting priorities and interferences limit interpretation, but they do provide a basis for comparison with the scientific literature.

Project History and Purpose

Preliminary studies (Stokes, Banderet, Francesconi, Cymerman & Sampson, 1975; Francesconi & Cymerman, 1975) of FDC teams in 1974 were conducted at USARIEM at simulated altitudes of 400 and 4300m. These studies indicated that although FDC team members experienced acute mountain sickness (AMS) and were obobviously ill and uncomfortable, most continued to perform reasonably well. Furthermore, performance appeared more influenced by acute hypoxia than by AMS symptomatology. Subsequently the FDC team simulation was updated with the as-

Table 1

Major Duties for Field Artillery Fire Direction Center (FDC) Personnel

TEAM MEMBER	DUTY CODE	MAJOR DUTIES
Radio-Telephone Operator (RTO)	10	receives, transmits, reads back information with radio sets
	11	requests caller authentication
	12	gives radio caller information (when rounds fired, when rounds will impact, when mission complete, etc)
	13	decodes radio messages
	14	communicates decoded information to appropriate individuals
Horizontal Control Operator (HCO)	20	plots targets or adjustments and shifts from known locations
	21	determines target range and direction
Vertical Control Operator (VCO)	20	plots targets or adjustments and shifts from known locations
	21	determines target range and direction
	22	determines altitude difference between target and guns
	23	calculates altitude correction, i.e. site
	24	plots unit location and direction of movement
Computer (COM)	31	communicates fire commands to guns
	32	calculates ballistic correction factors
	33	calculates gun tube displacement (lateral and vertical)
	34	plots meteorological correction factors on graphical firing tables
	35	specifies priority target data to guns
	36	sends preplanned target data to guns
	37	cancels old preplanned targets
	38	sends updated ballistic data to guns
Fire Direction Officer (FDO)	41	specifies fire commands for guns
	42	calculates ballistic correction factors
	43	calculates gun tube displacement (lateral and vertical)
	44	plots meteorological correction factors on graphical firing tables

NOTE Duty codes are used in another Table sistance the US Army Field Artillery School (USAFAS) and the 82d Airborne Division to reflect current emphases on sustained combat and target preplanning, a technique to achieve speed and accuracy of Artillery fire for suppression of enemy weapons.

In 1977 multidisciplinary studies of FDC teams in simulated, sustained operations were conducted jointly by USARIEM, the Walter Reed Army Institute of Research (WRAIR),and the Naval Health Research Center(NHRC). These studies were to evaluate the FDC experimental model for future studies of environmental stress effects and countermeasures (USARIEM), physiological and social factors related to neuropsychiatric "combat exhaustion" (WRAIR), and "sleep logistics" (NHRC). Of principle concern to USARIEM was whether simulation of FDC operations would yield sensitive indices of individual and team efficiency related to hours in the sustained operations, task characteristics, level of training, etc. If so, such operational changes could be evaluated for correlation with biological, psychological, social, and/or organizational factors.

Methods

Standardization of Task Demands

Much of the precision of conventional laboratory performance paradigms was applied to the complex mission demands of the Field Artillery to document changes in FDC performance and to reduce extraneous variance. This methodology was incorporated into a detailed script ("scenario") of radio messages which provided the task demands, as well as the supporting documents for various situations, e.g. map overlays and unit SOP. The scenario represented a tactical battle played on 1:50,000 scale maps and followed current doctrine for light infantry with armored cavalry advancing against a well-equipped screening force. Task demands were communicated by role players to the FDC over three simulated radio nets; other role players provided the telephone communications of the nearby gun crews and controlled the sound effects of the firing guns.

To permit performance assessment with time the scenario was organized into equivalent 6 h epochs of mission demands. In each 6 h, events of differing importance complexity, and urgency, requiring different individual and team responses, recurred with sufficient frequency to permit event pooling for analysis of performance data.

Standard scenario mission demands (events) are summarized in Table II. Also shown for each major scenario mission demand are the immediacy of the required actions, the associated task demands, responsible team member(s), and feedback characteristics. Mission demand classes included: 1) Unplanned Missions--Calls for Artillery fires on an intial target which were often followed by several subsequent adjustments, i.e. repetitions with small variations. These missions involved targets not specified to the FDC previously. These demands were externally initiated and required immediate responses. Such demands evoked serial and task processing; timeliness could be sacrificed to maintain accuracy. Positive and negative feedback were given to the FDC from simulation role players based upon the timlines and accuracy of the FDC's responses. 2) Preplanning -- These tasks were initiated by the receipt of encoded preplanned target messages but required a delayed response from most team members. All team members were involved. Ultimately, firing data for each target, including 2 correction

Table 2

Major Mission Demands and Associated FDC Duties, Immediacy of Actions Required, Responsible Personnel, and Feedback Criteria

	REQUIRED ACTIONS[1]			MAJOR DUTIES[2, 3]					FEEDBACK	NEGATIVE FEEDBACK CRITERIA[4]	
MAJOR MISSION DEMANDS	No.	IMMEDIATE	DELAYED	RTO	NCO	VCO	COM	FDO	GIVEN?	ACCURACY (DEV. ≥ MILS)	LATENCY (≥ SEC)
1. UNPLANNED MISSIONS											
a) Initial Target	4	1,2,3,4,5	—	10,11,12	20,21	20,21	31,32,33	42,43	YES	30	120-180
b) Subsequent Adjusts	22	1,2,3,4,5	—	10,12	20,21	20,21	31,33	43	YES	30	60-90
2. PREPLANNING (Encoded Message Targets)	28	1	1,2,3,4,5	10,11,13,14	20,21	20,21,22,23	32,33,36,37	42,43	NO	NA	NA
3. PRIORITIZING (Priority Targets)	22	1,4	—	10,11	—	—	35	—	NO	NA	NA
4. ON CALL MISSIONS											
a) Preplanned Target	16	1,4,5	—	10,11,12	—	—	31	—	YES	30	20-60
b) Subsequent Shifts	8	1,2,3,4,5,	—		20,21	20,21	31,32,33	42,43	YES	30	60
5. REVISING (Caused By Battery Moves)	12	—	2,3,4,5	—	21	21,22,23	32,33,36	42,43	NO	NA	NA
6. UPDATING (Caused by Weather Changes)	12	1	4,5	10	—	—	34,32,33,38	44,42,43	NO	NA	NA
7. MULTIPLE SESSION SEQUENCES											
a) Unplanned Missions	variable	1,2,3,4,5,	—	10,11,12	20,21	20,21	31,32,33	42,43	YES	30	60-180
b) On Call Missions	7 - 9	1,2,3,4,5	—	10,11,12			31		YES	30	20-60
c) Nonstandard Missions	variable	1,2,3,4,5	—	10,11,12	20,21	20,21	31,32,33	41,42,43	NO	NA	NA
d) Adjusts & Shifts	15 - 23	1,2,3,4,5	—	10,12	20,21	20,21	31,32,33	42,43	NO	NA	NA
8. POSITION REPORTS	9	1	1,3	10,11,13,14	—	24	—	—	NO	NA	NA
9. LULLS (No New Mission Demands)	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10. NONSTANDARD MISSIONS	6 - 8	1,2,3,4,5	1,2,3,4,5	10,11,12,13,14	20,21	20,21,22,23	31,32,33	41,42,43	NO	NA	NA

FOOTNOTES:

[1] Team Member Codes
1 = RTO
2 = NCO
3 = VCO
4 = COM
5 = FDO

[2] Duty Codes (See Personnel Duties Table)

[3] Work-breakdown structure assumes teams followed SOP and they were also current in their preplanning.

[4] The most demanding criteria are shown; additional negative feedback for continued inadequacy on a mission would also be given

factors, were to be computed and sent to the guns as time permitted. No external feedback was given to the FDC. 3) Prioritizing -- At any time, 2 of 16 preplanned targets were designated as having priority to emphasize that an especially rapid and accurate response might be required on these targets. As with preplanning no feedback was given. 4) On-call Missions -- These demands were calls for Artillery fires on preplanned targets. Typically, they occurred at least 15 min after receipt of encoded preplanned target messages. These missions probed and reinforced the state of readiness achieved by target preplanning. External positive and negative feedback were given for timeliness and accuracy, but timeliness criteria were more demanding than those for the unplanned missions. 5) Revising -- These initial 12 preplanned targets were encountered at the beginning of each 6 h epoch. Task demands differed somewhat from those of preplanning. Target information was given to the FDC as a written list so that decoding and involvement from the RTO were not required. The targets were also preplotted on the chart sheets so the HCO and VCO did not have to plot them. In addition, since these mission demands were encountered immediately after the "battery move" personnel were reorienting and processing information associated with a new "terrain" location. 6) Updating -- These mission demands occurred approximately 150 min into each epoch. Updating was to improve ballistic correction factors on 12 preplanned targets. This task was the responsibility of the CCM, but failure to perform this task resulted in only inaccuracies in the preplanned target data.

As with other target preplanning activities (preplanning, prioritizing, and revising) no negative feedback was associated with inadequate updating performance. 7) Multiple Mission Sequences -- Periods of intense fire mission activity included: unplanned missions, on-call missions, non-standard missions, adjusts and shifts. These simultaneous demands were not as well matched as single events since interactions were unpredictable. External negative feedback was given less consistently for these events. 8) Position Reports -- These less important demands required decoding maneuver units' positions and plotting their locations. Such demands had minimal consequences for inadequate performance. 9) Lulls -- These were two 10-12 min intervals in which no new mission demands were sent to the FDC although irrelevant radio traffic continued. These events created a standardized setting, embedded among other demands, where social interactions might be more likely to occur. Such intervals could also be used to complete prior preplanning activities. 10) Nonstandard Fire Missions -- These demands occurred occasionally to provide content validity, add variety, make the sequence of standard events less predictable and evoke special responses. Such events were unmatched as to kind and difficulty but required similar durations to complete them.

Experimental Designs

Two experimental designs were utilized. The designs differed only in number of sustained challenges and their durations. Design I had a single 86 h operational challenge; whereas, Design II had two 38 h challenges separated by a 34 h rest and relaxation interval. Both designs had identical, pre-challenge familiarization and training trials. Design I was intended to produce serious or total breakdown in performance capability which would require major reorganization of team structure. This design was essentially an "open ended" challenge since 86 h was judged to be beyond the limits for sleep deprived subjects to perform such cognitive tasks. Design II was to evaluate the potential of the experimental model for use in repeated-measures designs.

Subjects and Simulation Facilities

The 5-man, FDC teams were males aged 18-24 and fully informed volunteers from two battalions of the 82d Airborne Division. These teams used manual fire direction procedures exclusively, without the assistance of digital computers. Accordingly, standard manual FDC equipment was assembled in a tent inside a 6.1 x 2.7 x 2.4 m climate-controlled chamber at USARIEM. Ambient temperature was maintained between 20 and 24°c and relative humidity between 35 and 50%. Lighting conditions were superior to those in field FDCs so that continous videotaping could be accomplished. Each subject was instrumented with a microphone and small radio transmitter for individual voice reproduction, a small physiological cassette recorder, wrist actograph, ECG electrodes and, in some instances, EEG electrodes.

Simulation Procedures

Each team received an inital 5 h orientation followed by 3 days of operations (8 h/day) at the work load used in subsequent sustained trails; this training was intended to teach the common SOP for message formats and fire commands. It also minimized practice and novelty effects. Teams 1 and 4 then underwent a single challenge which they were told could run 86 h (Design I). Teams 2 and 3 underwent two 38 h challenges separated by a 34 h rest (Design II); they were told the challenges would each run 36 to 42 h. All challenges began at 0700 h.

Prior to sustained operations challenge all FDC personnel were awakened at 0500 h. Subjects were fed and outfitted with the recording and monitoring equipment. The FDC personnel then entered the simulation facility and completed pre-challenge questionnaires and self-rated scales. Afterwards, at 0700 the operational portion of the simulation was begun. This corresponded to the beginning of a 6-h scenario epoch. Subjects in Design I were instructed not to set shifts or withdraw to sleep, but received no instructions about job rotation. Subjects in Design II were also instructed not to set shifts or sleep. In addition, they were not to rotate tasks. In the FDC the team and its individual members were challenged and driven by the scenario demands described previously. During the simulation performance-contingent, positive and negative feedback were given to the FDC for certain scenario events from simulation role players (see Table II). Accuracy deviations were defined as the algebraic difference in mils [The mil is a unit of angular displacment; 6400 mils = 360°] between each FDC team's firing data and the correct solution for the shell and propellent charge specified, as computed manually by the Department of Gunnery, USAFAS. Timeliness was the latency between mission input and the team's output.

Each 6 h approximately 48 min were spent in non-operational, administrative activities. These periods, in the final portion of each 6-h epoch, corresponded to the time required for the guns and FDC to make a tactical move. Team members went into an adjacent environmental chamber configured like the interior of a vehicle and heard recorded helicopter sounds. During the simulated move, self-report questionnaires and psychological tests were administered, urine and sometimes venapuncture samples were collected, electrodes and instrumentation were maintained by "field medics" and meals and snacks were eaten. During the simulation the FDC teams did not physically move the FDC, erect camouflage, or dig emplacements. Suplemented C-rations, hot coffee and soda were available ad lib throughout the simulation.

Between simulated operational challenges each team was housed in a dormitory and ate cafeteria food or t.v. dinners. All team members completed sleep logs upon awakening; EEG, EOG, ECG were recorded from selected subjects. Although investigators from WRAIR also collaborated in the design and conduct of the study, only selected data obtained by USARIEM and NHRC investigators will be presented in this report.

Performance Assessment

Performance indices were derived for system (team) output as well as individual performance. After the studies, accuracy and timeliness data were scored from an audio recording with time code and compared with a second independent determination. Any discrepancies were resolved by further rescoring of the audiotapes. Other performance indices were derived from the examination of FDC records, e.g. radio-log book, chart operators' plotting sheets, and CCM records. For data analysis/reduction, accuracy criteria were established and applied to all studies, i.e. $\leq \pm 3$ mils in horizontal and vertical gun tube displacement was considered accurate. Deviations $> \pm 3$ mils were grouped into classes depending upon the magnitude of the product of deflection and quandrant errors. In deriving other performance indices various metrics were utilized: differences between matched pairs, median values with 25th and 75th percentile values, percentage of uncompleted task demand, number of occurrences, and cumulative occurrences.

Results and Discussion

Overview

The teams differed substantially in organizational style, social history, prior experience, and mastery of the simulated mission demands. Generally, teams 1 and 4 showed less initial mastery and greater performance changes over time (Design I). All teams responded to the competitive challenges and became quite involved with the simulation (Stokes & Banderet, 1978; Annual Progess Report FY 77, 1978; Francesconi, Stokes, Banderet, & Kowal, 1978).

Team 1 exercised the right to withdraw from the study at 0700 h after 48 h. The VCO appeared somnolent in the last 6 h, resolved to terminate, and the FDO decided that the team should leave together. The team had also made several errors in the previous 8 h which "endangered" friendly troops; the FDO expressed concern that his team would soon be ineffective. Team 4 withdrew voluntarily at 0400 h after 45 h. The younger enlisted personnel of this team had the least field experience and were very fatigued. The FDO showed signs of being especially fatigued from his continuous supervision but persevered until the CCM prompted him for the decision to stop.

Team 2 completed both 38 h challenges without gross performance deterioration. The FDO, CCM, and the VCO slept very poorly the night before the second 38 h challenge. Some napping in place did occur during the final 18 h of the second challenge with limited substitution or switching of roles. Team 3 also completed both 38 h trials with little performance deterioration; they slept well in the interim. The VCO terminated ater 6 h of the second trial; the remaining four men took this as a challenge and continued with the FDO operating the chart.

System Output: Accuracy

For all teams, accuracy of firing data for unplanned missions was generally well maintained, even until termination. In contrast, accuracy of firing data for preplanned targets fired upon during on-call missions was less for all teams and deteriorated progressively over time in Teams 1 and 4. Figure 1 shows the distribution of errors of different magnitudes for all Teams during the simulations.

Teams 1 and 4 showed clear, progressive increases of 7-14 mil errors. These occurred most frequently in preplanned target events and usually involved omissions of correction factors under circumstances which could be considered speed-accuracy tradeoffs. Generating preplanned target data required increased effort in comparison to unplanned mission calculations, e.g. decoding of grid coordinates inclusion and updating of correction factors. In addition, negative feedback criteria for the on-call missions involving preplanned targets were more demanding, e.g. 20-60 vs 60-180 sec. Hence, many errors reflected deliberate omissions or misapplications of correction factors and produced errors of 7-14 mils. Teams 2 and 3 showed greater variability in accuracy for the on-call missions than for the unplanned missions, but no progressive deterioration.

Team 1 showed an increase of serious errors (30-1798 mils) from 24 to 48 h. For the other teams such an increase does not occur. These larger errors covered a wide range of FDC functions, e.g. incorrect copying or decoding of target coordinates, incorrect plotting of coordinates or reading of range or the deflection values, incorrect setting or reading of nomogram scales, digit reversals in the transmission of data to the guns, specification of the wrong propellant charge for the data sent, and sending data for a different preplanned target than intended.

The magnitude of any given error in ballistic firing data depends in part on the nature of the mistake and chance. In spite of this somewhat arbitrary relationship between error magnitude and psychophysiologic function, it is still valuable to examine these "outliers" because of their very serious potential consequences in live-fire training and combat. Since it is reasonable to expect the FDC team, especially the FDO and COM, to detect particularly large errors, the occurrence of such errors may imply a lapse in short-term memory, perception, or higher cognitive functioning.

System Output: Timeliness

Accuracy for firing data for unplanned missions was generally well maintained for all teams; however, timeliness for these missions suffered in all but one team. For example, Figure 2 shows median latencies to accomplish the most standard and predictable subset of these demands, the subsequent adjustments, increased more than 35% from initial values during sustained operations for Teams 1, 2, and 4. The differences within each team between initial and final 6-h performance latencies were statistically significant ($p \leq 0.05$ for Teams 1 and 2; $p \leq .01$ for Team 4).

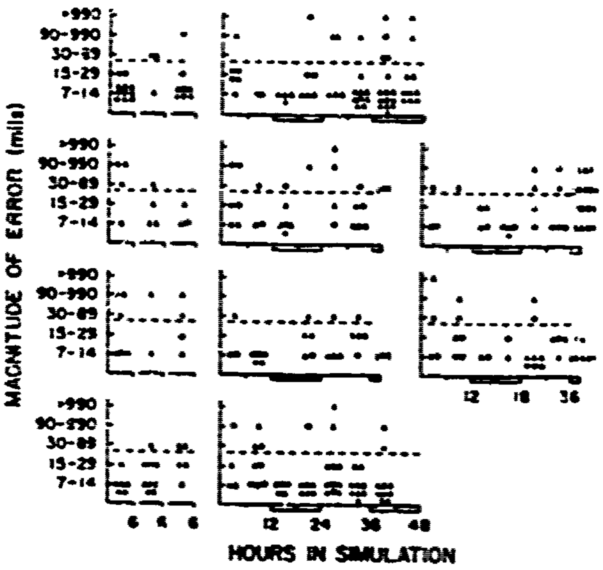

Figure 1. Errors in ballistic data (deviations from correct values) sent for firing by the four FDC teams. Errors were grouped in classes according to magnitude and are shown as a function of h in the simulation. Closed triangles indicate preplanned target errors; open circles, unplanned fire mission or subsequent adjustment errors. Errors > ±30 mils (above the broken line) usually incurred negative feedback from scenario role players regarding inaccuracy. Results for Teams 1,2,3, & 4 are arrayed from top to bottom; respectively.

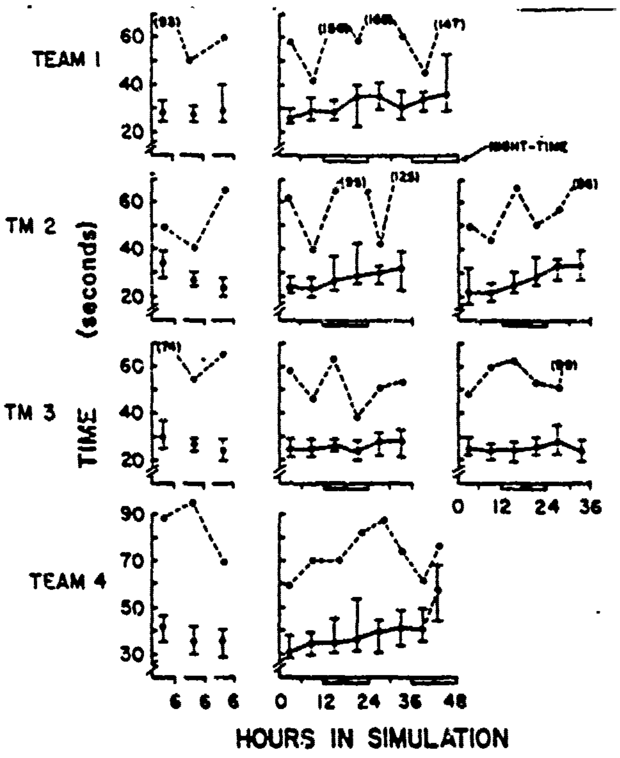

Figure 2. Computation latencies (standard adjustment sequences) for unplanned missions are shown as a function of h in the simulation for all four teams studied. Each data point with lower and upper bracket represents the 50, 25, and 75th percentile scores for a 6 h epoch. Maximum values are connected by the broken line.

The finding of increased latencies with little change in accuracies in the unplanned missions are as expected (Johnson & Naitoh, 1974; Woodward & Nelson, 1974) for highly overlearned tasks: 1) initiated by arousing external cues, 2) accomplished during a brief period of mobilization, and 3) which received prompt feedback for inadequate performance. It was apparent on the veido record that speed was sometimes sacrificed for accuracy through increased individual latencies and demands upon the team's internal double-check procedures. Such increased latencies are tactically significant. They indicate a loss of combat effectiveness for engaging battlefield targets and would increase FDC and battery vulnerability for detection and destruction by the enemy.

Timeliness for on-call missions, as well as accuracy, suffered in Teams 1 and 4, the teams undergoing the 86 h challenges (Design I). Latencies for firing upon preplanned targets (Figure 3) increased significantly after 42 h in Team 1 and after 30 h in Team 4 ($p< 0.01$). Teams 2 and 3 did not show a deterioration in speed of response to on-call missions although there was a period of slower responses from 18 to 30 h during Teams 2's second challenge ($p< 0.05$). These delays would also have serious tactical consequences in combat where delivery of Artillery fires within seconds on preplanned targets is essential to suppress hostile, wire-guided weapons.

As will be shown subsequently, Teams 1 and 4 were often behind on their preplanning. When an on-call mission was requested preplanned target data were often not precomputed nor available at the guns. This required data computation "on the spot". Increased latencies sometimes resulted for these teams; they also were more likely to make errors in haste or through deliberate omissions as they sought to respond quickly to on-call missions.

Systems Output: Preplanned Processing Efficiency

Examining the efficiency of preplanned target processing activities, (i.e. preplanning, prioritizing, revising, and updating) suggests how the observed differences in team effectiveness in responding to on-call mission events occurred. It has the added virtue of assessing the risk of serious mission failure for the total population of preplanned targets. Operationally, preplanning required processing target messages and sending the firing data for each target to the guns as soon as possible. Ideally, this was done well before a preplanned target was requested in an on-call mission, if indeed the target was requested (50-70% chance). Functionally, preplanning involved all team members; most individuals had to complete their work on a target before others could proceed (serial processing). Finally, unless quickly completed, other scenario events would inevitably interrupt the process.

One way to determine FDC efficiency was to apply queuing theory. For these analyses, the FDC was viewed as a service center to which users sent requests to be processed. Once processed, the resultant firing data for each target were called to the guns ready for delivery during possible subsequent on-call missions. The efficiency index of FDC performance was principally influenced by the number of requests in the queue and the processing time for each request. If the number of unprocessed preplanned targets increased and/or the interval between the request and when the data were called to the guns (processing time) increased, efficiency was decreased. Therefore, 0% efficiency meant no requests were ever processed; whereas, 100% implied instantaneous processing of each request.

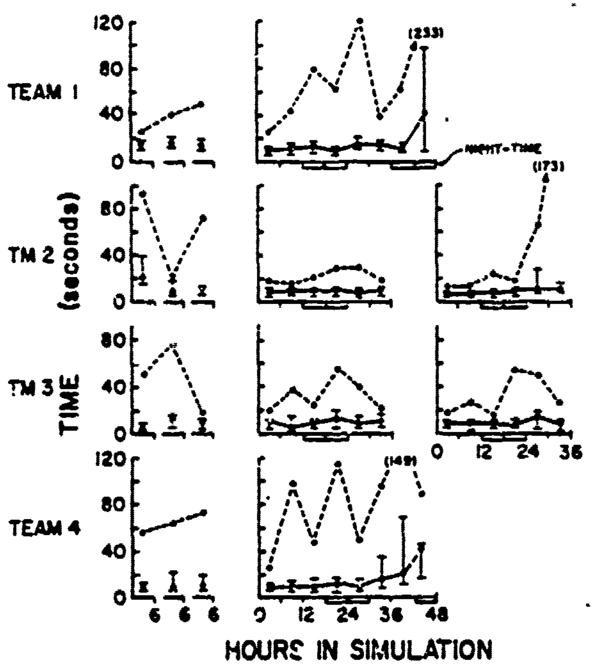

Figure 3. Latencies to on-call missions against preplanned targets as a function of h in the simulation are shown for all four teams studied. Each data point with lower and upper brackets represent the 50, 25, and 75th percentile scores for a 6- h epoch. Maximum values are connected by the broken line.

Figure 4 shows FDC efficiency with time for the four teams considering: 1) all preplanning, i.e. all targets sent in encoded target messages, 2) only prioritizing, i.e. those targets designated as having priority, 3) revising, i.e. the initial 12 preplanned targets after a battery move, and 4) updating, i.e. application of new weather correction factors to 12 preplanned targets for which data should have been generated previously by preplanning. All teams showed increased efficiency after the pretraining. During the sustained operations, Team 1's preplanning efficiency fell from a maximum of 77 to 33%, with most of that decrease in the last 6 h. For Team 4 the decrease was more gradual from 77 to 42% over 42 h, then falling to 18% in the last 3 h before termination. In contrast, Teams 2 and 3 processed preplanned targets more efficiently. Since Team 2 was usually prepared when preplanned target data were requested in an on-call mission they rarely made errors in haste, nor did they have to omit correction factors when called upon. Their efficiency in the second trial was slightly less; their minimum also occurred at 24-30 h. They also showed a greater decrease at 30-36 h than in the first challenge. Team 3's efficiency was between 75 and 68% during the first challenge, but was more variable (85 to 61%) in the second trial when functioning with only four men.

These results also indicated that in most cases, the teams maintained higher efficiency covering priority targets than the total population of targets. This would be expected given the operational significance of priority targets. The exception is Team 4, the least experienced team, who actually accomplished the priority target task less adequately than the preplanning task from 18 to 42 h. It is also of interest that prioritizing efficiency decreased with h in the simulation in Teams 1, 2 (2nd challenge), and 4. This occurred even though, on several occasions, preplanned data were already at the guns when a target was specified as priority by a simulation role player. Under these circumstances, each CCM only needed to announce the priority target number to the guns, but 3 of the 4 COMs increasingly failed to do so. Additional analyses are underway to determine why such changes occurred.

The importance given to a task by the initial instructions, the task's consequences, and the number of FDC team members involved with the task generally had a strong influence on the performance observed. The results of queuing analyses of the two less important tasks, revising and updating, are also shown in Figure 4. Failure to perform either task incurred only minor errors, i.e. 3-10 mils. Teams 1 and 4 both showed less efficiency in revising; Team 4 demonstrated <50% efficiency at the beginning of the challenge. Teams 2 and 3 were almost as efficient at revising as preplanning during both challenges. On the other hand, updating was rarely done by Team 1 and was quickly abandoned by Team 4 after initial token performance. For Team 2, updating was less efficient in the first and final 6 h of the first challenge; updating was the preplanning activity most sensitive to decrement between 24 and 30 h of the second challenge. For Team 3, updating was generally performed less efficiently than other preplanning activities and deteriorated more after 18 h in each challenge.

System Output: Unprocessed Preplanned Target Demands

The quantity of work never done may be more useful as an index of depletion of team reserve and decreased performance capacity than increased errors of latencies. Table III highlights the differences between the 4 teams on several preplanned activities for various duration comparisons. Table entries

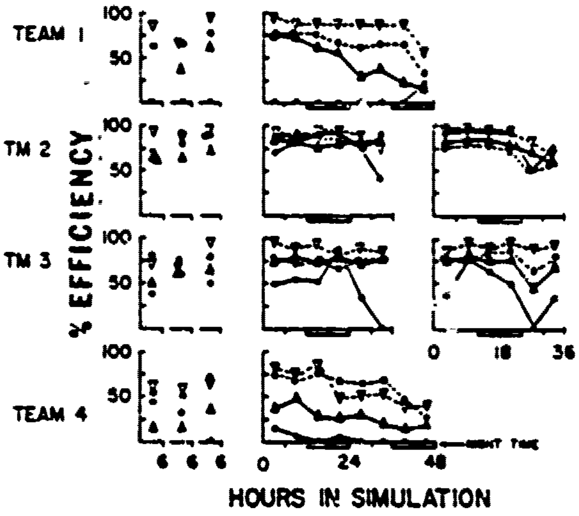

Figure 4. Queue Analysis measures of FDC efficiency for four preplanned target activities are shown for all four teams as a function of h in the simulation. Efficiency for targets which required updating are shown by closed circles; of targets which required revising, by closed triangles. Efficiency for preplanning new targets from encoded messages and for targets designated as priority are shown by open circles and open triangles, respectively.

Table 3

Percent. of Various Uncompleted, Preplanned Target Tasks. Values Are Shown for the 4 Teams Studied for the Initial 36 h in the Simulation. Second Challenge, 36 h Comparisons Are Also Shown for Teams 2 & 3. Team 1 & 4, 48 h Comparisons Are Also Indicated. Team 4 Values from the 45-48 h (Interval after Team 4's Termination) Were Extrapolated.

TEAM	PREPLANNING	PRIORITIZING	REVISING	UPDATING	% TOTAL TARGET PROCESSING NEVER COMPLETED
		INITIAL 36 HOUR COMPARISON (CHALLENGE 1)			
1	4	8	4	100	21
2	2	5	0	12	4
3	9	10	0	36	12
4	9	27	26	86	30
		SECOND 36 HOUR COMPARISON (CHALLENGE 2)			
2	2	11	0	11	6
3	12	7	0	19	10
		INITIAL 48 HOUR COMPARISON			
1	11	14	14	95	26
4	19	34	49	88	40

show the percentage of various preplanned target activities, as well as percentage of total target processing never completed. Several trends are evident. Preplanned target processing was less adequate at 36 h for Teams 1 and 4 (Design I) than for Teams 2 and 3 (Design II). Although one cannot rule out level of training, experience, and organizational variables these data suggest that uncertainties, expectancies, and demands of an 86 h challenge took an early toll on Teams 1 and 4. (This observation is further supported by trends in the biochemical and interaction process analysis data). Secondly, Team 4, the least experienced team, was the team with demonstrated the least adequate total target processing. Third, the challenge 1 and 2 data from Teams 2 and 3 indicated similiar outcomes on repeated measures. Lastly, this Table is consistent with the queuing analysis in that the updating task was the preplanned target activity most frequently not completed by all 4 teams. It is of interest, in contrast to other preplanned activities that the updating task was done by a single team member, and was not solicited, probed, or given external feedback. This provides a fitting lead into analysis of individual team performances.

Individual Team Member Performances

It is axiomatic that group performance is some complex resultant of the performances and interactions of the individual team members (3-5, 6). Hence, specific questions for these studies were: 1) Could meaningful individual performance data be extracted from the FDC simulation? 2) How does knowledge of an individual's performance increase understanding of system output? and 3) What are the characteristics of mission tasks which were sustained or degraded with time? Initial analyses have concentrated on Team 4 since they showed the greatest changes in system output and terminated in the middle of an operational epoch. Team 4's changes also occurred earlier in the simulation and were greater in magnitude.

The RTO is characteristically the newest member of the FDC but has a challenging task as a monitor and dispatcher of information. Table IV shows several measures of RTO performance deteriorated with increased h in the simulation even though each time period involved approximately equivalent message input and demands. Failures of the RTO to respond to the FDC's call sign are similar to the findings of classical vigilance studies (Johnson & Naitoh, 1974; Woodward & Nelson, 1974). Indeed, some occurrences appeared from observation of the video records to have reflected lapses into microsleep. Failure of the RTO to record the sender's call sign in the log book also increased after 24 h; such omissions contributed to confusion in the FDC if it became necessary to contact the sender. Other sensitive measures, e.g. the RTO's requests for the sender to "say again" items of information, and corrections in his log book, are behaviors which may compensate for microsleep, increased distractability or difficulties in perception. A fifth measures, the number of undecoded position reports in the log, was for a task which, like updating, was done by a single team member and had minimal consequences for inadequate perforformance. The numbers shown for this performance represented a rise from approximately 30% to 80% non-completion of task demand over the duration of the simulation. It must be emphasized that numerous measures of RTO performance did not change with time. For example, Table IV shows that the RTO almost always decoded preplanned target grids from the radio messages and passed this information to the HCO and VCO.

Table 4

Individual Performance Measures for Various Team 4 Members

PERFORMANCE MEASURE	STATISTIC	TEAM MEMBER	HOURS IN THE SIMULATION 0-12	12-24	24-36	36-48
Unresponsiveness to Call Sign	No.	RTO	1	7	8	6
Requests for "Say Again"	No.	RTO	1	12	28	27
Omissions in Logbook (Call Sign)	No.	RTO	0	2	8	4
Changes in Logbook Entry	No.	RTO	1	1	4	11
Unrecorded Position Reports	No.	RTO	17	27	34	36
Undecoded Targets from Messages	No.	RTO	0	0	4	0
Inaccurate Target Plots	%	HCO	8	16	28	38
		VCO	6	4	6	10
Unfinished Site Computations	%	HCO#	100	100	98	97
		VCO	15	18	28	63
Unplotted Targets From Messages	%	HCO	5	0	0*	48
		VCO	5	0	0*	61
Unprocessed Targets From Messages	%	COM	9	4	10*	61
Adjustment Information ratio (No. recorded/No. not recorded)	Ratio	COM	2.6	0.7	0.3	0.2
Changes Communicated To Guns	No.	COM	56	31	88	240

#The HCO normally does not perform this task.

*Excludes 4 targets not decoded by RTO.

Only one exception involving 4 targets occurred near the end of a 6 h epoch, a period when the team had little time for processing. It was shown in SYSTEM OUTPUT: PREPLANNED PROCESSING EFFICIENCY that Team 4's preplanning was one aspect of system performance which showed greatest differences from other teams. Less efficient processing, more errors, and failure to complete more and more targets were especially marked after 18 h in the simulation. As noted above, the RTO was consistent in completing his part of the task, although he contributed some longer latencies and committed some decoding errors.

The performance of the next team members in the serial preplanning tasks, the HCO and VCO, are also shown in Table IV. For % unplotted targets the performance of HCO and VCO was identical up to 30 h even though all task demands were rarely completed. This nonasymptotic correspondence suggests the influence of social and organizational factors. After 36 h, both showed decreased output, with the VCO completing substantially less of the task. However, the VCO's output presumably has a greaster influence on Team 4's accuracy for preplanned targets since he was consistently more precise in plotting than the HCO. Indeed, the probability that the HCO would produce an inaccurate plot increased progressively with time (p=0.08 to 0.36). Each time the values from the two charts failed to correspond within acceptable limits, extra time and involvement were required by the FDO, HCO, and VCO, while the COM had to wait.

Although the VCO was accurate and plotted a smaller number of targets, Table IV indicates he completed fewer site computations after 36 h. This measure of VCO performance suggests that the observed decrease in accuracy of Team 4's preplanned target data partially resulted from the failure of the VCO to compute this important correction factor. Thus, Table IV also highlights individual proficiency differences and performance changes with time which contributed to increased workload and disrupted information flow as the sustained operation continued.

Analysis of the COM's role in preplanning (Table IV) indicates that the COM consistently processed fewer targets from target messages than did the VCO except in the last epoch where their outputs were identical. Examination of the specific targets indicated that indeed, the COM allowed his performance at this task to be limited by the VCO, the chart operator who processed fewer targets, but more accurately than the HCO. Other measures of COM performance, i.e. adjustment information ratio and the number of changes communicated to the guns showed dramatic changes with h in the simulation, especially after 24 h. These trends are consistent with the time courses of many system output measures. This is not surprising. The COM has one of the more continuous tasks and is the person in the FDC who usually communicates with the guns. As his individual performance deteriorated, system output was also impacted. As the senior ranking enlisted person, the indirect impact on the team resulting from his losses in personal efficiency and his increased attention to task matters cannot be ignored either. Additional measures of COM performance are being derived from each COM's written records and from his verbal communications with the gun role players, to further document changes in efficiency of this critical individual.

Assessment of FDO performance over time presents the greatest challenge. The FDO's style of leadership and level of involvement in specific tasks properly varies depending upon the initial skills of team members and prior experiences of the team, as well as on any changes in individual/team efficiency with time. The Team 4 FDO provided task direction, double-checked charts, computed data, and showed concern for clearance of targets in restricted areas (another FDO responsibility) until he concurred with the COM's assessment that "the men have had it." Since the FDO was responsible for the team's output, the observed decrements technically represented decreased performance of his duties. It is moot whether this was due to degradation of his psychophysiological status or whether task demand (due to the decreased efficiency of the team) rose to exceed his span of control. Work is continuing to identify measures of FDO performance which can provide evidence of changes with time in sustained operations. Perhaps indices of FDO functioning may eventually be found in the analyses of team social processes currently underway.

The examples given for Team 4's RTO, HCO, VCO, and COM show how the present level of analysis enables one to infer differing organizational styles, individual capabilities and liabilities, and to determine how different members influence and set limits on team output. It should be emphasized again that the data arrayed were measures that changed with time; many others did not. This is an important observation since it suggests that when many of the real-world variables are incorporated into a performance study, (e.g., objective contingencies, task feedback, opportunities for "say again" requests, and double-checks), performance is likely to be more robust than that predicted by more traditional approaches to individual performance assessment.

Neuroendocrine, Physical Fitness and Sleep Findings

In addition to the evaluation of team and individual performance, many other biological and psychological measures were determined. These included: assays of urinary neuroendocrine hormones, tests of aerobic physical fitness and self-reports of sleep. For all measures it was recognized that individual differences would probably be important. The purpose of arraying these data was not to show universal relationships, but to illuminate patterns of change in the physiological and psychological statuses of individuals which would add perspective to the observed performances of teams and individuals. Only data from Teams 1 and 2 will be presented.

For Teams 1 and 2, aerobic fitness ($\dot{V}O_2$ max) of each individual was initially determined using the modified Taylor interrupted treadmill test. Subsequently, oxygen uptake ($\dot{V}O_2$ submax) and heart rate (HR submax) were measured using the Astrand bicycle ergometer at 60% of each individual's maximum capacity. These tests were conducted during the familiarization and pretraining week, immediately after each sustained operation, and after post-challenge (recovery) sleep. Each man's total urine output was collected every 6 h for 48 h during the familiarization week (after novelty effects were assumed to have attenuated). Urine collections continued every 6 h throughout the sustained operations. Aliquots were analyzed for 17-hydroxcosteroids (17-OHCS) and total catecholamines (Francesconi et al., 1978). Following every period of sleep in the dormitory all subjects filled out the NHRC Sleep Log.

Several explanatory hypotheses from the literature regarding the effects of sleep deprivation and stress on neuroendocrine response and on aerobic fitness may be helpful in interpreting the sometimes opposing responses of individual subjects. Urinary 17-OHCS have been related to generalized "stress" and especially to the perception of novelty, uncertainty or threat (Bourn). Total urinary catecholamines generally have been related to arousal level (Mason, 1968). Increased oxygen uptake at rest and during submaximal work (Harris & O'Hanlon, 1972) after sleep loss or in other stress situations has been interpreted as reflecting a metabolic shift from carbohydrate to fat utilization, presumably in response to neuroendocrine effects.

The results for Team 1 are summarized in Table V. four individuals showed increases in total catecholamine excretion over the 48 h sustained operation compared with the control period. Three also had elevated 17-OHCS excretions, although COM, the sergeant, showed a decrease. Urine collections were incomplete for the HCO, but in 6-h samples from equivalent times of day, he too tended to show higher catecholamines and 17-OHCS during the sustained operation. The 17-OHCS rise was especially great (55%) in the RTO, who had not been with the team long but had been picked to come to USARIEM (at his own request) in place of the regular RTO.

Team 1's junior enlisted men (RTO, VCO, HCO) had increased $\dot{V}O_2$ submax and HR submax at the end of the 48 h challenge, implying decreased aerobic fitness (i.e. increased physiological "cost" to perform the same work". The change in team mean HR was significant ($p<.05$), but notably the FDO and COM showed little change in HR and decreases in $\dot{V}O_2$ submax. Following a day and a night of recovery sleep, the HCO and VCO showed further increases in $\dot{V}O_2$ submax and COM's values were now increased, although the RTO had improved. It is interesting that the HCO, the man whose voluntary termination precipitated the team's withdrawal, showed the greatest relative increases in $\dot{V}O_2$ and HR. The Sleep Log indicated that the HCO slept less than usual the night before the trial and reproted himself less than fully alert upon awakening; this may have contributed to his apparent greater fatigue in the hours before termination. However, motivational factors clearly exerted an influence. The RTO (who, as noted above, had shown high motivation to participate) slept poorly throughout the entire baseline period (4 h vs his reported usual 8.5 h), but began the test reporting peak alertness. He, in contrast to the HCO, expressed disappointment when the challenge terminated at 48 h.

Team 2 results are also arrayed in Table V. Like Team 1, physical fitness after the first sustained challenge varied compared with control. However, all five members of Team 2 demonstrated increased $\dot{V}O_2$ submax and HR submax at the end of the second 38 h test and following the subsequent night's sleep; these changes were highly significant for both $\dot{V}O_2$ and HR ($p<.001$). The effect was evident in the FDO, COM, and RTO, individuals with the most continuous tasks. Sleep Logs showed that Team 2's FDO and VCO slept poorly and reported feeling sleepy before the first 38 h challenge. All team members slept well immediately after the first trial, but the FDO, VCO, HCO, and COM slept poorly the night before the second challenge and gave ratings of fatigue. Clearly, in the final hours of the second 38 h challenge, these team members (especially FDO and VCO) had accumlated sleep debts substantially greater than from just one night of deprivation.

In Team 2 the FDO consistently excreted less 17-OHCS and less catecholamines during the sustained operations than during the control period. The RTO showed even greater decreases in 17-OHCS as well as decreased catecholamines. The COM's excretion of 17-OHCS first increased in Challenge 1, but decreased

Table 5

Measures of Neuroendocrine Acitvity, Aerobic Physical Fitness, and Self-Reported Sleep of Individuals in Teams 1 & 2

		TEAM 1 MEMBERS					TEAM 2 MEMBERS				
MEASURE	CONDITION	FDO	COM	RTO	VCO	HCO	FDO	COM	RTO	VCO	HCO
Total Sleep (h) from NHRC Log	Control ($\bar{x}$ 5 nights)	6.4	6.2	4.2	7.1	7.2	6.7	5.8	7.0	7.2	7.1
	Pre-Challenge 1	6.5	7.0	5.5	7.0	5.5	4.5	6.0	6.5	3.0	6.5
	Post-Challenge 1	——	——	——	——	——	2.5	11.0	12.0	13.0	14.0
	Pre-Challenge 2	——	——	——	——	——	1.0	4.5	6.5	3.5	5.0
Urinary 17-OHCS (total mg)	Control*	12.7	14.2	13.7	10.2	——	0.4	8.9	11.0	——	7.5
	Challenge 1*	15.8	13.7	21.2	12.2	——	7.4	12.0	7.0	——	10.6
	Challenge 2*	——	——	——	——	——	6.0	7.2	2.5	——	10.8
Urinary Catechols. total μgm)	Control*	353	179	246	192	——	153	115	121	——	80
	Challenge 1*	365	202	307	267	——	116	181	104	——	87
	Challenge 2*	——	——	——	——	——	125	196	112	——	84
Submaximal Work $\dot{V}O_2$ (ml/kg·min)	Control	24.2	30.9	25.3	32.7	29.4	34.9	39.3	38.6	38.2	30.0
	Post-Challenge 1	20.5	29.5	32.2	34.9	31.1	37.2	42.6	38.4	32.2	30.6
	Post-Rest 1#	24.0	33.7	23.3	36.7	37.7	32.6	32.0	38.2	36.3	25.9
	Post-Challenge 2	——	——	——	——	——	41.4	41.5	45.5	37.1	30.2
	Post-Rest 2#	——	——	——	——	——	44.6	47.9	44.6	44.2	34.3
Submaximal Work Heart Rate (bpm)	Control	148	143	150	150	135	120	165	157	164	153
	Post-Challenge 1	147	145	157	168	160	115	170	169	152	156
	Post-Rest 1#	150	147	160	166	168	110	168	180	170	160
	Post-Challenge 2	——	——	——	——	——	135	180	181	174	168
	Post-Rest 2#	——	——	——	——	——	137	181	183	170	175

NOTES: *48 h for Team 1, 36 h for Team 2

#Sleep and light activity totalling 27 h for Team 1, 13 h for Team 2 during Challenge 2, compared to control. His catecholamines excretion, however, was elevated throughout both tests. The HCO had elevated urinary 17-OHCS during both challenges with negligible increases in total catecholamines. Collections from the VCO were inadequate in all conditions; his catecholamines appear consistently decreased in both experimental challenges compared with control, while there was no clear trend for 17-OHCS.

In summary, findings in Teams 1 and 2 suggest that sustained operations involving high mental workloads which preclude sleep may temporarily reduce physical aerobic endurance, and that this may not be reversed by a single night's sleep. Neuroendocrine responses during sustained operations ranged widely, with most Team 1 members showing increased excretions while most Team 2 members had decreases. The elevations of catecholamines and 17-OHCS in Team 1 may reasonably be attributed to the arousal, novelty and uncertainty inherent in the 86 h "openended" design and the fact that Team 1 was the first team to participate in the simulation. Interestingly, the HCO, the only member of Team 2 who showed elevations of both catecholamines and 17-OHCS, verbalized doubts after 28 h in the second challenge that the CCM could finish. The HCO was answered by the FDO, that the CCM had gone 38 h before and could do it again.

It might be argued that those individuals who showed decreased 17-OHCS were not "stressed" by the sustained operations. However, other evidence documents that they were certainly uncomfortable from the sleeplessness and confinement in the simulation. Furthermore, the sleep disturbances in Team 2 prior to the second challenge suggested a high level of anticipatory anxiety, especially in the FDO. Interpersonal tension between Team 2's FDO and the four enlisted men was high and persisted after the study was over. However, novelty and uncertainty were minimized in Design II, especially in the second challenge. Indeed, Team 2 complained that they knew all too well what they were in for. The finding of decreased 17-OHCS in some Team 2 subjects (and in the Team 1 CCM) is therefore consistent with the reports (Bourne) that this biochemical indicator may show suppression in experienced Army team members who are concentrating on well-learned tasks in spite of stress, espeically if the situation is relatively predictable and they are confident they can cope.

It should not be concluded from these findings, or from the performance results, that 48 h is a true limit for adequate sustained operations for FDCs (or for other teams with similar functions and tasks). It is likely that the circadian low which normally occurs between 0300 and 0700 h had a role in the decisions of the Design I teams to terminate. Had combat contingencies been involved, the teams could have continued for some uncertain time, perhaps with cycling or progressively deteriorating effectiveness. This study does support the expectation that well-trained manual FDC teams can function effectively in high task load situations for 38 h without sleep (assuming they are not chronically fatigued at the outset and that environmental conditions are benign). This may require increased reliance on double-check procedures and some trade-off speed to maintain accuracy. A rest interval of 34 h (and probably less) should be adequate to restore the ability to sustain another 38 h challenge. However, Team 2 demonstrated the problem in "sleep logistics" that simple provision of time, even in a favorable environment, cannot assure good quality sleep. Recurrent stress without adequate recovery may result in greater physiological "cost" and eventual performance degradation.

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THE CIRCADIAN PATTERN OF UNRESTRICTED SLEEP AND ITS RELATION TO BODY TEMPERATURE, HORMONES, AND ALERTNESS

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For many individuals shift work is detrimental to health and well-being (cf. Maurice, 1975; Agervold, 1976; Åkerstedt & Fröberg, 1976, 1979; Rutenfranz, Colquhoun, Knauth, & Ghata, 1977). The major problem is to keep awake during the night shift and to be able to sleep during the subsequent day. For a long time the cause of disturbed day sleep was attributed to factors in the environment and many survey studies tried to establish which factors were most disturbing. While extemely noisy environmental conditions, of course, will affect sleep, it now appears that the normal range of sleep environments (e.g. housing conditions) can hardly be of more than marginal importance as shown e.g., in survey studies by Aanonsen (1964), Åkerstedt and Zamore (1977), Åkerstedt and Torsvall (1977). This is supported by the fact that EEG-recorded sleep of shift workers has been found to be shorter and to have a different distribution during day sleep not only at home but also under noise-free environmental conditions in the laboratory (Bryden & Holdstock, 1973; Ehrenstein, Müller-Limmroth, Schaffler, & Thebaud, 1970; Foret & Benoit, 1972, 1974, 1978; Matsumoto, 1978). Also studies of night workers without a comparable day shift show unusually short sleep during the day (Lille, 1967; Kripke, Cook, & Lewis, 1971).

Typical sleep problems may be illustrated by results from one of our own studies. In Figure 1 are presented data from 3-shift work with an exceptionally early shift change schedule of 0445h-1245h-2045h. Self-ratings ranged from "never" to "practically always", scored from 1 to 4. The figure shows that the unrestricted sleep after the afternoon shift was longest and most satisfying. Night sleep before the morning shift was short and very early terminated (by the alarm clock). Day sleep after the night shift was as short as the night sleep and as little satisfying. In spite of day sleep being unrestricted, subjects reported that they were unable to retain sleep. In addition, sleep length after the night shift correlated r = .65 (p <.001) with satisfaction with sleep while no such relation was found for the other shifts Thus, the questionnaire data suggest that day sleep is inferior to night sleep because of "internal" factors terminating sleep too early.

The cause of the difficulties of day time sleep may be the conflict between the sleep/wake pattern demanded by work and the conditions offered by the circadian system (cf. Aschoff, 1978). Thus, sleep may presumably be differentially successful depending on circadian phase. The deactivation required by sleep may be interfered with by the high day time levels of activation while low levels of activation during the night may conflict with the demands required by work tasks. As far as we can see, the circadian aspects of unrestricted sleep have not been systematically studied. They have been touched upon mainly in comparisons of day and night sleep in shift work studies as

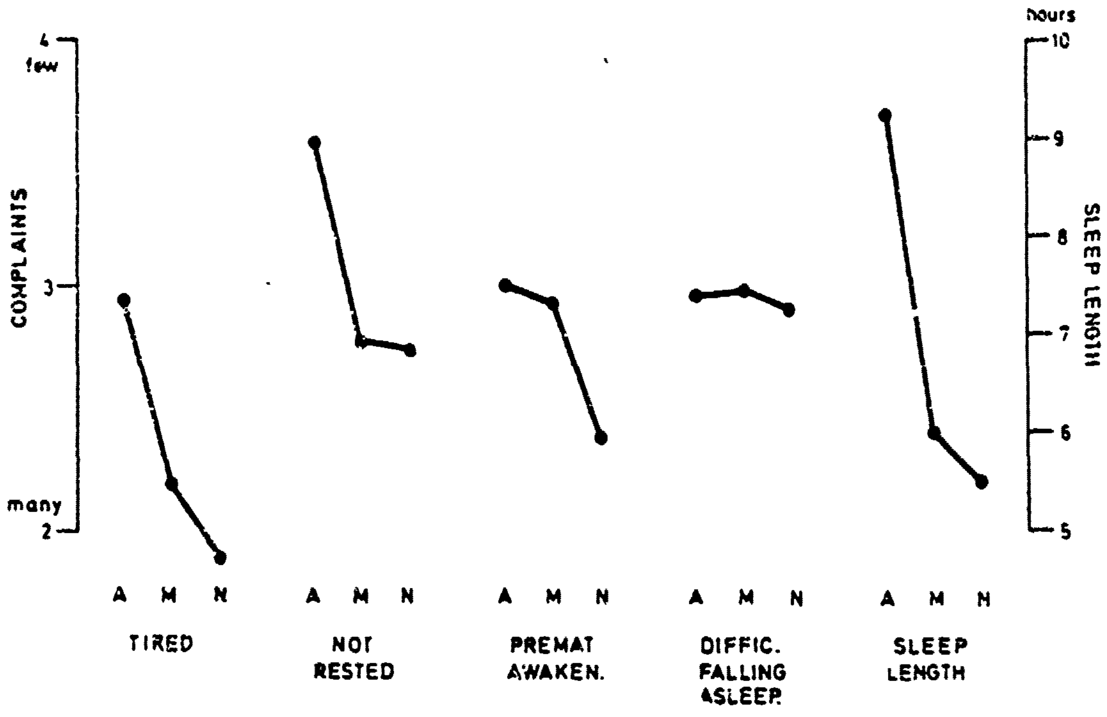

Figure 1. Sleep length and self-ratings of sleep quality in a group of 300 3-shift workers on morning (M), afternoon (A), and night shifts (N).

cited above, and in laboratory simulations of phase shifts (Weitzman, Kripke, Goldmacher, McGregor, & Nogeire, 1970; Berger, Walker, Scott, Magnuson, & Pollack,1971; Webb, Agnew, & Williams, 1971; Knauth & Rutenfranz, 1972; Evans, Christie, Lewis, Daly, & Moore-Robinson, 1972; Taub & Berger, 1973a, b, 1974, 1976; Webb & Agnew, 1978). The laboratory simulations, however, do not show the same impaired day sleep as the field studies.

Information on circadian properties of sleep has also been obtained from studies of scheduled napping. Studies of day time naps have shown that REM sleep is concentrated to the morning hours, while slow wave sleep (SWS) is a function of the amount of prior wakefulness (Maron, Rechtschaffen, & Wolpert, 1964; Webb, Agnew, & Sterntahl, 1966; Webb & Agnew, 1967; Karacan, Finley, Williams, & Hursch, 1970; Webb & Agnew, 1971a, b; Agnew & Webb, 1973). The day time nap studies have also been extended to cover the entire nychthemeron in regimes with several consecutive ultradian sleep/wake cycles (Weitzman, Nogeire, Perlow, Fukushima, Sassin, McGregor, Gallagher, & Hellman, 1974; Moses, Hord, Lubin, Johnson, & Naitoh, 1975; Webb & Agnew, 1975, 1977; Carskadon, & Dement, 1975, 1977; Lubin, Hord, Tracy, & Johnson, 1976; Hume & Mills, 1977; Moses, Lubin, Naitoh, & Johnson, 1978). Generally, these studies have confirmed the pronounced circadian patterning of sleep. However, interesting as these "nap" studies are, it is doubtful whether they can be applied to the shift work situation. Restricted ultradian sleep/wake regimes, as several authors point out, certainly are not miniatures of normal, unrestricted sleep.

If sleep does show a pronounced circadian rhythmicity there is an obvious interest in knowing why this occurs, or at least to know which other circadian parameters may be predictive of sleep characteristics. Nothing conclusive has been published on this subject although there exist some indirect data, particularly in relation to body temperature. Thus, the large number of isolation studies of the Aschoff group show that sleep during free-run tends to commence shortly before the temperature trough and end shortly before the peak (cf. Wever, 1979). Such results have been confirmed by Weitzman, Czeisler, Fusco, and Moore-Ede (1976). Zulley (1979) has shown a relation to exist between sleep during free-run and the temporal position of the circadian temperature trough. For night and morning sleep, results by Breithaupt, Hildebrandt, Dohre, Josch, Sieber, and Werner (1978) show shorter sleep being associated with increasing body temperature. For ultradian sleep/wake studies Moses et al. (1975) and Weitzman et al. (1974) have shown negative intraindividual correlations between body temperature and sleep length. Finally, case studies of patients with free-running rhythms have found clear relations between the circadian rhythm of body temperature and the positioning of sleep, the latter being difficult on the rising portion of the temperature rhythm (Kokkoris, Weitzman, Pollack, Spielman, Czeisler, & Bradlow, 1978; Miles, Raynal, & Wilson, 1977). Very little data exist on the relation between sleep and other circadian parameters.

As an independent variable, sleep strongly affects the physiology; it may e.g., synchronize the circadian system (Webb & Agnew, 1974; Aschoff, 1978; Wever,1979). Aside from such central effects on the pacemaker(s), the effects of sleep on the overt manifestations of rhythms will interfere with attempts to estimate the phasing of the central pacemaker. Such "masking" effects (Aschoff, 1978; Mills, Minors, & Waterhouse, 1978) may lead to entirely false conclusions about the extent of circadian adjustment. However, little is yet known about such effects.

Some of our recent research has a bearing on the issues discussed above and may be of relevance to the theme of this symposium. The purpose of the present paper is to summarize the relevant results from this research. In particular, attention will be focussed on the circadian pattern of unrestricted sleep and its relation to, and effect on other circadian rhythms of possible importance to sleep/wake alternation, e.g., subjective alertness, body temperature, and the urinary excretion of catecholamines, cortisol, and melatonin. Data are still being analysed and the results to be presented are preliminary.

Methods

The investigation was carried out with six subjects in the age range 29-45 yr. The subjects were exposed to one sleep session/condition per week in such a way that the nychthemeron was covered with bedtimes in 4-hour intervals, beginning with a normal bedtime at 2300 h after 16 hours awake and ending with the seventh bedtime at 2300 hours after 40 hours awake (see Figure 2). The order of bedtime conditions was counterbalanced.

For each session the subject reported to the laboratory at 1800 h after a normal day of sedentary work. After electrode application, measurements started at 1900 h and continued to bedtime. During this time activity was controlled according to a 2-hour module system (see Figure 2). In each module urine was collected, self-ratings made, and 300 ml of water and a standard sandwich was consumed. All modules were standardized as far as possible also with respect to physical and mental activity. The subjects spent all time in the sleep laboratory and were isolated from external synchronizers, but had a rough idea of time of day because of the measurement intervals. At bedtime, particular care was taken to instruct the subjects to sleep until they felt that sleep no longer was needed. Immediately after rising the subjects completed self-ratings and voided urine before being allowed any contact with time cues.

The self-ratings of sleepiness consisted of a 13 point scale, varying between "extremely alert" and "extremely sleepy". Rectal temperature was recorded continuously. Biochemical analyses of catecholamines, cortisol, and melatonin were carried out according to Andersson, Hovmöller, Karlsson, and Swenson (1974); Gustavsson and Sigurdsson (1979); Wetterberg, Eriksson, Friberg, and Vangbo (1978),respectively. Scoring of sleep stages followed the recommendations of Rechtschaffen and Kales (1968). For statistical analysis data from the seven bedtime conditions were combined to a sequence to which a one factor analysis of variance for repeated measures was applied (Winer, 1971). In some instances also two-tailed t-tests for repeated observations were employed.

Results

Circadian Patterns of EEG-Sleep

Figure 3 illustrates the main results for EEG sleep parameters. Sleep

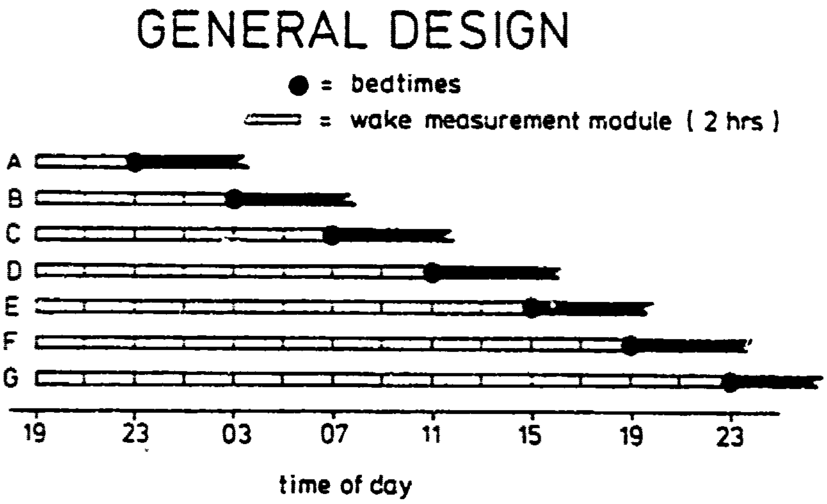

Figure 2. General design.

length showed a highly significant circadian variation with maximum sleep following after evening bed-times. Sleep after morning bedtimes was reduced to approximately half. The absolute amounts of Stage 2 and REM sleep showed the same pattern as total sleep while SWS did not vary significantly across bedtimes. Stage 1 sleep showed a significant gradual decrease. Sleep latencies were very short and did not vary over time. When relative amounts were computed Stage 2 retained the significant original pattern while the other stages were flattened.

Several points above need comments. Firstly, the circumstances around termination of sleep and the criteria for it is of central importance for many of the results in the present study—most studies of sleep/wake schedules have not allowed the subjects to spontaneously terminate sleep. In the present study, the last minute asleep before getting up was considered the end of sleep. In case of protracted oscillation between wake and Stage 1, sleep was considered to have ended immediately before a 10 minute sequence scored as waking. As the subjects had no way of knowing whether it would be day or night, they did not know whether it would be any "point in" leaving the bed. As a matter of fact, the subjects remained longer in bed after awakening from the short morning and day sleeps (about 30 minutes) than from the longer night sleeps (about 15 minutes). Presumably, this time was spent "deciding" whether to get up or not. Also, self-ratings of sleepiness were lower following the short day time sleeps. Thus, it appears that the day time awakenings and decisions to rise were due to a genuine feeling of having slept enough.

The short day time sleep is in line with the field studies of shift workers cited previously. As mentioned, these results contrast with those from artificial phase shift studies. Comparing the studies, it is noteworthy that the field studies and the present ("artificial" shift) study were carried out with subjects in age ranges rather representative of the working population while the other studies of artificial phase shifts have used young adults, mostly students. In our experience the ability to sleep during day time is sharply reduced with increasing age (Åkerstedt, 1976) and it is possible that age differences may be, at least, part of the cause of the discrepancy.

With respect to REM sleep the low absolute day time amounts agree with the previously mentioned phase shift studies. Most of the nap studies, however, show high amounts in the morning. To make our results comparable to these studies we isolated the first two hours of each bedtime condition and found a significant peak in REM sleep in the morning (see Figure 3). Thus, it appears that total REM sleep is cut short by the subjects' early awakening during morning sleep, as was also shown by Verdone (1967) in experiments on sleep satiation. SWS, in contrast, was not affected by the length of sleep but was practically always "finished" before it could be affected by the termination of sleep.

Sleep deprivation apparently did not affect the results to any great extent. Comparisons of conditions A and G suggested only a marginal increase in TST and SWS. The reason for this lack of effect could be that the present study falls in an intermediate range of wakefulness time. The latter varied between the normal prior wakefulness of 16 hours and the lowest amount of proper deprivation of sleep, i.e., 40 hours (if time of day is kept constant). From the results by Webb and Agnew (1971) it is clear that the linear relation

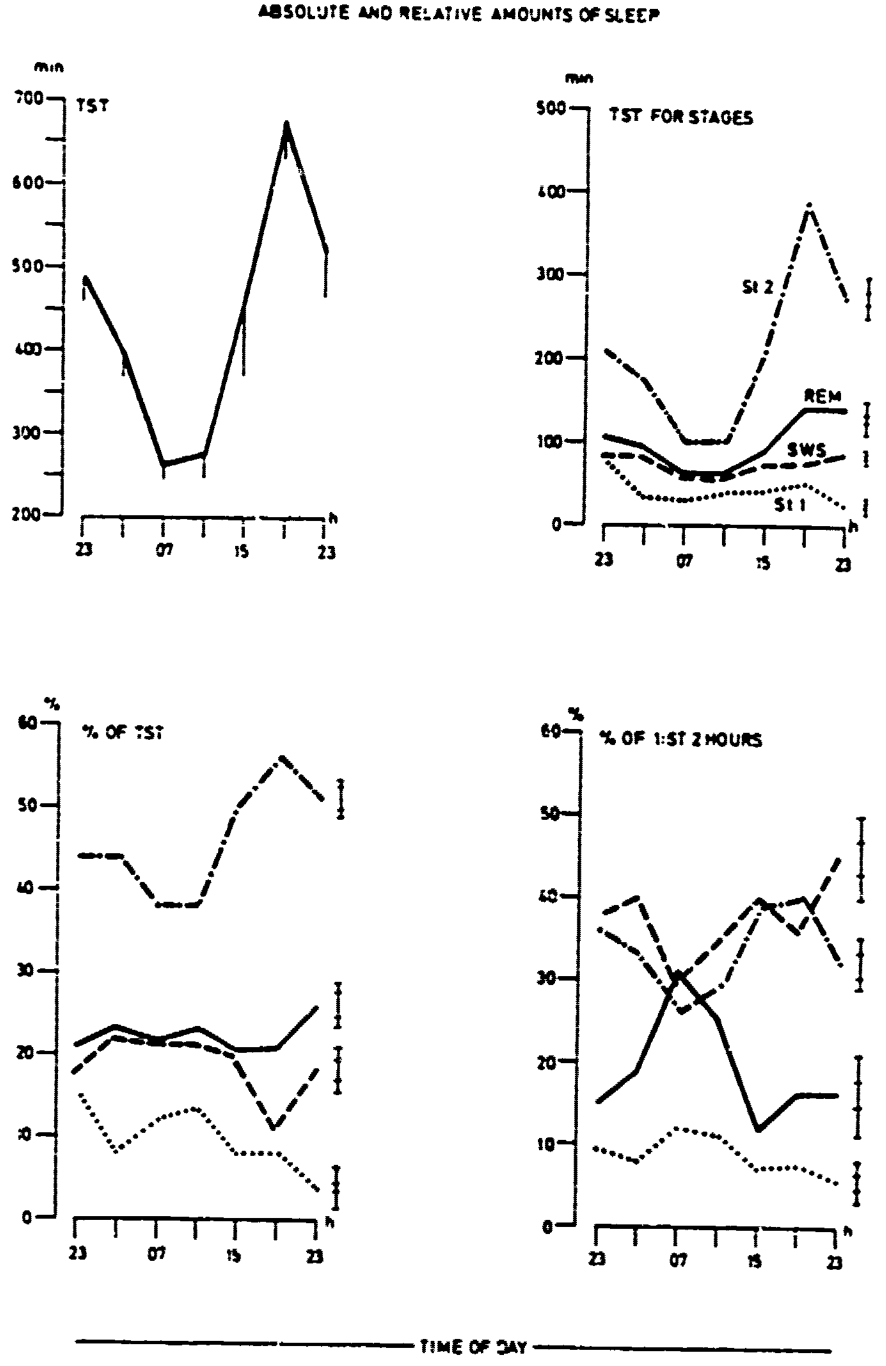

Figure 3. Means of different sleep parameters for a group of 6 subjects sleeping at 7 different times of day. Values plotted at bedtimes. 1 S.E. indicated either at where obtained or at the right hand side of each curve as largest and smallest value for the curve.

between prior wakefulness and SWS (Hume & Mills, 1977) is valid only within the normal wakefulness interval 0-16 hours. Thereafter the curve rapidly levels off. As to TST, the fact that sleep at 1900 h (condition F, see Figure 2) was longer than sleep at 2300 h (condition G) suggests that recovery sleep from sleep deprivation may be cut short by the rising arousal rhythm in the morning if that sleep is taken at the "normal" time (2300 h). It is interesting to speculate if recovery from long periods of sleep deprivation could be sped up by advancing bedtime, thus allowing a longer time in bed before the morning rise of arousal.

Effects of Sleep on Circadian Rhythms

To estimate the effects of sleep at different times of day on urinary excretion levels, two types of analyses were carried out. First, the excretion values during waking were averaged over those periods that correspond to sleep time and the two values were compared (Figure 4). Second, the excretion during sleep was compared with that of the immediately preceding two-hour-module during waking and a difference score obtained (Figure 5).

For adrenaline excretion there was a pronounced circadian rhythm during waking. This was not the case, however, for excretion during sleep. Rather, the impression was one of an almost complete shut-off, resulting in significantly reduced levels mainly during day time. Interestingly, the lowest levels while awake (around 0300 h) were near sleep levels. The shut-off during sleep provides an explanation for the results of a preceding series of experiments in which adrenaline excretion was shown to exhibit a pronounced circadian rhythm over several days of sleep deprivation, while sleep, when allowed at night, emphasized the rhythm by reducing the trough further, and day time sleep abolished it by reducing the peak (cf. Åkerstedt, 1979). The fact that, in the present study, the lowest excretion values during waking reached levels (at night) seen during sleep suggests that body position probably is not the major component of the low excretion during sleep (cf. also Reinberg, Ghata, Halberg, Gervais, Abulker, Dupont, & Gaudeau, 1970).

The excretion of noradrenaline did not exhibit any rhythmicity neither during waking, nor during sleep, the latter being significantly reduced at all times. Apparently, the pronounced circadian rhythm seen under conditions of normal or phase shifted sleep/wake alternation (Åkerstedt, 1979) is due to the sizeable reduction during sleep, either due to sleep or to lying down, or to both (Reinberg, 1970; Sundin, 1956, 1958).

As expected, the circadian pattern of cortisol excretion was pronounced both during waking and sleeping. This agrees with many studies of day and night sleep (cf. review by Weitzman et al., 1975). Melatonin excretion also showed a pronounced circadian pattern, with even less effect of sleep, which is similar to that seen for normal night or day sleep (Lynch, Wurtman, Moskowitz, Archer, & Ho, 1975; Jimerson, Lynch, Post, Wurtman, & Bunney, 1977; Lynch, Jimerson, Ozaki, Post, Bunney, & Wurtman, 1978; Åkerstedt, Fröberg, Friberg, & Wetterberg, 1979). Apparently the basic melatonin excretion rhythm is very persistent even when subjected to sleep/wake alterations.

Body temperature was measured continuously and averaged hourly. Figure 6 shows the mean temperatures surrounding each bedtime, plus/minus four hours.

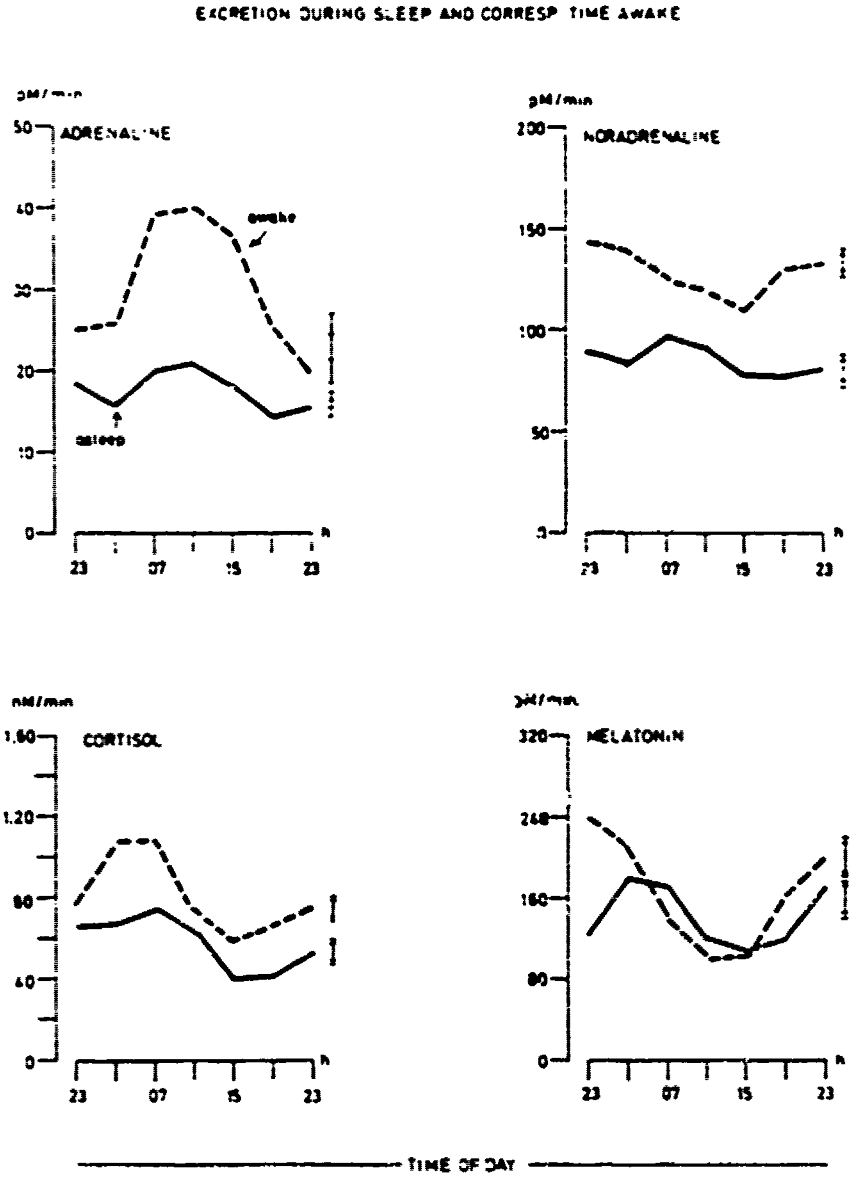

Figure 4. Mean excretion values during sleep for a group of 6 subjects sleeping at 7 different times of day. Also excretion values computed for the same periods during waking. Values plotted at bedtimes. S.E. as in preceding figure.

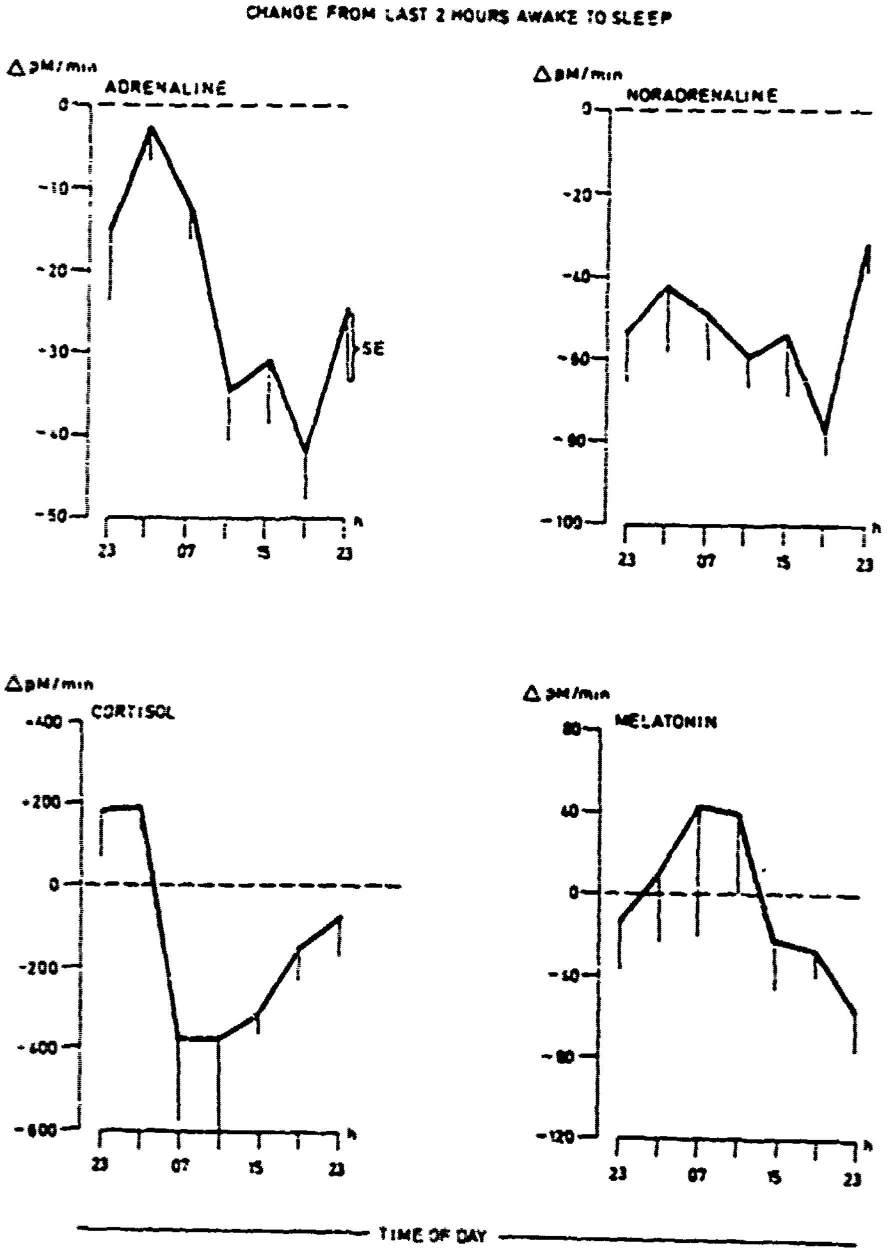

Figure 5. Mean change of excretion from last 2 hours awake to sleep for a group of 6 subjects sleeping at 7 different times of day. Values plotted at bedtimes. S.E. as in preceding figure.

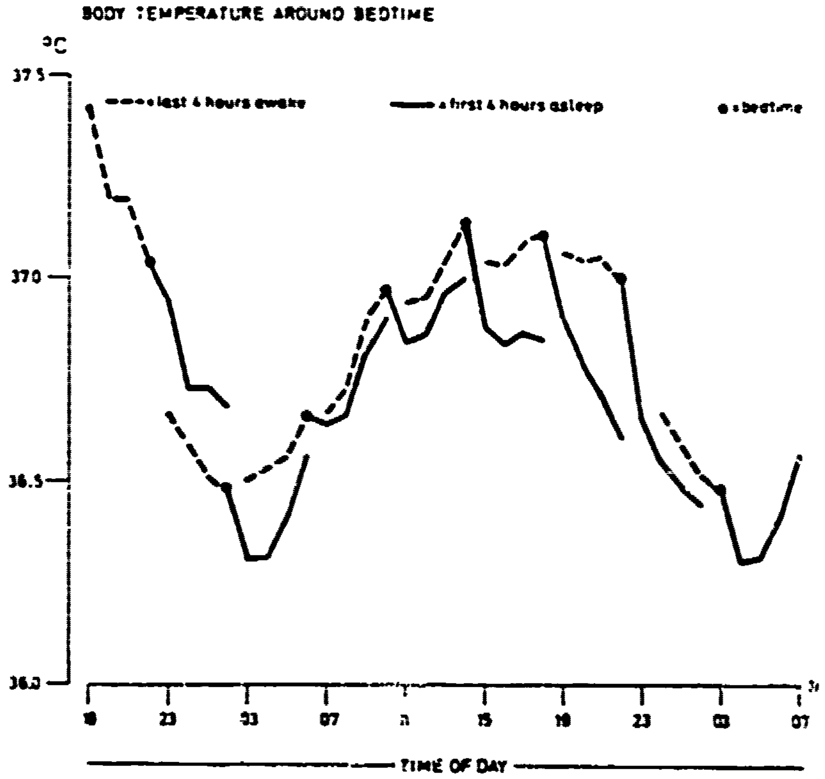

Figure 6. Rectal temperature during last 4 hours awake and first 4 hours asleep. Means for a group of 6 subjects sleeping at 7 different times of day. Second bedtime values (0300 h) repeated.

From the figure it is obvious that body temperature development during sleep is a direct function of circadian phase. Excluding the moderate initial drop, body temperature closely followed the usual pattern during wakefulness, i.e., morning and noon bedtimes were characterized by rising temperatures while evening temperatures fell. The results are similar to those of Mills, Minors, and Waterhouse (1978) in their study of split sleep periods, but cover the full nychthemeron.

Self-rated sleepiness showed a very pronounced circadian pattern peaking in the early morning (Figure 7). This pattern is in good agreement with several previous studies of sleep deprivation (Fröberg, Karlsson, Levi, & Lidberg, 1975a, b; Åkerstedt & Fröberg, 1977; Åkerstedt et al., 1979). Not surprisingly, ratings immediately after rising (before contact with any synchronizers) indicated greater alertness compared with corresponding times during the vigil. Of greater interest is the fact that sleepiness on rising followed approximately the same (significant) pattern as during the vigil. This suggests that an arousal rhythm continues to run also during sleep.

Phase Relations Between Sleep and Other Variables

With access to the present type of data it is tempting to compare sleep characteristics at different phases of the circadian cycle to the different arousal-related rhythms. Studying covariations certainly does not yield any evidence of causation, but it may generate new hypotheses or support old ones. Figure 8 summarizes the analyses. In the figure total sleep length has been plotted at the time of awakening, while for the other variables condition G (plotted twice) was used to represent the circadian cycle during waking.

From inspection of Figure 8 the general impression is that sleep is short when placed on the ascending portion of alertness, body temperature, and adrenaline rhythms, and the descending portion of the melatonin rhythm. The relationship with the cortisol rhythm is less apparent, while we refrain from interpreting the relation to noradrenaline as it failed to show a significant variation over time.

The pronounced circadian pattern of sleep length in the present study suggests regulation by an underlying oscillation of arousal (cf. Webb, 1971). This is supported by the close relation to sleepiness ratings during waking and upon awakening. Thus, awakening does not merely depend on having completed some sleep process of "restorative" value but also on the fact that a phase of the arousal cycle has been reached which does not seem to allow continued sleep. In any case, there is an interesting link between the psychological arousal rhythm and the outcome of sleep attempts at different times of the nychthemeron.

Also, the temperature rhythm is highly predictive of sleep characteristics (and of sleepiness). On the whole, sleep during the rising portion of the rhythm is greatly shortened, while sleep on the descending portion is lengthened. This is in close agreement with the other types of data on the relation between body temperature and sleep cited previously.

The excretion of adrenaline is a well established indicator of psychological arousal (cf. Frankenhaeuser, 1975). Essentially this fits in with the

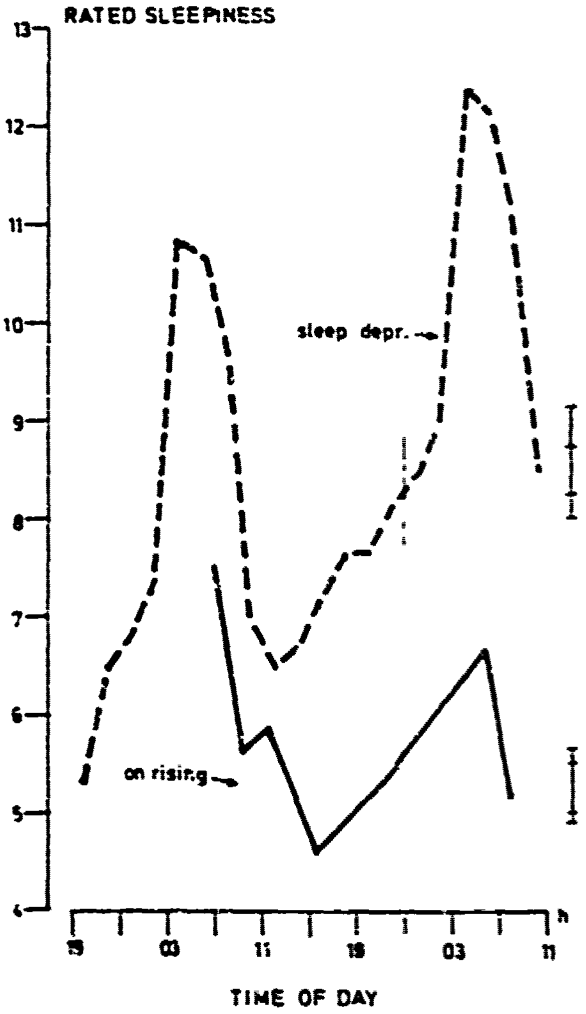

Figure 7. Self-rated sleepiness plotted 2-hourly during waking (broken line) and immediately after rising (continuous line) after each sleep condition. Ratings during waking were obtained from sleep condition G. To cover the whole period necessary the curve has been plotted twice. Ratings ranged between "extremely alert" = 1 and "extremely sleepy" =13. Means for a group of 6 subjects. S.E. as in preceding figures.

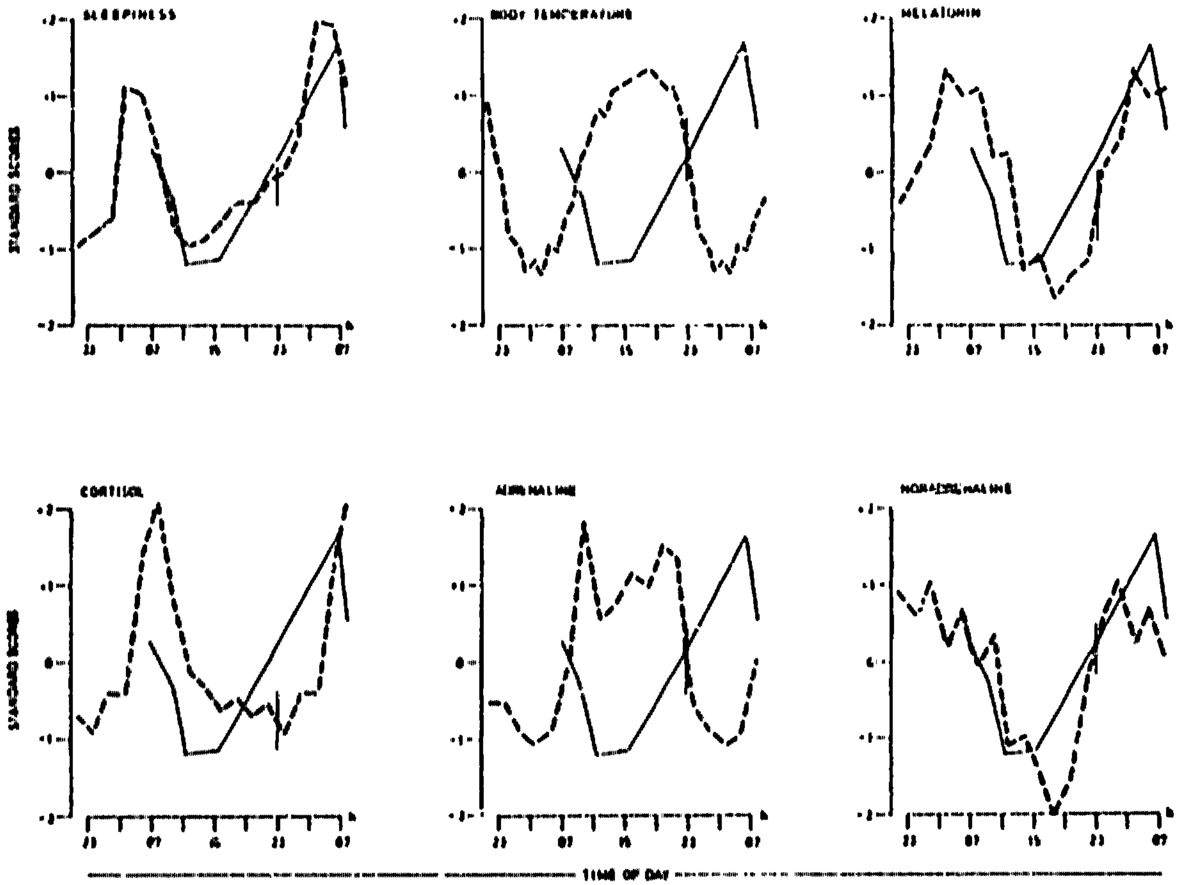

Figure 8. Sleep length plotted at the time of rising together with 2- or 1-hourly values from condition G for self-ratings, rectal temperature, and hormone excretion. All values from condition G have been plotted twice to cover the same time as the sleep length curve. Means for 6 subjects given as standard scores.

pronounced rhythmicity during waking and the lack of rhythmicity for sleep excretion. The results suggest that the connection with the central pacemaker is blocked during sleep and that the circadian rhythm of adrenaline excretion may be due to a passive dependence on some mediating rhythm.

The pineal has been suggested to be a major "tranquillizing" organ (Romijn, 1978), among other effects inducing sleep (Anton-Tay, Diaz, & Fernandez-Guardiola, 1971; Cramer, Rudolph, Consbruch, & Kendel, 1974). The high levels during long night sleep and low levels during short day sleep agree with such an interpretation. However, infusion experiments have been negative as well, failing to induce sleep (Wetterberg, 1978). For cortisol, the covariation is not as apparent as for the preceding variables. While awakening from night time sleep could be associated with the "preparatory" cortisol peak in the early morning, this peak, then obviously is not related to awakening from morning or noon sleep.

Conclusions

To conclude, it appears that sleep characteristics to a large extent are a a direct function of the circadian phase of an underlying arousal rhythm. Regardless of the particular functions responsible for the sleep rhythm, variables such as self-rated alertness, body temperature, melatonin or adrenaline excretion may predict sleep characteristics, at least on group level. Extended studies of the effects on sleep of manipulations of rhythmicity of various functions should eventually identify the major circadian determinants of sleep characteristics and possibly also part of the function of sleep. However, it is apparent that particular attention has to be paid to "masking" effects, perhaps by introducing the "constant conditions test" as suggested by Mills et al. (1978).

For work/rest scheduling the results clearly indicate that the sleep environment (housing, etc.) cannot be a major causative factor in the shift workers' sleep disturbances. Rather, sleep at day time is interfered with by internal factors. Clearly, there are certain portions of the nychthemeron which are suited for sleep while others are not. Possibly, simple self-ratings or body temperature registration could be used to predict outcomes of sleep attempts at different parts of the nychthemeron and be used as tools/criteria in designing work schedules and identifying reasons for maladjustment to shift work. However, there is also a need for extending the present type of study to the effects of sleep at different times of day on subsequent functioning and wellbeing; i.e.,is day sleep inferior to night sleep? If so, can poor day sleep be compensated through naps? What are the long term consequences of manipulations of sleep/wake schedules?

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CIRCADIAN "PROFILE" OF SHORT AND LONG SLEEPERS

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This study of the biorhythmic characteristics of naturally long and short sleepers was based on the hypothesis that the two types would show different responses to an abrupt change in the wake-activity cycle. We were hoping that, if found, these differences would account for the large discrepancies we had found in individual sleep behavior in studies on shiftwork. But there are many different reasons for being interested in long and short sleepers.

Description of Sleep Patterns

Definitive data in this area have been published by Webb and Agnew (1970) and Hartmann, Baekeland, Zwilling, and Hoy (1971). Other cases of extreme "healthy insomnia" have been reported (Jones & Oswald, 1968; Meddis, Pearson, & Langford, 1973; Stuss & Broughton, 1978; Velok, Passouant, Cadilhac,& Baldy-Mouliner, 1968). One of the clearest results is the constancy of the percentage of paradoxical sleep (PS). Figure 1 shows that if one compares PS amounts of short and long sleepers studied by various authors in various situations, the "need of PS" is almost perfectly linearly correlated with the total sleep time. This constancy seems to contradict the theory that need of PS depends on psychological and behavioral variables (Hartman, 1973).

Of course, the question of sleep need (Hartmann et al.,1971) was implicit in all the above mentioned studies. Studies of spontaneously extremely long and extremely short sleep have, in fact, made it possible to assess the constancy of the sleep requirement. The most striking result was the similarity of SWS amount (Stage 3 + 4) in sleeps of varying duration observed among naturally extremely short sleepers. Surprisingly enough, very few studies have been devoted to naturally short sleepers, perhaps because such people seem to be more difficult to find than naturally long sleepers, as demonstrated by the results of a study concerning the sleep of young students (Merle, 1979) (Figure 2).

Another possible approach is to regard the wake-sleep alternation as a circadian biological rhythm. Although the various and complex relationships between sleep and other biological rhythms (including those in both physiological functions) have been extensively documented, many of the studies were based on artificial modifications of the circadian rhythm (typically, lengthening of activity by sleep deprivation, or phase shifting by time-zone crossing or shiftwork). The purpose of these studies was to determine the ways in which the various biological rhythms respond to an abrupt change of the basic wake-sleep alternation. It seemed to us of considerable interest to study the characteristics of the biological rhythms in cases of spontaneously exceptional wake-sleep ratios.

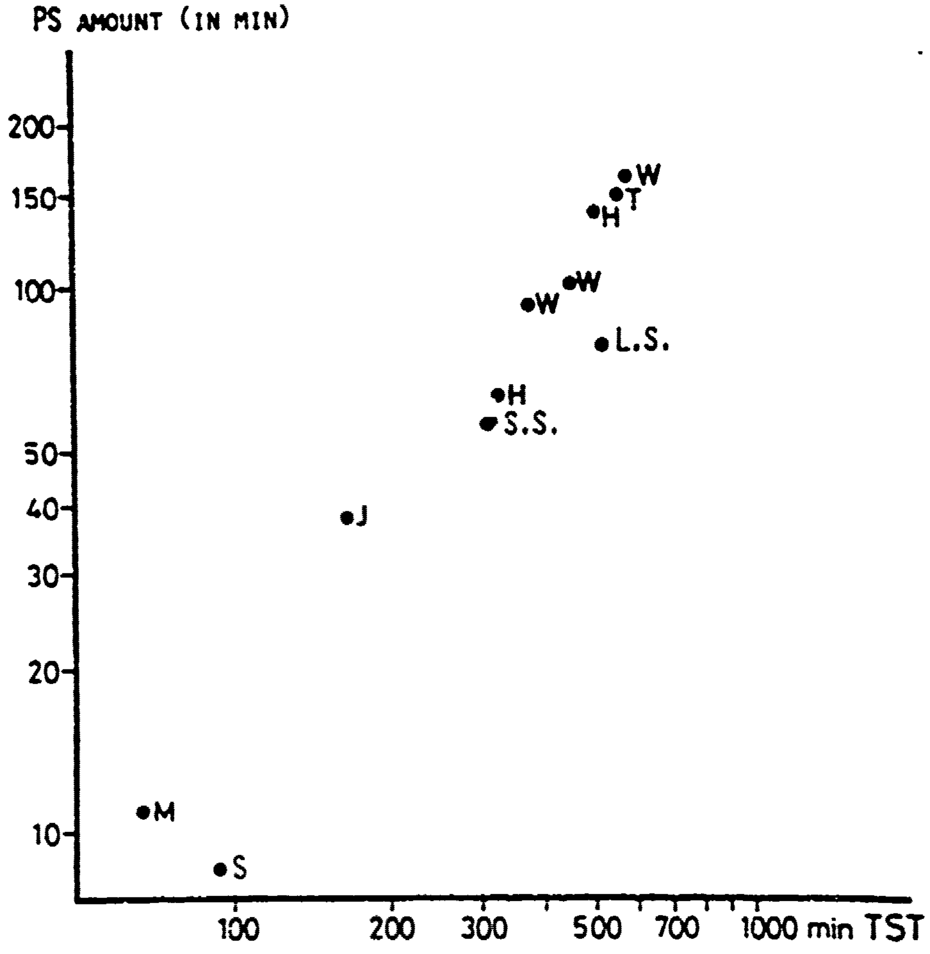

Figure 1. Duration (in minutes) of PS as a function of total sleep time (TST). M: Meddis et al. (1973); S: Stuss and Broughton (1978); J: Jones and Oswald (1968); H: Hartmann et al. (1971); W: Webb and Agnew (1970); T: Taub and Berger (1976b); LS and SS: the present study.

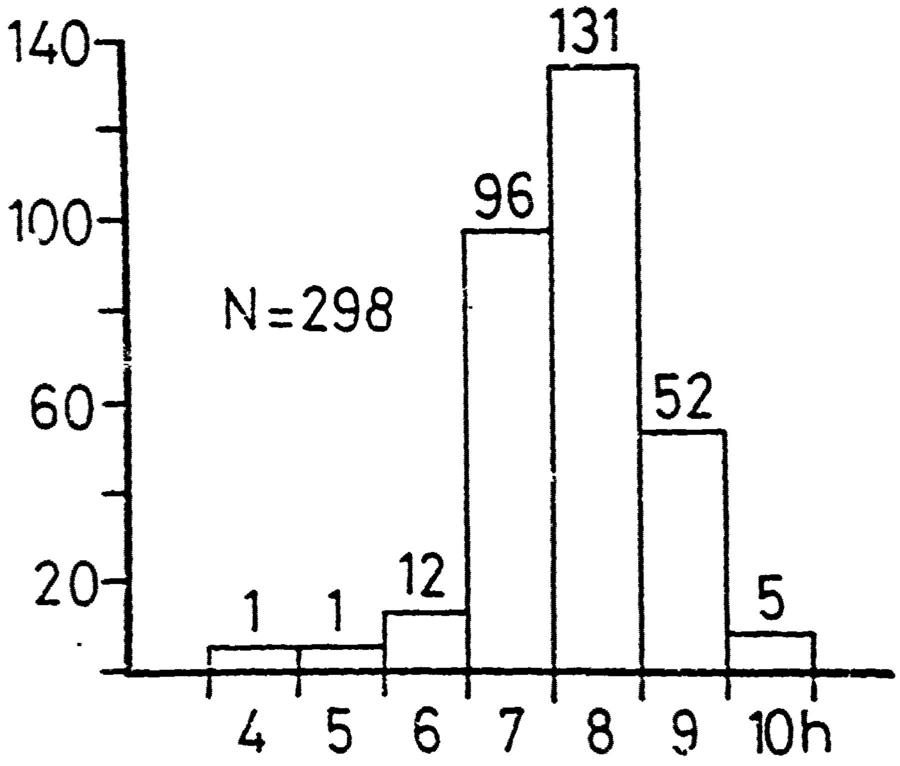

Figure 2. Frequency distribution of sleep durations (self-estimated) in a population of 310 students (age range: 19-24 years) (there were 12 non-responders).

A number of papers have been published on the transitory effects on physiological and performance measures of sudden changes in working schedules, as in shiftwork. They cover changes in sleep structure, body temperature, heart rate, self-rated mood, and many psychological variables (Colquhoun, 1972; Colquhoun, Folkard, Knauth, & Rutenfranz, 1975; Foret & Benoit, 1978a; 1978b; Merle, 1979). Essentially, there are two kinds of change: (a) when subjects go from day shift to night shift (this involves one sleep-deprived night), and (b) when they revert to day shift after a night shift period (in this case, two sleep periods—a morning and a night sleep—typically occur on the same day). In both situations, the variation of physiological and psychological responses (in particular, as regards sleep) is very large, even when environmental and other parameters such as type of task, socio-economic conditions, age, experience of shiftwork, etc., are not dissimilar.

This variation has not, as yet, been satisfactorily explained. It supports the hypothesis that there is a large natural variation in biological rhythms (including sleep). In relation to shiftwork, the important needs are (a) to achieve an appropriate description of this variability, and (b) to determine which parameters influence it most.

Several sleep-related factors have been suggested as partial mediators of the interindividual variability of responses to shiftwork. In particular, the factor "morningness-eveningness" has been emphasized. This factor has been held to correlate with the degree of extraversion-introversion (Blake & Corcoran, 1972; Hartman, Baekeland, & Zwilling, 1972). But the results remain controversial (Webb & Friel, 1971; Horne & Ostberg, 1977). The degree of estraversion-introversion is likely to influence circadian patterns of activity (reflected by the circadian rhythm of body temperature): "evening types" do, in fact, have significantly later peak times than "morning types". However, the degree of morningness is not correlated with sleep length, though Tune (1969) concluded that extraverts sleep less than introverts.

In summary, although some overall trends have been identified, it is very difficult, if not impossible, to draw clear-cut conclusions about the interrelationships between introversion-extraversion, morningness-eveningness, and long sleep-short sleep. On the other hand, the amplitude of certain circadian rhythms has recently been shown to be an important factor in the biorhythmic behavior of individuals subjected to an abrupt change of schedule (Reinberg, Vieux, Ghata, Chaumont, & Laporte, 1978). Indeed, this factor has been proposed as a predictor of the ability to adapt to shiftwork. But it is, as yet, not known to what extent the amplitude of, for instance, the body temperature rhythm is correlated with the other parameters previously mentioned: degree of extraversion, natural sleep length, and "morningness".

In addition to the studies already mentioned, the factor natural sleep length has also been investigated, in connection with the results of sleep deprivation studies (Taub & Berger, 1976a). Thus, one of the interests of the present study is the opportunity it affords to compare the effects on performance and mood of sleep deprivation in exceptionally long or short sleepers with those reported for normal sleepers.

Methods

The selection of long and short sleepers started with a survey of sleep length (SL) in a large population of students (N=310) with a small age range (20-24 years). Following this, 71 subjects who appeared to be short and long sleepers were selected. This sample consisted of 14 short sleepers (SL≤7h) and 57 long sleepers (SL≥9h).

We shall not discuss here the controversial question: were we dealing with real short and long sleepers? As Webb (1979) suggested, we simply regarded sleep length as the independent variable. Nevertheless, the asymmetry of the population is to be noted. In other words, it seems much easier to find long sleepers than short ones.

An interview followed, in order to eliminate subjects who:

- clearly had irregular sleep patterns;
- reported having had serious sleep troubles in the past;
- complained about their sleep;
- were under psychotherapeutic treatment;
- were using hypnotics or stimulant drugs (other than coffee or vitamin C in moderate amounts);
- had had accidents, or were suffering from pathological conditions likely to affect EEG or sleep (e.g., diabetes, exceptional weight or stature).

The remaining 40 subjects were asked to complete a sleep log for two weeks. From these logs, we chose the 10 with the shortest and the longest sleep lengths (i.e., about 3% of the original population) for the experiment. There were 5 short sleepers (2 women and 3 men) with a mean SL of 6h 10 min (S.D. 40 min) and 5 long sleepers (2 women and 3 men) with a mean SL of 8h 50 min (S.D. 60 min). The age range was 20-23 years.

Two levels of measurements were made:

(a) sleep recordings by conventional, well-standardized methods such as EEG, eye movements, muscle tonus, and body movements.

(b) measurements of circadian rhythms in heart rate (after 15 min rest when awake, and continuously during sleep recordings), axillary temperature, self-estimation of mood (using a 10 cm line, of which the extremities represented best and worst moods), and self-estimation of vigilance on a five-point scale.

The experimental procedure was as follows:

First Session: -(successively)
-two baseline nights (subjects went to bed and got up when they wanted (REF));
-one sleep-deprived night;
-one recovery night (that is, after 36 h wakefulness (RECOV 36)).

Second Session: -(successively)
-one baseline night (REF);
-one sleep-deprived night;
-one morning recovery sleep (that is, after 24 h wake-

fulness (RECOV 24));
-one recovery night (RECOV).

During the whole experiment, the subjects maintained most of their daily habits, in particular concerning food intake (type and timing) and sleep habits.

Results

Sleep

Table 1 summarizes the data obtained from the long sleepers (LS) and short sleepers (SS). In the reference conditions, the differences between LS and SS are accounted for mainly by light sleep (Stage 1 and Stage 2) and by PS. The most striking similarities between the two groups are the relative amount of PS (17.2% in SS, 16.1% in LS) and the absolute amount of SWS (116 min is SS, 110 min in LS).

It has been suggested by Verdone (1968) that SS have a more "efficient" sleep than LS. We computed the same index as Verdone, i.e., the ratio of the sum PS + SWS to the total sleep time (TST) (Figure 3), and confirmed that SS were in fact more "efficient", not only in normal sleep, but also in recovery sleep.

Figure 4 shows the hour-by-hour distribution of "intervening wakefulness", which appeared to be regularly distributed across the sleep period. This measure of "efficiency" was particularly poor during day sleep (RECOV 24). In contrast, the hourly distribution of PS was not significantly different in the different conditions. The average duration of episodes of PS, and its periodicity, were essentially the same for both LS and SS:

Average PS duration (Min)	18.8 (LS) s.d.=10.7	17.3 (SS) s.d.=11.7
Average PS period (Min)	93.3 (LS)	92.6 (SS)

Two features of day sleep (RECOV 24) that clearly distinguish it from other sleep are: (1) the dramatic reduction of TST in both LS and SS; and (2) the trend towards a similarity of the groups in terms of sleep stage amounts. In contrast to other sleeps, there were no significant differences in sleep characteristics between LS and SS in this condition. Thus, it can be assumed that the sleep deficit due to the schedule inversion was larger in LS than in SS.

Those results are in good agreement with other studies on long and short sleepers (Hartmann et al., 1971; Webb & Agnew, 1970). They are to be compared to other results (e.g., Foret & Benoit, 1974) which show that the sleep of the same subjects recorded in different situations (in particular, after schedule inversion) exhibits the same constancies in respect to absolute amount of SWS and percentage of PS. Also, results concerning sleep structure in elderly people (Feinberg, 1969) show that percentage of PS, in spite of the dramatic shortening of SWS, remains approximately the same as in younger adults. In sum, these other data give a picture of PS as a rather passive phenomenon closely linked with the total sleep time.

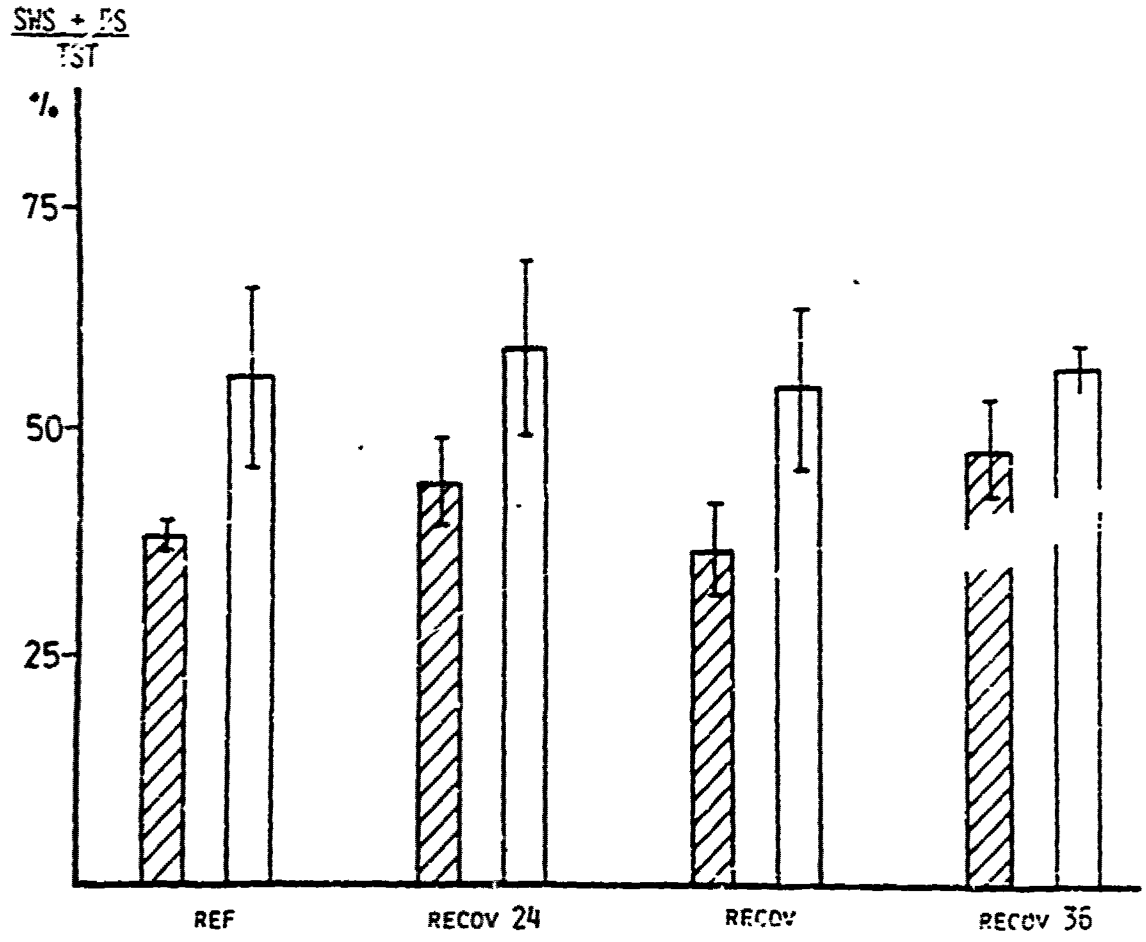

Figure 3. "Efficiency index" of sleep ($\frac{SWS+PS}{TST}$)% in the various experimental conditions (Hatched bars: LS; Open bars: SS).

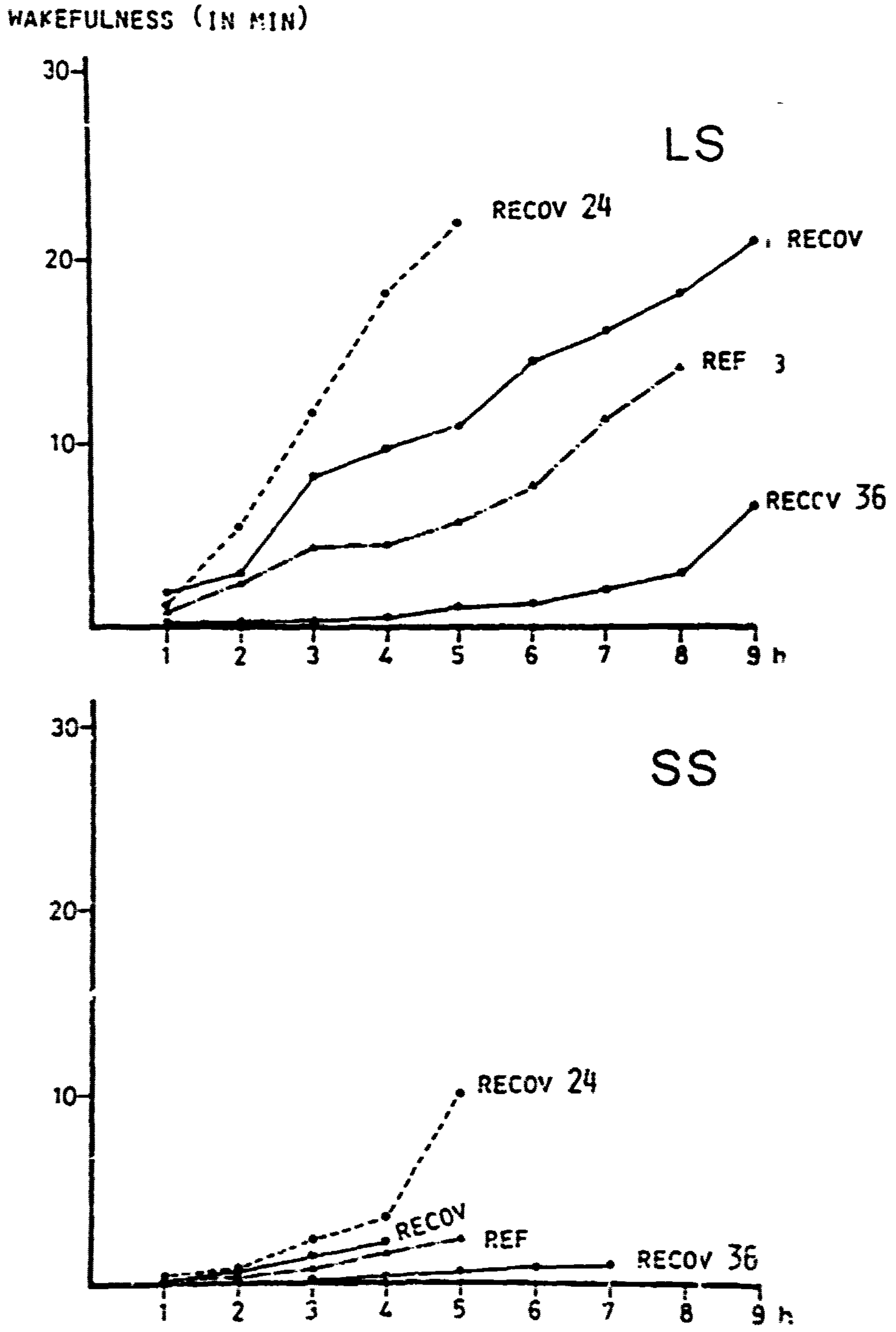

Figure 4. Hourly cumulated amount of intervening wakefulness in the various experimental situations.

Table 1

Sleep Data: Means and SDs (Mins)

	Sleep REF			Sleep RECOV 36			Sleep RECOV			Sleep RECOV 24		
	LS		SS	LS		SS	LS		SS	LS		SS
TST	533.6 ±32.9	***	303 ±55	560.3 ±17.9	***	402 ±41.6	554 ±58.4	***	271 ±68.7	287.8 ±69.7		240 ±73
Wake-fulness	12.3 ±16.1		3.3 ±3.7	5.9 ±6.4	(p <.1, NS)	0.4 ±0.5	13.7 ±5.3	**	3.8 ±4	17.7 ±15.4	(p <.1, NS)	4.1 ±4.4
Stage 1	78.6 ±29.6	**	32.1 ±19.8	46.9 ±12.3		31.7 ±5.9	79.3 ±39	*	24.4 ±13.7	38.9 ±13.8		29 ±20.6
Stage 2	237.6 ±14.9	***	102.2 ±21.3	235.7 ±23.7	***	141.4 ±26	259.4 ±44.6	***	98.9 ±38.6	109.4 ±37.2		68.9 ±25
SWS Stage 3+4	110.2 ±14.9		116.2 ±21.3	171.4 ±26.2		165.7 ±26.3	84.6 ±23		92.1 ±16.9	93.5 ±20.7		105.6 ±31.9
PS REM Sleep	91.8 ±21.4	***	48.9 ±18.8	95 ±26		62.2 ±30.6	112.9 ±14.8		52.5 ±21.9	27.3 ±23.5		32.4 ±13.8
Stage 2 Latency	18.7 ±7.3		10.7 ±7.3	8.5 ±3.4		8.1 ±2.9	25.9 ±10	**	9.6 ±3.3	10 ±8.2		4.8 ±3.1
Stage 4 Latency	16.5 ±7		15.3 ±4.7	10.7 ±5.6		11 ±6.7	37.7 ±34		25.3 ±9.7	12 ±5.8		12.3 ±2.3
PS Latency	117.9 ±52		105.7 ±65.6	128.5 ±49.9		98.9 ±47.9	68.5 ±49	(p <.1, NS)	69 ±29.1	114.4 ±46.7		79.4 ±57

Reference Conditions: Body Temperature (0°), Heart Rate (HR), Mood and Vigilance

For each individual, measurements of 0° collected over ten days were averaged for each hour (see Figure 5). The temperature rhythm of SS appeared to plateau for a longer time than that of LS. In addition, the amplitude of the rhythm (i.e., the difference between the average level of the diurnal maximum and that of the nocturnal minimum) was significantly smaller in SS than in LS (.42° and .62° respectively, $p = .07$, Mann-Whitney U-test).

Peak time. Precise determination of peak time was difficult (a) because of the variability in the data and (b) because (particularly in SS) the maximum was more a plateau than a peak; the cosinor method, by definition, fits the maximum of the sine curve (acrophase) around the middle of the plateau. This is probably the reason why the peak times of SS and LS estimated by this method (Table 2) were not significantly different. But if we take the beginning of the plateau as a definition of peak, the temperature curve of SS is seen to level up earlier than that of LS. There was a positive rank order correlation (Spearman) significant at $p < .01$ between the time of this peak and sleep length: the longer the sleep length, the later (and thus closer to bedtime) was the peak.

In contrast, Table 2 shows that when the cosinor method was applied to the data on self-estimated mood and vigilance, the acrophases in these variables were significantly later in SS.

Table 2

REF: Times of Acrophases (and Confidence Intervals)

	SS	LS
Temperature	18.3 (17.6—19.0)	17.2 (16.4—18.0)
Heart rate	15.8 (14.7—17.0)	16.8 (16.1—17.7)
Mood	21.1 (19.2—23.0)	15.6 (14.2—16.8)
Vigilance	15.8 (15.3—16.3)	14.5 (14.2—14.8)

It should also be noted that the rhythms of the four variables considered in this study were phase-synchronized much more closely in LS than in SS; the significance of this is not clear at present.

After Sleep Deprivation: Body Temperature, Heart Rate, Mood and Vigilance

Both types of sleep deprivation influenced SS and LS in different ways (see Tables 3 & 4). Because of the very large variability in the LS data, it was not possible to assess the acrophases of the rhythms in some cases in this group. However, it would seem that, on the whole, SS were less affected by sleep deprivation than LS, at least as regards the variables that we studied: thus, in RECOV 36, the shift in the phase of the temperature rhythm was much larger in LS than in SS. In RECOV 24, the time of the temperature peak was less affected in both groups.

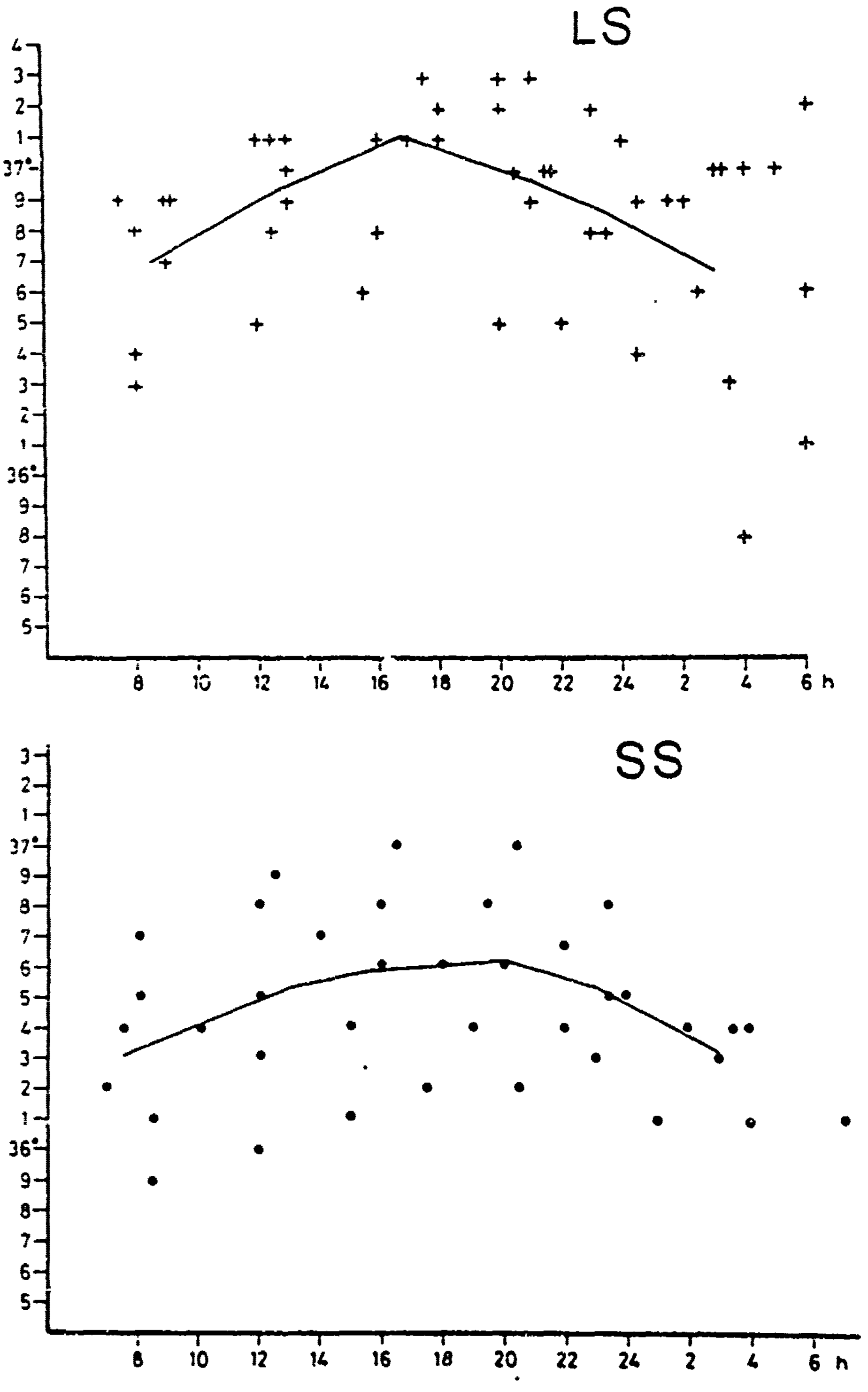

Figure 5. Mean hourly temperatures in SS and in LS. Mean sleep periods for SS were 01.40—07.40; for LS were 23.10—08.15.

Table 3

RECOV 36: Times of Acrophases (and Confidence Intervals)

	SS	LS
Temperature	17.2 (15.6—19.2)	not assessable
Heart Rate	15.5 (13.8—19.4)	19.8 (15.1—24.8)
Mood	20.8 (18.8—22.8)	not assessable
Vigilance	16.5 (15.5—20.6)	not assessable

Table 4

RECOV 24: Time of Acrophase (and Confidence Interval)

	SS	LS
Temperature	18.5 (16.9—20.3)	not assessable
Heart Rate	14.2 (8.4—19.4)	not assessable
Mood	22.3 (19.6—24.8)	16.4 (13.8—20.0)
Vigilance	17.9 (16.6—19.2)	17.6 (16.5—19.0)

According to the theory that different oscillators may influence sleep and body temperature (Aschoff & Wever, 1976), our results lead to the conclusion that the degree of coupling between the rhythm of activity and that of temperature is likely to be greater in LS than in SS.

After Sleep Deprivation: Correlation with Temperature Amplitude

In some cases, the amplitude of the temperature rhythm in the reference condition was found to be related to the shift in phase of the rhythm after sleep deprivation.

In 24 hours sleep deprivation (RECOV 24), there was a significant rank correlation between the amplitude of the temperature rhythm before deprivation and the shift in its peak the following day: the smaller the amplitude, the larger the shift in the peak (Spearman's rho, $p < .05$). [But it should be remembered that we did not find any clear difference in temperature amplitude between SS and LS.]

This result supports the hypothesis originally advanced by Aschoff (1978) (and confirmed by Reinberg et al., 1978) that people with a naturally small temperature range are more able to "adapt" quickly to schedule inversion. But the applicability of this finding is still open to question, since it has yet to be demonstrated whether a rapid shift in the phase of the temperature rhythm is actually conducive to an overall adaptation to shiftwork.

In the case of RECOV 36 (a condition that a real shiftworker almost never meets), there was a positive correlation only between sleep length and the extent of the phase-shift in temperature: The longer the spontaneous sleep length, the larger the shift of the temperature peak (Spearman's rho, $p<.02$).

Although there was no correlation between sleep length and temperature rhythm amplitude, LS tended to show a larger temperature amplitude than SS. Thus it seems that the extent to which the temperature peak shifted in this situation was determined by two opposing factors: A large temperature amplitude, which would produce a small shift; and a long sleep length, which would produce a large shift. This perhaps is why the results are not clear in LS.

Temporal Relationship Between Sleep and Temperature

(a) The level of the last temperature reading before going to bed (around 2200 for LS, 2400 for SS) was found to be significantly lower in SS ($p = .07$), when this level was expressed as a relative proportion of the total amplitude of the rhythm. However, the time interval between temperature peak and bedtime was found to be much longer in SS (SS = 10 h; LS = 5.1 h). These results show that there is no obvious relationship between thermic level and wake/sleep transition in a normal night of sleep.

(b) In contrast, the level of temperature recorded in the morning after a sleep deprived night seems to affect both the duration and the stage amounts of the subsequent morning sleep. There was a negative correlation between absolute temperature level and TST ($r = -.51$, $p <.05$), and also between absolute temperature level and percent PS ($r = -.60$, $p <.05$).

Conclusion

The sensitivity of an individual to a phase displacement appears to depend upon various factors. In the case of a transient displacement, natural sleep length, at least in its extreme values, plays an important part in determining the inter-individual differences observed. Variations in the well-known troubles reported by workers subject to changing working schedules may, in addition, be related to the normal amplitude of the individual's temperature rhythm.

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THE IMPACT OF TRANSMERIDIAN FLIGHT ON DEPLOYING SOLDIERS

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During the past two decades we have witnessed a growing military concern over our readiness to deploy combat units rapidly overseas. In most instances, such airlifts require a sudden shift in the work-sleep schedule of deploying soldiers. These shifts are dictated by the crossing of multiple time zones during the flight. While the physiological and behavioral consequences of rapid transmeridian flight are a common experience for today's commercial international travelers, they translate into a potentially serious problem for troops expected to fight with maximal effectiveness upon arriving at their destination. The modern, high technology battlefield leaves little room for performance failures due to "jet lag."

In designing a series of studies to deal with this potential problem, there are two considerations which must be addressed. The first concerns the extent to which rapid transmeridian flight detrimentally affects the ability of deploying soldiers to carry out their mission. The second concerns our ability to counteract these detrimental effects caused by the disruption of circadian rhythms. Civilian studies have demonstrated that several days or more are required for a person to adjust to a five or six-hour time zone shift (Aschoff, Hoffman, Pohl, & Wever, 1975). Is it possible to develop countermeasures which might accelerate this rate of adjustment in soldiers?

The literature contains numerous studies describing the desynchronization of circadian rhythms resulting from rapid transmeridian flight. These include documentation of various physiological and behavioral rhythms after eastward or westward flights crossing two to eleven time zones. The composite results were summarized by Aschoff and his colleagues (1975) who confirmed previous reports (Klein & Wegmann, 1974) that it requires longer to adjust the phase of a traveler's circadian rhythms after an eastward flight than after a westward flight. Averaging across all dependent variables they calculated a mean daily shift rate of 92 min/day after westward flights and 57 min/day after eastward flights. Klein and Wegmann (1974) have further demonstrated that this asymmetrical effect can not be attributed to the relative direction of flight, i.e., either outgoing or homegoing.

Military Populations

While these studies provide valuable information about the general characteristics of transmeridian dyschronism and the adjustment to new time zones, they do not necessarily provide a sound basis for assessing the extent of the problem among military populations. Their findings are primarily limited by the nature of the subjects who usually consist of small groups of students or individual civilian travelers. As compared to combat soldiers, these samples differ with regard to physical fitness, intelligence, motivation, age, social cohesion, and experience with disrupted work-sleep schedules. Furthermore, the civilian subjects were transported together with other paying passengers on commercial airliners flying normally scheduled routes. Thus, their cabin environment contrasts greatly with that encountered by deploying troops who may be transported on cramped military cargo jets equipped with suspended nylon web seats. The environmental factor also extends beyond the aircraft to those time periods surrounding the flight. Ambient temperature and weather conditions can change drastically as troops move from comfortable barracks and private homes into tents and makeshift quarters after landing. Furthermore, preparations for emergency deployment require a short, but intense period of activity just before the flight when equipment is readied and final personal arrangements are completed. Following the flight, the individual soldier may disembark only to encounter a life-threatening situation where alertness, rapid responding, and sound judgment are the keys to survival.

Whether these military factors combine to exacerbate the "jet lag" problem is not known. In fact, it may not be unreasonable to expect that the intense activity schedule and high stress of preparing for combat might actually reduce the desynchronization problem by minimizing the influence of external time cues on the soldier's circadian system. Of course, it is impossible to examine such predictions under peace-time conditions; however, there are other military factors noted previously which are common to all deploying units regardless of their entering the combat arena. The impact of these factors can be investigated in the course of normal transfer or training deployments.

Until we began our research only one other military translocation study had been reported in the open literature. It was conducted by the British Army in the late 1960's under the title "Exercise Medex" (Adam, Brown, Colquhoun, Hamilton, Orsborn, Thomas, & Worsley, 1972). A group of forty-nine enlisted men were airlifted eastward across 7.5 time zones from the United Kingdom to Singapore. Urine was collected and oral temperatures and pulse rates were measured every four hours over alternate 24-hr periods for 14 days in the U.K. and for 16 days immediately after arrival in Singapore. Subjects were equally divided into two groups which alternated measurement periods so that each group was undisturbed every other day. Also, during the usual waking hours, a series of cognitive performance tests was administered four times per day interspersed between the physiological measurements.

A preliminary report of the findings for the first ten days after arrival suggested rapid post-flight adaptation of the circadian rhythm for oral temperature. The temporal location of the daily minimum for group mean temperature indicated appropriate phase adjustment within the first three days for both groups. In one group, there was equally rapid adjustment of the daily maximum, although overall mean daily temperature remained elevated over baseline (U.K.) levels for nine days. The other group's daily maximum did not recover its baseline phase until Day 8. Furthermore, there was considerable variability for both groups in the daily range of oscillation during the ten days after arrival. Thus, the authors noted that, although adjustment of the temperature rhythm appeared to be unusually rapid, there may be reason to doubt the completeness of adaptation to the new time zone within the observation span. Unfortunately, there is no additional evidence to clarify the issue of physiological adjustment since no analyses of the urinary cortisol or electrolytes have been forthcoming. Results are available from two of the performance tests, simple addition and auditory vigilance. In general, they also indicate rapid, if not immediate, adjustment of performance rhythms to the new time zone.

In a subsequent paper, Colquhoun (1979) reanalyzed the temperature data from this study by using the cosinor procedure to fit simple 24-hour sine curves to each individual's daily set of readings. Using the daily shift in the mean estimated acrophase as the measure of adaptation, he concluded that the extent of initial adaptation was indeed greater than that usually observed in civilian studies, but that total adaptation was not actually completed any faster. Thus, in conjunction with the behavioral results reported earlier, it still appears that the British soldiers experienced less overall disruption of their circadian rhythms than that reported for civilians undergoing eastward transmeridian flights. Whether the same advantage holds for other military populations remains to be seen.

Several factors may have combined to produce this result. The subjects were highly select and specially trained paratroopers of above average intelligence who were experienced in conducting transmeridian airborne deployments. They formed a highly cohesive and motivated unit in which social synchronizers could be expected to strongly facilitate the rate of post-flight circadian adjustment. The outdoor nature of their activity upon arrival may also have contributed to more rapid adjustment, as Klein and Wegmann (1974) have demonstrated with students. Although the potential importance of these factors in explaining the results should not be underestimated, caution may be exercised especially since the contribution of the abrupt change in climate, from temperate to tropical, is unknown.

"Jet Lag" Countermeasures

In the past, several attempts have been made to develop chronobiologic remedies for the circadian desynchronization which accompanies rapid transmeridian flight. For the most part these attempts have met with failure or very limited success. Christie and Moore-Robinson (1970) tested the efficacy of a corticosteroid as a chronobiotic for a group of seven experimental and seven control subjects flown from London to San Francisco and back after a ten-day stay. Although their report does not provide the name, dosage, or dose schedule for the drug, it states that the compound was designed to deliberately upset the body's biochemical rhythms in an attempt to influence post-flight adaptation. Results based on oral temperatures indicated that there were no differences between the two groups following the flights in either direction.

A second double-blind trial of a chronobiotic was conducted in 1973 by Simpson and his colleagues. They studied the effects of "Quiadon" (3-alkyl pyrazolyl piperazine dihydrochloride, E. Merck, Darmstadt, FRG) on twelve, mostly young, males undergoing an 8-hr phase delay in the continuous daylight of the arctic environment. After a 7-day control span on British Standard Time, they initiated the 14-day treatment be resetting their watches and consuming a once daily dose of drug or placebo just before retiring at 2300 hrs. The treatment rationale was based on independent evidence that the drug acted both as a tranquilizer which lacked any sedative effects and a depletor of 5-hydroxytryptamine (5-HT) in the central nervous system. The former characteristic would reduce anxiety during delays in falling asleep or in disrupted sleep, while its role as a 5-HT depletor would serve to drive the circadian rhythm of pineal 5-HT, and presumably other components of the circadian system, onto the new daily schedule. Unforturately, both groups of subjects exhibited extremely rapid resynchronization of their circadian rhythms for urine temperature, urinary electrolytes, and performance. Thus, there was no group phase-lag for the drug to act upon. Possible explanations offered for this atypical result include rigid meal and rest-exercise schedules, a lack of competing synchronizers, the relative youth of the subjects, and the potential predisposing effect of natural arctic illumination towards a phase delay. No subsequent trials of "Quiadon" were ever conducted.

Although human research in this area has remained dormant for several years, Ehret and colleagues have undertaken a series of animal experiments using rats to demonstrate the usefulness of dietary manipulations and mealtiming to induce more rapid phase-shifting after changes in synchronizer schedules. The first of these studies demonstrated that injections of methylated xanthines, i.e., theophylline, can advance or delay the daily maximum for body temperature depending on when they are administered with respect to the circadian cycle (Ehret, Potter, & Dobra, 1975). If they are administered just before or during the early active phase of the cycle (i.e., rising body temperature), a phase delay results, whereas if they are administered during the late active, early inactive phase (i.e., just before or just after the thermal peak), a phase advance results.

Secondly, it can be shown that more rapid phase adjustment of the temperature rhythm can be induced by (a) fasting a rat on the day prior to a phase delay in the light-dark (LD) cycle and (b) restoring food coincidental with the first new active phase of the LD cycle (Ehret, Groh, & Meinert, 1978). Presumably, this chronobiotic effect is mediated by the depletion of liver glycogen stores during the fast followed by the reinitiation of feeding at the chronotypically appropriate time in the revised LD cycle. Other investigators have also demonstrated the importance of mealtiming as a synchronizer of circadian rhythms in humans (Levine, Halberg, Halberg, Thompson, Graeber, Thompson, & Jacobs, 1977; Graeber, Gatty, Halberg, & Levine, 1978) and other mammals (Edmonds & Adler, 1977; Fuller & Snoddy, 1968; Krieger & Hauser, 1978; Mayersbach, Muller, Phillipens, Scheving, & Brock, 1973; Nelson, Scheving, & Halberg, 1975; Sulzman, Fuller, & Moore-Ede, 1978).

Related work by Wurtman and Fernstrom has demonstrated that changes in nutritional state can rapidly affect neurotransmitter synthesis (Fernstrom, 1976; Fernstrom & Wurtman, 1971, 1973; Wurtman, 1979). Rats fasted for 15 hrs exhibit a significant increase in brain tryptophan and serotonin following a single, high carbohydrate, low protein meal. This effect occurs within one hour after the meal and appears to be mediated by an increase in serum tryptophan levels elicited by insulin secretion. Fasted rats also manifest a rapid increase in brain catecholamine levels, particularly norepinephrine, following a meal which is relatively rich in protein. This enhanced synthesis of catecholamines can be traced directly to disproportionate increases in plasma tyrosine which in turn produce similar increases in brain tyrosine levels. In the case of noradrenergic brain neurons, catecholamine synthesis has been shown to be directly dependent on the availability of this amino acid precursor (Gibson & Wurtman, 1978); while in dopaminergic neurons, tyrosine hydroxylase must be activated before tyrosine levels can control dopamine formation (Scally & Wurtman, 1977).

Ehret and his colleagues have combined these findings into a suggested "diet" plan for individuals undergoing rapid transmeridian flight (Ehret, Groh, & Meinert, 1978). The underlying concept is to maximize the synchronizing effects of mealtiming by alternating daily fasts with three regular meals on alternate days preceding the flight, to restrict consumption of the methylated xanthines (i.e., coffee, tea, and other caffeinated beverages) to the appropriate time in the circadian cycle on the day of departure (i.e., to morning only, if traveling west), and upon arriving to vary the protein: carbohydrate content of meals according to the appropriate phase of the rest-activity cycle for the new time zone. The latter action is based on the assumption that meals high in protein taken in the morning and at lunch on the day of arrival will facilitate the rise in brain catecholamine synthesis associated with the active phase of the circadian rest-activity cycle (e.g., Perlow, Ebert, Gordon, Ziegler, Lake, & Chase, 1978). Conversely, a large, high carbohydrate dinner eaten at a time in synchrony with the destination populace will facilitate the increase in brain serotonin synthesis which typically precedes sleep (e.g., Quay, 1965).

In designing countermeasures for use with eastward deploying soldiers, we decided to follow the basic notions of Ehret's model in conjunction with the manipulation of social cues, light-dark cycles, and rest-activity patterns which are known to be effective synchronizers of human circadian rhythms. The operational requirements of a large-scale military exercise limited the extent and duration of possible experimental interventions to those which could be instituted on the day of departure and carried out with minimal disruption to mission accomplishment. Likewise, operational considerations required that data collection be restricted to relatively few days before and after the flight with minimal interference in the ability of subjects to carry out their military duties. The basic strategy in both studies was to induce a more rapid phase advance of the circadian system by controlling the timing of rest-activity schedules, social interaction, meals, and caffeine/theophylline consumption.

Field Study Procedures

The countermeasures were tested in two field studies with troops deploying from the U.S. to West Germany. A more complete description of the methods can be found in Graeber, Cutnbert, Sing, Schneider, and Sessions (in press) and Cuthbert, Graeber, Sing, and Schneider (in press). Subjects in the first study were 179 male soldiers being transferred overseas as a unit in October, 1978. The study design divided the participants into an experimental aircraft (n = 84) and a control aircraft (n = 95); both flights departed the U.S. in mid-day and arrived in Germany early the next morning, CET.

Oral temperature was recorded from all subjects. A sub-sample of 15 soldiers in each group was studied more intensively: in addition to temperature, measures taken at each test session included addition of random pairs of single digits, four-choice reaction time, a fatigue checklist, and a 24-hour diary of sleep, eating and drinking, bowel movements, and physical illness symptoms. Subjects in these "intensive" subgroups, all living in the barracks, were tested every four hours around-the-clock for four days about two weeks prior to departure. Baseline measurements for the remaining subjects were taken at 0800, 1200, and 1600 only, as these subjects lived off-post and were unavailable outside of normal duty hours. All subjects were tested every four hours for six days after arrival in Germany.

The flights utilized chartered commercial aircraft and involved a time advance of six hours. Experimental subjects received the countermeasures procedures, which were initiated on the morning of departure. Subjects were restricted to a light, low carbohydrate breakfast with fruit juice, milk, and decaffeinated coffee; however, the majority ate nothing that morning. Napping was prohibited throughout the day by constant monitoring of the subjects' activities. Upon boarding the airplane, subjects were instructed by the senior sergeant to reset their watches 6 hours ahead. A light "supper" was then served at 1745 CET (1145 CDT), consisting of a ham and cheese sandwich, salad, cheese, and fresh fruit, with no caffeinated beverages or sweetened soft drinks allowed. At 2220 CET subjects were each given 100 mg dimenhydrinate to induce sleepiness, and at 2300 the lights were turned off and everyone was instructed to sleep. The lights were turned on again at 0405 CET. A high-protein breakfast including steak and a 2-egg cheese omelet was served at 0430, and consumption of caffeinated beverages was encouraged. Napping was again prohibited for the rest of the day, which was largely spent unpacking at the training base following a ninety-minute bus ride from the airport.

Control subjects followed a normal airline routine. Subjects ate lunch and dinner on the aircraft at normal U.S. times, and were then given a breakfast snack at 0810 CET. Alcoholic beverages were unavailable. The cabin lights were turned off from 0215 to 0550 CET, but individual reading lights were available and no constraints were placed on subjects' activities. Control subjects were also allowed to nap when duties permitted following arrival at the training base.

All subjects were assigned light duties for the remaining 6 days of the study. No physical training or heavy labor were scheduled.

The second study, comprising two distinct experiments, was carried out in January, 1979 during a NATO field training exercise from the central U.S. to Germany. Conditions differed markedly from the first study. Extreme winter weather prevailed on both sides of the Atlantic, and in Germany troops lived in field tents. The aircraft were USAF C-141 jet transports. They were configured with nylon webbed seats in four rows down the length of the aircraft, an uncomfortable and cramped arrangement which made sleeping difficult. Testing in Germany was done mostly in large tents which were poorly illuminated and heated.

Training and baseline testing were carried out for both experiments during the week immediately prior to deployment from the troops' home post. Formal testing was conducted for four days, with three test periods each day roughly corresponding to breakfast (0800), lunch (1200), and dinner (1630) times. Following deployment (+ 7 hours), troops were tested for 3 to 5 days beyond the day of arrival. An additional night test (at about 2100 hours) was added so that four test sessions were held each day after arrival.

The first part of the experiment duplicated as much as possible the earlier study. The approximately 120 subjects were deployed on four aircraft; two followed the countermeasures regimen while the others maintained usual military airlift procedures. The countermeasures were necessarily adapted slightly to conform to operational limitations of Air Force flight schedules, standardized in-flight meals, poor seating arrangements, etc., but remained essentially the same as those for the October study. Subjects filled out the fatigue scale and sleep and bowel movement logs as in the first study; temperature was not recorded due to the weather conditions. In addition, new measures included a map coordinate alpha-numeric encoding-decoding task (3 min), and self-report scales for the subjects to rate their ability to process information, reason clearly, make accurate decisions, and concentrate.

The second part of the experiment was designed to investigate age differences in cognitive performance following deployment. Subjects were selected to form two disparate age groups, with a mean age of 21.0 for the 31 younger subjects as compared to 34.2 years for the 29 "older" subjects. Due to subject availability problems, this difference was not as great as had been hoped. These soldiers deployed on several different C-141 aircraft. No countermeasures were administered, and schedules varied for the different flights.

The test battery was expanded to include several more tasks in addition to those for the countermeasure subjects. These included a logical reasoning task (Baddely, 1968), the trails test, letter cancellation (Fort & Mills, 1972), and short-term word recall. This battery was printed in a small booklet and required about 15 minutes to complete. All testing for both parts of the study was carried out under the supervision of the investigators and technical staff. Each performance test was allotted a fixed time, with the length predetermined to preclude subjects from ever finishing the test.

Countermeasure Effectiveness

Fatigue and sleep. The primary complaint of persons experiencing "jet lag" is fatigue with a corresponding desire for sleep. The countermeasures appeared to be effective in this regard. The experimental subjects slept for a significantly shorter time as compared to control soldiers during the first two days in Germany (Figure 1). This was true even when sleep before 1800 on the first day was excluded from the analysis (4.4 vs. 8.1 hrs, $p < .005$, t-test), as countermeasure subjects were prohibited from daytime napping. It also appears that the results can not be attributed to group differences in the amount of sleep obtained aboard the aircraft. Measures by on-board observers of the amount of time spent by subjects resting with their eyes shut (the best available estimate of sleep) revealed that both groups slept about 5.5 hours. The fatigue scale results showed a consonant effect. Control subjects reported significantly greater levels of fatigue during the first 24 hrs than countermeasure subjects, who indicated little change from baseline levels (Figure 2). The somewhat short overall sleep durations may be attributable to the testing procedure, which necessitated awakening subjects at 0200 and 0600. While the countermeasure sleep times in particular seem somewhat low, these subjects' lower fatigue scale scores suggest that this is not due to difficulties in falling or staying asleep. A design which allows ad libitum, uninterrupted sleep is probably necessary to resolve any uncertainty about this point.

The second field study confirmed the effectiveness of the countermeasures under rigorous field conditions. While all subjects reported some increases in fatigue relative to baseline following deployment, once again the experimental subjects reported significantly lower fatigue than the controls ($p < .05$, t-test) for the first two days in Germany (Figure 3). Both groups recovered partially by the third day, but persisted in slightly elevated fati-

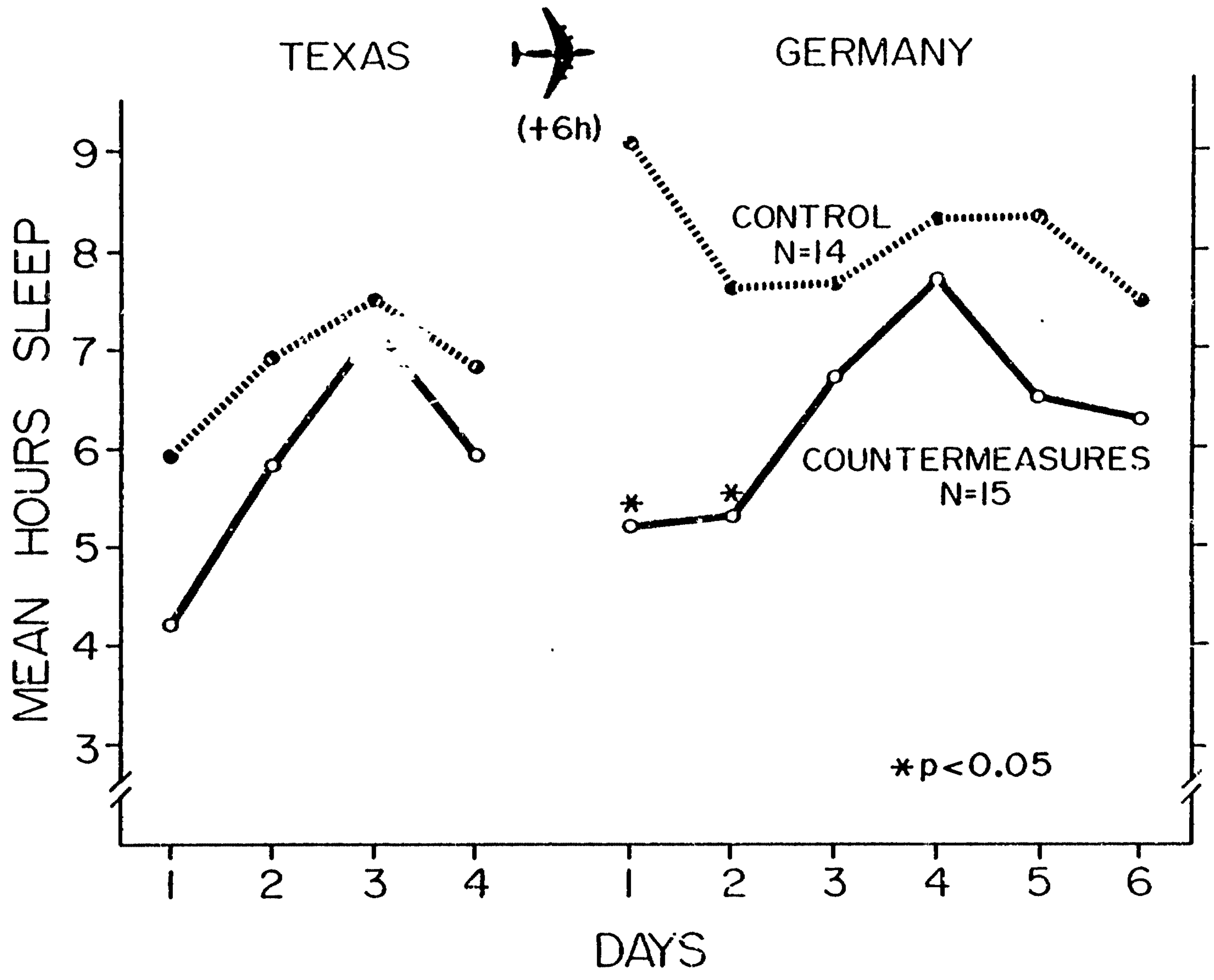

Figure 1. Sleep results for groups in Experiment 1. One control subject is omitted due to loss of the sleep diary in Germany.

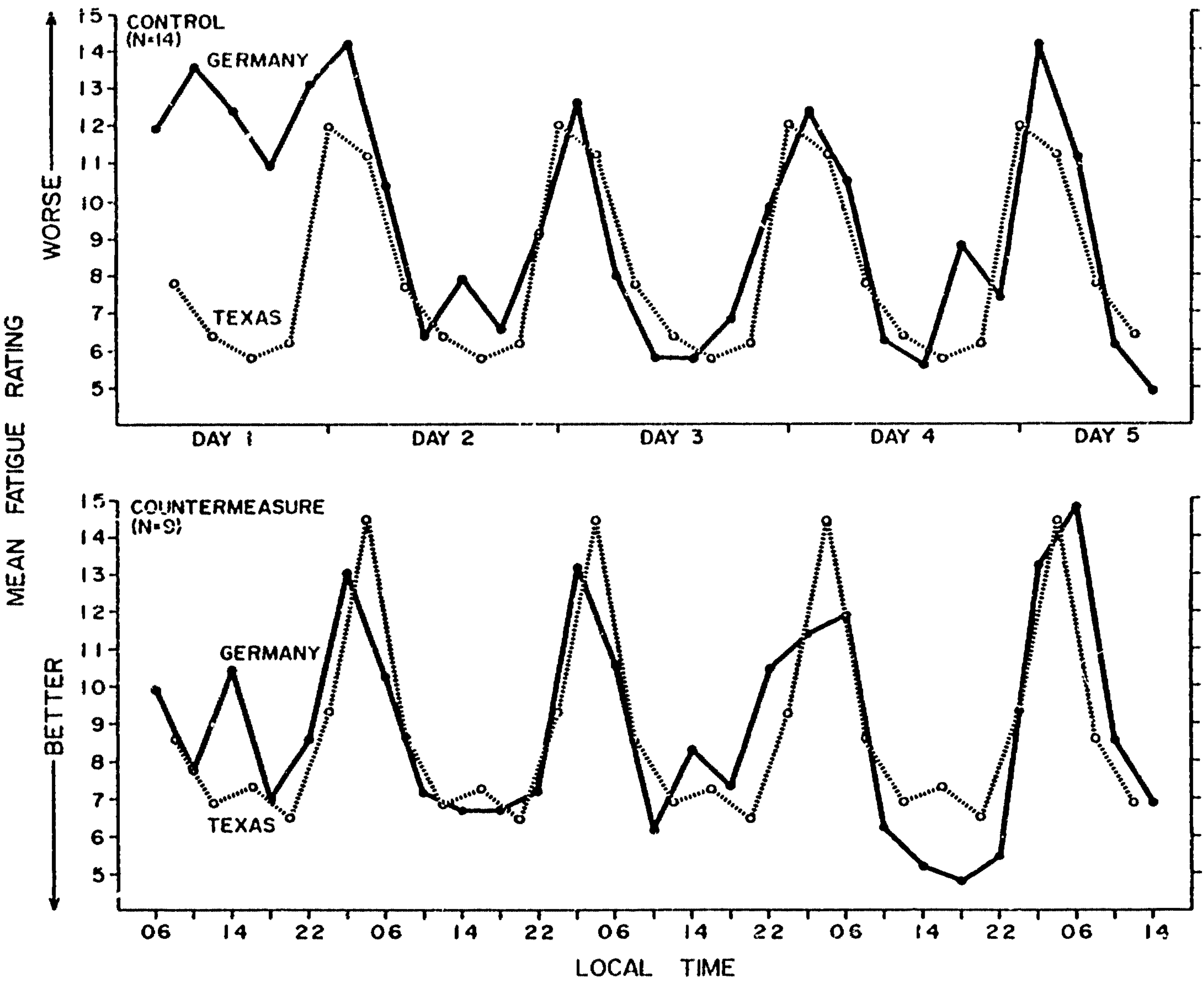

Figure 2. Self-rating of fatigue following deployment to Germany superimposed upon each group's phase-shifted (+6 hrs) 4-day mean baseline ratings in Texas. Seven subjects are omitted because of contradictory checklist responses or loss of diary.

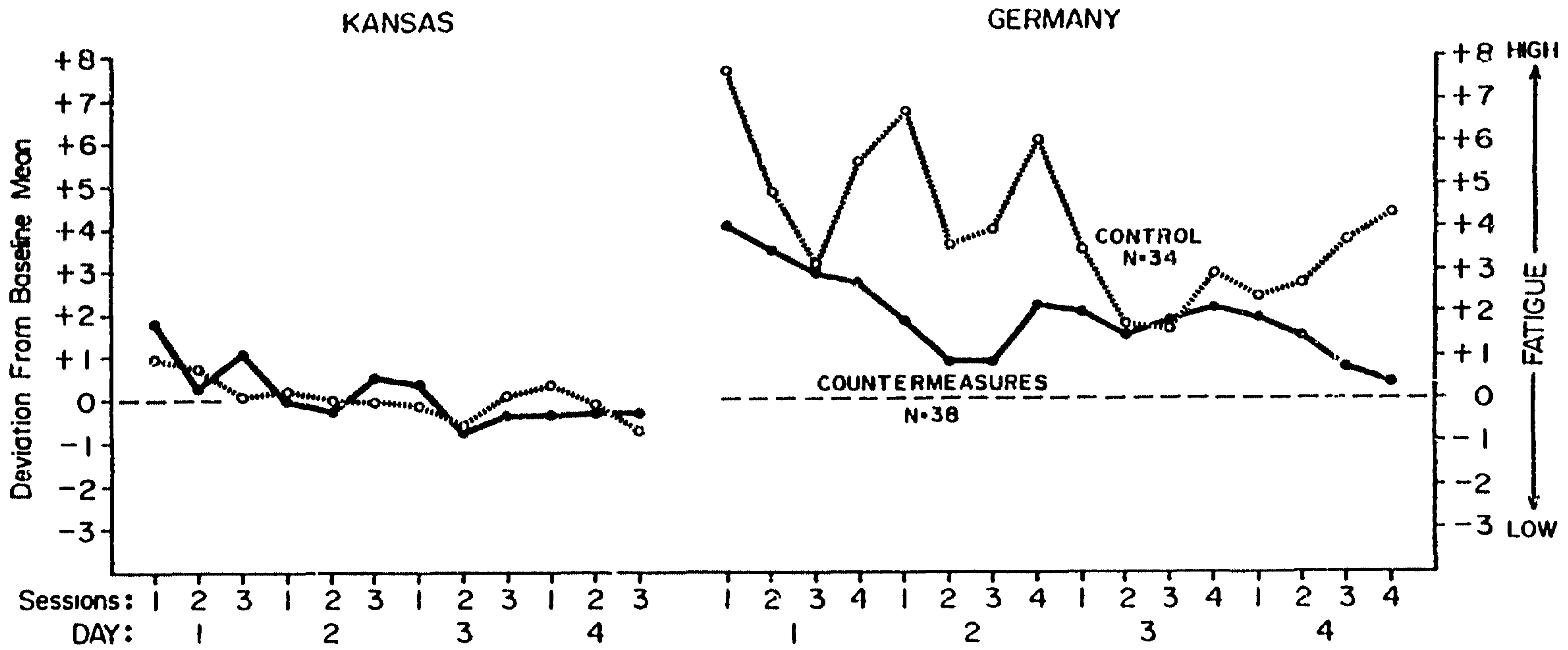

Figure 3. Group differences in self-rated fatigue in winter study as compared to mean baseline ratings during last day in Kansas.

gue ratings for the remainder of the study. This effect was further confirmed by the data for the self-report scales of information processing, concentration, etc. (Figure 4). Control subjects rated themselves significantly poorer than those in the experimental group for the first two days in Germany ($p < .05$, t-test), after which both groups exhibited partial recovery for the remaining days. Sleep results are difficult to interpret due to operational effects. Mean sleep time for control subjects was significantly less on the first night in Germany, due to the requirement for one plane-load of soldiers to draw equipment most of the night of arrival (Figure 5). A possible compensating effect is seen in the longer sleep for control subjects on the second post-flight night. While this initial sleep deficit may have contributed to the second day's fatigue scores, the significant fatigue differences on the first day were recorded before the sleep loss occurred; additionally, the unaffected control subjects also reported higher fatigue than experimentals on the second day. Thus, the fatigue self-rating results cannot be considered an artifact of sleep differences.

Body temperature. The oral temperature results are more equivocal than the fatigue data regarding countermeasure effectiveness. In general, their interpretation is limited by the lack of an adequate around-the-clock baseline for the large groups and the relatively short five-day post-flight observation span for all subjects. Although some support is provided for accelerated adaptation by the experimental group, substantial individual differences require that caution be exercised before any firm conclusions can be made about more rapid physiological adaptation to the new time zone.

The mean oral temperature rhythms for both groups exhibited very rapid initial adaptation to the new time zone. This finding is consistent with the reports on "Exercise Medex" (Adam et al., 1972; Colquhoun, 1979). As Figure 6 shows, however, there were subtle differences that suggest a beneficial effect of the countermeasure procedures. Note that the shape of the countermeasure function is almost identical to that of the intensive group's phase-shifted baseline function on the day after landing, whereas the control function's shape and amplitude do not begin to approximate the appropriate pattern until the third day. Whether both groups have reached their final state of adaptation by Day 6 is unclear since no baseline data are available for these particular subjects and additional post-arrival data could not be collected.

The use of group mean temperatures to assess time zone adaptation may obscure the oscillatory nature of this process. While Figure 6 implies a smooth and continuous progression toward ultimate adaptation of phase and amplitude, more detailed rhythmic analyses indicate that this is not the case. Figure 7 represents the combined outcome of a complex demodulation (CD) analysis (Walter, 1968; Orr & Hoffman, 1974) of each subject's post-arrival temperature data. The results are expressed as the percentage of subjects whose CD-estimated acrophase was outside a one standard deviation range about the predeployment mean acrophase (1713 ± 2.9 hrs) of the combined intensive groups. Here it can be seen that phase adaptation for both groups continues to vary throughout the six-day span in a manner resembling a three-day cycle. While on some days one group appears to have adapted better, on other days the reverse is true.

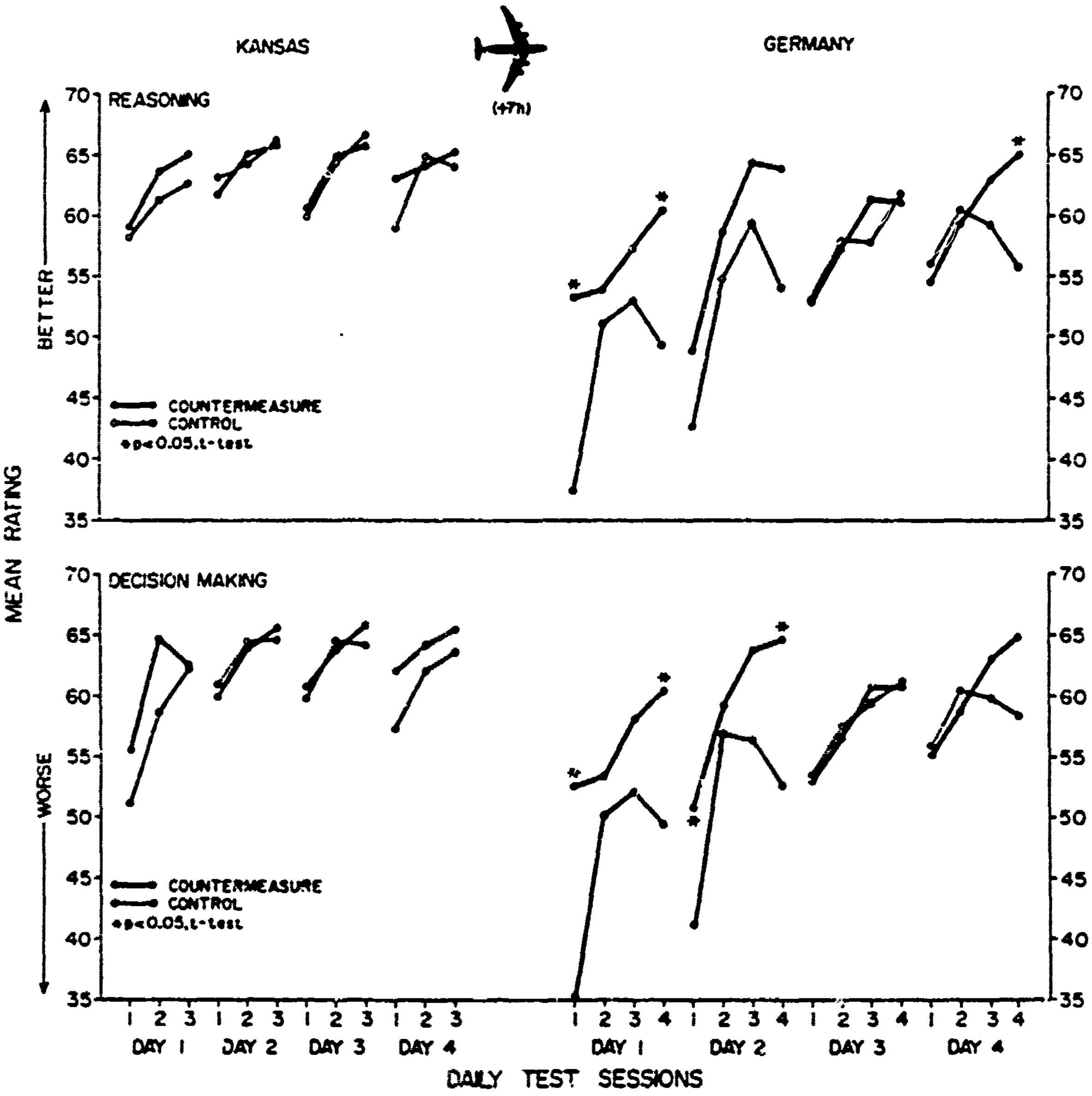

Figure 4. Influence of countermeasures on two self-rated cognitive abilities following transmeridian deployment.

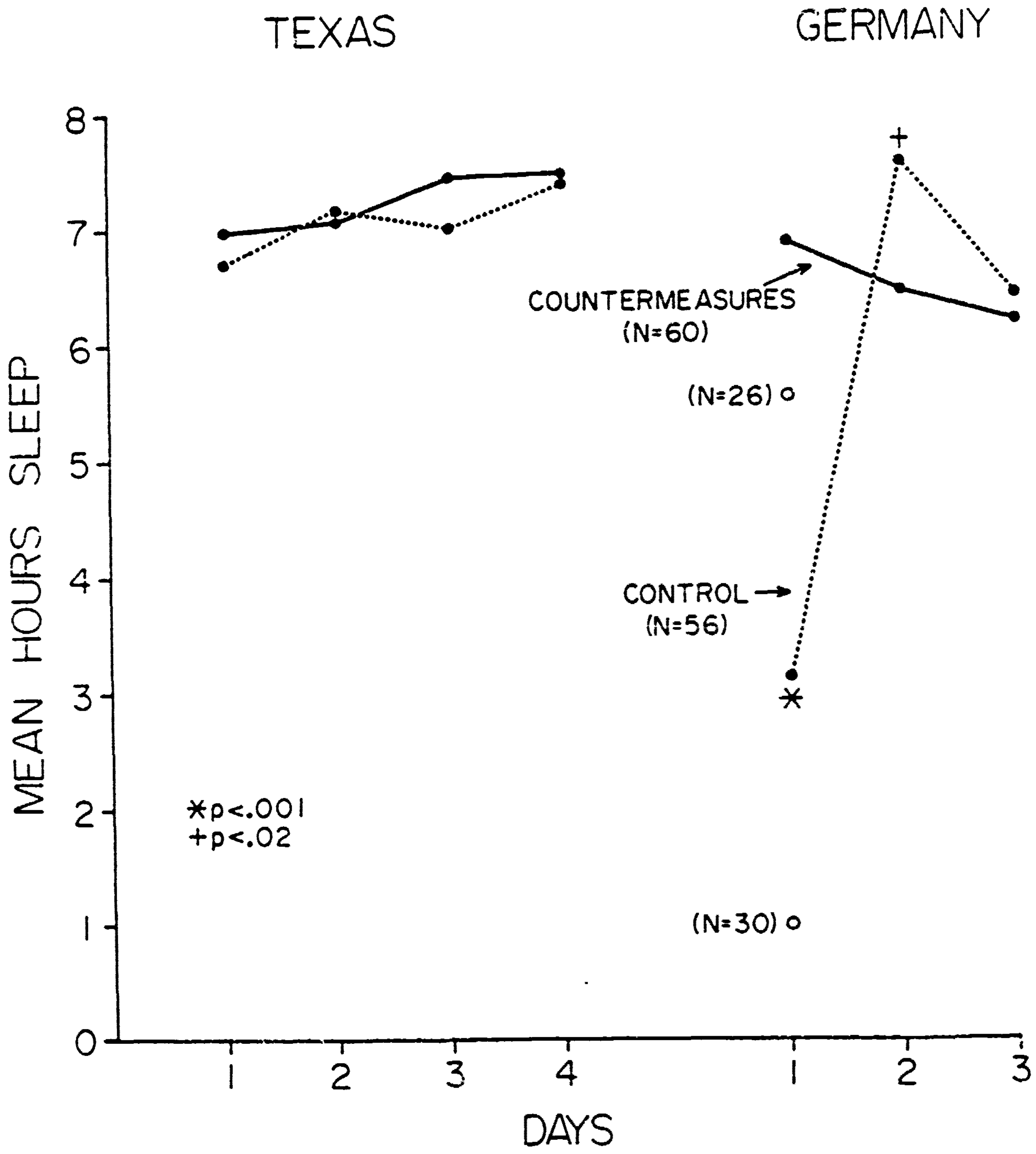

Figure 5. Sleep results for countermeasure and control groups in winter study. Open circles for Day 1 in Germany denote separate means for the two planeloads of control subjects (see text).

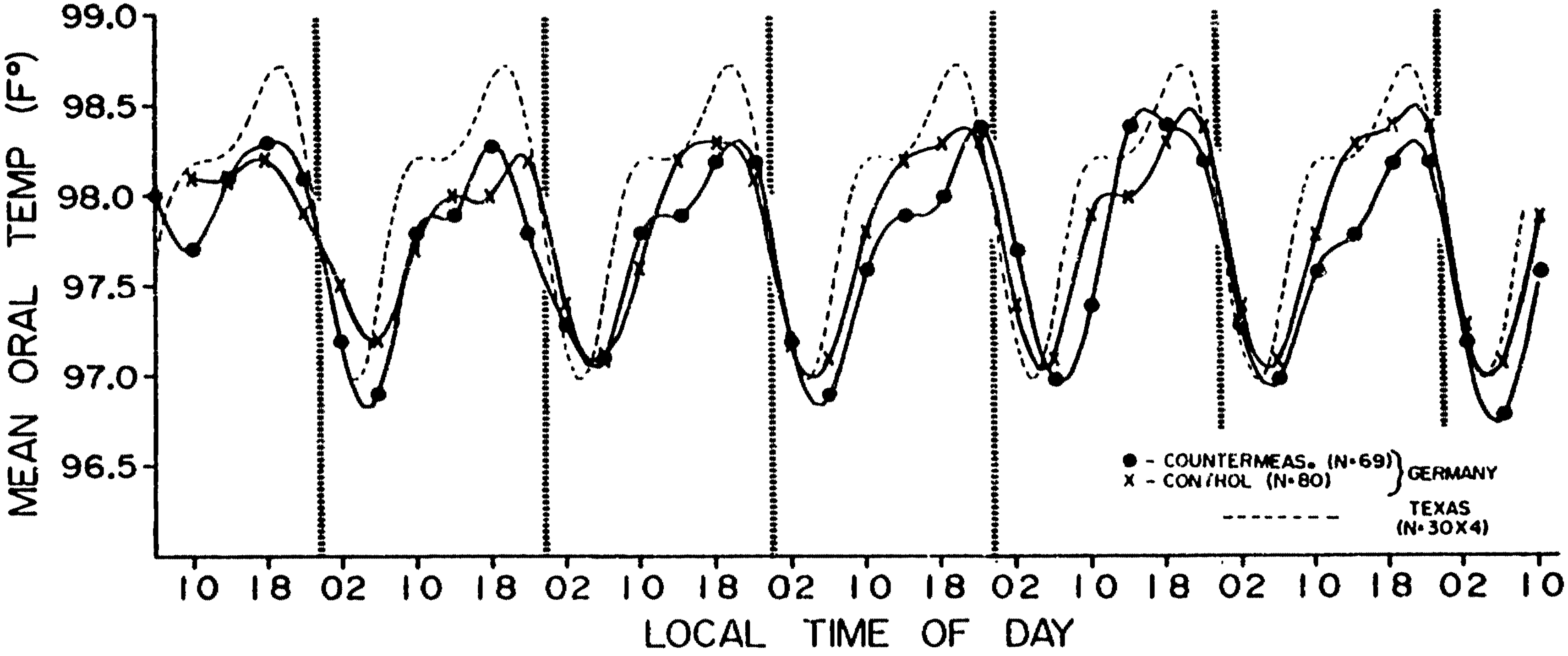

Figure 6. Mean oral temperature rhythms of large groups after deployment. Spline-fit functions are superimposed upon a phase-shifted (+6 hrs) estimate of the predeployment rhythm based on the mean daily temperature variation of the combined intensive groups in Texas.

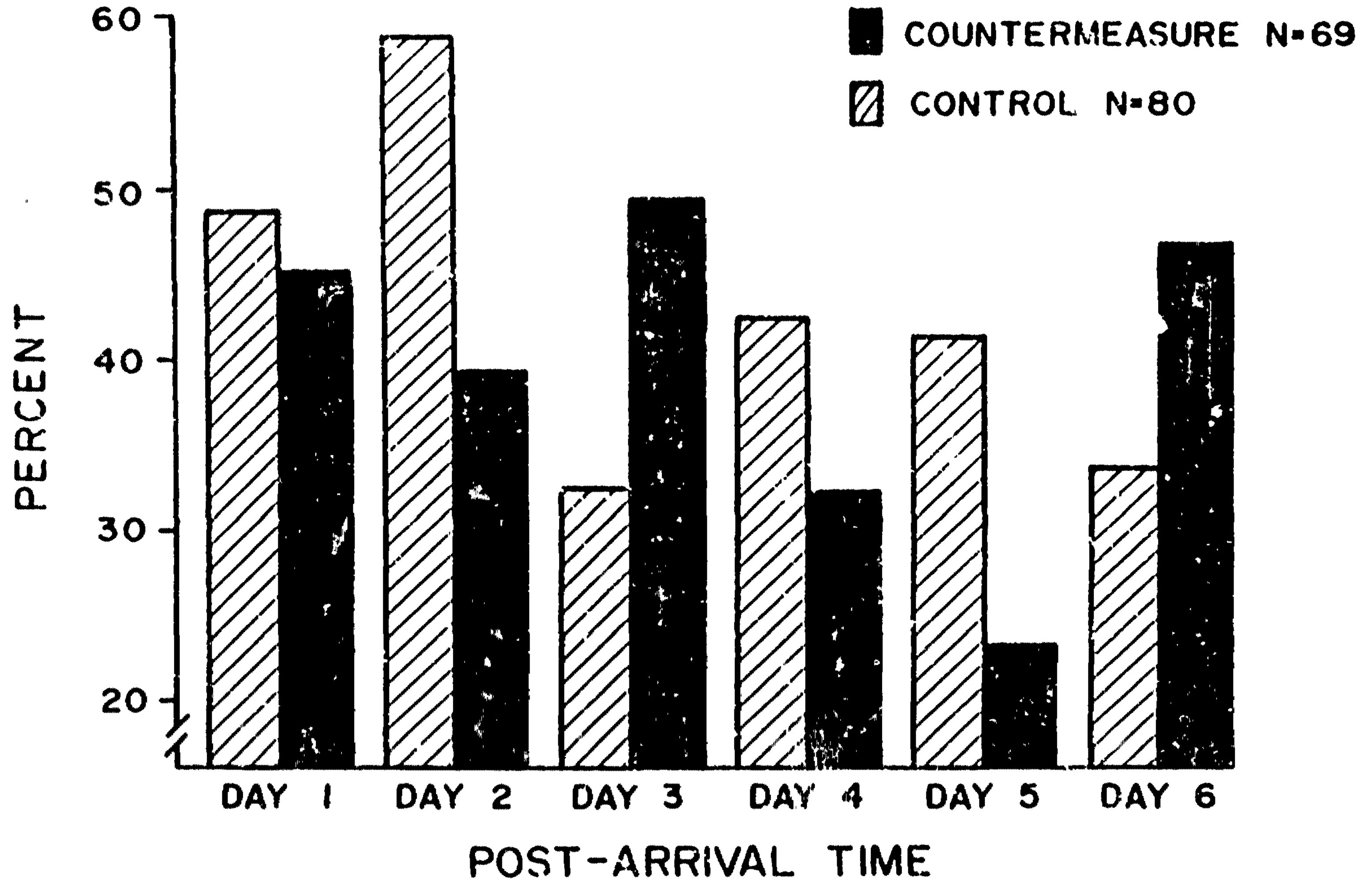

Figure 7. Daily percent of subjects in large groups whose CD-computed thermal acrophase indicated lack of phase adjustment after arrival (i.e., outside a one s.d. range about the mean thermal acrophase of the combined intensive groups in Texas).

Figure 8 presents the mean oral temperature results for the intensive groups who underwent around-the-clock measurements every 4 hrs in both Texas and Germany. It is evident that these curves are not consistent with those for the large groups (Figure 6), especially during the first four days following arrival. Both groups exhibit significant daily variability in both phase and amplitude, possibly due, in part, to the rather small number of subjects and the rigorous schedule which required subjects to be awakened for 30-45 min at each night test session. As in the large groups, adaptation as judged by group means appears to be largely complete by Day 6.

More detailed individual analyses by CD reveals the rhythmic structure underlying this adaptation process. Given a Nyquist frequency of 3 cycles per day, we were able to reduce each subject's raw data into a circadian and an ultradian component. Initially, these CD results were collapsed over days into the pre- and post-flight observation spans. Then subjects in each group were further subdivided into those who showed an increase in the percent of mean spectrum energy due to the circadian component following the flight and those who showed a decrease. As Figure 9 indicates, the countermeasure subjects maintained a relatively higher percentage of ultradian spectral energy regardless of whether they increased or decreased the percentage of spectral energy derived from the circadian component. The presence of significant ultradian components strongly suggests an active transitional state wherein the underlying oscillator is readjusting itself to the phase requirements of a shift in the synchronizer schedule. A similar explanation may underlie the pattern of variability seen in Figure 7. If this were the case, one would expect that the percentage of spectral energy derived from the ultradian component would gradually diminish as the individual becomes more and more adapted to the new time zone. Such a shift is apparent in Figure 10, where the daily mean power ratios are plotted for each group. While there is considerable day-to-day variability during the baseline measurement period, even greater fluctuations occur after the flight. During the six post-flight days the control group displays inconsistent fluctuations in the higher frequency components, while the countermeasure group exhibits a gradual and steady progression from days of relatively high ultradian energy to lesser amounts until it reaches baseline levels.

Previous reports on the effects of rapid transmeridain flight on body temperature have noted that the mean daily temperature is often affected in addition to the phase and amplitude of the circadian rhythm for temperature (Klein, Wegmann, & Hunt, 1972). In the present study a similar effect was seen in the lowering of mean body temperature (Figure 11). Both the control and experimental intensive groups had identical mean daily temperatures over the four days in Texas; however, the control group exhibited a consistently greater decrease in this value after the first day in Germany. This finding offers further support for the beneficial effect of the countermeasure procedures.

Cognitive Performance

Self-report scales and physiological measures provide only an indirect assessment of whether the countermeasures will improve human performance after rapid transmeridain flight. It is obviously more desireable to obtain direct measurements of cognitive performance changes following the deployment of con-

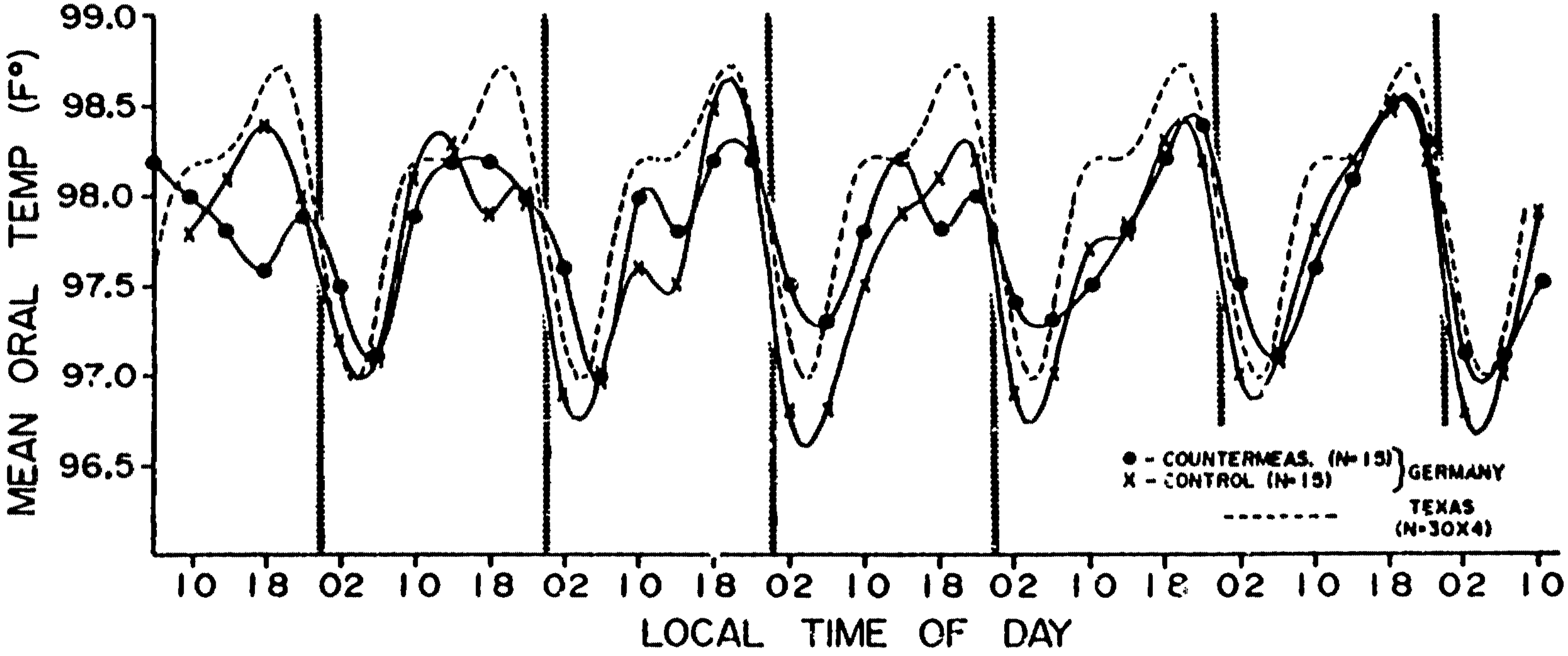

Figure 8. Mean oral temperature rhythms of intensive groups after deployment. Spline-fit functions are superimposed upon the phase-shifted (+6 hrs) predeployment rhythm of their combined mean daily temperature variations in Texas.

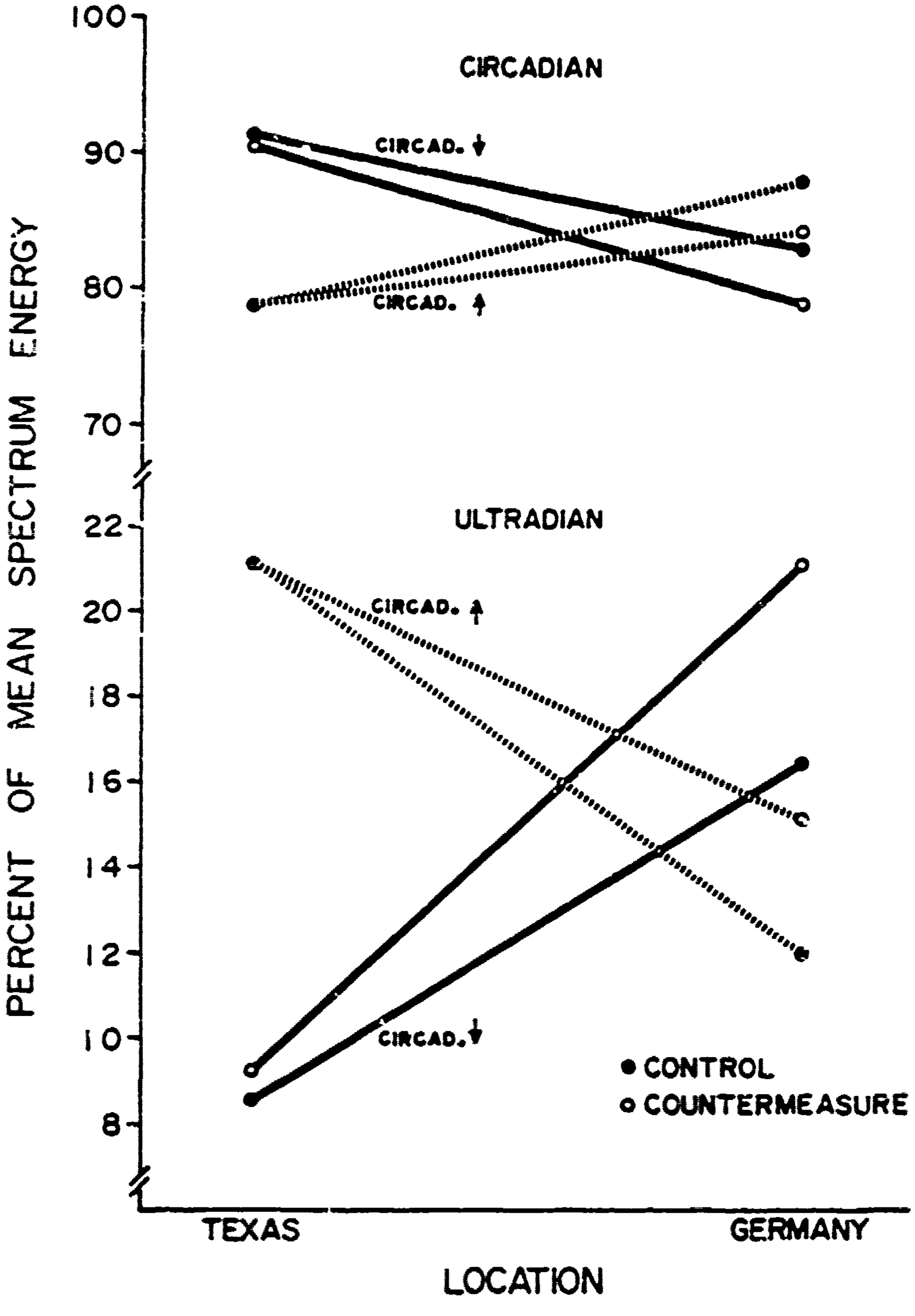

Figure 9. Shifts in CD-computed spectral energy of oral temperature rhythms after eastward (+6 hrs) transmeridian flight. Results are taken from intensive groups subdivided into subjects who increased circadian energy (Control = 7, Countermeasure = 6) and those who decreased circadian energy (Control = 8, Countermeasures = 9) during the post-flight observation span as compared to the pre-flight span.

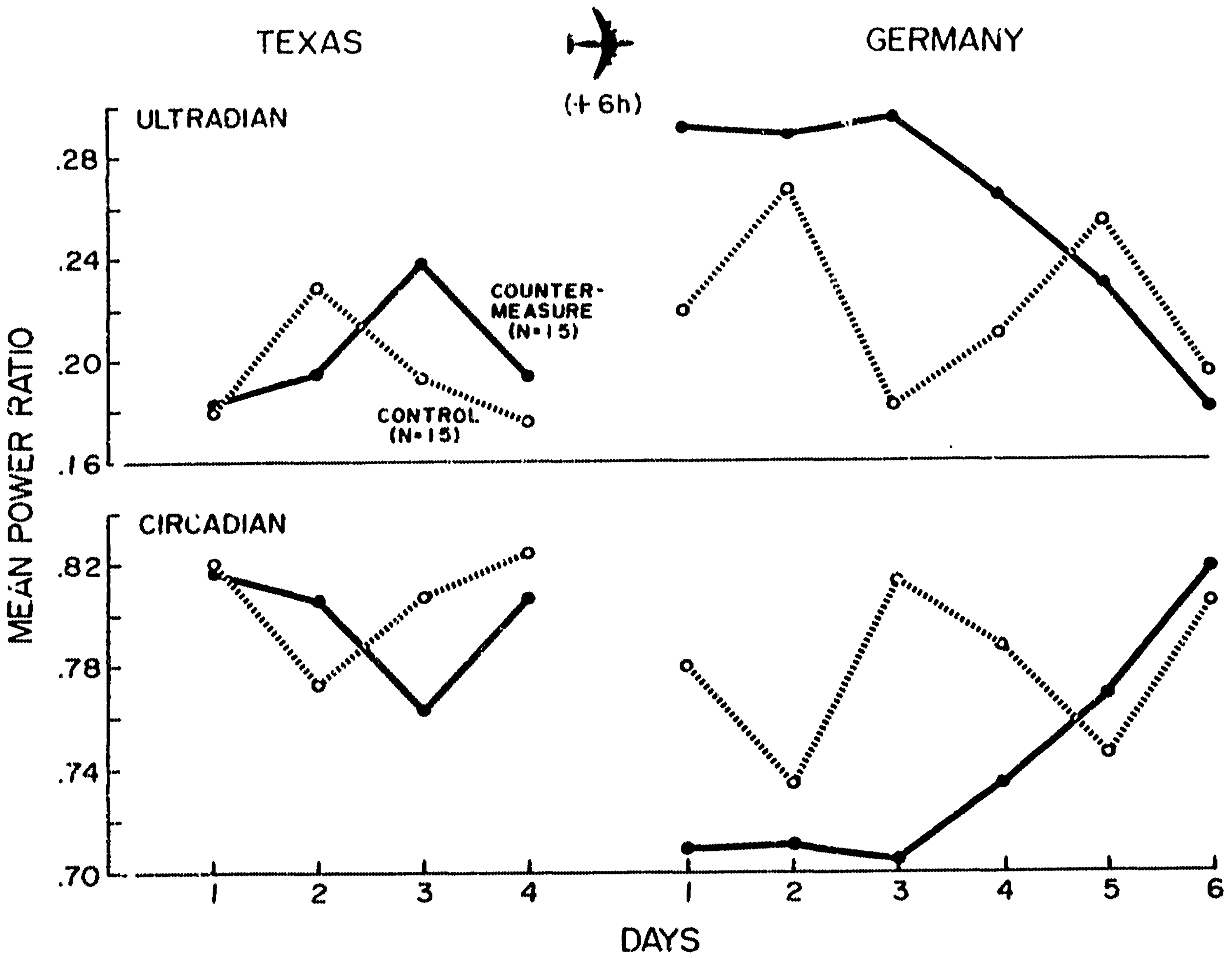

Figure 10. Daily mean power ratios of thermal circadian and ultradian frequencies before and after deployment of intensive groups. Ultradian and circadian components of the control group are significantly different ($p < .001$, t-test on arc sin transforms) from those of the countermeasure group on Days 1, 3, and 4 in Germany and on Day 3 in Texas ($p < .01$ for circadian).

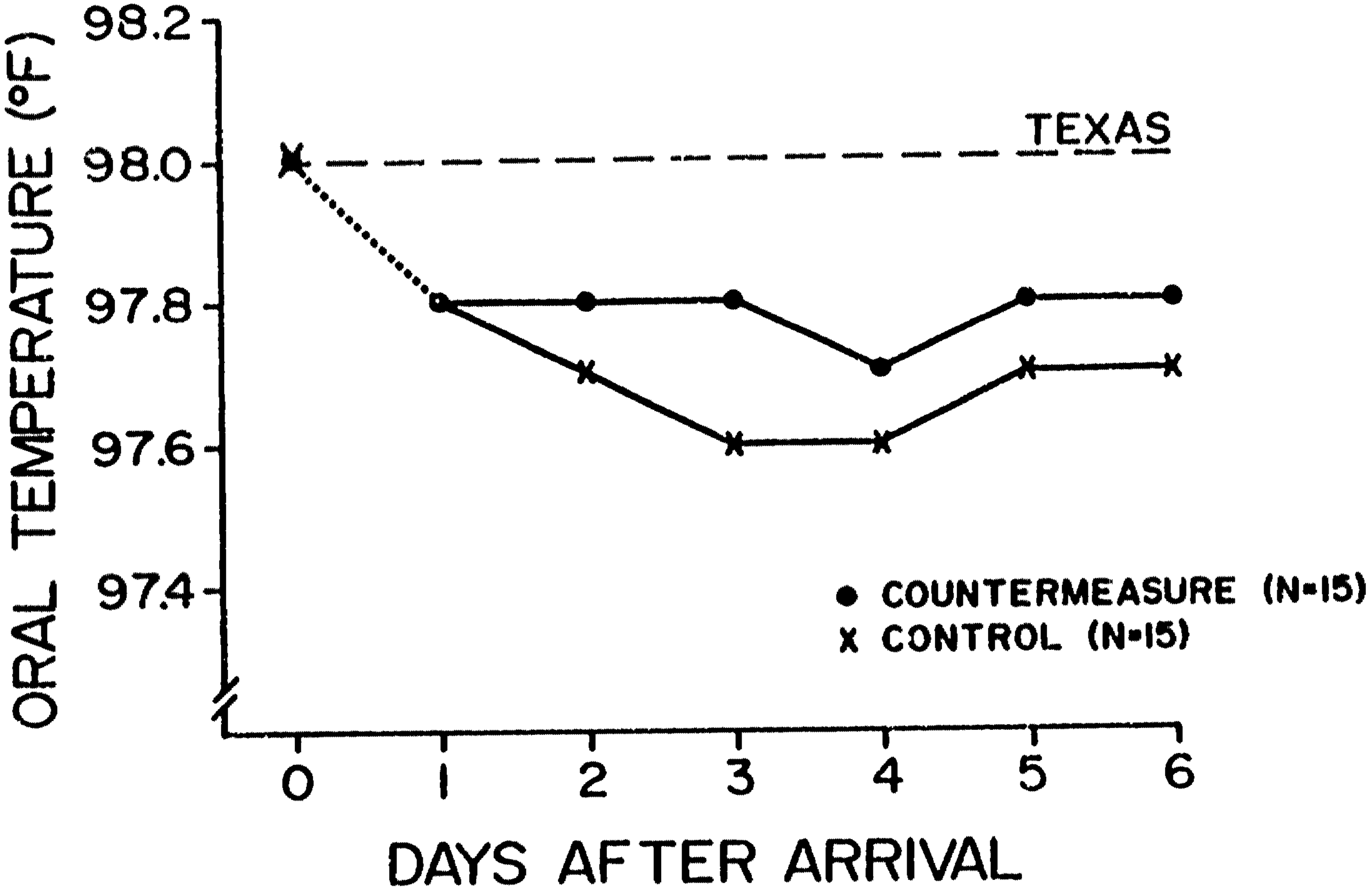

Figure 11. Mean daily oral temperatures of intensive groups after arrival in Germany as compared to their respective overall mean daily temperatures in Texas.

trol and experimental subjects. Due to operational limitations, our efforts have not been as complete as we would like. Because the four-choice reaction time data are still being analyzed, the only results currently available from the first study are for the sequential digit-pair addition task.

Figure 12 presents the adding speed data for the intensive groups of Experiment 1. The post-flight scores are superimposed upon the corresponding average baseline performance. Clear circadian patterning is evident, as is the persisting learning effect shown by the higher scores in Germany. However, no losses in performance speed or accuracy were observed by either group. Some loss of synchrony occurred on Day 4, but returned to normal phase again by Day 6. In retrospect, it would seem that this task was insufficiently demanding to produce any tangible deficits following the flight.

The encoding-decoding task used in the winter study proved more successful in detecting a post-flight performance decrement. Countermeasure subjects consistently completed more items than controls on this task. However, no differential changes in response speed (i.e., number correct) were seen following deployment (Figure 13). Both groups exhibited decreases in the number correct on the first day, followed by gradual recovery over the next three days (Figure 14). Experimental subjects maintained stable accuracy levels of 97-98% following the flight; controls matched this performance for the first two days, then dropped five percent in accuracy on Day 3 (Figure 13). Control subjects thus increased their response rate only at the cost of a loss in accuracy.

While there is thus some suggestion that the countermeasures may preserve post-flight performance, a more comprehensive assessment in this area is necessary before any firm conclusions can be made. Such an expansion is indicated for physiological measures as well in order to document thoroughly the relationship between self-reports, cognitive performance, and physiological rhythms after deployment with or without countermeasure procedures. A thorough analysis would also require a longer post-flight observation period than was possible in the present studies. Ideally, stable rhythm parameters should be documented before terminating any such experiment.

Age and Cognitive Performance

As mentioned earlier, any concern for the successful development of "jet lag" countermeasures is predicated upon the extent to which performance is degraded by rapid transmeridian deployment. The types of performance deficits typically associated with intercontinental flight involve losses in cognitive ability and psychomotor skills. Most previous field studies have limited themselves to examining the impact of such flights on eye-hand coordination, reaction time, manual dexterity, visual search, flicker perception, and simple addition (Aschoff et al., 1975). Although these data are relevant for predicting performance decrements for pilots and other equipment operators, they provide little information about commonly reported deficits in abstract thinking, information processing, decision making, and other higher order cognitive processes. From a military standpoint, it is the latter type of performance loss which is most likely to have a serious impact upon the largest number of soldiers in a combat situation. Command and control elements are required to operate under a high, continuous cognitive load and to make decisions

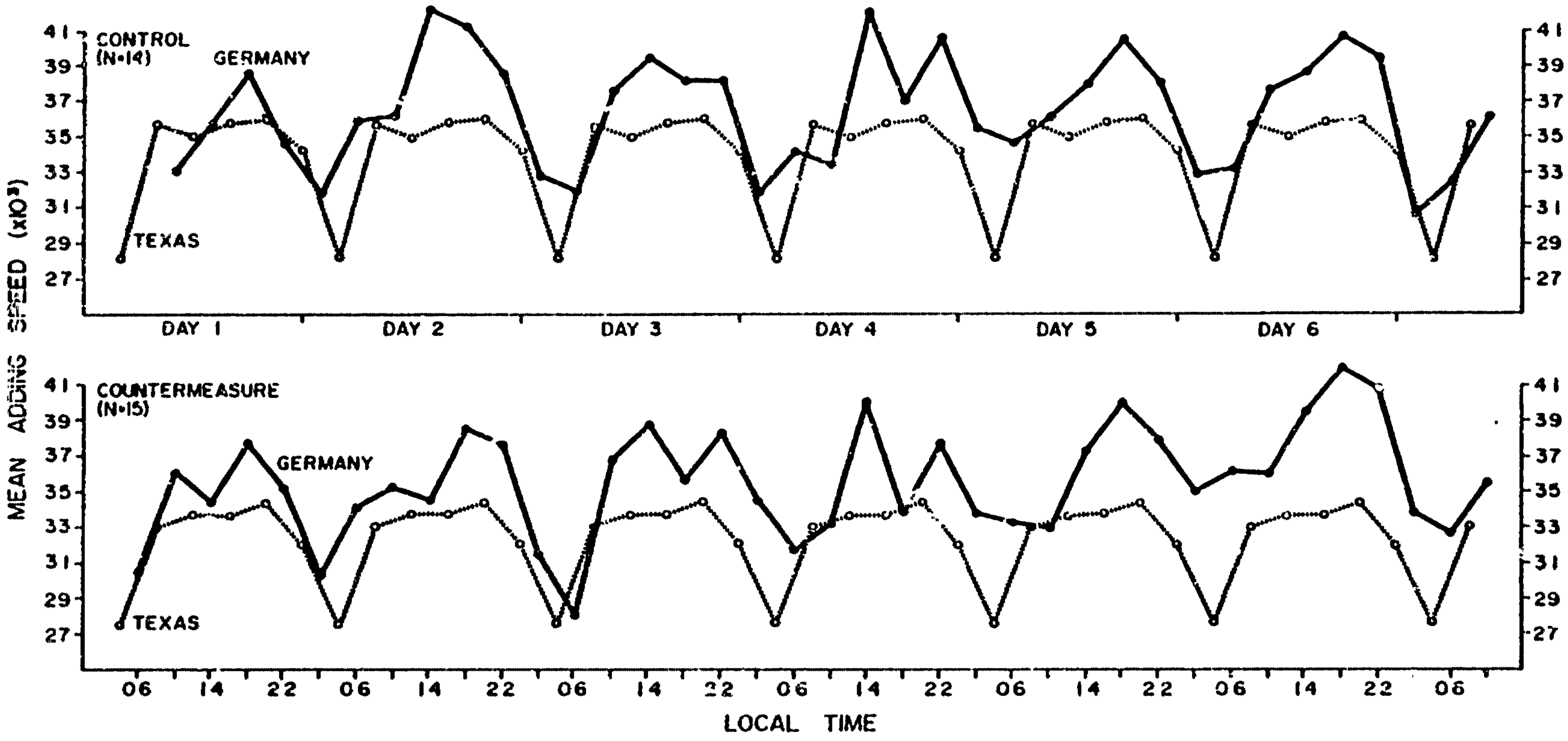

Figure 12. Performance on sequential digit-pair addition task by intensive groups after deployment to Germany. Adding speed, i.e., (1/sec) X 10^3, is compared to phase-shifted (+6 hrs) predeployment rhythm of their combined mean performance in Texas.

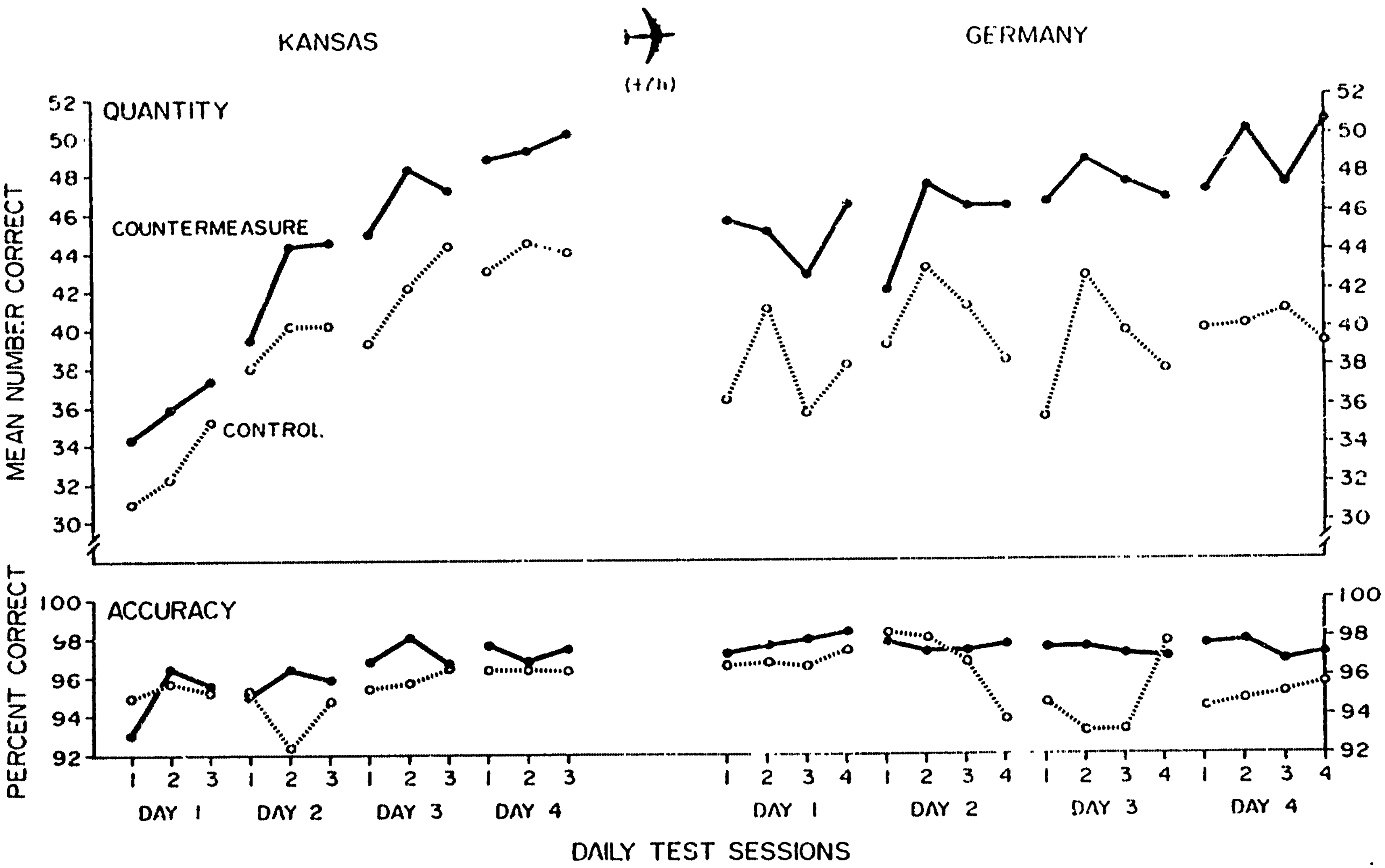

Figure 13. Influence of countermeasures on mean encoding-decoding performance during winter study (Control N = 34, Countermeasure N = 38).

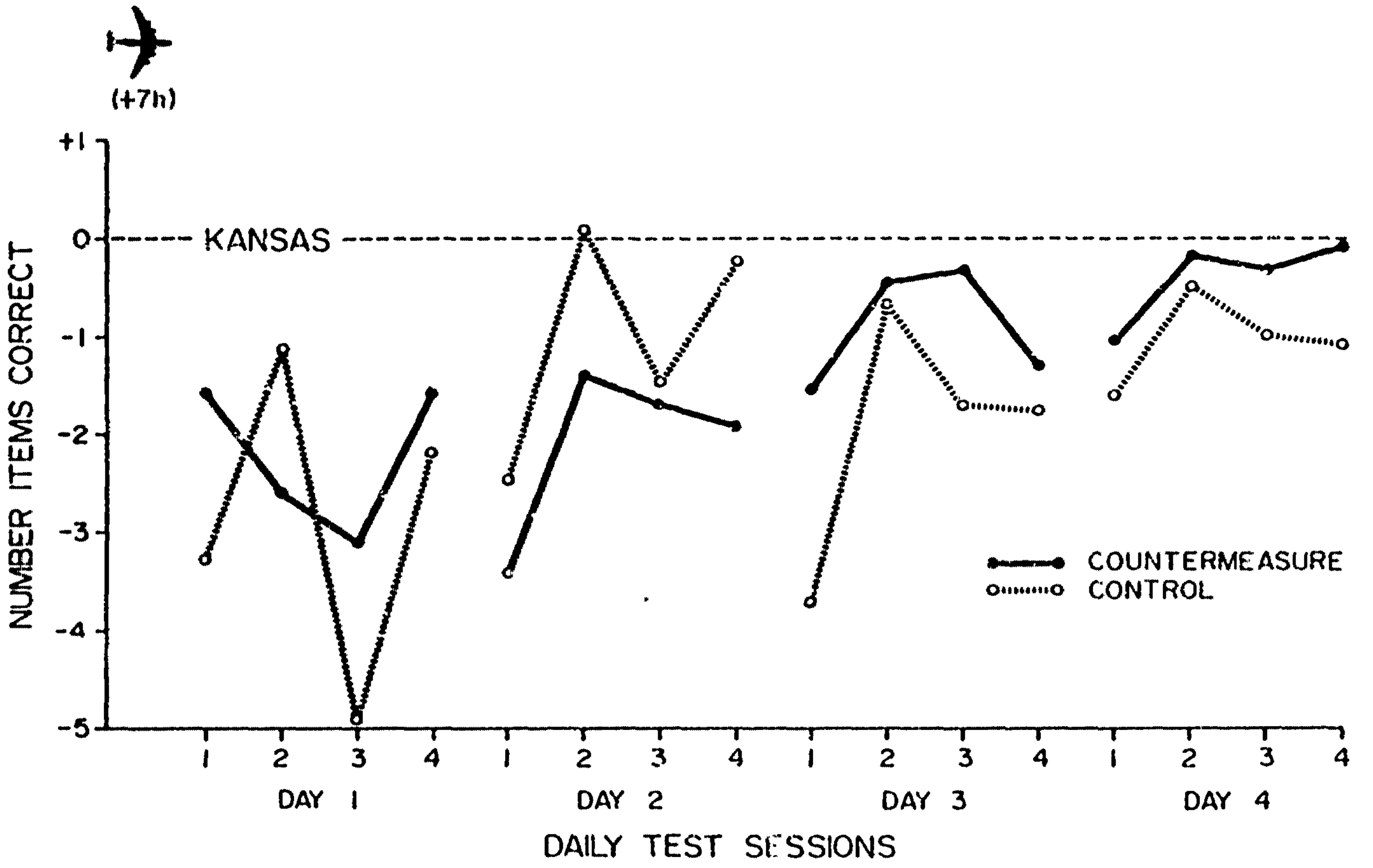

Figure 14. Mean differences in pre- vs. post-flight encoding-decoding performance of countermeasure and control groups. Each subject's post-flight scores were compared to his own overall mean performance on the last day in Kansas.

which directly affect the welfare of all troops under their supervision. It is for this reason that we carried out the second part of the winter deployment study. Furthermore, we decided to specifically examine the interaction of age with cognitive performance for two reasons. First, commanders and the senior staff of most units greater than company size tend to be older than about thirty-five years of age. Secondly, other investigators have previously suggested that older individuals may experience greater difficulty in adjusting to time zone transitions (Klein, Wegmann, Athanassenas, & Hohlweck, 1976).

Fatigue scale ratings did not differ between older and younger subjects in the second part of the winter study. Both age groups exhibited a post-flight increase in fatigue followed by partial recovery, similar to that seen in the control group used for countermeasure comparison (Figure 15). Younger subjects did report consistently lower scores on the cognitive self-rating scales throughout the study; however, scores were not differentially affected by deployment. Both these measures duplicated the previously described pattern of post-deployment decrements followed by recovery on Day 3. Sleep duration reports indicated that older soldiers slept about 20 min less per day than younger troops throughout the study. It is not clear whether this reflects differential duties, decreased sleep need for older subjects, or other factors.

The cognitive performance battery generally failed to reveal any marked or consistent differences between old and young subjects. The general pattern was one of decreased performance after arrival followed by a gradual recovery to baseline over the next one to four days, depending on the task.

Logical reasoning, generally rated by subjects as the most difficult of the tests, was the most severely affected. During the first day in Germany the mean number of items correct decreased a maximum of 20% and 27% for young and old respectively as compared to the final pre-deployment day and did not regain the baseline level of performance until the fourth day (Figure 16). Accuracy was more variable after the flight but, except for Day 3, remained consistent enough so that number correct was primarily related to the number of items attempted. Performance for the griddle task was similar to that of subjects in the countermeasure part of the study. The number of correct responses (i.e., response speed) was down 10 to 15 percent after arrival, and returned to baseline by Day 3 (Figure 17). Accuracy during the first two post-flight days tended to be highest in the morning and then decline towards night. This diurnal pattern disappeared over the next two days, and by Day 4 accuracy stablilized at pre-flight levels. Mean word recall dropped about one word per test on Day 1 and returned essentially to baseline on Day 2. No change at all was seen for either group in the speed or accuracy of performance on the letter cancellation task. While the false positive rate was much higher for the first two than for the last two days in Germany, the high rate seen also in the U.S. renders this result somewhat difficult to interpret.

The general pattern thus accords with other reports (e.g., McCally, Wegmann, Lund, & Howard, 1973) that the recovery time for performance tasks is directly proportional to task complexity. One measure, the trails test, actually showed an increase in performance following deployment which persisted at or above baseline levels for the remainder of the study (Figure 18). This task required the subject to draw an unbroken line connecting a series of irreg-

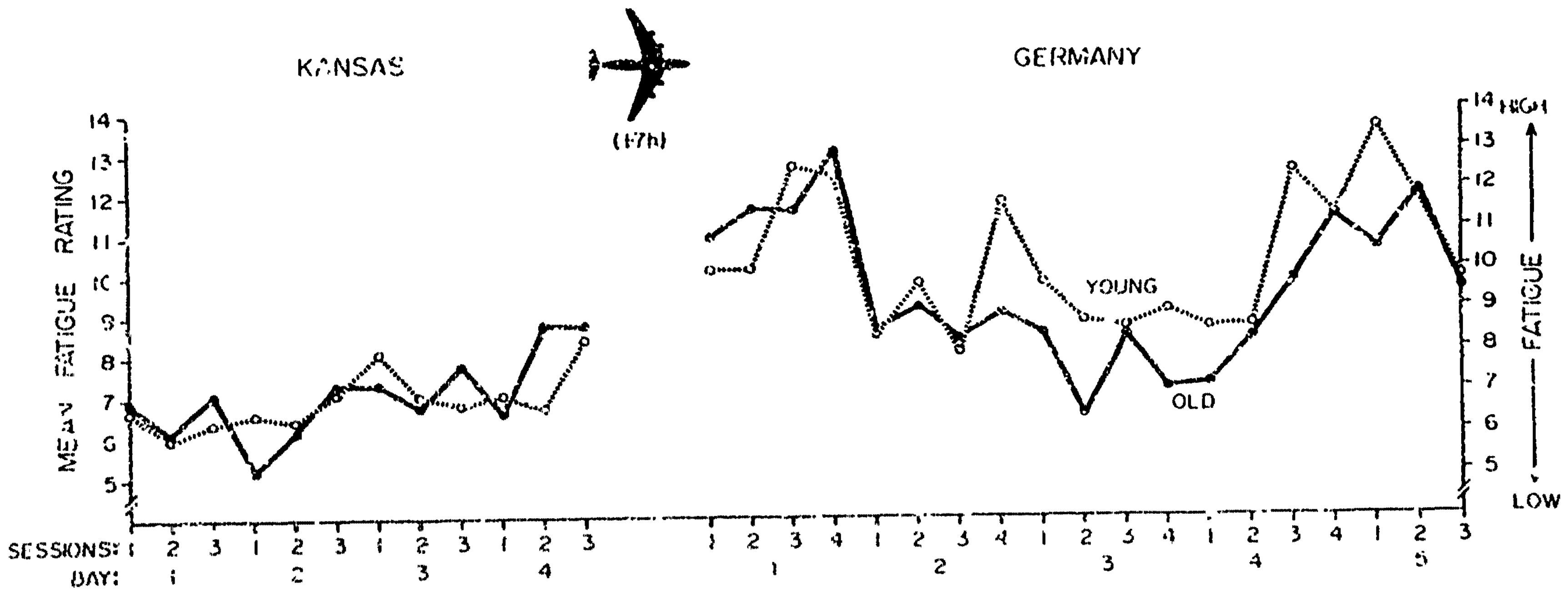

Figure 15. Self-ratings of fatigue following winter deployment of older and younger soldiers to Germany.

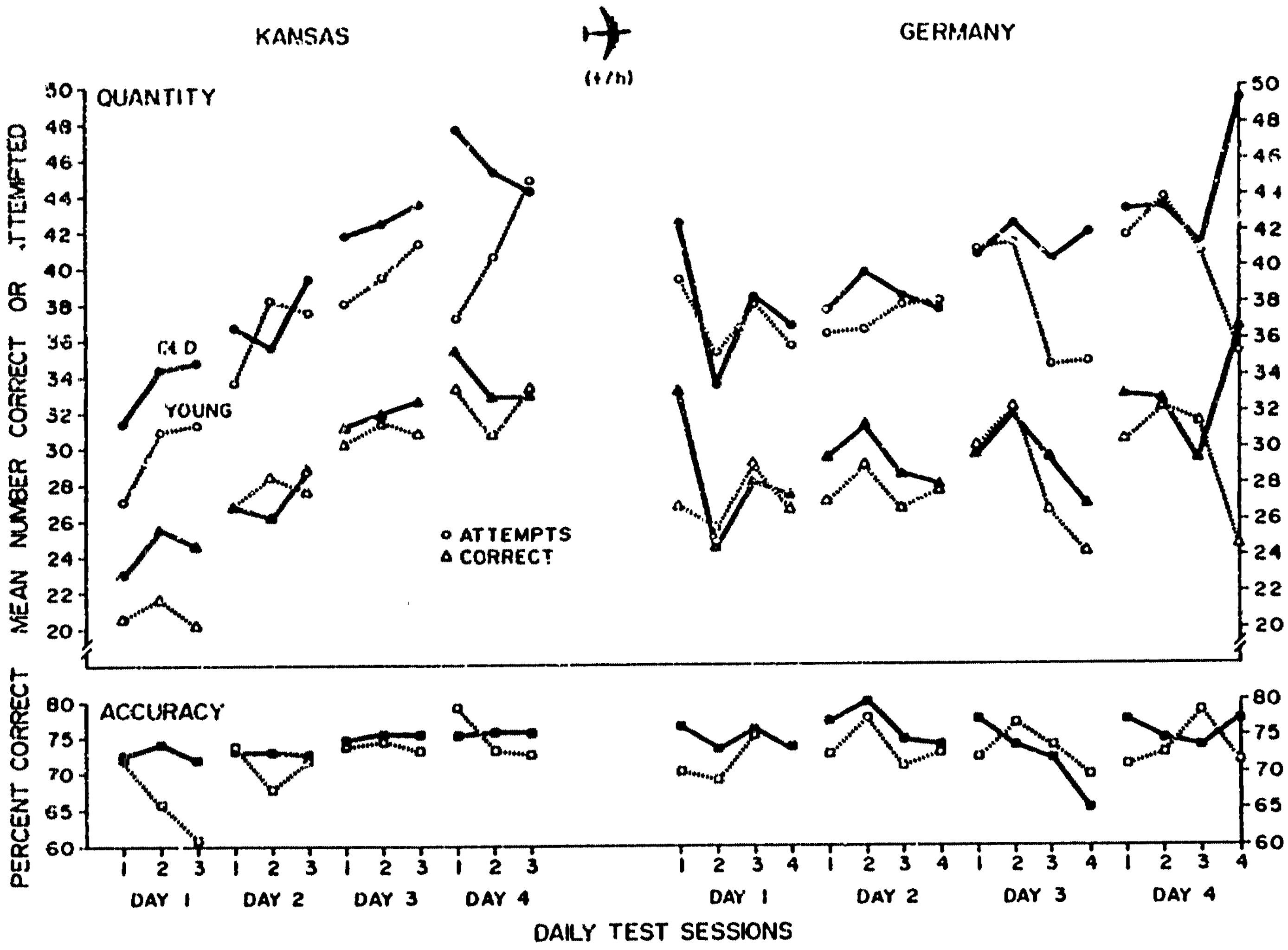

Figure 16. Effects of winter deployment on logical reasoning by older and young soldiers.

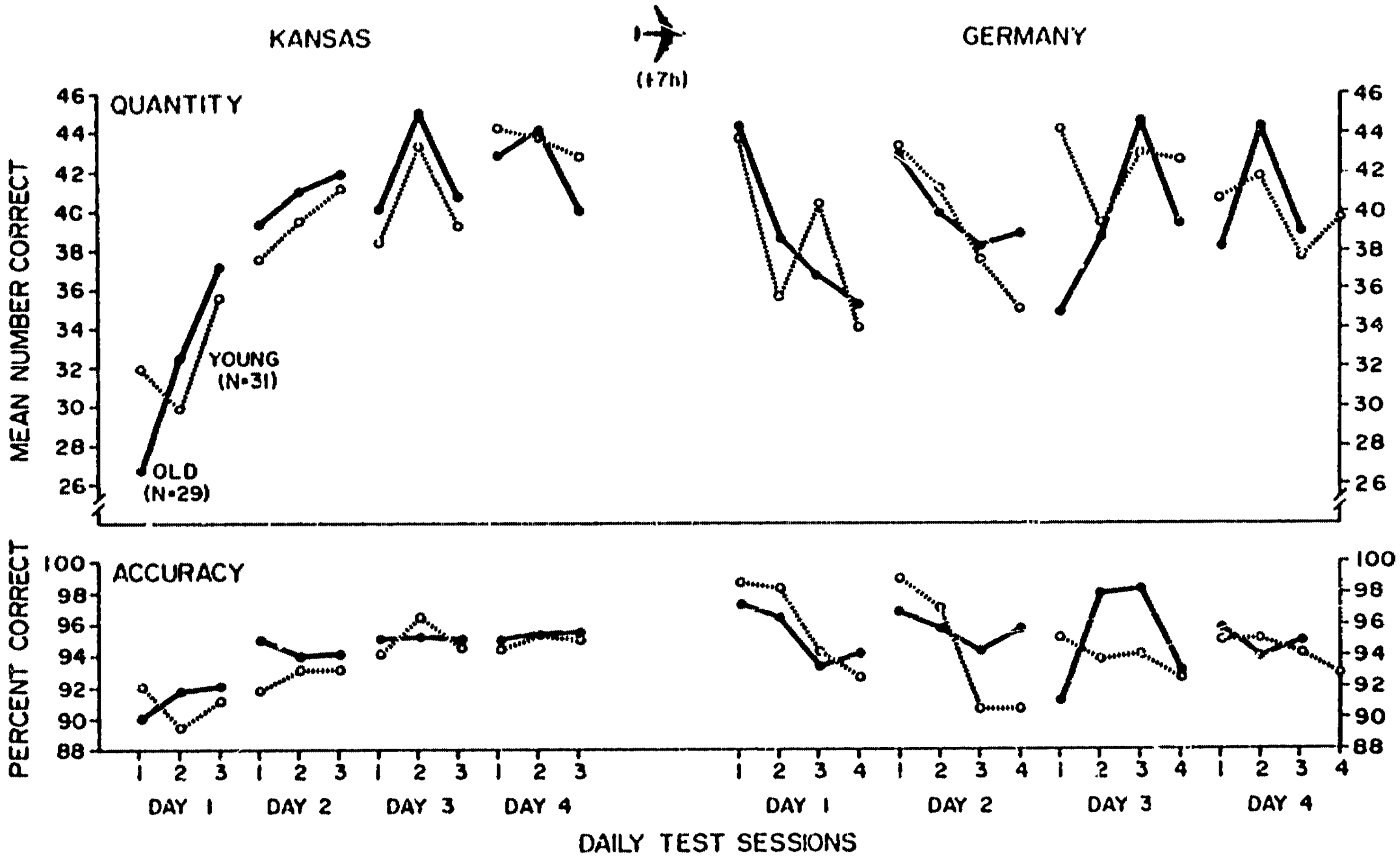

Figure 17. Effects of winter deployment on encoding-decoding performance by older and younger soldiers.

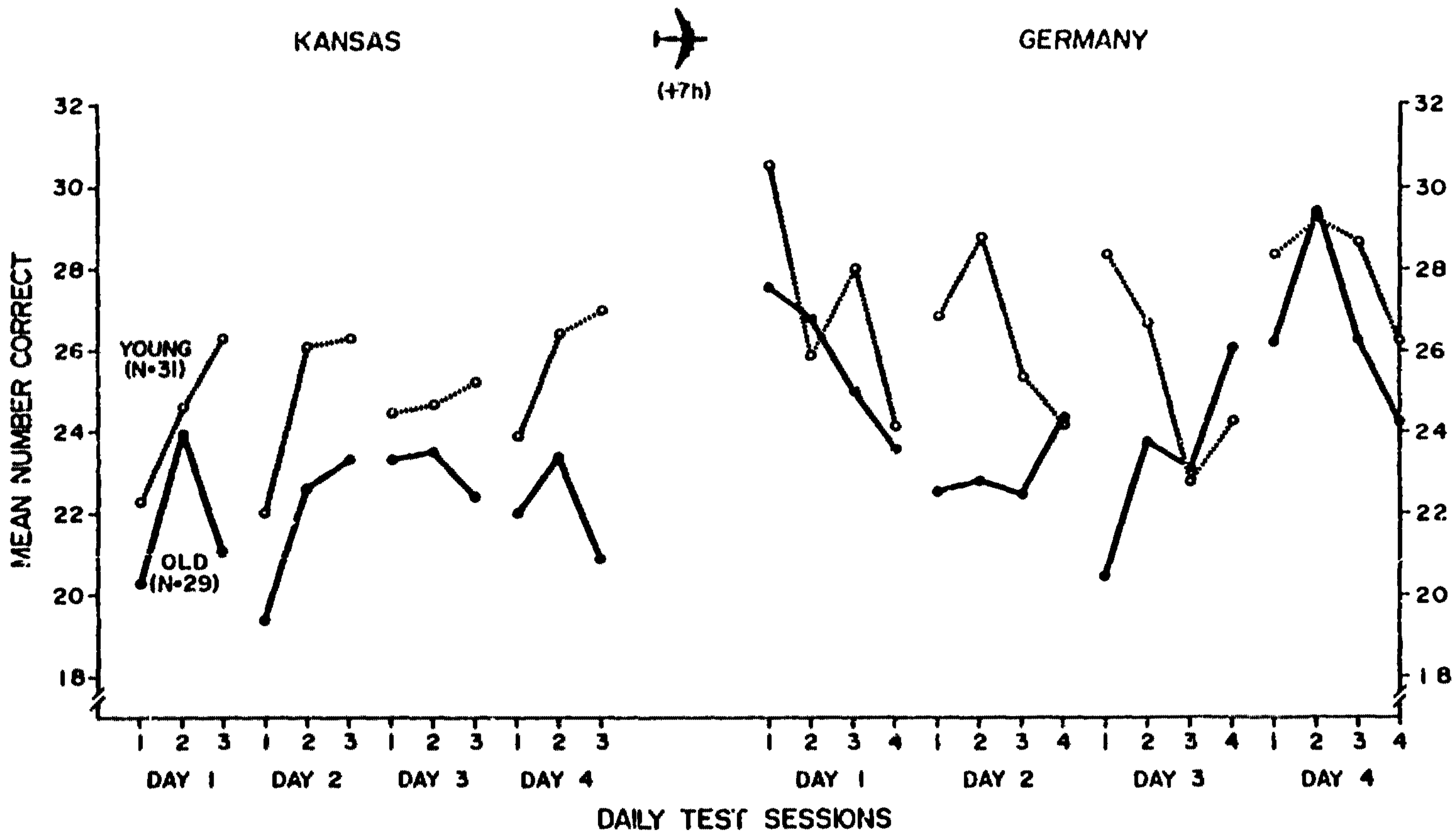

Figure 18. Effects of winter deployment on trails test performance by older and younger soldiers.

ularly spaced small circles (Figure 19). A fixed sequence had to be followed in which circles were connected in ascending order alternating between the numbered and lettered items. Thus, successful performance required substantial visuospatial ability and an ability to alternate response set between alphanumeric stimuli. The meaning of this unanticipated finding is not yet clear. Given the dramatically sharp rise in performance, especially for the older group, it is unlikely that the shift reflects a practice effect. Possibly, the enhancement was due to true facilitation of some performance capacity unique to this task or to a disinhibition of non-verbal, non-quantitative response tendencies. This hypothesis is supported by Wever's (in press) recent discovery that performance and psycholoical mood often show an improvement when subjects become desynchronized in a chamber environment where the light-dark cycle is beyond the range of entrainment. However, additional data need to be collected on similar tasks before any conclusions can be drawn. Regardless, this finding underscores the need for more comprehensive cognitive test batteries which assess performance mediated by the right, as well as by the left, cerebral hemisphere.

Immediately following each test session, subjects were asked to rate their own performance (Figure 20). As with the subjective rating scales for concentration, etc., older subjects consistently marked themselves higher than did the younger soldiers. This was particularly marked in Germany, where older subjects' ratings followed approximately the course of actual performance recovery while younger subjects consistently rated their performance much lower than it actually was. This finding suggests that young, inexperienced soldiers may be more likely to underestimate their performance ability following transmeridian deployment.

Despite the lack of any significant differences in cognitive performance or fatigue related to age, we are currently somewhat reluctant to conclude that age may not be an important factor in determining the effects of rapid transmeridian deployment. There are several reasons for our hesitancy. The primary one is that the age of the older group was probably too low to demonstrate the more serious adjustment difficulties usually described by older travelers. Although their mean age was 34.2 years, their individual ages ranged from 27.1 to 43.8 years, while the younger group ranged in age from 18.4 to 25.1 years. The age of most senior personnel in the division headquarters originally targeted for this study was at, or beyond, the upper limit of this "older" age range. Secondly, the test battery was designed to challenge individuals accustomed to performing high-level cognitive tasks. The use of maintenance personnel as subjects may have inadvertently resulted in a "floor" effect which restricted the sensitivity of the tasks to flight induced cognitive deficits. This possibility is suggested by the consistently much higher scores obtained by a few of the subjects. Finally, it should be noted that the adverse winter weather and relatively poor lighting conditions may have contaminated the data by introducing excessive variance and lower mean scores throughout the entire post-deployment observation span.

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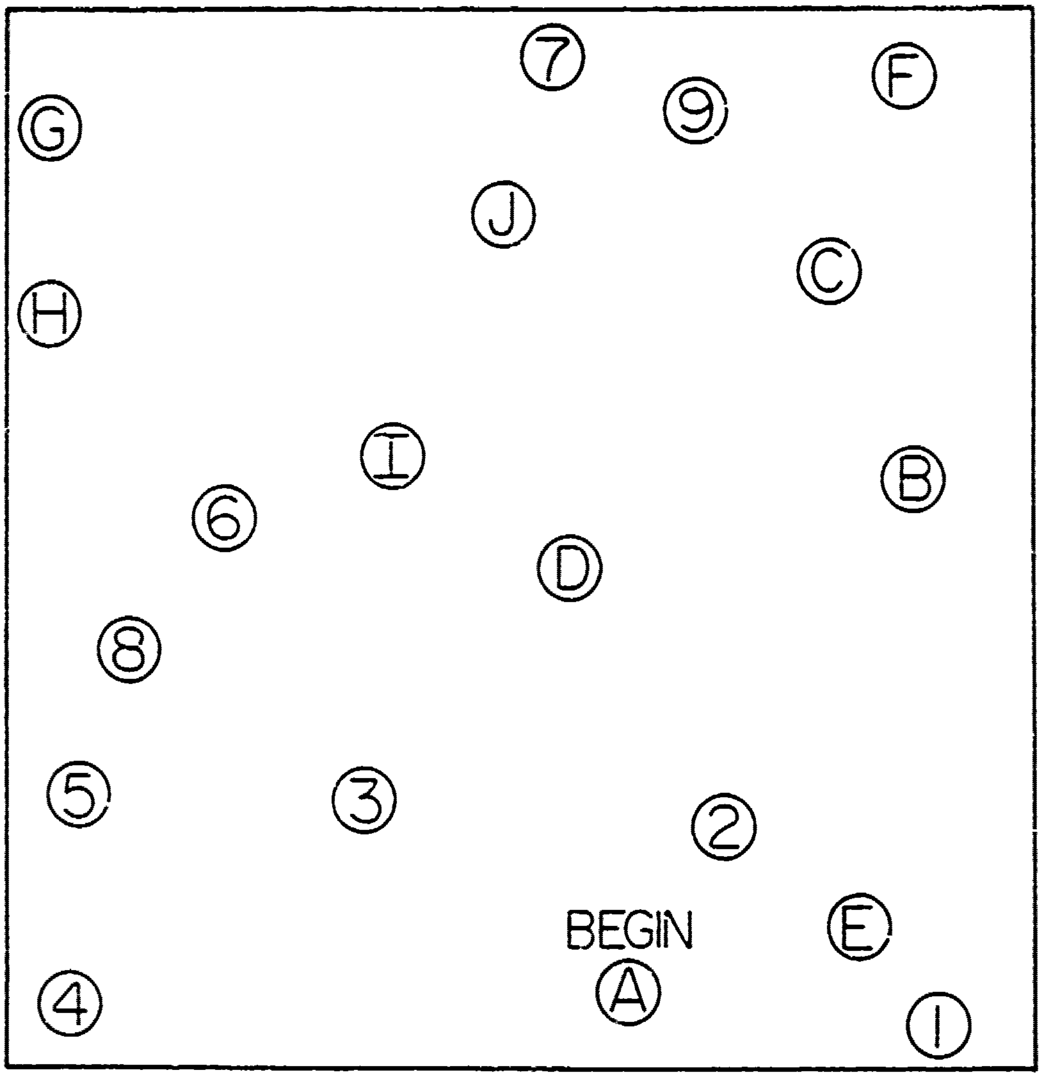

Figure 19. Sample form of trails test. Subjects were required to draw a continuous line starting at "Begin" and alternately connecting lettered and numbered circles in ascending order. They were given 1 min per session to complete as many of the four forms (out of 48) as possible. Only 1 error was scored for an incorrect connection providing the subsequent connections were in alternate and ascending order.

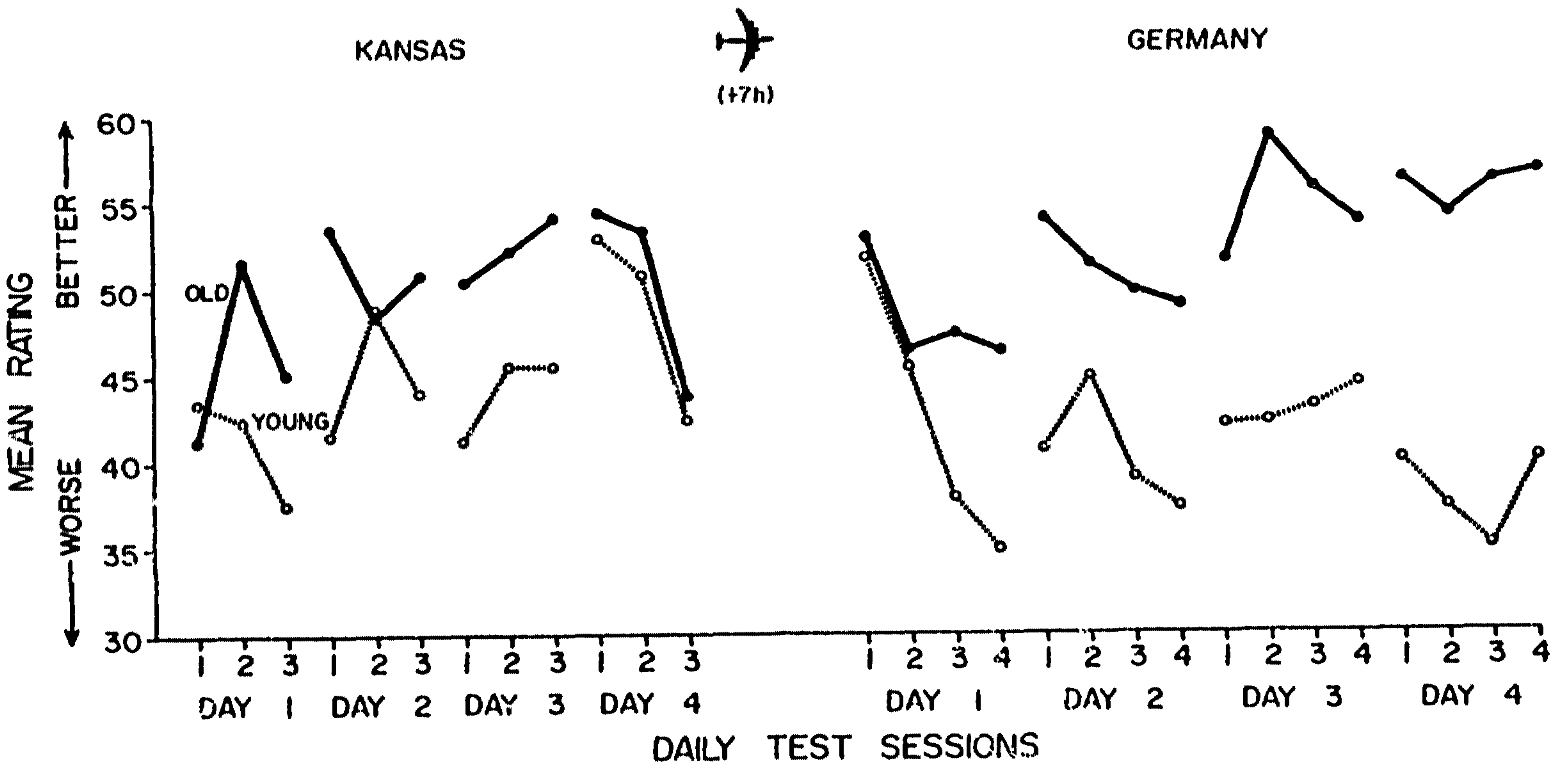

Figure 20. Self-rated estimates of performance on cognitive test battery by older and younger soldiers before and after winter deployment. Significant group differences (p <.05, t-test) occurred only on post-flight Day 3 (Session 2) and Day 4 (Sessions 1, 2, & 3).

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PERFORMANCE AFTER NAPS IN SLEEP-CONDUCIVE AND ALERTING ENVIRONMENTS

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Situations involving quasi-continuous performance for durations beyond a usual work day, such as those experienced by some pilots and military personnel, may require an individual to remain awake for days, thereby compromising performance due to cumulative effects of sleep loss. We have sought to investigate napping to evaluate its potential to facilitate recovery from fatigue in settings that preclude the typical eight-hour monophasic sleep cycle. Recent studies of napping and short periods of sleep clearly indicate that naps are disproportionately effective toward maintaining performance when compared to the effects of no sleep (cf. Angiboust & Gouars, 1972; Lubin, Hord, Tracy, & Johnson, 1976).

While napping appears to be an effective way to prevent some of the long-term deterioration of performance normally seen in totally sleep-deprived individuals, there is, nevertheless, an apparently inevitable impairment of performance immediately upon awakening from sleep. This post-sleep decrement has long been recognized, was described by Kleitman (1963) as less effective functioning immediately upon awakening compared to before sleep, and has more recently been referred to as sleep inertia (Lubin et al., 1976). It is a serious constraint to the use of napping during quasi-continuous work settings if the individual may be required to function at full capacity, at a moment's notice and at unpredictable times. Thus, the study of this ubiquitous, transient, post-sleep performance decrement is relevant to the practical problem of implementing napping in the context of quasi-continuous performance, as well as helping to clarify basic questions concerning the nature of nap sleep and sleep stages.

Since the basic study of Langdon and Hartman (1961), investigations revealing a loss in performance following rapid awakening from nighttime sleep have been numerous. Decrements have been demonstrated on a variety of tasks, including simple reaction time (Williams, Morlock, & Morlock, 1966; Okuma, Majamura, Hayashi, & Fujimori, 1966; Wilkinson & Stretton, 1971); complex reaction time (Goodenough, Lewis, Shapiro, Jaret, & Sleser, 1965; Scott, 1969; Seminara & Shavelson, 1969); grip strength (Jeanneret & Webb, 1963; Tebbs & Foulkes, 1966); steadiness and coordination (Omwake, 1932; Wilkinson & Stretton, 1971); visual-perceptual tasks (Scott & Snyder, 1968; Scott, 1969); memory (Stones, 1977; Åkerstedt & Gillberg, 1979); time estimates (Carlson, Feinberg, & Goodenough, 1978); complex behavior simulation tasks (Langdon & Hartman, 1961; Hartman & Langdon, 1965; Hartman, Langdon, & McKenzie, 1965; Seminara & Shavelson, 1969); and a host of cognitive tasks like mental addition, cancellation, and clock reversal (Pritchett, 1964; Scott, 1969; Wilkinson & Stretton, 1971; Fort & Mills, 1972; Tebbs, 1972).

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The degree and length of performance decrement following awakening has been associated with the complexity of the task, time between awakening and testing, sleep stage at awakening, amount of slow-wave sleep, sleep depth, anxiety, and diurnal variations. While it is likely that interactions among these factors contribute to a given performance decrement, it is also likely that each factor is not equally relevant to all types of tasks. Unfortunately, the bulk of investigations into the post-sleep performance decrement have confounded a number of these factors, especially diurnal effects and sleep infrastructure parameters, making it difficult to determine the relative roles played by normal circadian variation and aspects of prior sleep in producing a particular task decrement. Without empirical or statistical separation of circadian and sleep effects, there is no way to be certain of the importance of relationships between performance, sleep parameters, and sleepiness (Moses, Lubin, Naitoh, & Johnson, 1978).

Attempts to separate diurnal and sleep infrastructure effects on performance at sudden awakening from sleep have generally led to the conclusion that both factors can affect a task, and the effects can be additive. Wilkinson and Stretton (1971) found that performance decrement reached maximum levels at different times of the night for different tasks, implicating both sleep depth (on reaction time task) and diurnal effects (on addition task). However, their subjects were not tested until 4 minutes after awakening, and no physiological data were collected to determine the sleep infrastructure prior to awakening.

Fort and Mills (1972) employed a design comparing performance on a cancellation test administered at the same time of night to two groups, one totally sleep-deprived and the other suddenly awakened from sleep. They found performance to be worse upon awakening, particularly in the first half of the night, and noted that performance recovered quickly following awakening from Stage 2 sleep, but not following awakening from Stage 4 sleep. While the sleep-deprived group showed typical diurnal variations in performance, both diurnal and sleep factors appeared additive in the group allowed to sleep. Clearly, some aspects of nocturnal sleep can adversely affect performance upon sudden awakening independent of time-of-night effects, but the effects are not easily attributed to a specific component of prior sleep during the night.

Napping provides a paradigm for studying post-sleep performance decrements wherein diurnal variation is minimized by the timing of the nap within the circadian cycle; and the brevity of the nap limits the complexity of sleep staging (infrastructure),thus allowing specific aspects of sleep to be related to performance. However, performance immediately upon awakening from daytime naps has received scant attention. Webb and Agnew (1964) carried out the only published study we are aware of on performance following sudden awakening from afternoon naps. They found that simple and serial reaction time were depressed immediately upon awakening from non-REM sleep (mostly Stage 4), but recovered quickly in one to five minutes.

The study we report here was part of a larger investigation seeking to replicate and extend previously reported differences between habitual nappers and non-nappers (Evan, Cook, Cohen, Orne, & Orne, 1977). We sought to explore three basic questions concerning the nature and malleability of performance immediately upon awakening from afternoon naps. These were: 1) Are both reaction time and complex cognitive performance adversely affected following awakening from a brief nap? 2) Will an alerting napping environment and an intense waking stimulus attenuate these post-nap performance decrements? and 3) To what extent are these decrements related to different aspects of nap sleep?

Method

Subjects

Sixty-seven healthy young adults, 36 males and 31 females, between the ages of 18 and 33, participated in the study. Volunteers were solicited from a college population based upon their responses to a questionnaire detailing their daytime and nocturnal sleep patterns. The experimenter handling the nap sessions, as well as post-experimental interviewers were blind to subjects' sleep and nap patterns. [At the time of this symposium final data collection and analyses were not completed and thus, the investigators were not as yet unblinded to subjects' napping classification.] Subjects were reimbursed at the rate of $2.50/hour for time spent in the laboratory.

Procedure

The study involved four separate sessions in the laboratory for an average of four hours per session. Subjects were run individually. The first visit included a detailed description of the study, additional sleep questionnaires, practice on the descending subtraction task (DST), and subjects were given a sleep diary to complete each morning for the next 30 days. No nap took place on this initial acclimation day.

One week later subjects returned to the laboratory for the first afternoon nap session (Nap Day 1), which took place in a sleep-conducive environment typical of most sleep laboratories. This involved napping in a bed in a dark, temperature-controlled, sound-attenuated room. After arriving, subjects performed the subtraction task (60 mins pre-nap), and electrodes were applied for standard sleep recordings (Rechtschaffen & Kales, 1968). Upon completion of electrode application, subjects again performed the DST (5 mins pre-nap) while lying in bed, in the dark. A five-minute period of relaxed waking physiological activity was then recorded in the dark at the end of which subjects were told they could go to sleep and reminded to answer the telephone next to the bed as soon as it rang signalling the end of the nap. Subjects were not told the length of time that would be available to sleep, and no external time cues were available. After precisely 60 minutes, and regardless of whether a subject was awake or asleep, a 72-dB (s.p.l. re.0002 dynes/cm^2) bell rang continuously, and a small light appeared on the phone next to the subject's bed. As soon as the subject answered the phone subjective sleepiness was assessed orally (within 10 seconds), and the subject immediately began performing the DST (less than 1 min post-nap). Subsequently, another five-minute wake control period of physiological activity was recorded. The end of this period was also signalled by the phone ringing, which the subject answered. Electrodes were then removed, and a final DST trial was performed (35 mins post-nap). Following this a second investigator conducted a post-experimental inquiry with the subject.

Nap Day 2 was identical to Nap Day 1 in all procedural aspects, the major exception being the environment in which the nap was taken. For Nap Day 2, subjects were told that they would be provided an opportunity to nap in an environment more similar to what they might encounter at home or in the dormitory. Specifically, they were asked to nap in a different room from Day 1, while sitting up in a lounge chair (with foot rest) with the light on. They were also told that unlike the Day 1 room, the Day 2 room was not sound-attenuated and consequently they would hear some noise from the corridor and outside the building. In fact, a prepared tape recording of common building sounds such as footsteps, paging, doors closing, etc. (14 different types of sounds in all) was played through a speaker concealed in the wall above the ceiling during the three hours the subject was in the Day 2 room. The occurrence of each sound during the nap period was registered on a channel of the polygraph along with a description of the sound. There were approximately 48 periods of sound in the 60-minute nap period of Day 2, varying in duration from a few milliseconds (door slam) to two minutes (computer teletype), and ranging in intensity from 40 dB (conversation) to 62 dB (cart being dragged) with a median intensity of 50 dB (adjusted for 46 dB ambient noise level of room). Sounds seemed to be coming from a corridor on the floor above. Post-experimental inquiries by an independent experimenter at the end of Nap Day 2 and the experiment, suggest that all but two subjects accepted the noises as natural occurrences. Finally, Nap Day 2 differed from Nap Day 1 in that the telephone bell on Day 2 was increased in intensity from 72 dB to 93 dB.

Two weeks elapsed between Nap Day 2 and the final laboratory session which involved performing the DST before and after a 60-minute wake control period, and ended with an extensive defriefing covering the entire study.

Performance

Reaction time (RT). The RT measure employed was somewhat more complex than a simple RT task and was similar to a technique used by Goodenough et al. (1965). Subjects were told that a telephone situated next to them would ring to signal the end of the nap session. They were instructed to answer the phone as quickly as possible when it rang; the phone bell was arranged to ring continuously until the receiver was lifted. The time from bell onset to receiver pick-up was electronically recorded on a polygraph channel and served as the RT measure. Fifteen minutes after each nap day, at the end of a resting wake baseline period the phone rang again, thus providing an RT from the wake condition following each nap. The Day 2 bell was 21 dB more intense than the Day 1 bell.

Descending subtraction task (DST). The DST was specifically devised to tax the cognitive functioning of an individual for a relatively brief period of time. It can be carried out by a subject while lying in a bed in the dark, and it does not require the presence of the experimenter in the room. Thus it allows testing within seconds of awakening. The subject is initially given a three-digit number such as 832 which he is asked to repeat aloud. He is then required to mentally subtract the number 9 from 832 and to say the remainder (823) aloud. Eight hundred twenty three now becomes the new minuend from which he is required to subtract 8. The remainder (815) is again said aloud. In this fashion the subtrahend progressively decreases by one until, having reached the value of 2, it returns to 9, and the series is continued in this manner. The subject continues until, at the end of three minutes, he is told to stop. The instructions emphasize repeatedly that the subject "should work as fast as possible and keep a steady pace. It is also important that you be as accurate as possible." A typical sequence of correct subtractions by a subject is as follows: 832, 823, 815, 808, 802, 797, 793, 790, 788, 779, 771, etc. The subtractions are done silently; only the answers are said aloud. With multiple trials, the starting number of the task is always different, and a large enough number is selected to assure that even the fastest subject can not reach zero within three minutes. Since the task clearly requires that the subject keep both the subtrahend and minuend in mind, and since both change after each response, a considerable load is placed on short-term memory during the task. Subjects are encouraged to correct any of their responses if they think there are errors but, in any case, to go on. Thus, if they get completely lost in a sequence, they are to guess where they are and continue. The task can be scored for speed (total number of responses), accuracy (total number of errors), or both speed and accuracy simultaneously (number correct per second). The DST shows a practice effect over the first 9 trials that should be taken into account when small increments in performance are studied. The DST was performed four times on each visit to the laboratory, including 60 minutes and 5 minutes before each nap session, as well as less than 1 minute and 35 minutes after each nap session. In the post-experimental inquiry nearly all subjects commented on the task's difficulty.

Results

Using Stage 2 sleep as a criterion of sleep onset, 66 of 67 subjects slept on at least one nap day, with 60 subjects sleeping on Nap Day 1 and 62 subjects sleeping on Nap Day 2. Table 1 displays group averages of sleep infrastructure characteristics on Nap Days 1 and 2, as well as the value of t-tests for correlated measures (within subjects between the two days). Examination of the table reveals that subjects went to sleep as fast and napped as long in both nap settings. However, naps in the alerting environment of Day 2 were generally composed of more Stage 1 sleep and reciprocally less Stage 4 sleep compared to Day 1 naps in the sleep-conducive environment.

Of the two nap days, Day 1 was similar to nocturnal studies of post-sleep performance decrement in that the nap environment was devised to maximize the likelihood of sleep. It seemed reasonable, therefore, to predict that performance decrements were more likely to occur on Day 1. Indeed, as Figure 1 illustrates, subjects averaged significantly slower RT ($\underline{t} = 3.56$, $p < .001$), as well as slower DST speed ($\underline{t} = 11.23$, $p < .0001$) and lower DST accuracy ($\underline{t} = 4.22$, $p < .0001$; $\underline{t} = 2.52$, $p < .02$) immediately after the Day 1 nap compared to pre-nap and later post-nap performance. Figure 2 presents the equivalent measures for Nap Day 2. While RT and DST speed were again both significantly slower at the end of the nap ($\underline{t} = 2.32$, $p < .05$, and $\underline{t} = 6.81$, $p < .0001$), the DST accuracy measures were not significantly lower ($\underline{t} = 1.52$, $p < .20$, and $\underline{t} = 1.45$, $p < .20$). Wilcoxon matched-pairs signed-ranks tests confirmed these findings. For subsequent analyses of the DST decrement a score reflecting both speed and accuracy was employed. This was the number correct per unit time.

Having established that some decrement in performance occurs immediately after both nap days, we sought to understand what aspects of afternoon nap

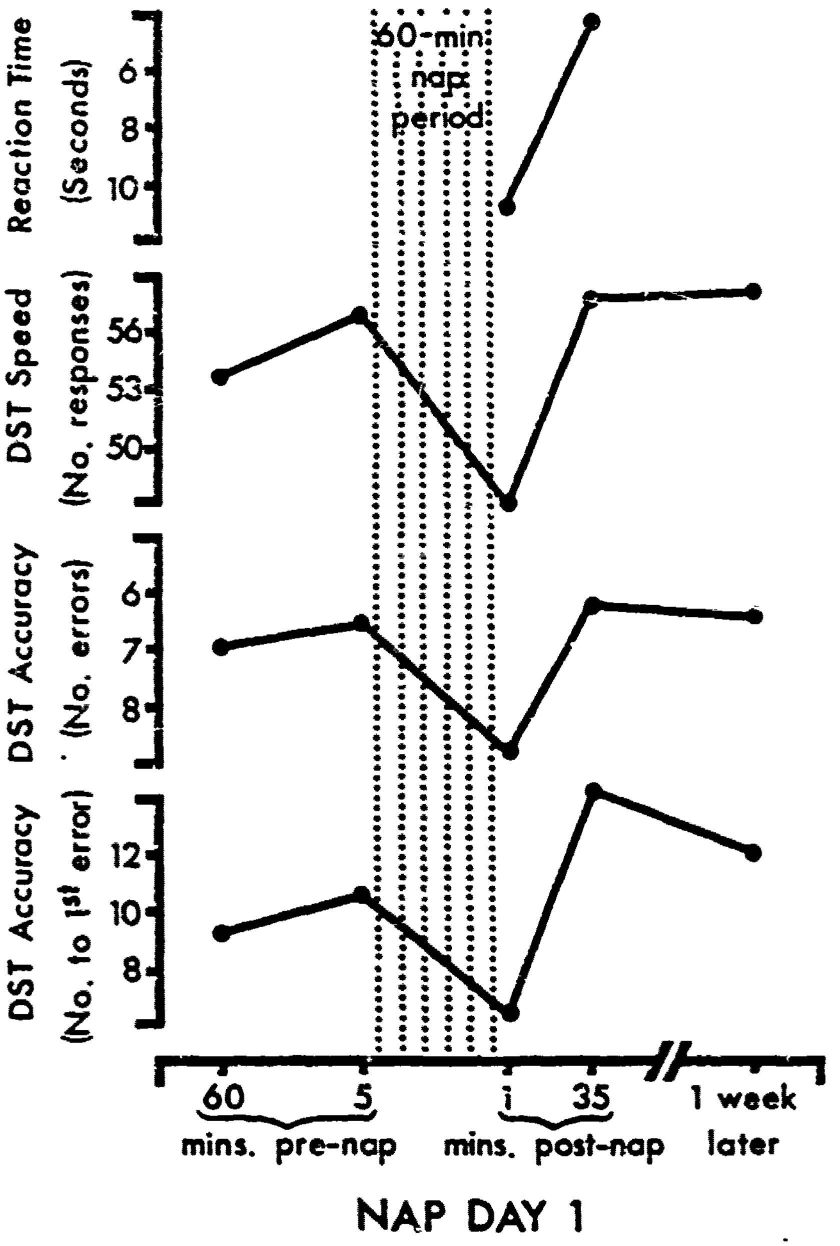

Figure 1. Mean performance on RT and three measures of DST for 67 young adults before and after the Day 1 afternoon nap in a bed in a dark, quiet, sleep-conducive environment.

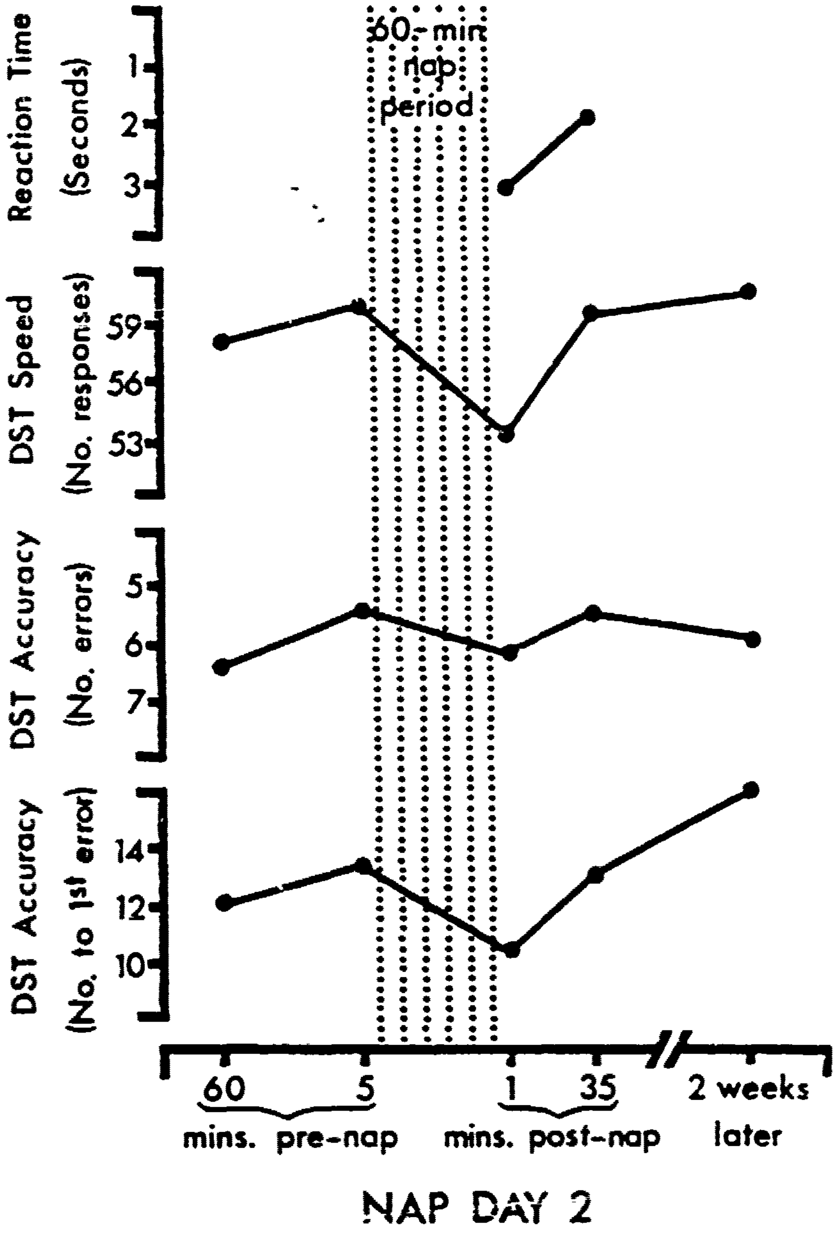

Figure 2. Mean performance on RT and three measures of DST for 67 young adults before and after the Day 2 afternoon nap in a chair in a lighted, noisy, alerting environment.

Table 1

Comparison of Mean Nap Sleep Parameters (in Minutes)* of 67 Young Adults
Who Napped in a Sleep-Conducive Environment (Day 1)
and Alerting Environment (Day 2)

Sleep Parameter	Nap Day 1	Nap Day 2	Paired t	p<
Stage 1 onset	6.7	6.5	0.2	ns
Stage 2 onset	15.7	13.6	1.4	ns
Stage 3-4 onset	34.9	39.5	2.2	ns
TST (1 onset)	42.8	42.9	0.1	ns
TST (2 onset)	36.5	34.3	1.2	ns
Stage 1 **	10.1	14.7	5.1	.0001
Stage 2	14.6	16.4	1.5	ns
Stage 3	5.1	4.3	1.7	ns
Stage 4	12.7	7.1	4.1	.0002

* Since both Day 1 and Day 2 were 60-minute nap periods, and since there were no significant differences in total sleep time (TST) between Days 1 and 2, the analysis of minutes of each sleep stage was redundant of analysis of sleep stage percentages. Thus, only the former is presented.

** Stage 1-REM sleep was rarely seen in these brief afternoon naps. Stage 1 here refers to non-REM Stage 1.

sleep were associated with the decrements. Correlational and chi square analyses were employed as a first step. Based on prior literature specific aspects of the nap sleep infrastructure were evaluated for their possible relationship to performance impairments. These were: the amount of Stages 1, 2, 3, and 4 sleep and combinations of these as well as the amount of time awake or in Stage 1 sleep directly prior to the bell, and the stage at the bell. Since many variables were being assessed, conservative two-tailed significance levels (derived from procedures for confidence intervals when many comparisons are made) were employed to maintain the .05 rejection level.

Only one aspect of nap sleep infrastructure was significantly related to immediate post-nap RT performance. This was the stage of sleep at nap termination. Figure 3 graphically displays mean RTs as a function of stage at nap termination on both Days 1 and 2, along with RTs recorded 15 minutes later on each day in the wake condition. On both nap days RT to the bell signalling the end of the nap was longest for those subjects in Stage 4 sleep at the bell. Two-way analysis of variance within each nap day yielded a main effect between groups [Day 1 $F(4, 62) = 3.43$, $p < .025$; Day 2 $F(4, 62) = 3.43$, $p < .025$], a main effect within groups [Day 1 $F(1, 62) = 15.13$, $p < .001$; Day 2 $F(1, 62) = 6.23$, $p < .001$], and a significant interaction [Day 1 $F(4, 62) = 4.18$, $p < .005$; Day 2 $F(4, 62) = 4.54$, $p < .01$]. Conservative post-hoc Scheffe comparisons between means within each nap day revealed that RT from Stage 4 sleep was significantly longer ($p < .01$ or less) than RT from all other stages.

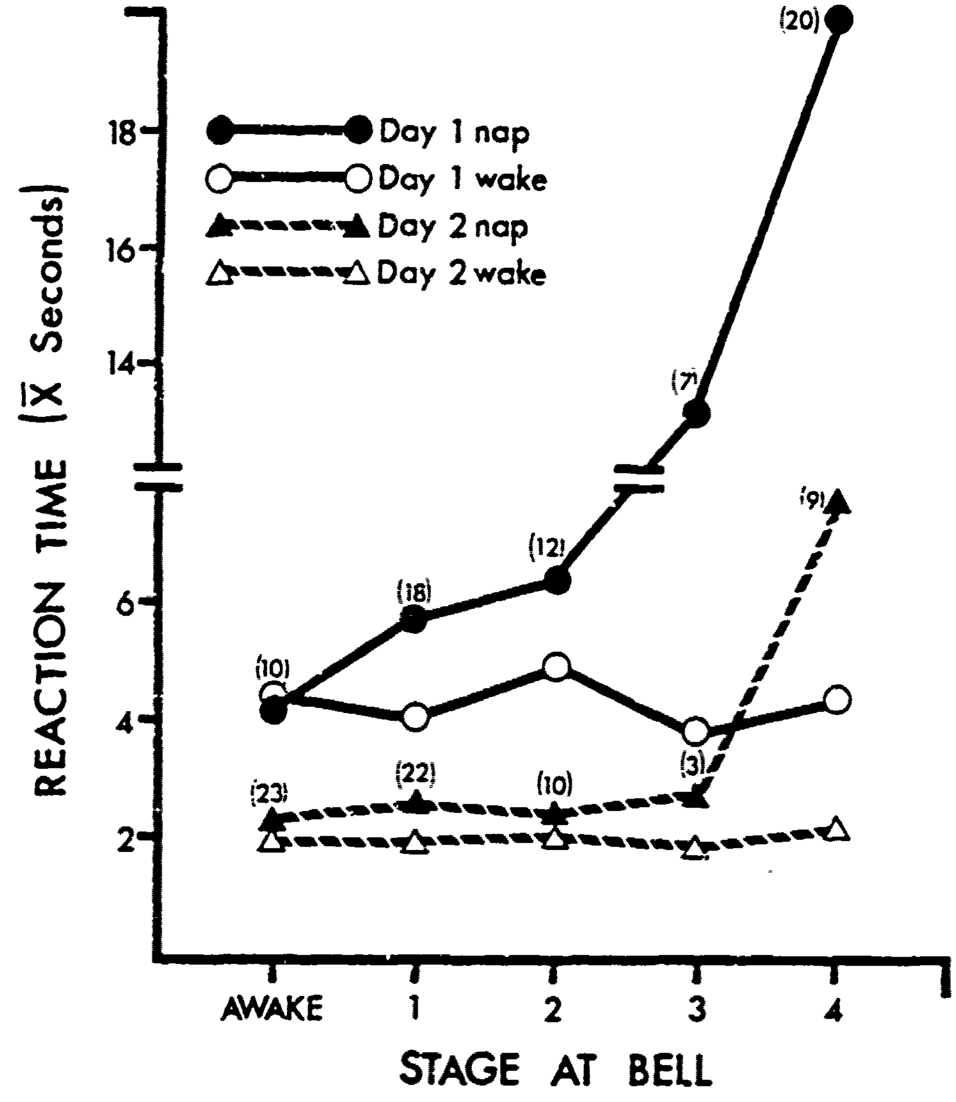

Figure 3. Mean reaction times to answering a telephone for young adults in various stages of wake and sleep at the termination of 60-minute afternoon nap periods in sleep-conducive (Day 1) and alerting (Day 2) environments. Values in parentheses are the number of subjects included in each data point on each nap day. The wake condition (broken line) was the mean RT for subject groups 15 minutes after a nap. Day 1 RTs were to a 72 dB bell whereas Day 2 RTs were to a 93 dB bell.

While there was a tendency for slightly longer RTs across sleep stages on Day 1, this was not present on Day 2 except for Stage 4 sleep.

While awakening from Stage 4 sleep had a profound effect on behavioral RT, it did not appear to differentially affect complex cognitive functioning as assessed by the DST. Post-nap subtraction performance decrements were not correlated with post-nap RT decrements. That is, within a given nap day, subjects with greater DST decrements did not necessarily also have greater RT decrements. As Table 2 shows, DST decrements were significantly related to the amount of Stages 3+4 sleep, Stages 2+3+4 sleep, and Stages 1+2+3+4 sleep, with more total sleep time being associated with greater DST decrements. RT decrements were unrelated to any measure of sleep stage lengths. The highest DST coefficients within each nap day were for the relationship between Stages 2,3, and 4 sleep lengths combined (Stages 2+3+4). Though total sleep time as assessed by Stages 1+2+3+4 was also significantly related to DST, Stage 1 alone was not related, and when combined with Stages 2+3+4 it did not increase the correlation. However, when Stage 2 sleep was combined with Stages 3+4, resulting in Stages 2+3+4, the coefficients increased to .48 for Day 1 and .60 for Day 2, both of which accounted for more variance than the Stage 2 sleep or Stages 3+4 sleep alone. These relationships were also confirmed nonparametrically using Spearman rank order correlations. Similarly, chi square analysis between the two nap days indicated that a nap day of greater Stages 2+3+4 sleep length for a subject was likely to be a day of greater DST decrement ($X^2(1) = 11.66$, $p < .001$). This was not the case, however, for the relationship between stage at nap termination and DST decrement ($X^2(1) = .44$, $p > .05$).

Table 2

Product Moment Correlations Between Immediate Post-Nap Performance Decrements and Nap Sleep Stage Lengths of 67 Young Adults in Sleep-Conducive (Day 1) and Alerting (Day 2) Nap Environments

			Total Time in Sleep Stages				
Task	Nap Day	DST	1	2	3+4	2+3+4	1+2+3+4
RT	1	.00	-.08	-.05	.14	.13	.15
	2	-.17	-.02	-.07	.18	.09	.12
DST	1		-.03	.35	.38*	.48*	.45*
	2		-.08	.23	.58*	.60*	.52*

* p < .05 by two-tailed Bonferroni procedure (Larzelere & Mulaik, 1977).

Figure 4 illustrates the relationship between amount of Stages 2+3+4 sleep and the percent DST drop in performance immediately after each nap. Stages 2+3+4 sleep amount is broken into approximately equal intervals, and the DST score is the mean percent decrement of subjects who fell within those sleep intervals. For Nap Day 1 there is a clear and steady drop in DST performance as sleep length increases. However, even subjects who had only 5 minutes of

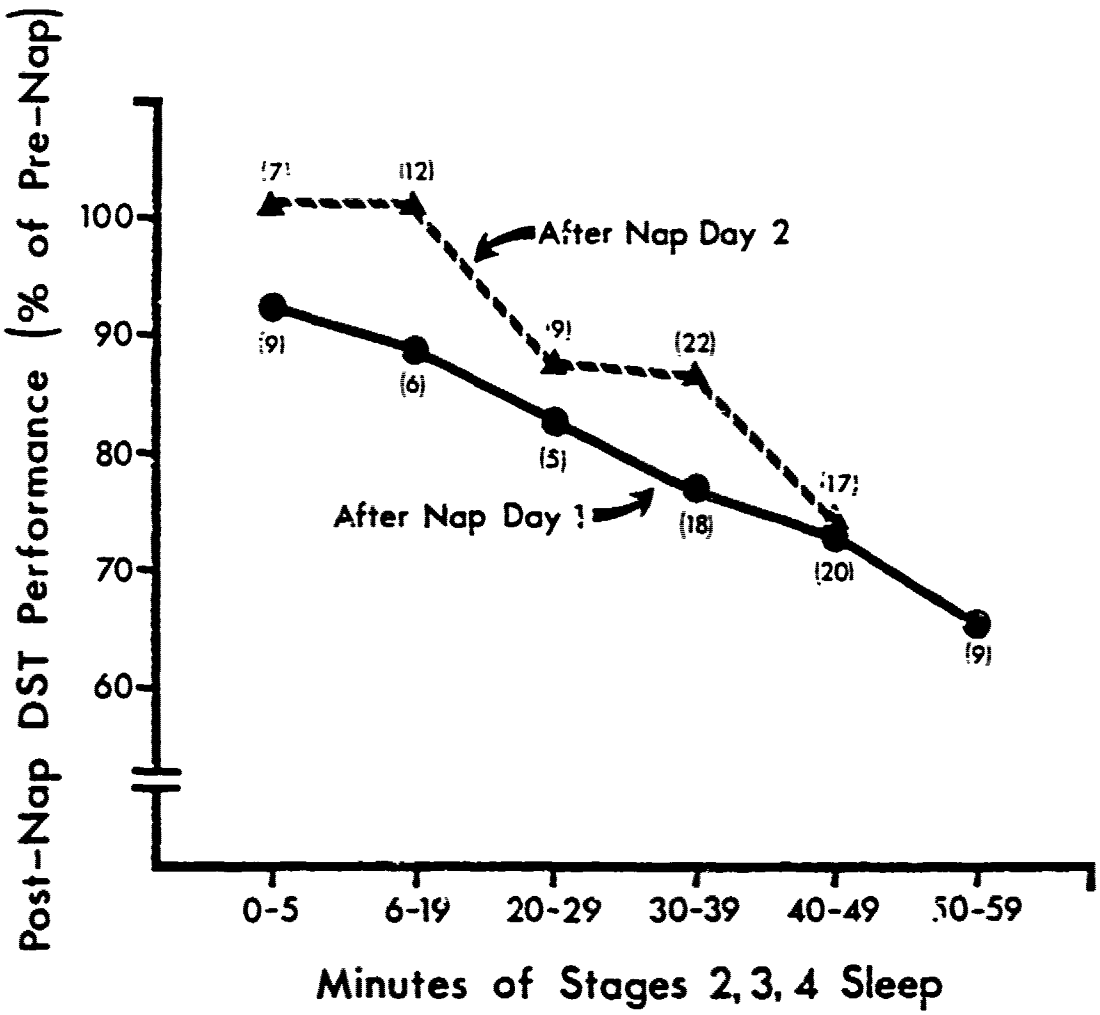

Figure 4. Post-nap DST performance as percent of pre-nap levels for young adults varying in amount of Stages 2+3+4 sleep during 60-minute afternoon nap periods in sleep-conducive (Day 1) and alerting (Day 2) environments. The DST measure employed was the number of correct responses per second times 1000, and thus includes adjustment for speed and accuracy during the 3-minute task. Values in parentheses are the number of subjects included in each data point on each nap day. No subject had more than 50 minutes of Stages 2+3+4 on Nap Day 2.

sleep averaged an 8% DST decrement. This was not the case in the alerting environment of Day 2, where subjects who averaged less than 20 minutes of Stages 2+3+4 sleep had immediate post-nap performance levels equal to pre-nap performance. For middle amounts of sleep on Day 2, performance was about 13% below pre-nap levels, but an average of 5% to 10% above Day 1 performance for equivalent sleep length groups. On the other hand, for the Day 2 subjects who slept the longest (Stages 2+3+4 between 40 and 50 minutes) the DST post-nap decrement was 26% below pre-nap levels, fully equivalent to that seen in the Nap Day 1 group. A closer look at this group of 17 long sleepers on Nap Day 2 revealed that they had a significant drop in both DST speed and accuracy considered independently, similar to the Day 1 groups.

While the study was not designed to track the time course of the post-nap performance decrements, it does allow some comparisons of the effects of varying periods of wakefulness and light sleep (Stage 1) prior to being tested. Though the amounts of Stages 2+3+4 sleep appeared to be the major predictor of degree of DST post-nap decrement, it seemed reasonable to expect that subjects who had been awake longer prior to the bell would show less post-nap decrement than subjects who awoke immediately prior to the bell, even if both groups had the same amount of Stages 2+3+4 sleep. Table 3 presents the median DST decrements and amount of Stages 2+3+4 sleep for these groups on each nap day, as well as subjects with similar amounts of Stages 2+3+4 sleep who were awakened from Stage 2 and Stage 4 sleep. Stages Awake and 1 sleep were combined in the table because analyses on them separately yielded similar results.

Table 3

Median Values of DST Decrement for Groups Varying in Condition Just Prior to Nap Termination

	Nap Day	Awake or Stage 1 5-10 min pre-bell	Awake or Stage 1 < 5 min pre-bell	Stage 2 at bell	Stage 4 at bell
Number of	1	1	10	10	16
Subjects	2	6	13	7	9
Post-Nap DST	1	-13.1	-24.7	-31.1	-24.2
% Decrement	2	- 7.3	-21.3	-20.8	-28.6
Mins. Stages	1	42.3	36.5	43.5	42.9
2+3+4 in Nap	2	36.5	35.8	36.0	41.3

Inspection of Table 3 confirms our earlier finding that stage at the bell is not particularly relevant to the degree of post-nap DST decrement. There were no significant differences by Mann-Whitney U tests in DST decrement on either nap day between subjects who were awake or in Stage 1 within 5 minutes of the bell, versus subjects who were in either Stage 2 sleep or Stage 4 sleep at the bell. Only subjects who had been awake or in Stage 1 more than 5 minutes before the bell had less DST performance decrement. For this small group of long-sleeping subjects (n = 6) on Nap Day 2 who were awake or in Stage 1 between 5 and 10 minutes prior to nap termination, DST decrement was significantly less than the other three Day 2 groups in Table 3. While Day 1 data are in the same direction, equivalent comparisons within Day 1 were not possible due to only one long-sleeping subject being awake beyond 5 minutes of the Day 1 bell. DST performance for all subjects returned to or above pre-nap levels on both nap days when subjects were tested a second time, 35 minutes after nap termination.

Discussion

While all of us have experienced the difficulty of functioning when suddenly aroused in the middle of the night, one would not necessarily expect to encounter the same kind of difficulty after a relatively short daytime nap. Nevertheless, our data clearly demonstrate profound performance decrements in both behavioral reaction time and cognitive performance following brief naps.

Simple motor reaction time was clearly depressed immediately after naps where individuals had been awakened from Stage 4 sleep. This confirms findings from nocturnal studies of sudden awakening (Goodenough et al., 1965; Okuma et al., 1966; Scott & Snyder, 1968) and Webb and Agnew's (1964) study of afternoon naps. Reaction time performance is related to stage of sleep immediately prior to being awakened, and not related to length of time spent in Stage 4, or any other cumulative effect of sleep.

Awakening from Stage 4 sleep did not, however, differentially affect cognitive functioning immediately after daytime naps. Rather, cognitive deficits were a function of the total amount of Stages 2+3+4 sleep which subjects had during the nap. Indeed, we noted a clear-cut, monotonic relationship between the total amount of sleep and the severity of the post-nap cognitive performance decrement. If the same systematic relationship between total sleep time and performance decrement existed in nighttime sleep, the amount of post-sleep cognitive deficit on awakening in the morning would have to be far greater than that seen in the middle of the night.

While Wilkinson and Stretton (1971) report different performance decrement curves across the night for RT and a cognitive task, only the RT task data is congruent with what we observed in daytime naps. That is, RT decrement is greatest early in the night, when subjects are most likely to have been awakened from Stage 4 sleep. The post-sleep cognitive performance decrement they report, however, gradually increases during the first half of the night and decreases thereafter. Wilkinson and Stretton (1971) sought to explain this U-shaped performance function as due to diurnal effects.

However, as Langdon and Hartman (1961) pointed out, the nocturnal post-sleep decrement cannot be explained solely by the diurnal cycle. Fort and Mills (1972) elegantly showed that diurnal effects are additive with those effects due to nocturnal sleep in producing the nighttime post-sleep cognitive performance decrement. Similarly, diurnal factors cannot account for the consistency in the maximal amount of post-sleep decrement in nocturnal studies, ranging from 19% to 25% (cf. Pritchett,1964; Hartman & Langdon,1965; Wilkinson

& Stretton, 1971), and our finding of 20% after a brief nap—particularly since, in our study at least, time-of-day was not related to the degree of cognitive impairment following naps. On the other hand, if cognitive performance decrements found in nocturnal studies were simply a function of total sleep time, the order of magnitude of performance deficits in those studies should be much greater than that observed after a brief nap.

How might we account for the clear relationship between the amount of sleep and cognitive performance decrement in data based on afternoon naps, and the obvious lack of such a simple relationship in nighttime sleep? It is possible we have fortuitously selected a segment of sleep sufficiently short so that neither diurnal effects nor other mechanisms, which over time might attenuate the post-sleep decrement, can occur. It would appear that nighttime sleep must have inherent a process that dissipates whatever neurophysiological or biochemical substrates underlie post-sleep cognitive performance decrements. Though lacking substantive evidence, it is difficult to resist the temptation to implicate REM sleep as reflecting a process which among its other functions initiates reversal of non-REM sleep-induced interference with cognitive functioning.

Regardless of the possible physiological mechanisms which may help dissipate the post-sleep cognitive performance decrement in nocturnal sleep, external stimulation appears to have little effect on the phenomenon. Hartman, Storm, Vanderveen, Vanderveen, Hale, and Bollinger (1974) find that the use of loud stimuli to awaken subjects does not substantially affect the post-sleep decrement. This was equally true in our study for daytime post-nap performance; except insofar as environmental differences altered the infrastructure of the nap, we were unable to find environmental effects on post-nap performance.

In sum, it appears that even a small amount of afternoon sleep is capable of producing transient, but profound decrements in cognitive performance. These decrements persisted despite an alerting nap environment and a very loud bell at nap termination. In the nap setting, at least, the cognitive performance decrement is a function of the total amount of sleep, and becomes attenuated only after having been awake for more than 5 minutes. It is essentially dissipated within 35 minutes.

Though the post-nap performance decrement seems to be a stable and robust phenomenon, anecdotal reports suggest that pre-sleep sets, motiviational factors, and a variety of alerting behaviors may serve to modify it. There is virtually no systematic data addressing these issues. The investigation of factors affecting the duration and intensity of the post-nap performance decrement should not only help to shed light on important question about the nature of sleep, but also have considerable significance for the potential use of napping to maintain performance in quasi-continuous work settings.

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CIRCADIAN CYCLES AND RESTORATIVE POWER OF NAPS

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> 8 am (50 hours of sleep loss) --- Thought it was all over until about 3:30 when we finally got a sing-along, a Sorry game, and finally a bridge game going. Tiredness is definitely here and we'll have to evolve methods to deal with it. It seems to come in waves. --- One effect all of us have noticed is a tendency to forget names. Just now, I had the damndest time remembering Hav's name. After five days we should know each other's name at least.
>
> From the diary of a subject in a 205-hour sleep deprivation study conducted at UCLA in 1966.

Sleep-deprived men and women show deterioration in mood and behavioral efficiency. A nap is viewed by many as having recuperative power, reducing fatigue and sleepiness. Taub and Berger (1973) have reported, however, that if a subject does not habitually nap, the initial effects of a nap would be detrimental to mood and task performance. For accustomed nappers, afternoon napping improved subjects' performance and mood within a 1.5- to 2-hour time period after awakening from the nap (Taub, 1979; Taub et al., 1976, 1977). Taub et al. also observed that accustomed naps early in the morning (0935-1135) and late at night (2135-2335) were "to some extent (but not completely)" equally beneficial as the afternoon nap (1500-1700). They found that the recuperative power of habitual napping was observed in more rapid psychomotor performance, improved short-term memory, reduced sleepiness, and more positive affective states.

Lubin et al. (1976) and Hartley (1975) reported that naps were usually beneficial in maintaining task performances and mood in laboratory studies. In a field study, Opstad et al. (1978) noted that naps, cumulating to a total of 3-6 hours in the middle of 92-120 hours of continuous combat training, significantly reduced the profound loss in behavioral efficiency of the cadets. Haslam (this volume) similarly noticed the recuperative power of small amounts of sleep in maintaining job performance.

Although naps may help in maintaining performance over long periods, the immediate performance upon awakening from a nap may show no improvement and often may be lower than pre-nap levels. Since Langdon and Hartman (1961) reported on loss of performance efficiency after sudden awakening from nocturnal sleep, "sleep inertia" has been extensively studied. Sleep inertia has been observed in simple, as well as complex, reaction time tasks (Goodenough et al., 1965; Wilkinson & Stretton, 1971), grip strength (Jeanneret & Webb, 1963), short-term memory (Stones, 1977; Åkerstedt & Gillberg, this volume), and in complex visual and cognitive tasks (Seminara & Shavelson, 1969; Scott & Snyder, 1968; Pritchett, 1964). Sleep inertia is usually short-lasting, and is quickly followed by the recuperative phase of a nap. Sleep inertia has been estimated to last about 15 minutes after awakening (Wilkinson & Stretton, 1971). Webb and Agnew (1974) observed that sleep inertia disappeared in 1-5 minutes after awakening from an afternoon nap. But it is quite possible that a nap taken after a prolonged period of wakefulness would cause a more severe and longer period of sleep inertia, making the nap disadvantageous for behavioral efficiency.

The primary purpose of this study was to determine the recuperative power of a 2-hour nap after either 45 hours (Phase 1 of this study) or 53 hours (Phase 2) of a [illegible]l. The recuperative power was simply defined as those beneficial effects that restore human behavioral efficiency and subjective feelings of vigor and arousal. This study also attempted to answer whether the recuperative power of a nap would depend on the time of day it was taken. If sleep inertia reflects difficulty in becoming fully awake and mobilizing mental and physical energy, then it might be anticipated that basic circadian mechanisms controlling the level of arousal would be closely involved in determining the severity and duration of sleep inertia. This would, in turn, limit the beneficial effects of the nap. To evaluate the potential circadian effect on the recuperative power of a nap, naps were taken at the early morning hours of 0400-0600 and at the midday hours of 1200-1400. The early morning nap corresponded to the nadir of many human circadian rhythms, and the midday nap occurred at the slowly rising pre-peak circadian phase. Circadian rhythms in mood, fatigue, sleepiness, and task performances were carefully analyzed both during the baseline and vigil phases to establish their phase relations to the naps.

Methods and Materials

Experimental Design. Fifteen sailors (average age 21.5 years old, ranging from 18-30) were in Group 1 and participated in Phase 1. Eight sailors (average age 18.6 years old, ranging from 18-21) were in Group 2 and completed Phase 2 (Figures 1 & 2). The experiment required all subjects to live, two at a time, in a sleep laboratory for 6 consecutive days.

Phase 1. The period of continuous work was 45 hours for this group. The continuous work started on awakening at 0700 on Tuesday (Day 2) and continued until 0400 on Thursday (Day 4), representing 2 days and 2 nights of sustained wakefulness. Then the subjects were allowed to nap for 2 hours, from 0400 to 0600, on Thursday. The selection of a 2-hour nap was based primarily on the previous studies of Wilkinson (1970), Hamilton et al. (1972), Johnson and Naitoh (1974), Hartley (1974), Friedmann et al. (1977), Opstad et al. (1978), and Haslam (this volume); all had suggested that a 2-hour nap would be the minimal sleep duration to expect some recuperation. Time of the early morning nap was set to coincide with the troughs of circadian rhythms for most physiological and psychological variables. The recuperative power of this early morning nap was evaluated every 2 hours from the time of subjects' awakening until noon, 6 hours after being awakened. From 1200-1400, the subjects took their second 2-hour nap. After the second nap, the subjects were asked to resume their tasks for an additional period of 10 hours until bedtime at midnight. On Friday (Day 5), the subjects continued to work on their tasks until 1600, the end of this study. Polygraphic records for sleep-staging (Rechtschaffen & Kales, 1968) were obtained on baseline nights, naps, and on the recovery night (see Figures 1 & 2).

ACTIVITY SCHEDULE FOR FRAGMENTED SLEEP STUDY
PHASE 1

	Sunday	Baseline Monday	Baseline Tuesday	Vigil Wednesday	Fragmented Sleep Thursday	Recovery Friday
0000		Sleep	Sleep_B			Sleep_R
0030						
0100						
0130						
0200				Bio-17	Bio-29	
0230				Chore 5	Chore 9	
0300						
0330				Bio-18	Bio-30	
0400					Sleep_{F_1}	
0430						
0500						
0530						
0600				Bio-19	Bio-31	
0630				Chore 6	Chore 10	
0700						
0730						
0800			Bio-8	Bio-20	Bio-32	Bio-41
0830		Breakfast	Breakfast	Breakfast	Breakfast	Breakfast
0900		Orientation	Watch 2a	Watch 4a	Watch 6a	Watch 8a
0930						
1000			Bio-9	Bio-21	Bio-33	Bio-42
1030						
1100					Bio-34	
1130	Subject pick-up and orientation Demo. ques. FRT and MAST tng	Bio-1	Bio-10	Bio-22	Lunch	Bio-43
1200		Lunch Aud. Vig. Tng.	Lunch	Lunch	Sleep_{F_2}	Lunch
1230						
1300						
1330						
1400		Bio-2	Bio-11	Bio-23	Bio-35	Bio-44
1430		Chore 1	Chore 3	Chore 7	Chore 11	Chore 13
1500						
1530		Bio-3	Bio-12	Bio-24	Bio-36	Bio-45
1600	Dinner	Dinner	Dinner	Dinner	Dinner	Debriefing Return to base
1630						
1700						
1730		Bio-4	Bio-13	Bio-25	Bio-37	
1800		Chore 2	Chore 4	Chore 8	Chore 12	
1830						
1900		Bio-5	Bio-14	Bio-26	Bio-38	
1930		Watch 1a	Watch 3a	Watch 5a	Watch 7a	
2000						
2030						
2100						
2130		Bio-6	Bio-15	Bio-27	Bio-39	
2200						
2230						
2300		Bio-7	Bio-16	Bio-28	Bio-40	
2330						

Figure 1. Experimental schedule for Group 1. Shaded areas show sleep (including two 2-hour naps) periods.

FRAGMENTED SLEEP ACTIVITY SCHEDULE
PHASE 2

	Sunday	Baseline Monday	Baseline Tuesday	Vigil Wednesday	Fragmented Sleep Thursday	Recovery Friday
0000						
0030						
0100						
0130						
0200				Bio-17	Bio-29	
0230		Sleep	Sleep_B	Chore 5	Chore 9	Sleep_R
0300						
0330				Bio-18	Bio-30	
0400						
0430						
0500				Bio-18A	Bio-30A	
0530						
0600				Bio-19	Bio-31	
0630						
0700				Chore 6	Chore 10	
0730						
0800			Bio-8	Bio-20	Bio-32	Bio-41
0830		Breakfast	Breakfast	Breakfast	Breakfast	Breakfast
0900						
0930		Orientation	Watch 2a	Watch 4a	Watch 6a	Watch 8a
1000			Bio-9	Bio-21	Bio-33	Bio-42
1030						
1100					Bio-34	
1130		Bio-1	Bio-10	Bio-22	Lunch	Bio-43
1200	Subject pick-up and orientation					
1230		Lunch Aud. Vig. Tng.	Lunch	Lunch	Sleep_{F_2}	Lunch
1300						
1330	Demo. ques. FRT and MAST tng					
1400		Bio-2	Bio-11	Bio-23	Bio-35	Bio-44
1430						
1500		Chore 1	Chore 3	Chore 7	Chore 11	Chore 13
1530		Bio-3	Bio-12	Bio-24	Bio-36	Bio-45
1600						
1630		Dinner	Dinner	Dinner	Dinner	Debriefing Return to base
1700						
1730	Dinner	Bio-4	Bio-13	Bio-25	Bio-37	
1800						
1830		Chore 2	Chore 4	Chore 8	Chore 12	
1900		Bio-5	Bio-14	Bio-26	Bio-38	
1930						
2000		Watch 1a	Watch 3a	Watch 5a	Watch 7a	
2030						
2100						
2130		Bio-6	Bio-15	Bio-27	Bio-39	
2200						
2230						
2300		Bio-7	Bio-16	Bio-28	Bio-40	
2330						

Figure 2. Experimental schedule for Group 2. Shaded areas show sleep (including one 2-hour nap) periods.

Phase 2. In Phase 2, the early morning nap was omitted and the 8 subjects continued to work for 53 hours until time for the midday nap. This group, thus, provided control data to establish whether the early morning nap improved mood and behavioral efficiency when compared with subjects who remained sleepless. Group 2 was allowed to nap from 1200-1400 after 53 hours of continuous work (in contrast to 45 hours of continuous work for Group 1). The dependent variables observed during the post-midday nap period in Group 2 were compared with those in the post-early morning nap period for Group 1, to reveal any differences in recuperative power between the early morning and midday naps. These comparisons gave only a rough estimation of the recuperative power of the early morning nap in reference to the midday nap because Group 2 experienced 8 hours of additional wakefulness. Similarly, performance and mood following the two 2-hour naps in Group 1 could be compared to performance and mood after the single midday nap of Group 2. If there were no differences in the recuperative power between the two 2-hour naps and the one midday nap, then the 2-hour early morning nap could be considered not to have contributed significantly to the recuperative power. Except for the difference in nap schedules, the subjects in Group 2 were treated in much the same way as those in Group 1. No polygraphic sleep records were obtained from this group.

Description of Tests. During Sunday and Monday, all subjects were trained to obtain oral temperature, pulse rate and some perfromance measures, and how to complete adjective checklists. Also, during these two days, they received extensive training on psychological tasks so that they would be performing these tasks near the asymptotic level before the start of Tuesday (Day 2), the second baseline day.

Three kinds of task sessions were used: (1) 45 bio-sessions; (2) 13 chore-sessions, and (3) 8 watch-sessions. For Group 1, the bio-sessions were repeated every 2 hours during the day on Monday, Tuesday, and Friday, and every 2 hours, both day and night, on Wednesday and Thursday. Group 2 had the same bio-sessions as Group 1, except a four-choice serial reaction time task was added. The tasks used in the bio-, chore-, and watch-sessions are listed in Table 1. Table 1 shows the tasks in the exact sequence presented to the subjects.

Sleep Logs were modeled after the one developed by Hartman and Cantrell (1976). The subjects completed it upon awakening from the major sleep period. Sleep Logs questioned not only sleep duration, but also trouble going to sleep, how well-rested they felt following sleep, and need for more sleep.

Oral temperature was measured by an electronic digital thermometer. Three readings were obtained at each bio-session. Pulse rate was measured by a photo-electrical device which detected pulsations of the middle finger. Blood pressure was measured with an automatic device which sensed Korotokoff sounds. A Jamar dynamometer was used to measure the grip-strength of the dominant hand. Spiral aftereffect was measured by asking the subjects to look at a rotating disk with an Archimedes type spiral. The details of grip-strength and spiral aftereffect will not be discussed in this paper.

The Memory and Search Test (MAST), designed by Folkard et al. (1976), consisted of searching line after line, through lines of 20 letters, for the lines containing letters of a specified target. The target letters (2, 4, or

Table 1

List of Tasks Used in This Study

Tasks to be Performed	Approximate Time to Complete*
45 Bio-Sessions/Two Hourly	
1. Sleep Logs[1†]	30 sec.
2. Oral Temperature	30 sec./reading:Three readings
3. Pulse rate	30 sec. - 1 min.
4. Blood pressure	1 - 2 min.
5. Grip strength[†]	30 sec.
6. Spiral Aftereffect Test[†]	5 min. (Timed)[2]
7. Memory and Search Task (MAST)	2 min./test:6 min. total (Timed)
8. NHRC Mood Scale	1 - 2 min.
9. Stanford Sleepiness Scale (SSS)	1 min.
10. SAM Subjective Fatigue Checklist	1 - 2 min.
11. Thayer's AD-ACL	2 min.
12. Humphries Response Alternation	6 min. (Timed)
13. Fitt's Reciprocal Tapping	1 min. (Timed)
14. Four-Choice Serial Reaction Time	6 min. (Timed)[3]
13 Chore Sessions/4 - 8 Hourly	
1. Four-Choice Serial Reaction Time	16 min. (Timed)
2. Short-Term Memory	3 min./Timed Recall:10 min. total
3. Miller's Reading (Reading) Miller's Reading (Examination)	10 min. (Timed) Approximately 5 min.
4. Wisher Eye Movements Task[4†]	Approximately 30 min.
8 Watch Sessions/12 Hourly	
1. Wilkinson's Auditory Vigilance test	50 min.

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* For single subject. † Results were discussed elsewhere. 1. Recorded only after awakening from major sleep periods. 2. The task was timed by experimenter. 3. Only for Group 2. 4. Only for Group 1.

6 letters) were listed at the top of each test sheet. The subjects were asked to place a check mark along the line containing the target letters, and an X mark for the remainder. Each test with 2, 4, or 6 target letters was timed to last for 2 minutes. The score was the total number of lines scanned in 2 minutes (which included both correctly and incorrectly evaluated lines). Only the results of the MAST with 2 target letters are reported in this paper because the MAST task with 4 or 6 letters yielded similar results.

The NHRC Mood Scale (also known as the NPRU Mood Scale), developed by Moses et al. (1974), has been reported in some detail by Johnson and Naitoh (1974). Recently, the NHRC Mood Scale was used successfully by Opstad et al. (1978). The scale has two scores: positive and negative moods. Previously, sleep loss was found to increase the negative score and to decrease the positive score.

The Stanford Sleepiness Scale (SSS) was developed by Hoddes et al. (1973) to obtain self-ratings on a 7-point scale of feeling drowsy. The larger the score, the greater the extent of subjectively rated sleepiness.

The School of Aerospace Medicine (SAM) subjective fatigue checklist, developed by Pearson and Byars (1956), has been used extensively to evaluate subjective ratings of fatigue in air crews (e.g., Harris et al., 1971) and in crews working under an atypical demanding work-rest schedule (Storm & Gray, 1978). The scale consisted of ten statements. The score of this scale ranged from 0-20 points, where the lower scores indicated greater subjective feelings of fatigue.

On Thayer's Activation-Deactivation Adjective Check List (AD-ACL) (Thayer, 1967, 1978), subjects described their feelings at the moment by checking off each of 48 adjectives or statements, such as "carefree" and "engaged-in-thought", by selecting one of the four alternatives. The AD-ACL yielded a General Activation score based on the subjects' checking affirmatively on "peppy", "energetic", "vigorous", "lively", "activated", "full-of-pep", and "active".

Humphries' Task of Response Alternation Performance (TRAP) is described by Humphries and Naitoh (in preparation), and was used in a gradual sleep reduction study by Friedmann et al. (1977). This task requires the subjects to press one of two response buttons alternately and repeatedly at a pace set by the subjects. If the inter-tapping interval exceeded 2.5 seconds (i.e., a "lapse" in attention), a buzzing noise was given to the subjects through headphones. The subjects performed this task with their eyes closed. The tappings were recorded on cassette tapes for later analysis. Two response measures were obtained: (1) TRAP 1, the total number of button tappings in 5 minutes, and (2) TRAP2, the 10 percentile of the longest inter-tapping intervals.

Fitts' reciprocal tapping task (Fitts, 1954; Fitts & Peterson, 1964) was modified by Graeber et al. (1977) to be a paper-and-pencil self-administered test. Each subject had a tapping sheet on which was a parallel series of 12 circles separated by 8.75 cm. The subjects were to mark, with a pencil, inside each target circle from left to right down the sheet. Accuracy rather than speed was stressed, but the subjects were to complete this task as rapidly as possible. Any marks outside the circles or any marks extending outside a circle were counted as errors. The subjects used a stopwatch to measure time needed to complete tapping these 12 circles. An "efficiency" of tapping score was defined as the ratio of the total number of successful tappings divided by the number of seconds required to complete the task. A smaller ratio reflected less efficiency in tapping.

The Wilkinson four-choice reaction time task (Wilkinson & Houghton, 1975) consisted of a modified cassette recorder which had a display of four lights arranged in a square. Below this display were four similarly arranged push-buttons. The task required the subjects to press the button corresponding geometrically to the illuminated light. All button-presses were recorded on cassette tapes for later analysis. The task performance was evaluated by two measures: (1) number of both correct and incorrect responses, and (2) 10 percentile of the slowest inter-response intervals.

The short-term memory test (Williams et al., 1966) consisted of 15 tape-recorded words. In performing this task, each word was first pronounced, spelled, and pronounced again. This was followed by 10 seconds of silence during which the subjects wrote the word down. After the list was completed, the subjects had 3 minutes to recall as many words as possible, in any order, and write them down on a recall sheet. Three such lists were used in the chore-session. A misspelled word, if legible, was counted as a correct recall. The score was the percentage of the words correctly recalled.

Details of the Miller Reading Efficiency test and Wisher's eye movement task will be discussed elsewhere.

During the Wilkinson's auditory vigilance task (Wilkinson, 1970), the subject was in bed in a soundproof room and listened to a 600 Hz tone pulse coming from a loudspeaker. This 600 Hz tone lasted for 500 msec and recurred every 2 seconds on a background of white noise. Forty of these tones, occurring randomly ten times in every 15 minutes of the vigilance test, were of slightly shorter duration, 360 msec. The subjects' task was to detect these shorter tones and report them by pressing a button as quickly as possible. Then the subjects were to indicate how confident they were that the tone was indeed a signal by pressing one of three buttons. Background noise was set at about 85 dB. Two measures were used: (1) percent correct signal detection, and (2) average reaction time of all responses.

Results

Statistical Analysis of Data

Statistical analyses were divided into two major parts: (1) quantitative analysis for circadian rhythms for the baseline and vigil data, and (2) statistical evlaution of the recuperative power of the naps.

Circadian analysis. The group mean cosinor analysis, as described by Halberg et al. (1967), was used by programming a PDP-12 computer first to fit a 24-hour/cycle cosinusoidal wave to the data one subject after another, and then to calculate and plot a 95% confidance ellipse for each dependent variable. In fitting a 24-hour/cycle cosinusoidal wave to the data, the "monosinusoidal method" by Naitoh et al. (in press) was employed. In the analysis, 11 data points (starting from the 8th bio-session) were grouped together to provide the baseline, and analyzed by the group mean cosinor method. This "baseline" period included 0800 Tuesday to 0400 Wednesday, corresponding to 21 hours of continuous wakefulness. Thus, this baseline was slightly contaminated by data points which could also belong to the vigil time period, i.e., the data obtained at 0200 and 0400 Wednesday. Another 11 data points from the 20th bio-session to the 30th bio-session were analyzed by the group mean cosinor method to represent the time period of sleep loss or vigil. This vigil period was from 0800 Wednesday to 0400 Thursday. Beginning at 0800 Tuesday, there were 45 hours of continuous wakefulness before the 0400 Thursday nap.

To determine if the vigil caused the acrophase angle (or Time-of-Peak, TOP) of the dependent variable to shift from the normally expected time, the Rayleigh test, as described by Batschelet (1965), was used.

Bio-sessions. Only a portion of data from the 45 bio-sessions was used. First, the average of bio-sessions 8 through 16 (0800 Tuesday to 2400 Tuesday) was calculated for each subject and used to represent his baseline score. Another average for bio-sessions 20 through 28 (0800 Wednesday to 2400 Wednesday) was calculated to represent the "vigil" score for each subject. The value observed in bio-session 31 (which occurred after the first nap for Group 1) was used to represent the effects of Nap 1, or a continuous vigil of 47 hours for Group 2. Bio-sessions 32 through 34 were averaged to represent either the period of partial recovery in Group 1 or the continuing vigil in Group 2. Then bio-session 35 was used to represent either the effect of Nap 1 plus Nap 2 for Group 1, or the effect of the first nap for Group 2. Finally, an average of bio-sessions 36 through 40 was used to represent the period of partial recovery for Group 1 and Group 2. Thus, the data obtained in the bio-sessions were grouped into six discrete conditions: C1, the baseline for both groups; C2, the vigil for both groups; C3, Nap 1 for Group 1 and continuing vigil for Group 2; C4, partial recovery for Group 1 and continuing vigil for Group 2; C5, Nap 2 for Group 1 and the single nap for Group 2; and C6, the second partial recovery period for Group 1 and partial recovery for Group 2. Table 2 shows the bio-sessions partitioned into the six conditioned.

Oral temperature can be used to illustrate how the group mean scores were obtained for the six conditions. Oral temperature readings during bio-sessions 8-16 were averaged for each subject, and then the mean of these averages over subjects was computed to get the mean oral temperature for each group for each condition, e.g., 98.06 F + 0.35 F was the mean baseline oral temperature for Group 1. Similarly, the average for Group 2 for the baseline was 97.84 F (see Table 2).

In the statistical evaluation, only 11 of the 15 subjects in Group 1 had complete data for all of the dependent variables. Thus, the statistical evaluation was based on 11 subjects in Group 1 and 8 subjects in Group 2.

As seen in Table 2, each variable could be subjected to a two-way ANOVA for the "two factor experiment with repeated measures on one factor (Winer, 1971). The two factors were groups and conditions, and the conditions factor was measured repeatedly. In this study, however, the exact multivariate solution for the two-sample multivariate profile analysis of Timm (1975) was

Table 2

Summary of Results of Physiological and Performance Measures and Subjective Ratings

	C1	C2	C3	C4	C5	C6
Group 1	Baseline	Vigil	Nap 1	PR 1	Nap 2	PR 2
Group 2	Baseline	Vigil	Vigil	Vigil	Nap	PR 1
Dependent Measures	Bio 8-16	Bio 20-28	Bio 31	Bio 32-34	Bio 35	Bio 36-40
Oral Temperature (F°)						
Group 1	98.06(0.35)	97.86(0.36)	96.69(0.59)*	97.41(0.56)*	97.48(0.71)	98.11(0.36)
Group 2	97.84(0.37)	97.58(0.52)	97.11(0.46)*	97.35(0.55)*	97.39(0.43)	97.54(0.63)
Pulse (BPM)						
Group 1	63.0 (5.9)	66.0 (6.3)	64.2 (10.4)	65.1 (5.0)	67.0 (9.2)	68.3 (3.9)
Group 2	67.3 (5.3)	66.2 (5.8)	59.5 (5.4)	58.8 (6.9)	55.8 (6.5)	56.4 (9.2)
Blood Pressure (mmHg)						
Systolic: Group 1	121.6 (8.3)	122.8 (8.2)	116.3 (8.1)	127.7(11.8)	128.5(12.2)*	114.4 (4.3)
Systolic: Group 2	129.4 (6.2)	118.9 (4.6)	112.5 (8.2)	129.7(9.1)	128.3(11.3)*	110.4 (15.2)
Diastolic:Group 1	59.9 (8.1)	70.5 (5.5)	75.9(10.2)	71.3(7.9)	72.5(9.4)	67.1 (10.3)
Diastolic:Group 2	70.3 (5.6)	69.5 (5.3)	72.8(8.9)	72.7(3.9)	77.0(3.2)	68.2 (7.9)
MAST (2 letters)						
# Lines : Group 1	62.5(18.1)	59.8(16.3)	53.7(8.1)*	59.3(17.7)	54.8(21.6)*	65.4 (16.6)
# Lines : Group 2	51.3(9.5)	45.0(8.3)	32.3(9.3)*	45.6(21.8)	31.8(13.3)*	43.9 (8.3)
TRAP						
# Response:Group 1	1044(273)	1024(288)	783(285)	972(272)	929(210)	1116(276)
# Response:Group 2	1046(210)	1036(289)	854(295)	953(229)	781(250)	1092(149)
10%ile slow:Group 1	497(150)	768(454)	1510(991)*	1055(533)*	844(658)	542(278)
10%ile slow:Group 2	445(53)	754(256)	1292(931)*	1221(687)*	1761(1067)	764(320)
Fitts Reciprocal Tappings						
Efficiency:Group 1	1.02(0.41)	0.99(0.42)	0.72(0.44)*	0.93(0.46)	0.93(0.47)	0.98(0.44)
Efficiency:Group 2	1.12(0.21)	1.12(0.27)	1.02(0.33)*	1.11(0.25)	0.90(0.33)	1.14(0.26)
SAM Fatigue Checklist						
Group 1	13.3(1.5)	11.6(3.2)	6.9(4.5)*	8.9(3.6)*	10.2(3.1)*	10.7(2.8)*
Group 2	12.4(1.0)	9.8(2.6)	8.0(3.7)*	9.2(3.4)*	7.9(3.2)*	8.6(3.0)*
SSS						
Group 1	1.99(0.52)	2.74(0.31)*	4.18(1.32)*	3.09(1.01)	3.09(0.94)*	2.64(0.54)
Group 2	2.07(0.59)	2.56(0.63)*	4.38(1.36)*	3.25(1.32)	3.38(0.99)*	3.08(1.21)
MPRC Positive						
Group 1	33.4(7.4)	30.8(9.3)	17.0(7.8)*	25.6(9.5)	25.7(8.6)*	28.1(7.6)
Group 2	32.8(5.8)	28.9(7.7)	19.4(10.1)*	27.6(9.0)	22.0(9.9)*	25.3(10.0)
MPRC Negative						
Group 1	2.6(3.8)	5.4(4.8)*	9.4(6.2)*	7.9(6.5)	7.8(5.9)	5.4(5.1)
Group 2	2.7(1.9)	5.0(3.2)*	8.9(5.1)*	8.5(7.3)	8.6(7.6)	9.3(5.0)
Thayer's AD-ACL						
GA*:Group 1	2.54(0.47)	2.33(0.60)	1.74(0.82)*	2.11(0.51)*	2.13(0.47)*	2.26(0.61)*
GA :Group 2	2.53(0.52)	1.88(0.56)	1.79(0.70)*	1.97(0.64)*	1.93(0.64)*	1.84(0.58)*

* = Average of two groups is significantly different from the baseline (average of Bio-sessions 8 - 16).

Nap 1 = The first nap for Group 1. Nap 2 = The second nap for Group 1. Nap = Only nap allowed for Group 2.

For definitions of some dependent measures, see the text. * = General Activation.

used instead of a univariate ANOVA. To supplement the multivariate omnibus Hotelling's T^2 statistics, multivariate simultaneous confidence intervals for 95% confidence levels were generated to determine the loci of the significant omnibus Hotelling's T^2. Thus, the problem of multiple comparisons was avoided. Also avoided was the assumption of compound symmetry. However, two-sample Hotelling's T^2 assumes homogeneous covariance matrices of the two samples. Hakstian et al. (1979) showed that two-sample Hotelling's T was robust, even when this assumption was violated. A FORTRAN program was written for the PDP-12 to do a two-sample multivariate profile analysis for each of the 13 variables listed in Table 2.

Chore- and watch-sessions. The same multivariate analysis was applied to the data of the four-choice serial reaction time, Williams' Word Memory, and Wilkinson's auditory vigilance (Table 3). The multivariate analysis was repeated five times, once for each dependent variable.

Circadian Rhythms and Vigil

In Table 4 is a summary of the group mean cosinor analysis. Statistically signigicant circadian rhythms were detected in the baseline data of all of the 12 dependent variables listed in Table 3. The data and cosinor plot of oral temperature, systolic blood pressure, SAM fatigue checklist, SSS, TRAP 1 and TRAP 2 measures are given in Figures 3, 4, and 5.

Each figure shows the chronograms to the left and the group-mean cosinor plots to the right. In the cosinor plot, the 95% confidence ellipse bounded by the longer tangent lines intersecting into the clockface represents the vigil phase. Figures 3, 4, and 5 (top rows only) show that the circadian rhythms of these variables persisted throughout the period of prolonged wakefulness. The circadian rhythm of the TRAP 2 measure, which is shown in the bottom row of Figure 5, was lost during the vigil. In addition to the TRAP 2 measure, diastolic blood pressure and total number of responses in the four-choice serial reaction time task also lost their circadian rhythms during the vigil (see Table 4).

The most consistent change in circadian rhythms observed during the vigil was that the 95% confidence ellipses tended to be larger for data collected during the vigil, suggesting that continuous work caused individual differences to appear in terms of TOP. With the exception of diastolic blood pressure and pulse rate, the TOPs were reliably shifted by sleep loss (see Table 4). The shifts in TOPs were all within 2 hours, the sampling interval used in this study. The absence of large (greater than 2 hours) shifts in TOPs indicates that the values of these variables during the vigil could be compared directly with those obtained during baseline without complex phase-adjustment, as long as these values were observed at the same time during the baseline and vigil. Group TOPs of the TRAP 1 measure and MAST during the vigil were appreciably different from the baseline TOPs, but these changes were not statistically significant using the Rayleigh test.

A measure of percent (Amplitude/Mesor) was computed by dividing the average amplitude by an average mesor, and by multiplying this ratio by 100. Oral temperature, which is highly regulated homeostatically, had a small percent (Amplitude/Mesor), 0.6%. This means that the oral temperature could swing as

Table 3

Performance Measures Taken at Different Test Sessions

CHORES

Group 1 Group 2	Baseline(C5) Baseline(C5)	Vigil(C8) Vigil(C8)	Vigil(C9) Vigil(C9)	Nap 1(C10) Vigil(C10)	Nap 2(C11) Nap (C11)	R(C12) R(C12)
Four-Choice RT						
# of response:Group 1	507.5(52.0)	476.1(53.6)	465.3(87.7)	400.2(69.3)*	441.9(83.0)	470.2(64.7)
# of response:Group 2	540.5(88.8)	460.4(89.6)	490.0(87.5)	411.4(115.4)*	443.1(84.9)	483.0(102.4)
10%ile slow:Group 1	960(317)	1358(778)	1226(422)	2336(967)	1895(1759)	1957(1478)
10%ile slow:Group 2	956(277)	2023(1372)	1312(765)	4352(6536)	1967(1120)	1524(1027)
Williams' Word Memory						
% Recall: Group 1	55.1(10.8)	48.3(14.8)	51.8(9.3)	37.8(8.7)*	49.8(13.9)	54.2(14.7)
% Recall: Group 2	54.7(9.1)	43.9(5.8)	51.4(18.9)	41.1(17.5)*	42.8(12.3)	47.5(9.4)

WATCHES

Group 1 Group 2	Baseline(W3) Baseline(W3)	Vigil(W4) Vigil(W4)	Vigil(W5) Vigil(W5)	Nap 1(W6) Vigil(W6)	Nap 2(W7) Nap (W7)	R(W8) R(W8)
Wilkinson's Auditory Vigilance						
% Correct: Group 1	62.4(17.1)	37.5(12.5)*	48.2(14.5)	22.0(12.2)*	50.2(13.2)	38.2(13.7)
% Correct: Group 2	55.6(11.8)	39.7(9.4)*	39.0(9.4)	20.8(13.1)*	35.5(14.0)	39.1(9.8)
Average RT:Group 1	525(86)	556(88)	561(81)	511(69)	542(71)	538(98)
Average RT:Group 2	544(68)	556(69)	569(55)	597(79)	606(55)	624(44)

C stands for "Chore" in the schedule; W stands for "Watch" scheduled in this study. For details see the text.

* = Average of two groups is significantly different from the Baseline (Chore 5 or Watch 3 session).

Table 4

Cosinor Summary of Circadian Rhythm During Baseline (B) and Vigil (V) Periods

Variable	Epoch	N	PR	Mesor (SD)	Amplitude Mean (95% C.I.)	Acrophase (hrs min) Mean (95% C.I.)	%(Amp/ Mesor)	Rayleigh Zd
Oral Temp	B	23	54.5%	97.8(0.3)	0.5(0.4 to 0.7)	1722(1614 to 1819)	0.6%	
(°F)	V	23	43.5%	97.5(0.5)	0.4(0.3 to 0.5)	1641(1504 to 1813)	0.4%	13.6***
Blood Press.	B	19	38.3%	120.3(7.5)	6.9(3.8 to 10.0)	1037(0856 to 1234)	5.8%	
Systolic (mmHg)	V	19	51.2%	120.4(6.4)	9.0(5.6 to 12.5)	1006(0902 to 1119)	7.5%	10.7***
Blood Press.	B	19	27.7%	71.3(6.4)	2.7(1.0 to 4.6)	0420(0048 to 0605	3.8%	
Diastolic	V	19	29.9%	70.2(6.2)	1.8	0550	----	1.4
Pulse	B	19	31.5%	63.7(5.7)	2.8(0.7 to 5.2)	1503(1032 to 1736)	4.4%	
(beats/min)	V	19	37.5%	65.0(5.4)	3.3(1.3 to 5.4)	1525(1306 to 1702)	5.1%	2.8
NHRC +	B	23	47.3%	31.9(7.4)	4.0(2.3 to 5.7)	1432(1231 to 1623)	12.6%	
	V	23	31.7%	27.5(8.9)	3.2(1.4 to 5.2)	1500(1328 to 1722)	11.7%	10.8***
NHRC -	B	22	48.6%	3.5(2.8)	1.6(0.8 to 2.5)	0327(0206 to 0438)	45.7%	
	V	22	39.2%	6.8(4.0)	1.6(0.8 to 2.5)	0355(0154 to 0638)	23.6%	6.1**
SSS	B	22	55.7%	2.3(0.5)	0.7(0.5 to 1.0)	0236(0132 to 0321)	31.3%	
	V	22	35.7%	3.3(0.8)	0.5(0.3 to 0.8)	0339(0138 to 0538)	16.1%	8.8***
SAM Fatigue	B	23	56.1%	12.4(1.6)	2.1(1.3 to 3.0)	1407(1255 to 1504)	17.0%	
	V	23	35.3%	9.8(2.6)	1.6(1.0 to 2.7)	1511(1308 to 1728)	16.4%	5.6**
TRAP 1	B	19	36.7%	1033.6(237.0)	43.8(24.3 to 66.0)	1946(1741 to 2234)	4.3%	
(# Responses)	V	19	32.6%	1006.9(247.0)	45.7(4.35 to 88.2)	1707(1208 to 2120)	4.6%	2.5
TRAP 2	B	19	33.2%	503.9(151.9)	70.0(29.6 to 121.3)	0637(0410 to 1035)	13.9%	
(msec)	V	19	24.2%	798.9(372.9)	68.7	0623	-----	1.0
2 MAST	B	19	25.5%	57.2(15.1)	4.3(1.3 to 7.3)	1516(1319 to 1741)	7.5%	
(# Lines)	V	19	24.1%	53.1(15.0)	2.5(0.2 to 4.9)	2045(1931 to 0058)	4.8%	2.0
4-Choice	B	8	36.8%	547.8(59.7)	19.1(4.8 to 42.2)	1837(1445 to 2353)	3.5%	
(# Responses)	V	8	10.2%	489.5(85.5)	3.6	0701	----	1.1

** 1% or better.

*** [illegible]

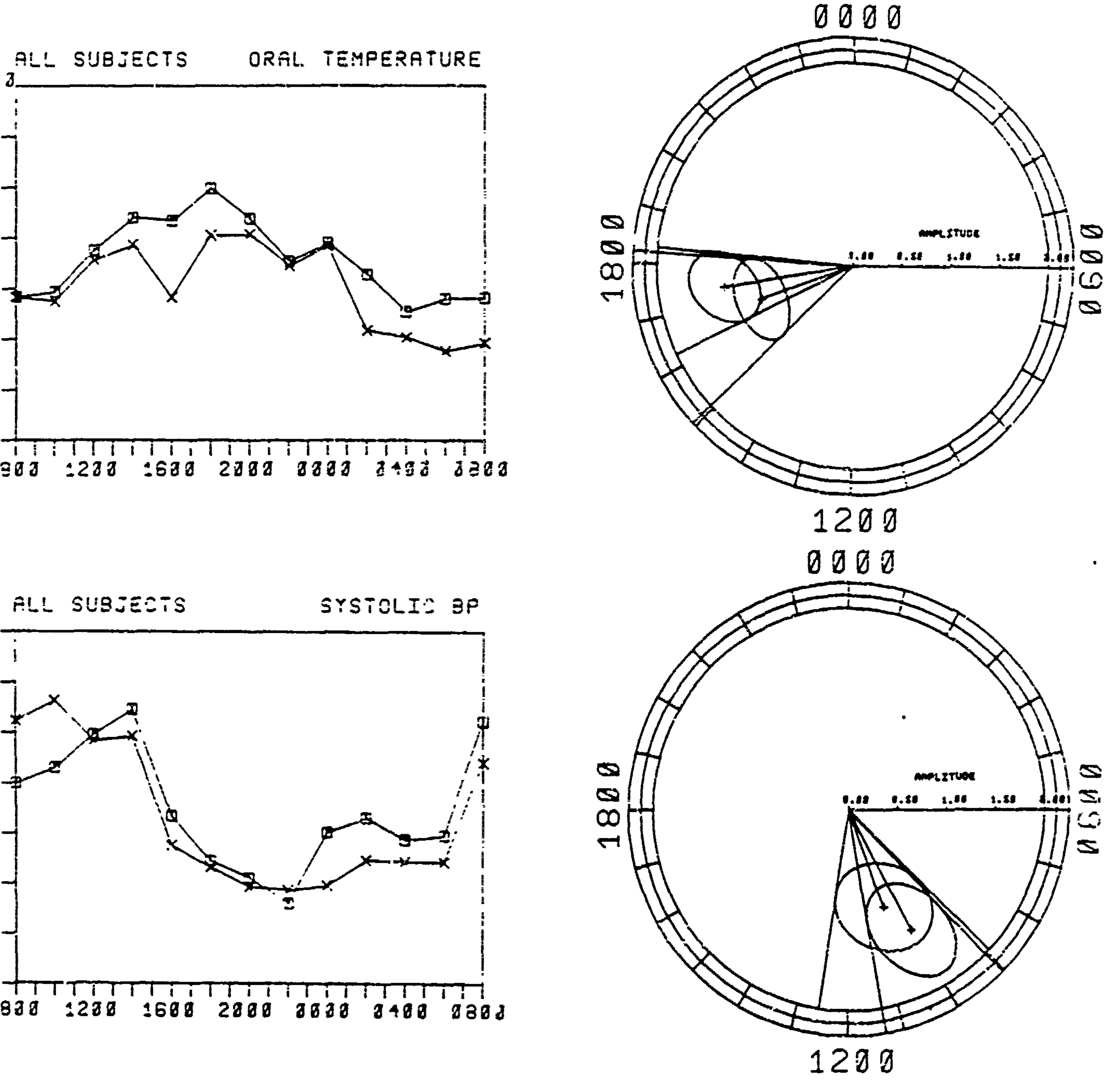

Figure 3. A chronogram (left) and cosinor plot (right) for oral temperature (top row), and for systolic blood pressure (bottom row). A chronogram is a plot of averages across all subjects. The squares identify the values observed during the vigil, and that with shorter lines for the baseline. The same procedures were used for Figures 4 and 5. The X-axis shows time of day. Y-axis for oral temperature is in F degree. Y-axis for systolic blood pressure is in mm Hg.

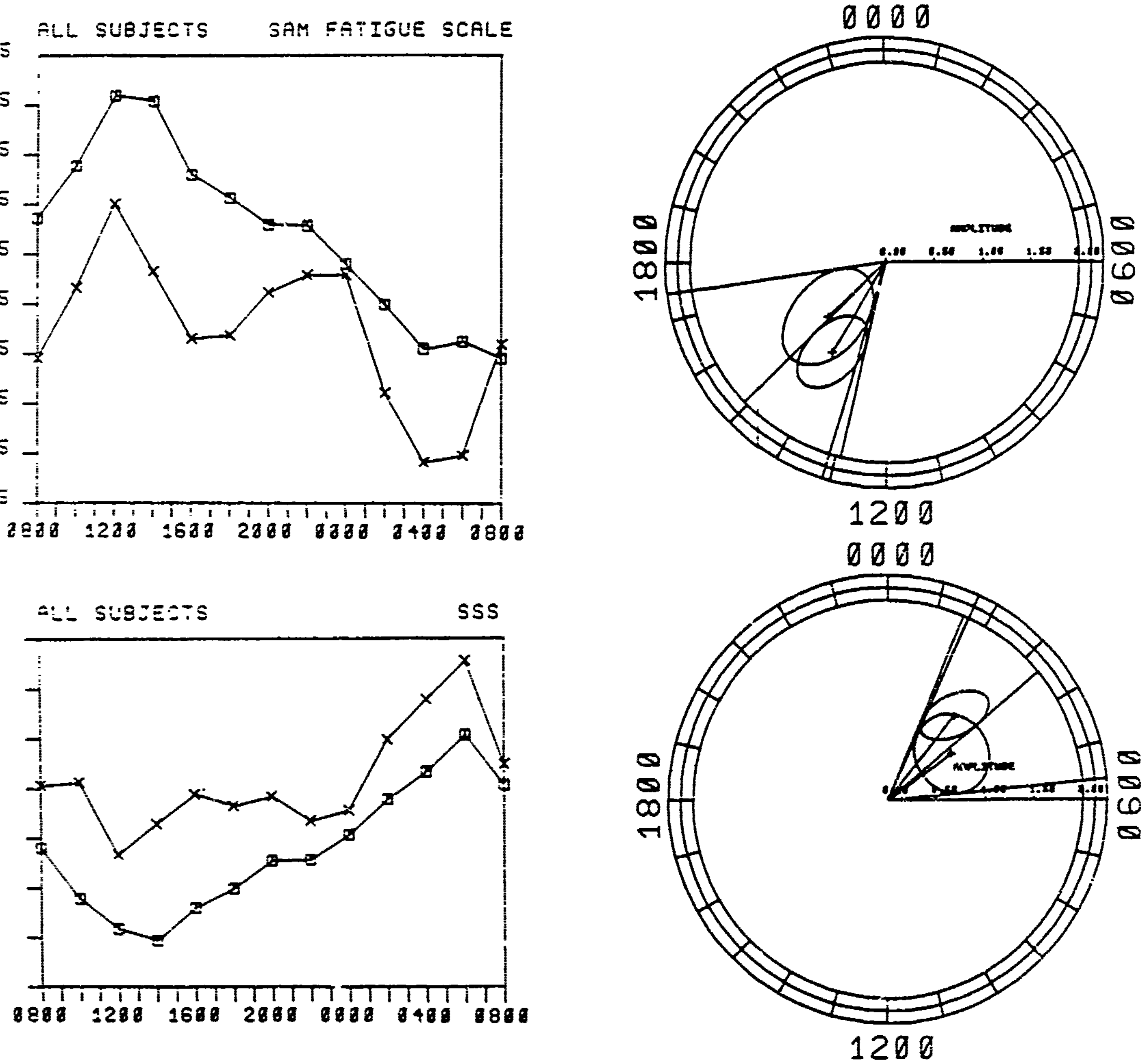

Figure 4. A chronogram (left) and cosinor plot (right) for the SAM subjective fatigue checklist (top row), and for the Stanford Sleepiness Scale (SSS). X-axis is time of day, and Y-axis for SAM subjective fatigue checklist is in an arbitrary scale, ranging from zero to 20. The larger number means less subjectively rated fatigue. Y-axis for chronogram of the SSS is in an arbitrary unit, ranging from zero to seven. The larger number means greater sleepiness.

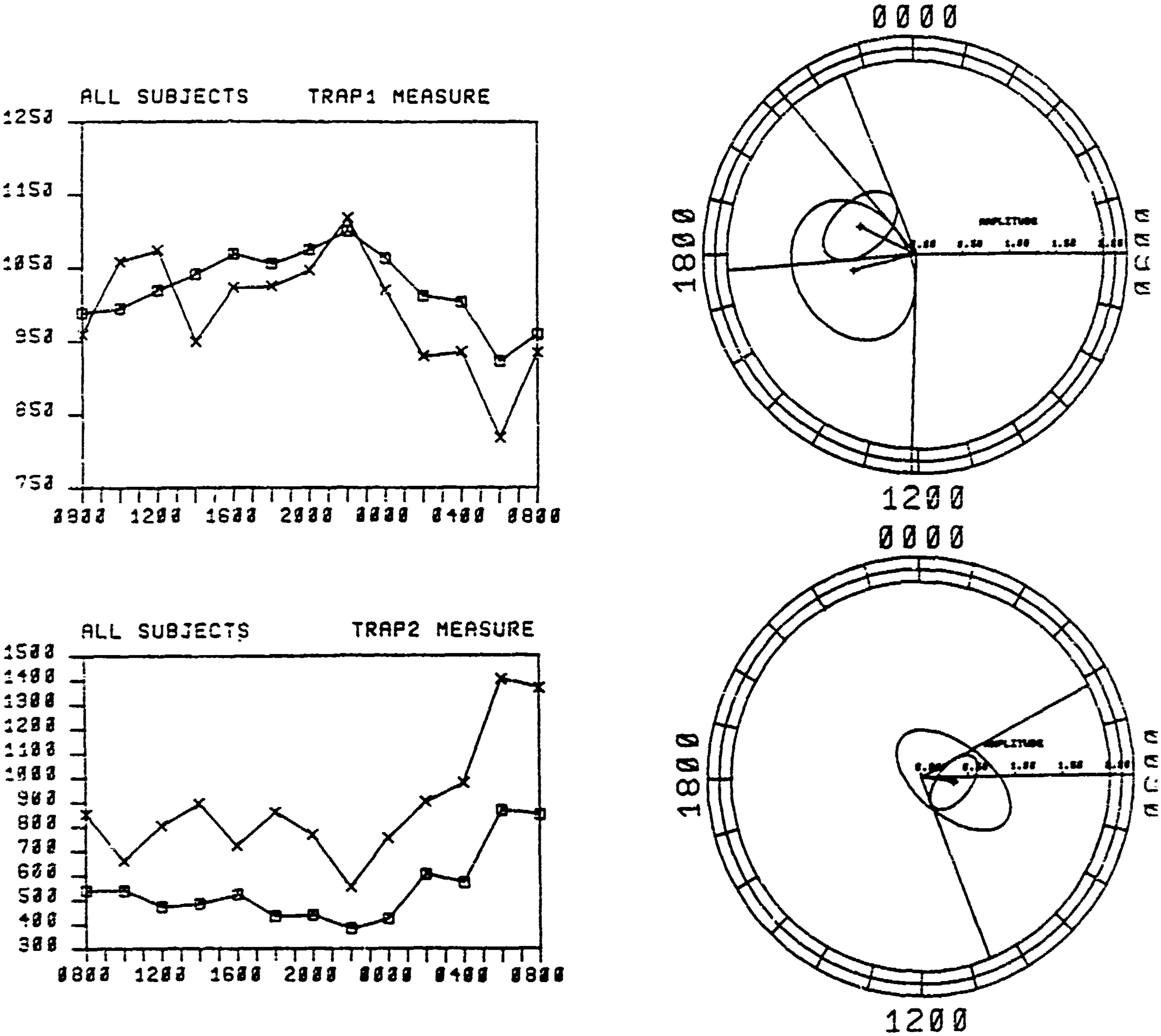

Figure 5. A chronogram (left) and a cosinor plot (right) of TRAP 1 measure (top row), and of TRAP 2 measure (bottom row). Y-axis for TRAP 1 measure is total number of tappings. Y-axis for TRAP 2 measure is 10 percentile of the slowest inter-tapping intervals.

much as 0.6% of its mesor, higher or lower, due to the circadian rhythm. The percent measure was much greater for other dependent variables, especially for mood, sleepiness, and fatigue. For example, the percent value for the NHRC Negative Scale suggested that it oscillated as much as 45.7% of the mesor due to the circadian rhythm. This finding suggests that the circadian rhythm component would be very large for self-ratings of mood, sleepiness, and fatigue.

The data in Table 4 show that the minimum oral temperature occurred at 0441 during the vigil. Systolic blood pressure was minimal at 2206, and pulse minimum occurred at 0325 during the vigil. The minima for subjective ratings for the NHRC Positive Scale, NHRC Negative Scale, SSS, and SAM Fatigue Scale during the vigil were 0300, 0355, 0339, and 0311, respectively. Performance minima for the TRAP 1 measure and MAST were 0507 and 0845, respectively. Thus, Nap 1 of Group 1 was placed near the troughs of many circadian rhythms, especially oral temperature and subjective ratings. Nap 2 of Group 1 and the only nap for Group 2, taken from 1200 to 1400, occurred very close to the TOPs of many circadian rhythms. Thus, these naps were placed at the intended phases of the circadian rhythms.

Recuperative Power of Naps

Groups by conditions interaction. In Tables 2 and 3 are the results of this analysis. The null hypothesis, first tested by multivariate two-sample profile analysis, was that the two groups would have parallel profiles. In a univariate ANOVA, this null hypothesis of parallelism corresponds to a null hypothesis of no interaction between groups and conditions. The differences (e.g., the slopes) of C1-C2, C2-C3, C3-C4, C4-C5, and C5-C6 of Group 1 were tested simultaneously against those of Group 2 to determine if any of these slopes were significantly different.

The null hypothesis of parallelism of the groups' profiles was tested 18 times, one null hypothesis test for each dependent measure (Tables 2 & 3). Using a significance level of 5%, none of the 18 null hypothesis tests for parallelisms could be rejected. For all variables, the two groups had similar profiles which went up or down together. There was no significant group-by-conditions interaction. The similarity of the two groups can be seen in the plots of the group means over experimental days 2 through 5 in Figures 6 through 9. Data obtained in the chore- and watch-sessions were not plotted, but the two groups showed very similar plots.

The second null hypothesis tested by multivariate two-sample profile analysis was that Group 1 did not differ over conditions from Group 2. Again, the null hypothesis was tested for each of the dependent measures. Only the MAST showed a large enough omnibus T^2 value to allow rejection of the null hypothesis. Further analysis with the 95% simultaneous confidence intervals, however, showed that Group 1 and Group 2 differed significantly from the very beginning of the experiment, and they remained different throughout the experiment (see top row of Figure 8).

Comparison over conditions. As the two groups had parallel profiles, they were combined into one group and the null hypothesis that no differences exist among conditions (or flatness hypothesis) was tested 18 times. The omnibus testing of all possible contrasts among the conditions indicated there

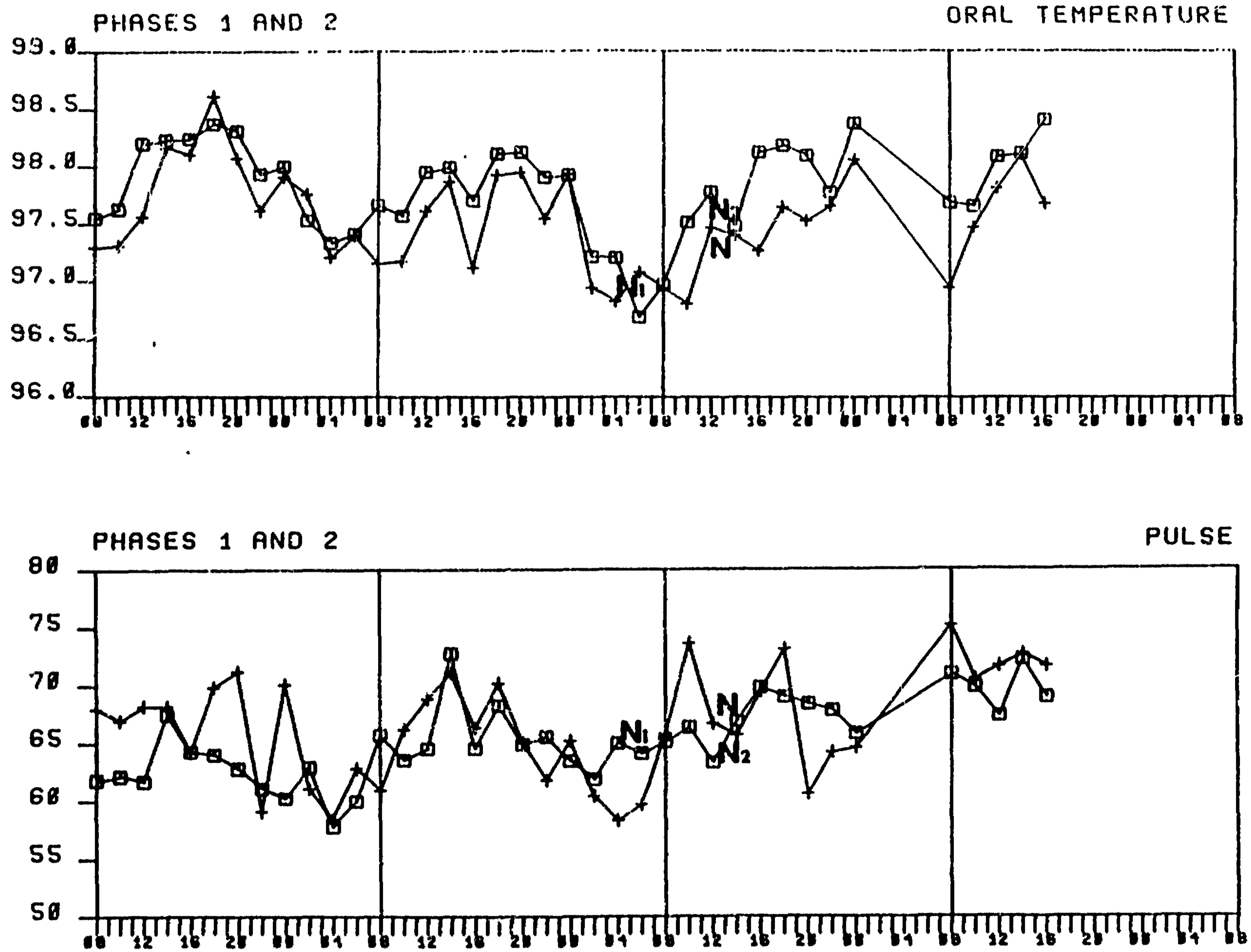

Figure 6. Plots of oral temperature and pulse rate separately for Group 1 and Group 2. Y-axis starts with 0800 Tuesday (Day 2 of the experiment) and continues to the end of the study at 1600 Friday (Day 5). For this and the remaining figures, N and N are the first and second 2-hour naps experienced by Group 1 (identified by the squares). N is the only 2-hour nap allowed for Group 2 (identified by plus [+]). Y-axis for pulse is in beats per minute.

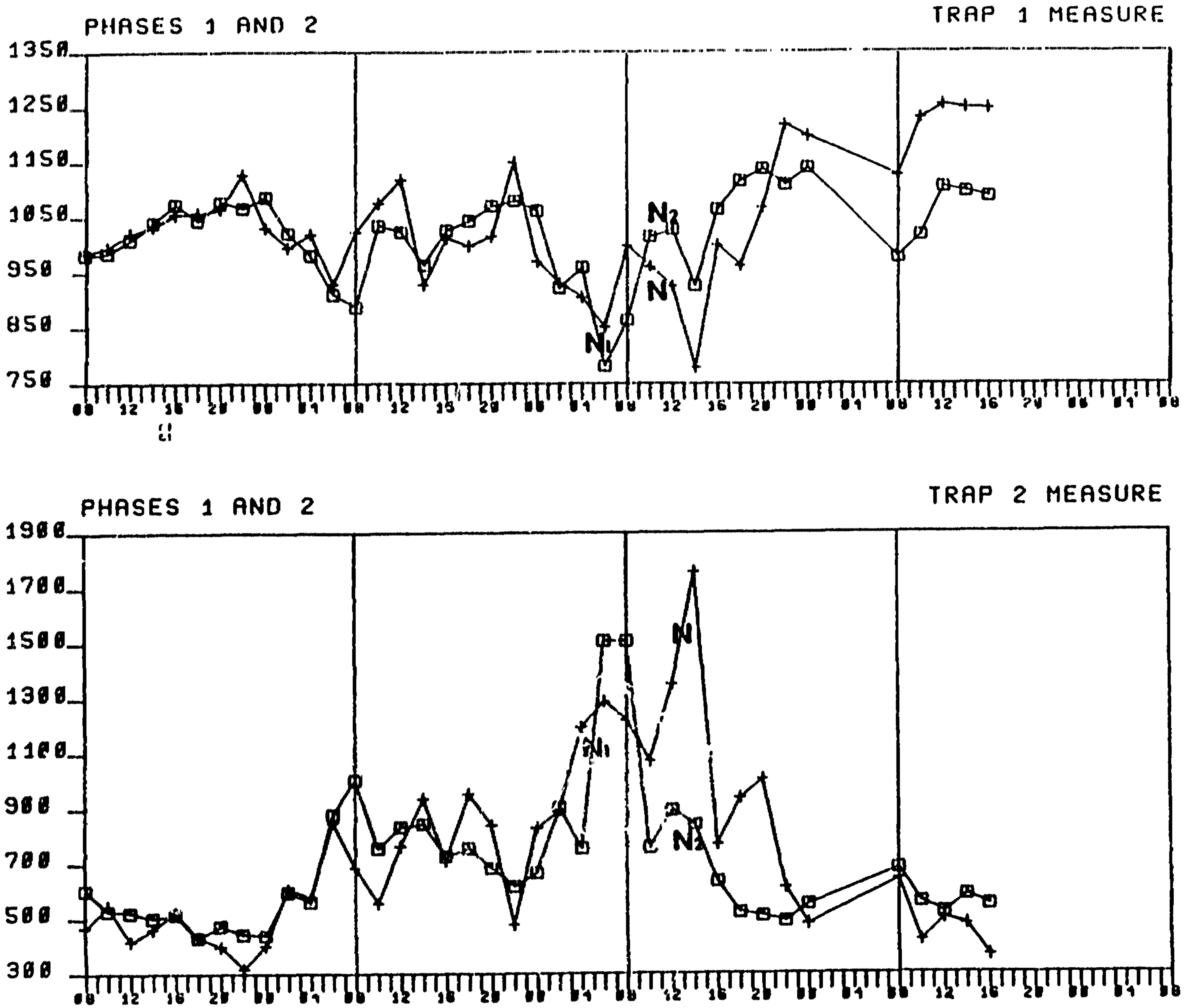

Figure 7. Plots of two measures of TRAP task performance separately for Group 1 and Group 2. TRAP 1 measure is in terms of total number of tappings. TRAP 2 measure is in milliseconds of elapse time between tappings. TRAP 2 measure shows averages of 10 percentile slowest inter-tapping intervals.

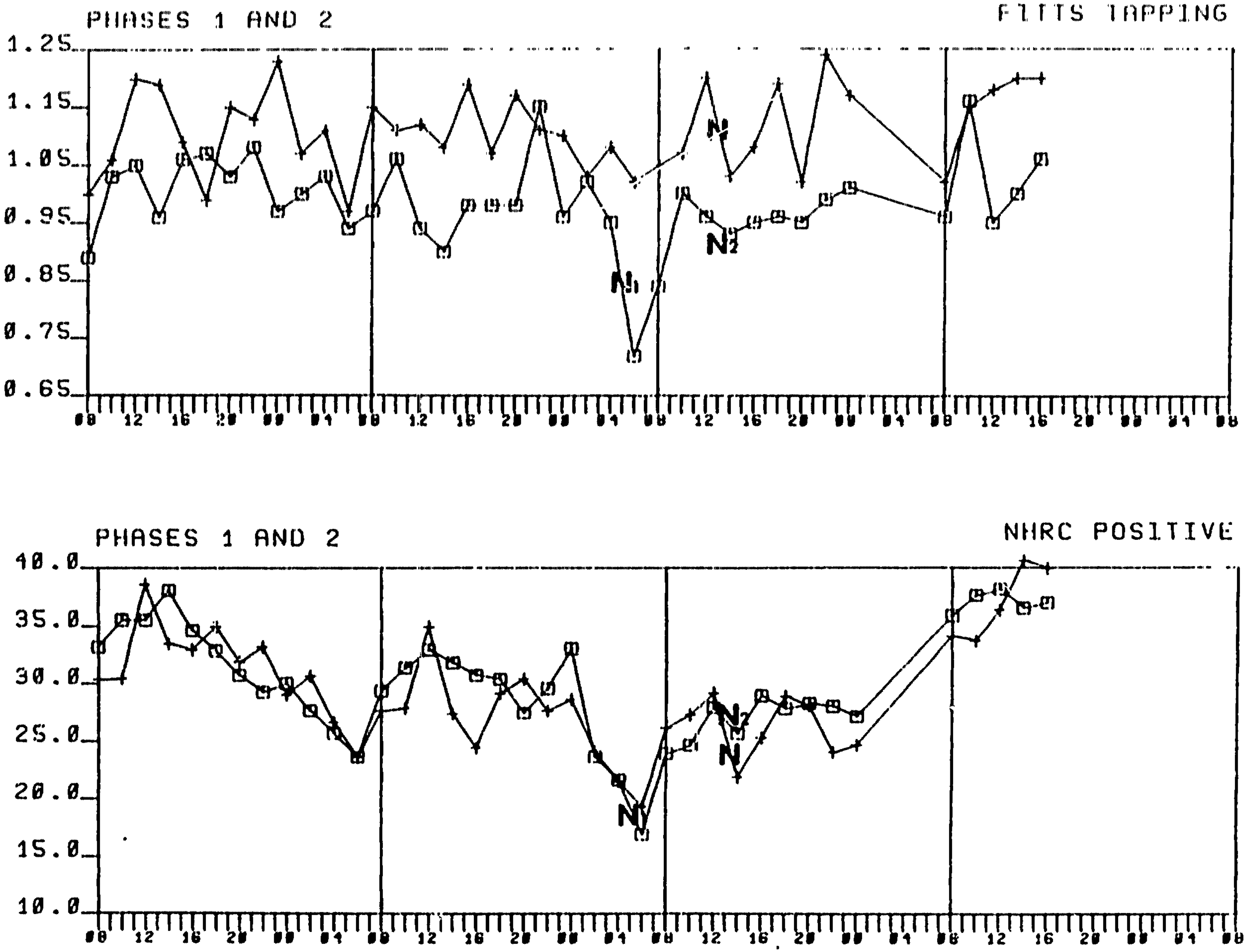

Figure 8. Plots of efficiency score of Fitts' reciprocal tapping task and NHRC positive score separately for Group 1 and Group 2. The efficiency score for Fitts' reciprocal tapping task was derived by dividing the number of successful tappings by time (in seconds) the subjects needed to complete the task. The larger Y-value represents a higher "efficiency". Y-axis for NHRC positive scale is an arbitrary scale, ranging from the minimum of 0 to the maximum of 76. Better mood is shown as a larger value along the Y-axis.

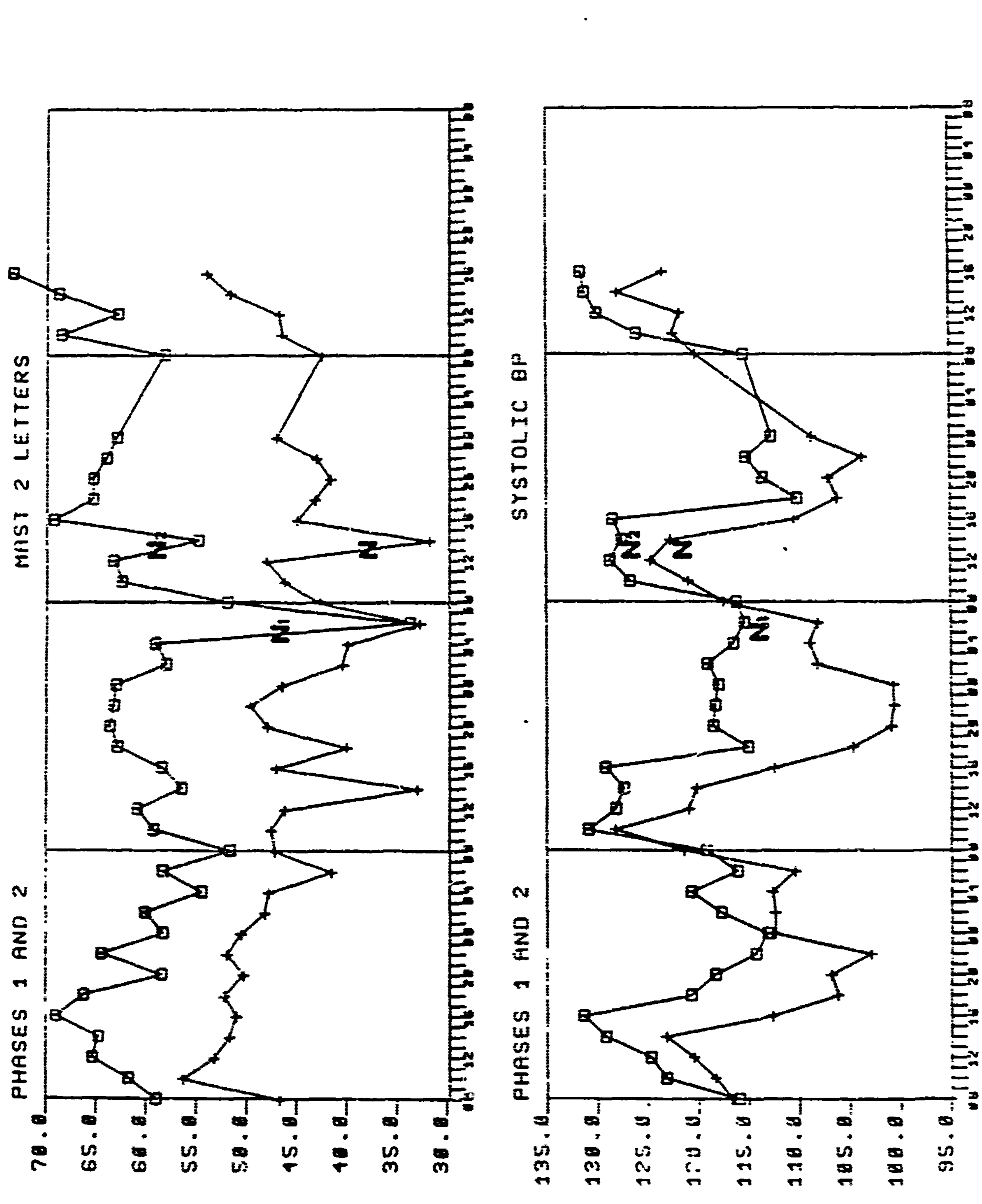

Figure 9. Plots of total number of lines scanned in MAST test (2-letter target) and systolic blood pressure separately for Group 1 and Group 2.

were no significant differences among the conditions for the following dependent measures: (1) pulse rate, (2) diastolic blood pressure, (3) TRAP 1 measure,(4) four-choice serial reaction time (10 percentile of the slowest inter-response intervals), and (5) average reaction time on Wilkinson's auditory vigilance test. These five measures, thus, were not reliably affected by any of the experimental treatments of the prolonged continuous work or of napping. They were not useful in understanding the recuperative power of naps or in detecting the effects of sleep loss. The dependent measure of systolic blood pressure also belongs in this group of non-contributing measures, although the omnibus T^2 for conditions was significant. Further analysis with the 95% simultaneous confidence intervals indicated that systolic blood pressure at bio-session 35 was significantly different from the baseline, C1, simply because of the sampling artifact and the manner in which the bio-sessions were partitioned (see the bottom graph of Figure 8).

The remaining dependent measures showed highly significant T^2 for conditions, and the null hypothesis of flatness was rejected. The results of comparing the baseline (bio-sessions 8-16) with each and every condition with the 95% simultaneous confidence intervals are shown in Tables 2 and 3.

Effects of continuous performance of 45 hours. Forty-five hours of sleep loss produced a significant change from baseline in subjective ratings of sleepiness, SSS (a greater sleepiness with sleep loss), increased negative effect on the NHRC Mood Scale, and reduced percent correct detections on Wilkinson's auditory vigilance task. Performance following Nap 1 for Group 1 and during continuous work for Group 2 showed similar changes from baseline. When C3 performance was compared to baseline for both groups, there was a significant drop in oral temperature, significantly fewer lines were scanned on the MAST, and the inter-response interval on the TRAP was significantly slower. On the four-choice serial reaction time task, both groups had significantly fewer responses, and on the Williams' Word Memory test, both groups showed a significant loss of immediate memory and recall. Finally, the two groups had significantly fewer correct signal detections on Wilkinson's auditory vigilance task during C3. Self-ratings of mood, fatigue, and sleepiness showed declines in mood and increased fatigue and sleepiness.

The similarity of detrimental changes that occurred in both groups during C3 leads to the inescapable conclusion that Nap 1, the early morning nap, had no recuperative power. In contrast, Group 1's performance was the same as the continuing vigil performance of Group 2. The early morning nap after prolonged prior wakefulness of 45 hours was not helpful. Figures 6 through 10 illustrate the ineffectiveness of the one 2-hour early morning nap in restoring performance and mood.

Results comparing baseline data with performance and mood before the midday nap (C4) showed that some dependent measures remained significantly deteriorated for both groups. Perhaps the reason for this continued deterioration in Group 1 was that Nap 1 was too short and "sleep inertia" persisted. Group 2 simply failed to show the anticipated circadian up-swing at this time of day due to sleep loss.

The dependent measures that showed significant improvements, from C3, during C4 were the MAST and NHRC Positive Mood Scale scores. These scores during

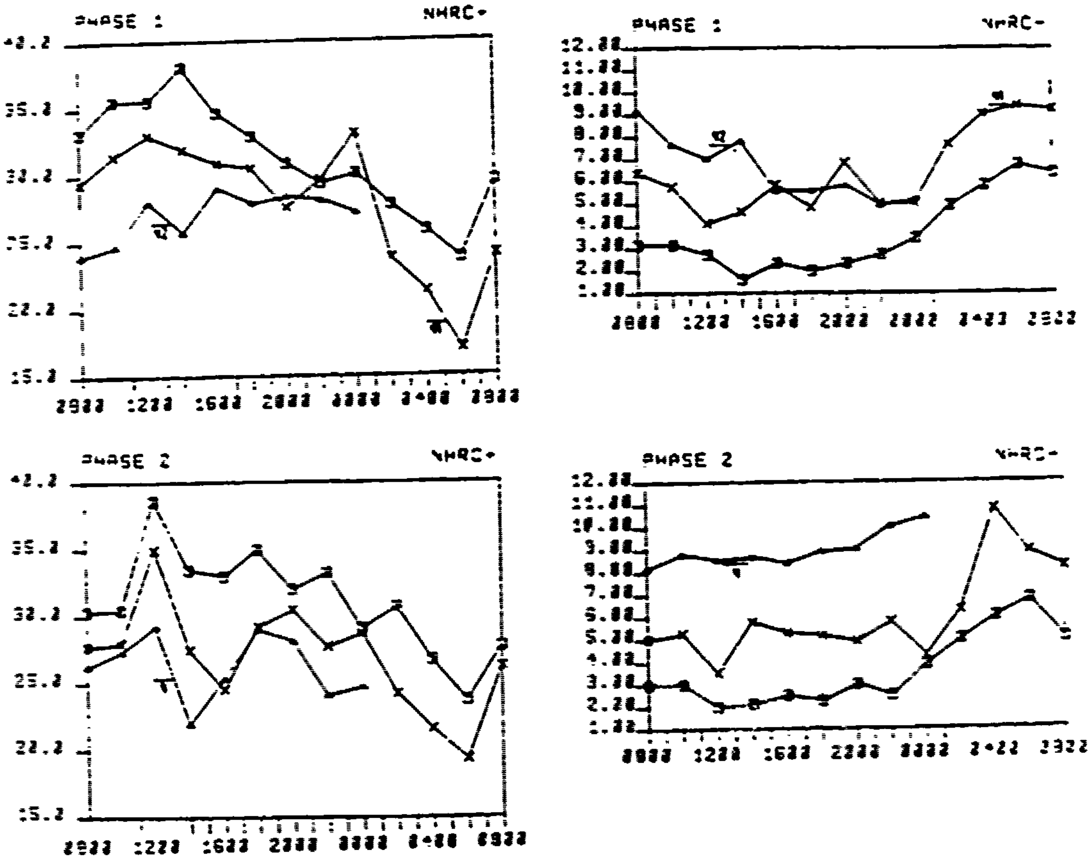

Figure 10. Chronogram plots of NHRC positive scale (the left column) and NHRC negative scale (the right column) to show inffectiveness of naps to restore mood to the baseline levels. A line marked with squares is for baseline (Tuesday, Day 2). The line marked with x's represents the data for the vigil (Wednesday, Day 3). and the line marked with triangles represents Thursday. Group 1 data are on the top row (i.e., Phase 1 data), and Group 2 data on the bottom row. Phase 1 = Group 1; Phase 2 = Group 2. X-axis shows the time of day. These lines are continuous. Compare NHRC plot with NHRC Positive plot in Figure 7. Day 5 data are not plotted in this Figure.

C4 did not differ significantly from baseline. The improved scores for Group 2 were probably due to the circadian up-swing. The improved scores for Group 1 could be attributed to Nap 1 or the circadian up-swing. Other dependent variables--Fitts' reciprocal tapping, SSS, and NHRC Negative Scale--were sufficiently improved, from C3, (but not significantly) during C4 so the scores for these variables did not differ significantly from baseline.

Comparisons of C5 with baseline, C1, showed that most dependent measures had recovered to baseline: oral temperature, TRAP 2 measure, Fitts; reciprocal tapping, NHRC Negative Scale, four-choice serial reaction time task (in terms of total number of responses), Williams' Word memory, and Wilkinson's auditory vigilance. For oral temperature, the midday nap by Group 2 resulted in the same rise in oral temperature as did the combined action of Naps 1 and 2 for Group 1. For performance on the four-choice serial reaction time task, the one 2-hour midday nap taken by Group 2 was as recuperative as were the two 2-hour naps taken by Group 1. The same conclusion can be drawn for Wilkinson's auditory vigilance task, as the midday nap restored percent correct detection in Group 2 to baseline levels. For the TRAP 2 measure, Nap 2 seemed to have improved the inter-response intervals by shortening them, but the single nap appeared detrimental to Group 2 by slowing down their tappings. But the difference between the groups was not significant due to the large standard deviation of Group 2.

The only performance measure which failed to recover to the baseline level was MAST. The gain seen in C4 was lost in C5. The subjective ratings of fatigue, sleepiness, positive mood, and arousal also failed to recover to baseline levels.

The overall conclusion that one 2-hour midday nap was as recuperative as two 2-hour naps seemed to be confirmed by the absence of prolonged sleep inertia during C6. With the exception of the SAM fatigue checklist and Thayer's AD-ACL scores, the values of the dependent measures recovered to baseline during C6.

Discussion

The results of this study suggest that the recuperative or beneficial power of naps depends on three major factors: (1) hours of prior wakefulness, (2) time when nap was taken, and (3) duration of nap. The clearest finding from this study was that if a 2-hour nap is taken early in the morning, 0400-0600, after 45 hours of continuous work without sleep, then task performances and self-rating of mood, fatigue, and sleepiness would remain deteriorated at the level of those who stayed awake. The deteriorated task performances and feelings of greater sleepiness, fatigue, and negative effects could be anticipated immediately after being awakened from short sleep, as it is quite normal to see this sleep inertia. Since the early study of Langdon and Hartman (1961), many have observed that sleep inertia invariably follows awakening from sleep. However, under normal circumstances, where subjects are not deprived of sleep for long periods of time, this sleep inertia is quickly replaced by "more rapid motor responses, higher levels of short-term memory, larger shifts in positive affective states (e.g., cheerful, energetic) and less reported sleepiness (e.g., inert-fatigued, Stanford Sleepiness Scale)" (Taub, 1979, p. 107). Taub (1979) noted that sleep inertia could be seen for as long as 2 hours. What is unusual about the finding of this study is that beneficial effects of the early morning nap were not observed during the first 2 hours, and up to 6 hours afterward, in some dependent measures. An early morning nap taken after prolonged wakefulness can cause sleep inertia for a long period of time after awakening.

This long sleep inertia was not observed when a nap of the same duration as the early morning nap was taken at 1200-1400, after 53 hours (instead of 45 hours) of continuous wakefulness. Following this midday nap, performance on some dependent measures exhibited signs of sleep inertia, but it was replaced by improvements. Similarly, subjects in Group 1 showed some sleep inertia after their second nap (i.e.,from 1200-1400), but it disappeared within 1 hour after awakening. Comparison of post-midday nap self-ratings and task performances of Group 2 with those of Group 1 revealed that the two groups recovered almost to baseline with no significant differences between groups. This finding suggests that one midday nap taken after 53 hours of wakefulness was as recuperative as the combined action of the early morning nap plus midday nap taken after a shorter period of wakefulness. This finding further suggests that the early morning nap was not helpful and the midday nap was the only nap that contributed substantially to recuperation. Thus, the local time of day when a nap is taken seems to be an important factor in determining the duration of sleep inertia; hence, how quickly the recuperative powers of a nap would be felt.

The effects of sleep loss and nap inertia varied from one dependent measure to another. The self-ratings of fatigue, sleepiness, positive and negative mood, and arousal were profoundly influenced by sleep loss and sleep inertia, and some of these dependent measures recovered only after 7 hours of recovery sleep (see bottom graph of Figure 7). These subjective measures of feeling tones may be used as sensitive measures of the recuperative power of naps.

In this study, sleep records were obtained to see if the subjects slept well during the assigned sleep periods. Sleep-stage analysis of the two naps taken by Group 1 showed, as expected, highly elevated amounts of stages 3 and 4, slow wave sleep (SWS). Recovery sleep obtained from 2400 Thursday to 0700 Friday showed a typical SWS increase over the baseline level by about 22%. This SWS "rebound" can be contrasted with an expected SWS rebound of 50% in those who stayed awake for 40 hours. Thus, two 2-hour naps appeared to have achieved a partial recuperation by lessening the SWS rebound during the first recovery sleep.

This study has shown that the recuperative power of naps can be determined by knowing the prior hours of wakefulness, time-of-day the nap will be taken, and the duration of each nap. The importance of circadian cycles in the recuperative power of naps was indicated in this study, but further studies are necessary before it can be firmly established.

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SLEEP IN THE NATURAL ENVIRONMENT:
PHYSIOLOGICAL AND PSYCHOLOGICAL RECORDING AND ANALYSING TECHNIQUES

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In the past twenty years, a vast number of studies have been devoted to sleep. The large majority of these studies have been carried out in unnatural environments such as the laboratory or in the hospital. Beyond the inconvenience to certain groups of people, the actual laboratory situation itself may contribute to what has come to be known as the "first-night" effect (Agnew, Webb, & Williams, 1966) in which the first night or two of sleep have been found to be quite different from others monitored later in the week. Over the past two years, we have been engaged in a programme of adapting modern biomedical technology to the requirements of recording sleep in the natural environment of the subject or patient, as for example, in the home.

The objectives of the endeavour were established to be (1) the faithful recording of at least 4 physiological channels over an 8 hour period, (2) a considerable reduction in the size and weight of existing apparatus, (3) a complete isolation of the subject from the main power supply since he/she would not be monitored during the sleeping period, (4) for the sake of economy, the recording of at least two subjects simultaneously, and (5) the physiological data to be in a form that would allow off-line automatic computer analysis at a fast playback speed.

In the laboratory, it had been our custom to investigate the effects of the quality of the night's sleep on a number of performance indices the following day. While some of these tests could be adapted for the field with only minor modifications, others required extensive revision, yet still had to monitor essentially the identical behavioural constructs. Finally, questionnaires that asked the subjects to rate various dimensions of their sleep were, of course, readily available for field use.

The analysis of the data collected in the homes of subjects called for high-speed, off-line automatic scoring procedures. Due to the restrictions inherent in the recording system, innovative programming techniques had to be introduced.

This article summarizes each of these developments and provides examples derived from recent data.

Physiological Recording

In the mid-1970's, a small lightweight 4-channel cassette unit become available for the 24 hr monitoring of EKG activity (Cashman & Stott, 1974). The unit was modified to enable the recording of the EEG and EOG for the study of sleep (Wilkinson & Mullaney, 1976), a task simultaneously and independently undertaken as well by Ives and Woods (1975). Although the dynamic range of the instrument was limited to just over 30 dB, initial tests of sleep in the home and in such inconvenient locations as an overnight train (Wilkinson, Herbert, & Branton, 1973) suggested that the unit was capable of recording sleep activity. There was, however, one major drawback. A sharp amplitude drop was apparent at low frequencies -- precisely where one would expect to find the presence of slow wave sleep. The problem has apparently been recently overcome. The 4-channel limit, nevertheless, was barely adequate for sleep physiology.

As a result, an entirely new system was developed (Campbell, Weller, & Wilkinson, in press). A small portable lightweight unit containing 2 EEG, 1 EOG, and 1 EKG preamplifiers as well as a fifth channel serving as an indication of signalled awakenings requiring only a switch closure was constructed. A sixth channel was linked to a sound level meter to encode the level of environmental noise in the subject's room, often a source of disturbance. The problem of storing such a large number of channels (12 channels with two subjects) was overcome by the use of pulse interval modulation (PIM) multiplexing, which is considerably less expensive than the more widely known time division multiplexing (TDM) in conjunction with pulse code modulation (PCM). In PIM, a train of fixed duration pulses is generated, one pulse for each channel, and the time interval between consecutive pulses is made to vary with signal amplitude. Each channel is allocated to a particular time slot, one of the time slots being made unique for synchronization purposes. The sampling rate is therefore proportional to signal level. Thus, with excessively large amplitude signals, the sampling rate could become very low. To prevent this, a limit has been placed on the excursions of each time slot. If a signal causes the interval to exceed upper or lower preset levels, the next channel is immediately selected and the amplitude of the previous signal is clipped. The sampling rate cannot then fall below a predetermined rate and the synchronization time slot is never confused with signal time slots. The 6 channel system uses pulse intervals of 360 µsec (180-540 µsec) compensation channel. The minimum sampling rate is therefore:

$$\frac{10^6}{(6 \times 540) + 648}$$

If only one subject is being recorded, the multiplexed signal is transmitted over the British medical band (104.6-105.0 MHz) via a single stage frequency modulated transmitter. Telemetry of course allows the subject considerable freedom of movement as well as overcoming potential fear of electrical shock. When two or more subjects have been recorded simultaneously, reception at times has been incomplete, thus, the adoption of the alternative, cable-telemetry. Even though the signal is sent via a pulse transformer along a hand-wire, the lead has not proven to be an encumbrance to the subjects. Also, as Weller (1974) has pointed out, the method is as safe and reliable as radio-telemetry. The entire system is housed in a shielded plastic case (Figure 1). The general properties of the multiplexing/telemetry package are as follows:

Channels: 6

Weight: 125 g including the power source

Full-scale deflection: 300 µV (EEG), 500 µV (EOG), 4 mV (EKG)

Bandwidth: down 3 dB at 0.2 and 43 Hz (minimum)

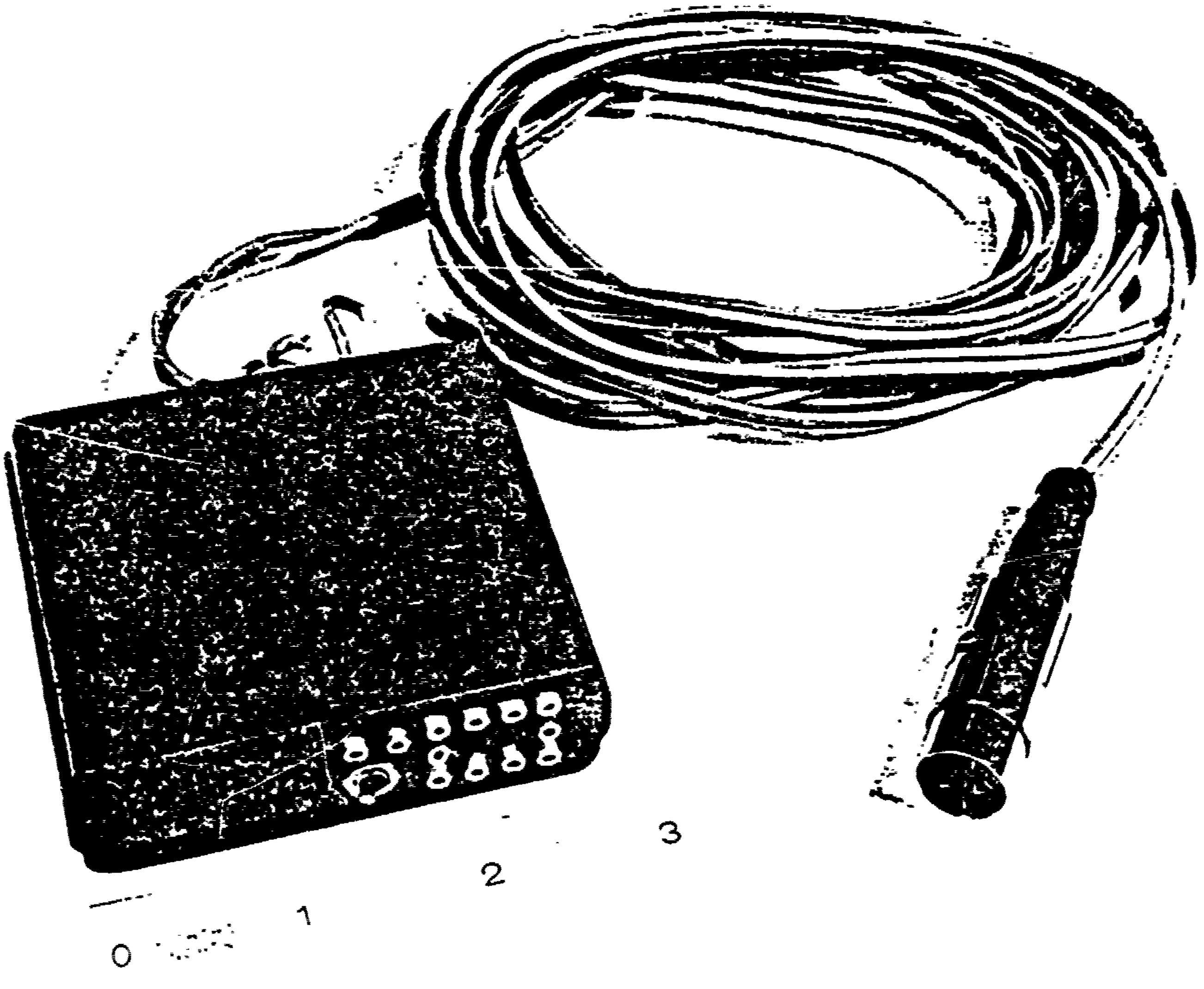


Figure 1. Portable sleep recording unit. In the plastic case are found 4 preamplifiers, a multiplexer and a radio-transmitter.

Signal-to-noise and crosstalk: 40 dB

Power: 6.75 V mercury battery

Current consumption: 3 mA

Battery life: 70 hrs from mercury cells of 210 mAh capacity.

As can be observed in Figure 2 the bandpass characteristic of the EEG preamplifiers are such as to enable the recording of low frequency, delta activity and high frequency spindle transients.

Unfortunately, the upper limit does not permit the recording of EMG. Whether EMG provides additional relevant information for the interpretation of the sleep profile has been a subject of debate. Some laboratories (see, for example, Smith, 1978), including the present one, believe its activity is too inconsistent to prove useful. On the other hand others (see, for example, Gaillard & Tissot, 1973) employ it for the definition of a particular period of sleep, Stage REM.

The modulated carrier signal is recorded in the direct mode on a single track Racal 4D reel-to-reel tape recorder, the triple play tape lasting 8 1/4 hours. Typically, one of the other tracks is used for recording the analogue noise (frequency range, 100-8,000 Hz) occurring during the night. Thus, if sleep is disturbed, it is relatively easy to locate and identify the environmental influence immediately prior to the disturbance.

Early in the evening, a technician arrives at the subject's home to place the silver-silver cholride electrodes (to overcome polarization during the 8 hour monitoring). EEG recording is between C_3 and M_2 with a secondary backup of $C_4 - M_1$ in case of failure of the primary location. EOG electrodes are placed on the outer canthi of each eye, one electrode being slightly inferior to the socket, the other slightly superior, enabling the complete monitoring of horizontal and partial vertical eye movement. Because of the compactness and lightness of the unit it can be placed directly on the subject's head being attached to a specially designed cap. The EEG leads can thus be of minimal length, measuring not more than 30 cm. A demultiplexer permits the reconstruction of the six original signals which may be examined on a portable oscilloscope. Once the integrity of the system is verified, the technician leaves for the night, returning in the morning to remove the electrodes and administer questionnaires and the performance battery. Schematics for the sleep environment are depicted in Figure 3a, while the details of the head-mounted unit are illustrated in Figure 3b.

Over 300 nights of sleep have now been recorded in natural environments for a variety of studies--the effects of traffic noise on sleep, variation in sleep patterns with age, the effects of shift work on sleep. The amount of data collected during an 8 hour session is indeed considerable. The task of visually analyzing them is certainly laborious and not entirely reliable. At an early stage it was, thus, decided that automatic analysis was required not only to provide an efficient means of handling the data but also as an objective method of interpreting them.

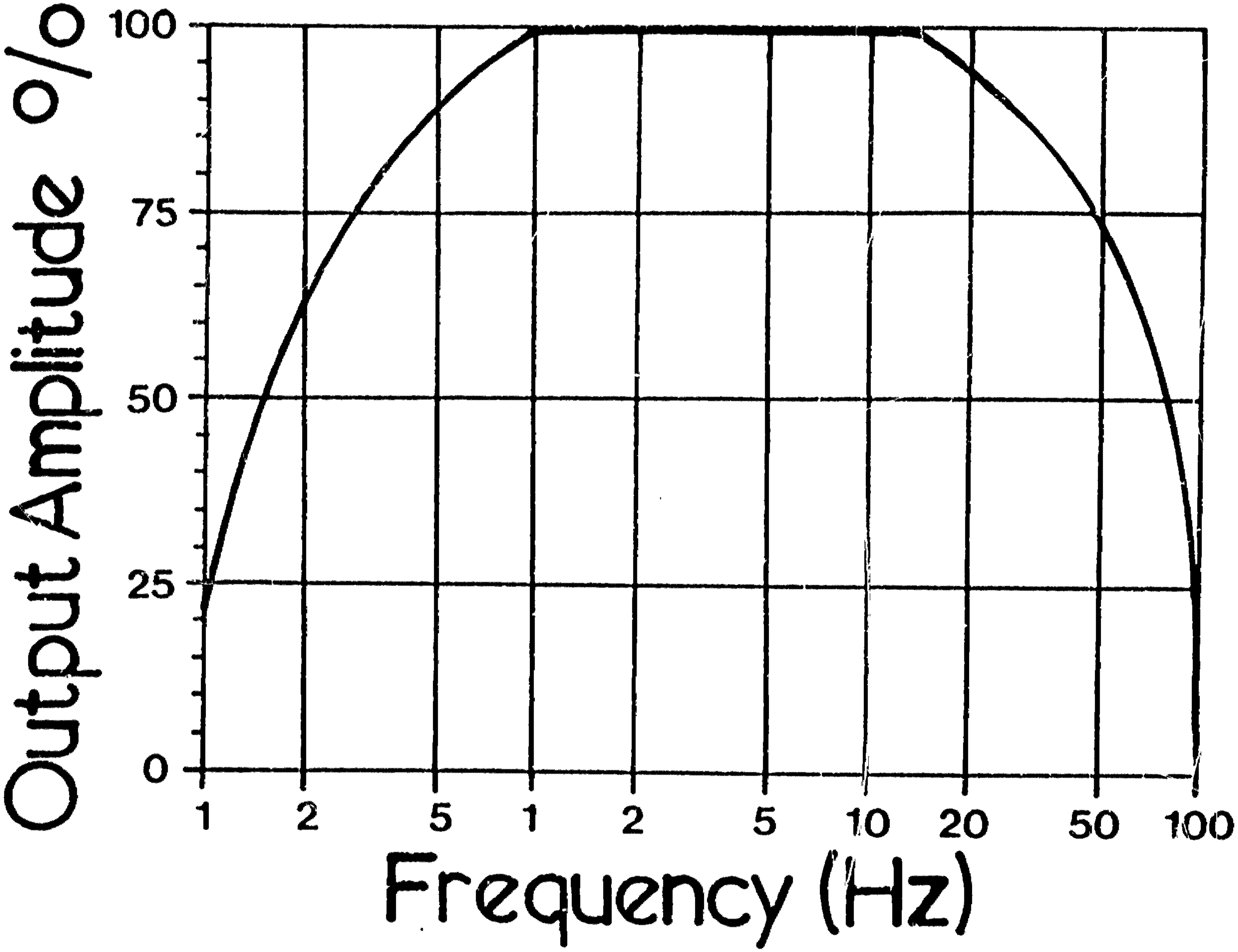
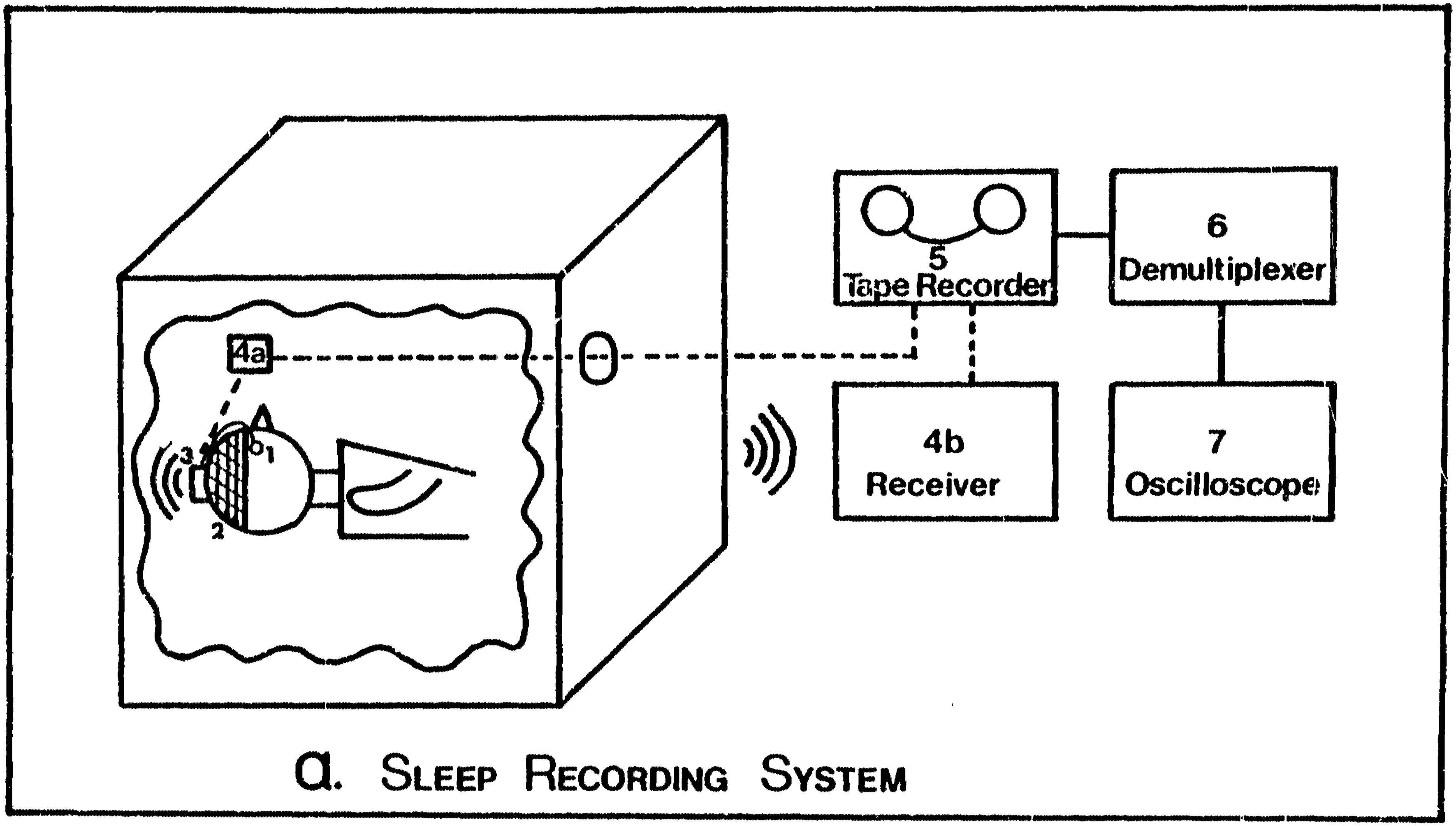


Figure 2. Frequency response curve of the sleep recording unit. Known, constant voltage sine waves of varying frequency were fed into one of the EEG inputs, amplified, multiplexed, tape recorded, played back, and demultiplexed. The output signal voltage is illustrated on the Y-axis, the input signal, the X-axis.



a. SLEEP RECORDING SYSTEM

Figure 3A. Physiological activity is picked up by the electrodes (1) and amplified in the head-mounted unit (3), which is attached to a lightweight cap (2) on the subject's head. The signals are multiplexed and sent either via radio-telemetry to a receiver (4a) or via cable-telemetry to a junction box (4b). The signal from the receiver or junction box is recorded on a reel-to-reel tape recorder (5) in the direct mode. For purposes of verification of functioning of the system, the output from the tape recorder is demultiplexed (6) to reconstruct the original signals which are monitored on an oscilloscope (7).

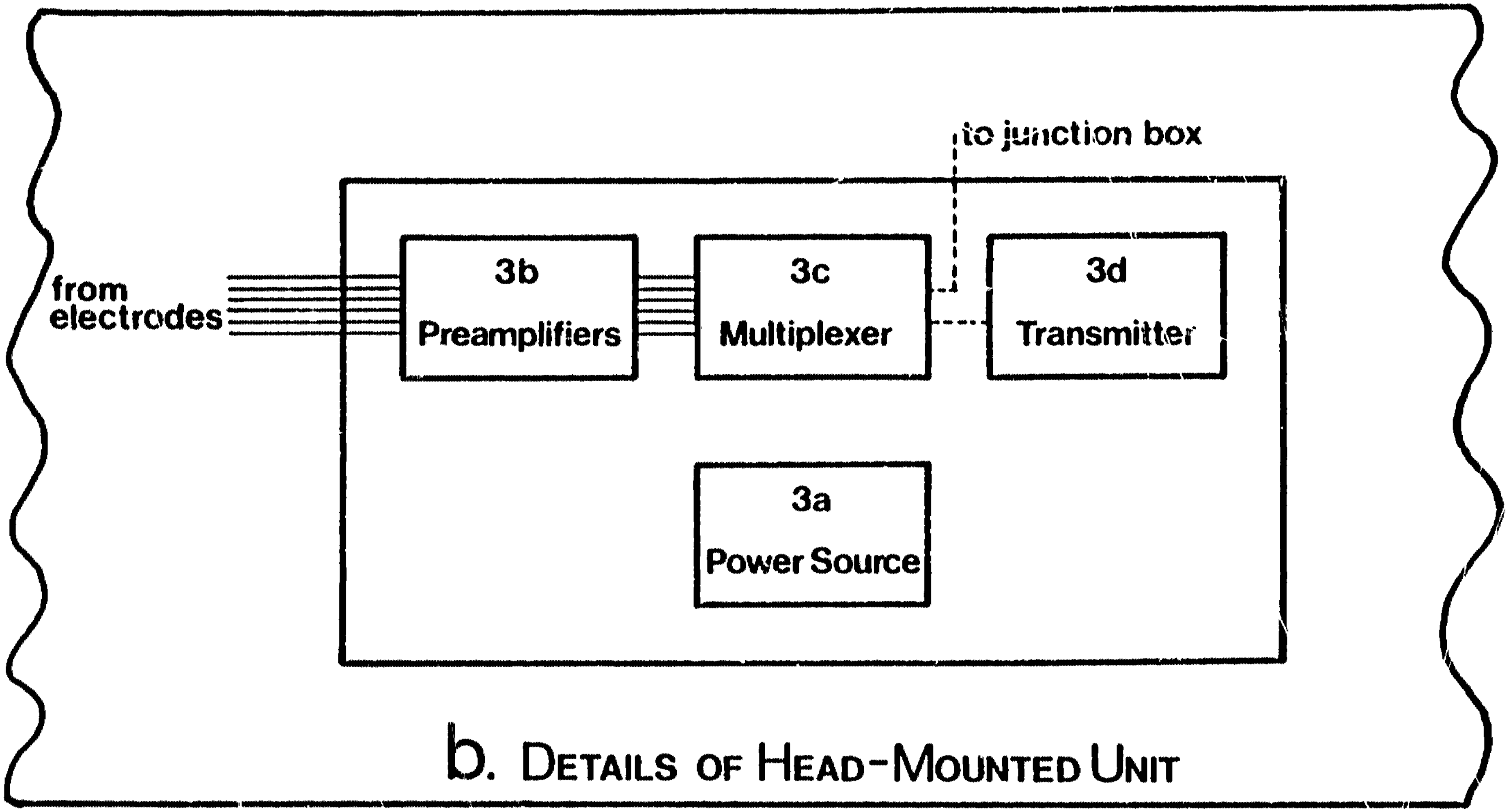


Figure 3B. Details of head-mounted unit. Two EEG, 1 EOG, 1 EKG, and 1 behavioural awakening signals (3a) are amplified and multiplexed to form a unique signal (3c) which is transmitted via radio or cable-telemetry (3d). The power source for the unit is a 6.75 V mercury battery.

Computer Analyses of Sleep

Staging

Figure 4 illustrates the types (or "stages") of activity that may be present in a recording session. The waking stage, Stage W, is distinguished by the dominance of rhythmic alpha waves. There may also be muscle artifact and large amplitude eye movements. The subject first enters Stage 1 from the awake state. For purposes of classification, Stage 1 is unusual in that the EEG has no real distinguishing features. Although alpha may have largely disappeared, none of the features of other stages are present. The EOG often takes on a slow, rolling appearance which is unique to this stage. After a short duration, rhythmic 12-14 Hz transients called spindles mark the commencement of Stage 2. The first episode of Stage 2 sleep is variable, from a few minutes to almost an hour in length. Towards the end of Stage 2, the EEG comes to be characterized by the appearance of large amplitude 0.5-2.0 Hz delta waves. When this slow wave activity comes to occupy 20% of the record, it is arbitrarily classified as Stage 3. When the figure reaches 50% delta, the subject is said to be in Stage 4. After approximately 1 1/2 hours of sleep, the EEG changes to an awake or Stage 1-like pattern. What makes this activity unusual is that the EOG exhibits rapid eye movement (REM). Although the EEG is suggestive that the person is in a light stage of sleep, in reality, it is extremely difficult to awaken them, hence, the alternative name, paradoxical sleep. If awoken, the subject often reports episodes of dreaming.

The classification of more than a kilometre of paper recording into the various stages of sleep usually takes 2-3 hours to complete, often longer if there is are unusual features to interpret. While staging now appears to have become part of the standard repetoire of the sleep researcher, it is, nonetheless, accomplished at a cost of a tremendous loss of other potential data. Many other types of analyses that theoretically could be carried out, are ignored in practice due to the volume of data that can overwhem the keenest investigator. And even the objectivity of what the human can analyze has been questioned. Monroe (1969) has demonstrated that there is only approximately 75% agreement on human sleep stage classification between scorers when the same record is sent to different laboratories.

Computer analysis of sleep opened not only the feasibility of examining the minute details hidden in the data but also because of its objectivity, offered considerable scope for the sharing of these data between laboratories. Some attempt had previously been made at automation. Itil, Shapiro, Fink, and Kassebaum (1969) have used digital period analysis methods while Larsen and Walter (1970), Lubin, Johnson, and Austin (1969) and Martin, Johnson, Vigiolone, Naitoh, Joseph, and Moses (1972) have attempted software spectral analysis in conjunction with linear and nonlinear discriminant analysis. Their application was limited by the relatively slow running time (up to 3 hours) and consequent high cost. The time and cost factors also clearly limit the extent of on-line usage. Moreover, agreement between human and software scoring was unfortunately barely acceptable.

A second approach relies on both hard and software methods (Smith & Karacan, 1971; Gaillard & Tissot, 1973; Kumar, 1977). These hybrid systems rely on hardware preprocessing of the physiological data, the output of the

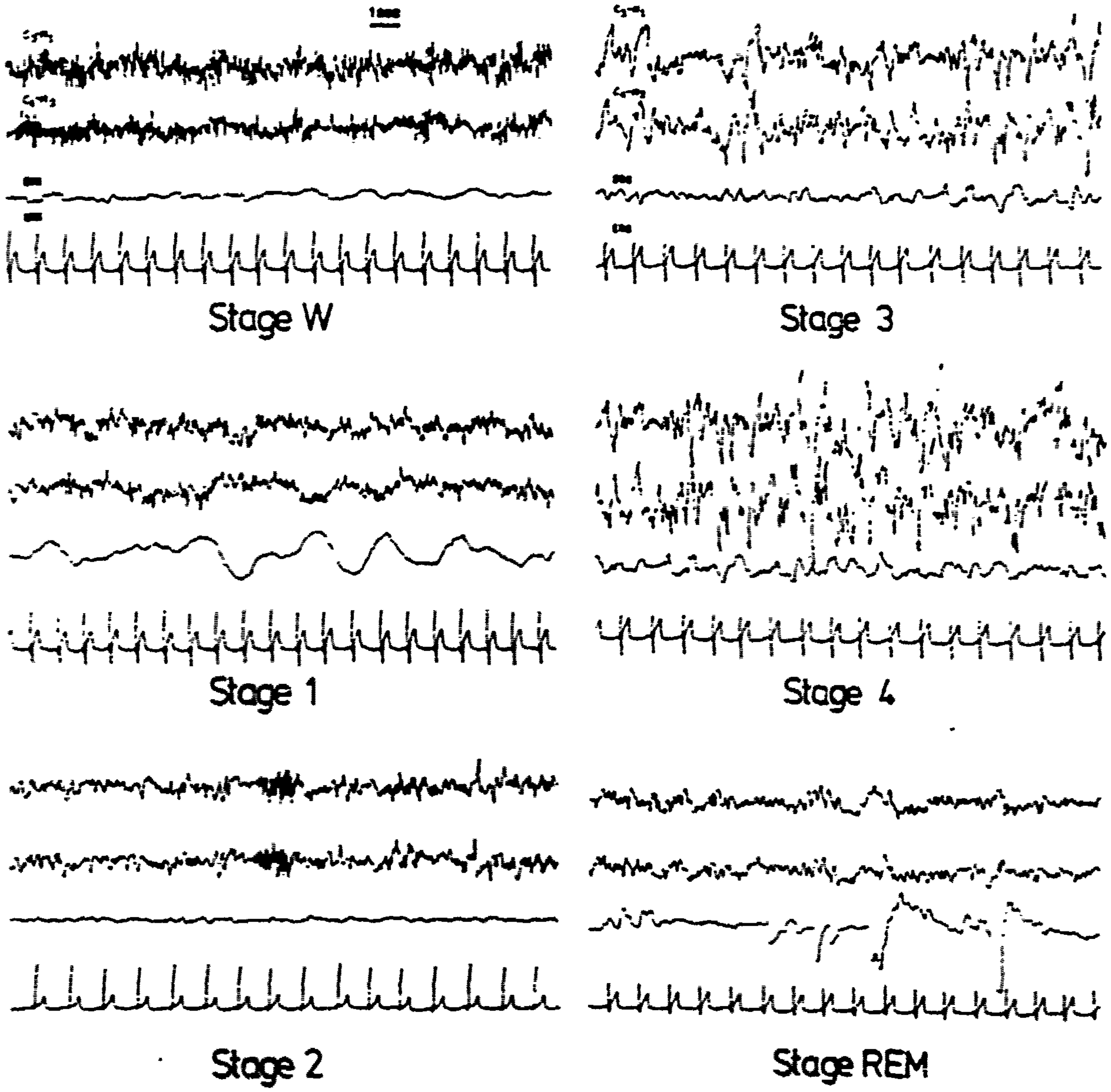


Figure 4. The stages of sleep. The awake (Stage W) EEG is typified by the presence of alpha waves. As the subject becomes drowsy and enters Stage 1, slow rolling eye movements often appear. The entrance of Stage 2 is announced by spindle transients. Stages 3 and 4 see the more and more increasing presence of slow-frequency, high amplitude delta waves. The EEG of Stage REM is similar to that of Stage 1, but is distinguished from it by the presence of rapid eye movements. The illustrations were taken from a home recording using the portable apparatus previously described. The writeout was obtained by passing the signals, unamplified and unfiltered to a Grass polygraph's paper recorder.

preprocessors being fed into a digital computer which makes the actual decisions. The hardware in the form of a bank of filters (Gaillard & Tissot,1973) or specially designed detectors (Smith & Karacan, 1971) remove a considerable burden of data processing from the digital computer, freeing it for relatively simple calculations and storage matters. The advantage of such a scheme is that data can be played back at very high speeds without loss of information. The performance of the hybrid system is impressive--approximately 85% overall agreement with human scorers.

In Canada, an analogue preprocessor has been developed (Green, 1975; Broughton, Healey, Maru, Green, & Pagurek, 1978) that closely imitates the universally employed Rechtschaffen and Kales (1968) standard scoring system. This system was modified for the purposes of our multiplexing system and linked to a minicomputer, a task that had previously not been attempted.

At present, four hardware circuits have been constructed: alpha, spindle and delta detectors for the EEG lead and a rapid eye movement detector in the EOG. The reader is referred to Broughton et al. (1968) for a description of the spindle detector and Green (1975) for the description of the alpha and delta detectors. Briefly, the spindle and alpha detectors are based on phase locked loop (PLL) circuitry, (Johns, Stear, & Hanley, 1974) except that instead of using the phase error signal of the PLL to determine the presence of spindle or alpha activity, the more reliable approach of a quadrature phase detector was substituted. Delta detection is based on zero-crossing and minimum amplitude measuring techniques similar to Smith, Funke, Yeo, and Ambuehl (1975). The REM circuit consisted of a simple filter and minimum amplitude detector. A fifth device detected abnormally high positive or negative voltage in the EEG.

The frequency ranges (at real-time) and minimum amplitudes required for binary output from each of the detectors were: for alpha, 8 to 12 Hz at 25 µV; for spindles, 11.5 to 15 Hz at 25 µV; and for delta, 0.5 to 2.5 Hz at 75 µV. The tapes recorded in the homes of the subjects were played back at 8x through a second demultiplexer. Examples of the analogue processing of various segments of one subject's sleep are illustrated in Figure 5.

Computation on and storage of the binary output of the preprocessor is carried out by a Data General Eclipse S200 minicomputer equipped with a 16 bit, 32K core memory. The data are processed in 30 second real-time epochs, a period more or less standard for most laboratories. During these 30/8 seconds (the tapes are played back at 8x), the gate of the digital interface is opened 128 times, i.e., once every 29.29 msec or at a sampling rate of 34.1 Hz. The output of each detector is digitized by one bit ("0" or "1"). For purposes other than staging, some form of storage is necessary. Once the 32K core is full, the contents are transferred to the system's 2.5 megabyte removable disc unit. To achieve a continuous stream of data through the processor, a double buffering scheme is employed (Figure 6). While one of the memory buffers is being filled from the digital input channel, the other is emptied onto the disc. The processes are switched back and forth as the operation proceeds. Once the entire disc is full (8 sleep records), it is put into permanent storage on magnetic tape, the disc then being cleared. Even with the substantial memory capacities of modern computers, it can readily be noted that a single sleep experiment can tax it to the limits. The complete data handling and storage procedures are shown in Figure 7.

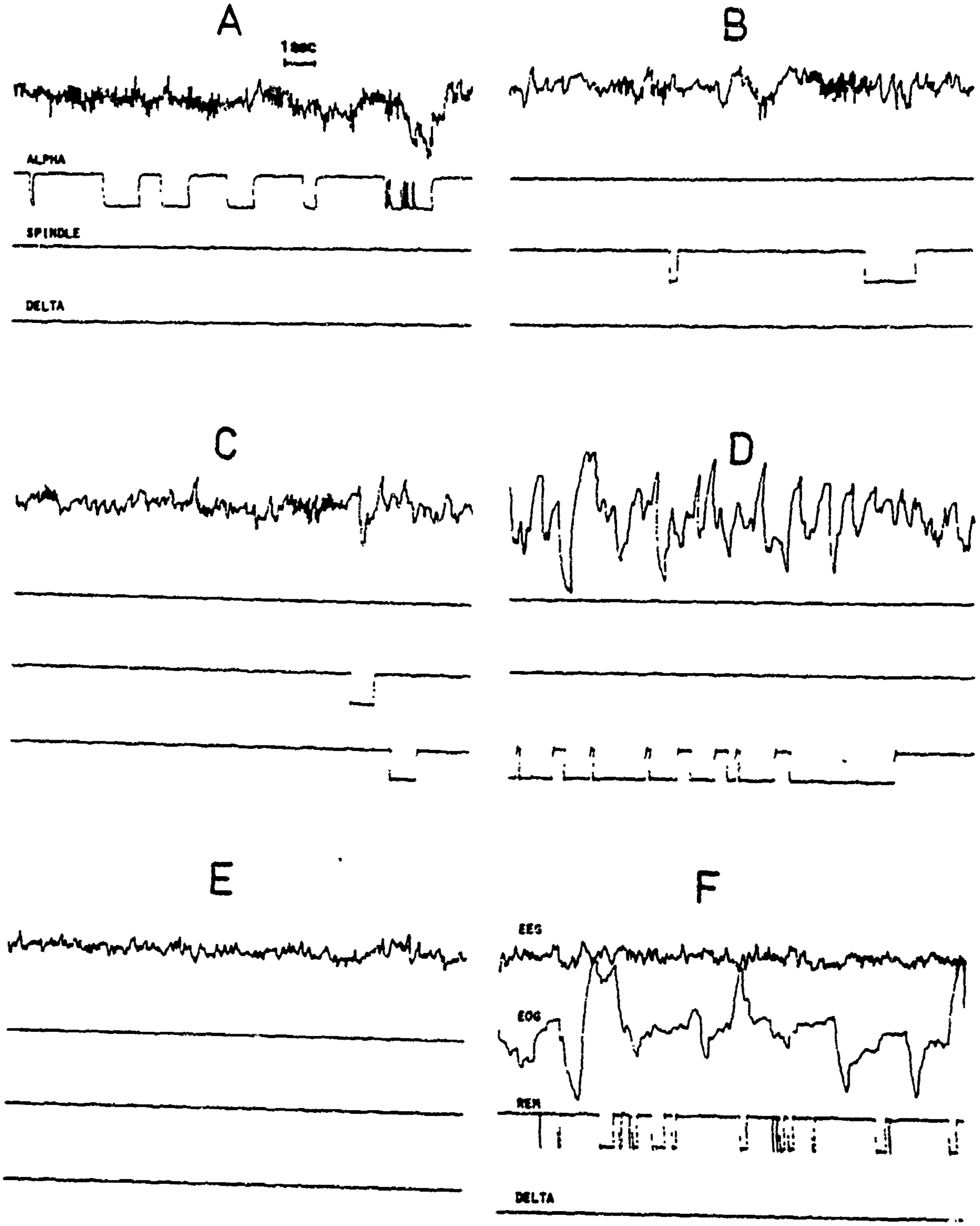


Figure 5. Analogue preprocessing of EEG and EOG activity. In (A), the dominance of alpha triggers the appropriate detector. In this and all other portions of the figure, a positive detection is noted by a downward deflection. In B, detection of poorly defined and a "classic" spindle. In C, a spindle transient followed immediately by a slow wave. In D, obvious Stage 4 activity as indicated by the delta detector. In E and F, the EEG detectors are silent. In F, EOG activity is also illustrated which quite apparently in conjunction with the "silent" EEG would be classified as Stage REM. The binary output of the preprocessor is strobed at a rate of 4.25 Hz (real time).

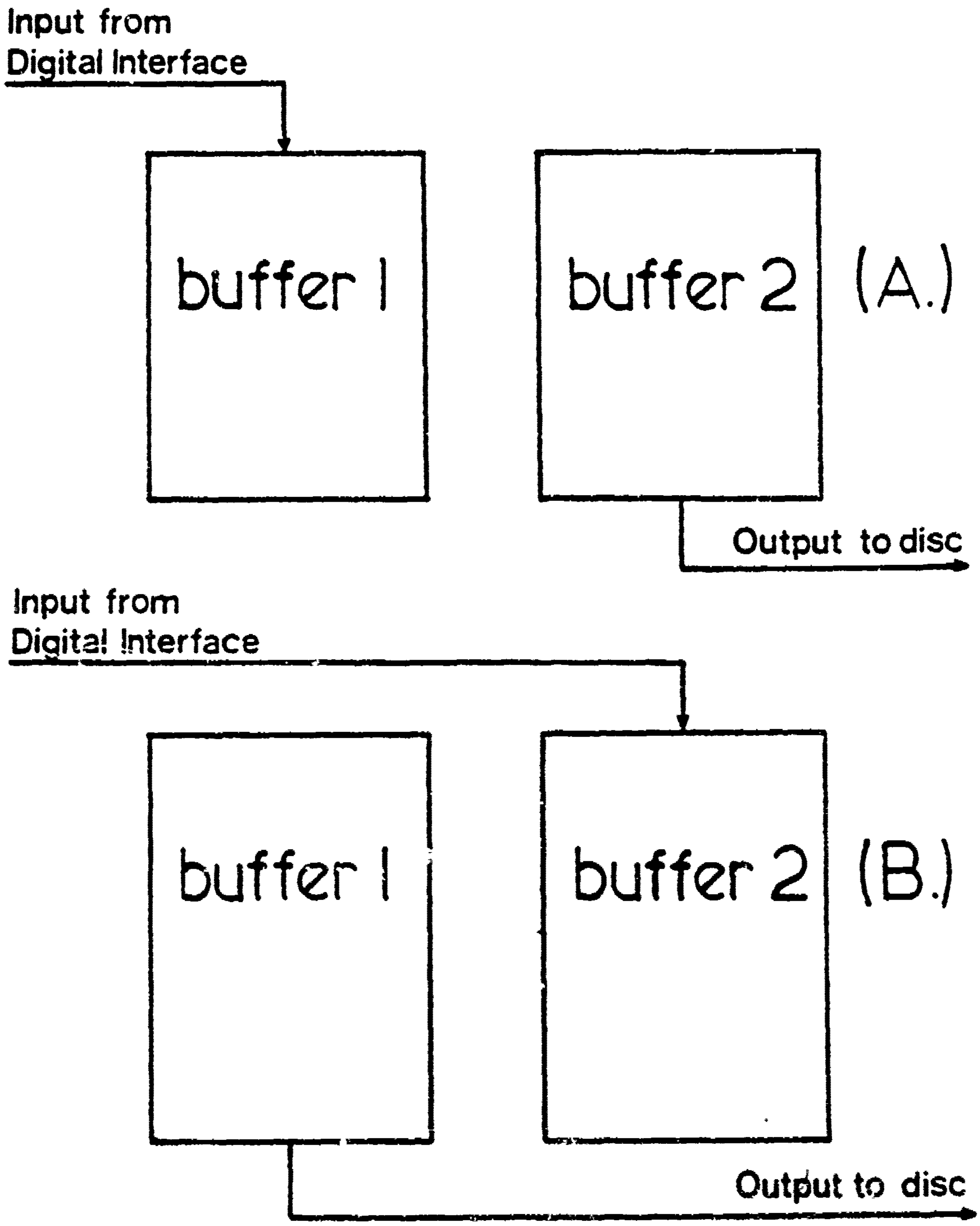


Figure 6. Double buffering technique for data streaming in the context of Figure 7.

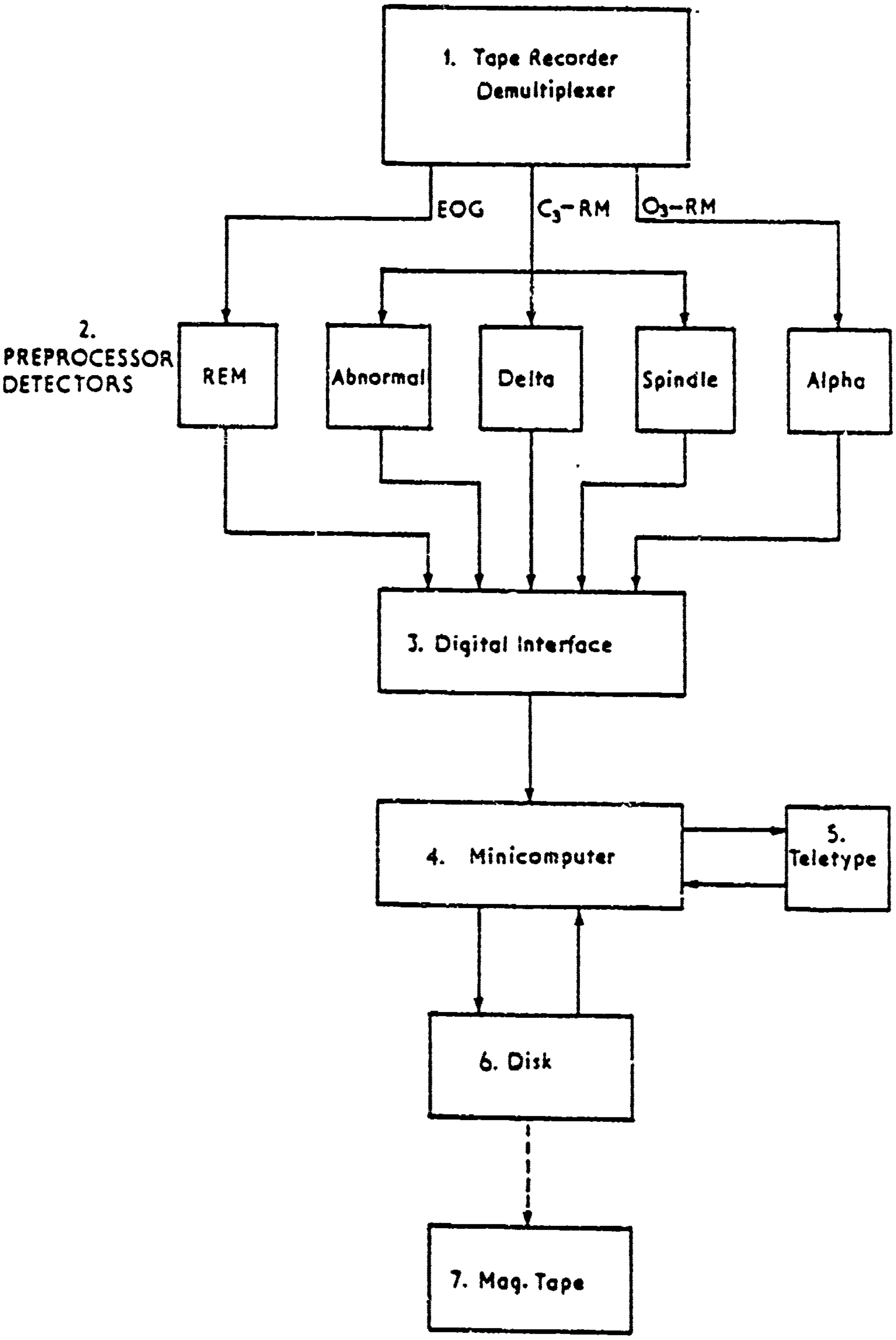


Figure 7. Schematics of the hybrid computer analysis system.

The logic of the software was designed to imitate human scoring procedures. Some changes from standard human scoring procedures were nevertheless made as these were found to provide better man/machine agreement than the direct implementation of the visual scoring criteria. A count is made of alpha, spindle, delta and REM events, a stage diagnosis being made following each 30 second real-time epoch.

Computation of the stages commences according to the following logic: if delta occupied 50% of the epoch, it was classified as Stage 4. If it occupied less than 50% but more than 25% (instead of the human criterion of 20%) it was designated to be Stage 3 sleep. If the delta count was less than 25% of the epoch but greater than 10% it was classified as Stage 2 (again, a departure from human scoring). If delta was less than 10%, then the computer had to decide between Stages W, 1 and 2, and REM. If a spindle was detected, it was considered to be Stage 2. If alpha occupied 40% of the epoch (usually 50% in the human scoring),then it was Stage W. By process of elimination, if none of the above were apparent in the EEG, then it was classified as Stage 1. Stage Rem is determined by both EEG and EOG criteria. If sufficient eye movements occur (arbitrarily set at 3) in what would be classified as Stage 1 on the basis of EEG alone, it is reclassified as stage REM. Often, human scorers label a Stage 1 epoch as stage REM even when eye movements are not apparent providing immediately prior and following epochs contain them. It was thus decided to reclassify all Stage 1 epochs following two consecutive Stage REMs as being REM provided no other change of stage was encountered. Similarly for Stage 2 scoring "if less than 3 minutes of a record which would ordinarily meet the requirements for Stage 1 intervenes between sleep spindles and/or K complexes these intervening epochs are scored as Stage 2" (Rechschaffen & Kales, 1969, p. 6).

On the basis of 8 records, the overall agreement between the automatic system and human scoring was 84% with a low of 59% agreement for Stage 1 and a high of 92% for Stage 4. The discrimination between Stages 1 and W and 1 and REM remains an area in need of further development. In defense of the present hybrid system, Stage 1 classification provides considerable difficulty for other existing automatic systems and human scorers.

Because there was a possibility of a bias in the human scoring procedure towards the classification logic of the computer, further evaluation was made with other scorers at CERN in Lyon, France employing data recorded in their laboratory. Again the comparison proved to be quite satisfactory. A further comparison of the hybrid computer's performance was made with a second, automatic system (Kumar, 1977). Although the basis of this system was entirely different from the Cambridge one, inter-system agreement ranged from 80 to 90% on 40 nights of recordings made at the TNO laboratory in Delft,the Netherlands.

Finally, because Stage 2 classification in the present format is critically dependent on precise detection of spindle activity, further verification of the functioning of the spindle circuit was deemed necessary. A second hardware detector relying on complex demodulation methods for spindle detection (Kumar, 1975) was utilized for the comparison. The two automatic devices functioned virtually identically being triggered by more than 80% of all EEG activity labelled as spindles by human judges (Campbell, Kumar, & Hofman, manuscript in preparation).

An example of the classification of an 8-hour sleep record is shown in the top part of Figure 12. Table 1 presents a breakdown of the values of classical sleep parameters for over 60 nights of sleep of young subjects. These data were recorded in the home of the subjects and analysed with the hybrid system. A comparison is made with the norms of males and females (collapsed) aged 20-29 as established by Williams, Karacan, and Hursch (1974). The values of the two laboratories are remarkably similar. Stages 3 and 4 are slightly overestimated, Stage 1 underestimated. The former may be due to individual differences between samples or to the fact that our subjects were sleeping in their natural environment. The latter discrepancy is probably a function of the logic of the automatic analysis. The larger number of stages detected by the computer as compared to the human scorers in Williams et al.'s (1974) study is almost certainly due to the fact that the latter's human scoring procedures neglect some stage transitions in favour of a more general smoothing procedure.

Temporal Organization of Sleep

Sleep scoring as typified in Table 1 furnishes only a gross overview of the total accumulation of a particular stage at the end of a night. No indication of the manner in which the respective stages have developed is provided. Recently, Gaillard (1977a, b) has developed a method for investigating the temporal organization of human sleep. Only a summary of the calculations will be made here, the reader being referred to the original sources for more complete details. The general trends in the development of the various stages of sleep can be evaluated and used to generate a theoretical model of sleep. The model has been particularly useful in the study of the effect of noise on the development of Stages 3 and 4 during the night as well as a comparison of the sleep of younger and older subjects. The same analysis technique is currently being employed to investigate the effects of shift work on sleep trends.

In making the computations, all awakenings during the night are removed from the calculations, the time base thus referring only to sleep time. All recordings are synchronized at sleep onset with each night being divided into 15 minute intervals. The number of minutes of each stage is counted in each 15 minute interval and these counts accumulated over the night (Table 2). The corresponding series of numbers over several nights for the same subject are averaged and the individual subjects' totals also averaged. The rationale behind the computation of a grand mean is that the cumulated occurrences of individual stages on a single night form an irregular "noisy" curve. The random variability disappears through the averaging process.

Figures 8, 9, and 10 present the cumulated occurrences of Stages 2, 3-4 and REM averaged across 10 nights of sleep of 5 younger (less than 32 years of age) and 5 older (+40 years) subjects. The lower portion of these figures represents the cumulation of the occurrence of a stage in minutes, while the top portion is the cumulation of a stage in terms of the proportion of the total amount of its occurrence over the night, thus providing an equal base for comparison of the different groups. It may be observed that no stage develops in a linear manner. Stage 2 (Figure 8) develops slowly early in the night but then increases in a linear fashion. Older subjects tend to have more Stage 2 sleep than younger ones. In relative terms, however, the devel-

Table 1

Comparison of Sleep Parameter Norms as Established by Williams et al. (1974) for the 20-29 Age Group with Those Determined by the Cambridge Hybrid Computer

Sleep parameter	Cambridge data	Data of Williams et al.
Total sleep time	431.4	424.3
Stage 1 (mins)	12.8	18.2
Stage 2	202.4	206.9
Stage 3	36.4	24.5
Stage 4	61.9	57.5
Stage REM	110.8	112.7
Stage 1 (% of total sleep time)	3.0	4.3
Stage 2	47.3	48.8
Stage 3	8.5	5.8
Stage 4	14.4	13.6
Stage REM	25.9	26.6
Sleep latency (mins)	12.8	13.8
Latency to Stage 3 (mins)	20.1	22.2
Latency to Stage 4 (mins)	25.3	28.6
Latency to Stage REM (mins)	71.2	94.0
Number of cycles	4.6	4.5
Mean duration of cycles (mins)	105.9	110.8
Number of stages	49.8	37.4

Table 2

Procedure for the Calculation of Cumulated Occurences of Sleep Time

	Sleep stage diagnosis	Summation of stages per 15 min Stages				Summation of successive 15 min Stages			
		1	2	3	4	1	2	3	4
	W								
	W								
	W								
1st 15 min interval	1								
	1								
	1								
	2								
	2								
	2								
	2								
	3								
	2								
	2								
	3								
	3								
	3								
	3								
	3	3	6	6	0	0	0	0	0
2nd 15 min interval	3								
	3								
	2								
	1								
	W								
	W								
	W								
	1								
	1								
	2								
	3								
	4								
	4								
	4								
	4								
	3								
	4								
	4	3	2	4	6	6	8	10	6

Note that all waking (W) episodes are discarded. Thus, the second interval contains 18 min of recording time but only 15 min of sleep. Although epochs are are indicated as being one minute in duration,in actuality they are 30 secs in length (after Gaillard, 1977b).

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Figure 7

Campbell

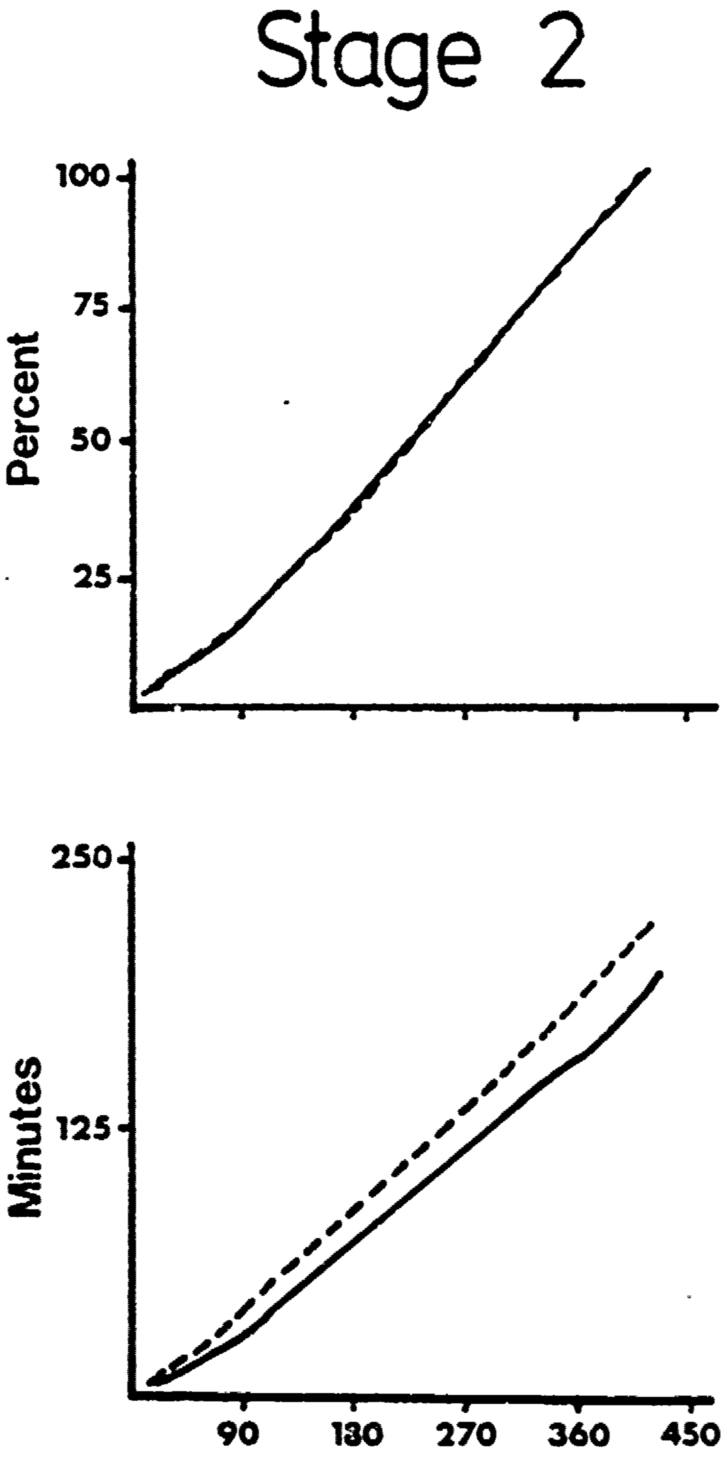

Figure 3. General trend of development of Stage 2 sleep for younger and older subjects recorded in the home.

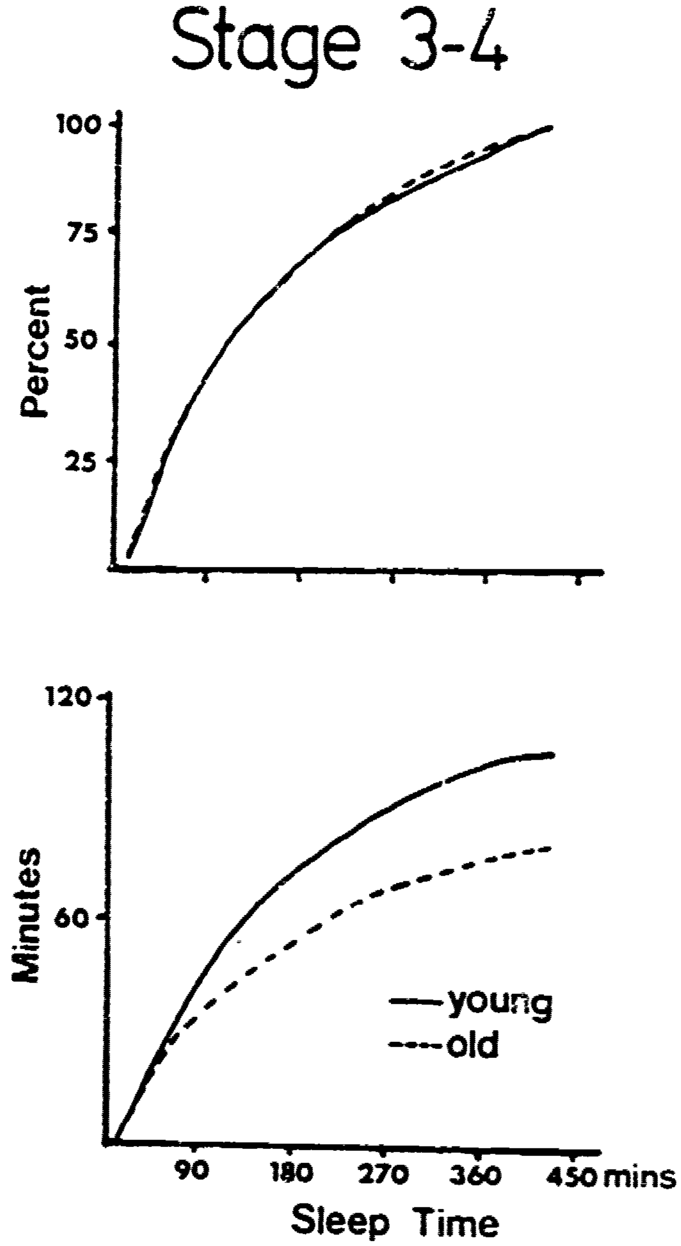

Figure 9. General trend of development of Stages 3 and 4 sleep for younger and older subjects recorded in the home.

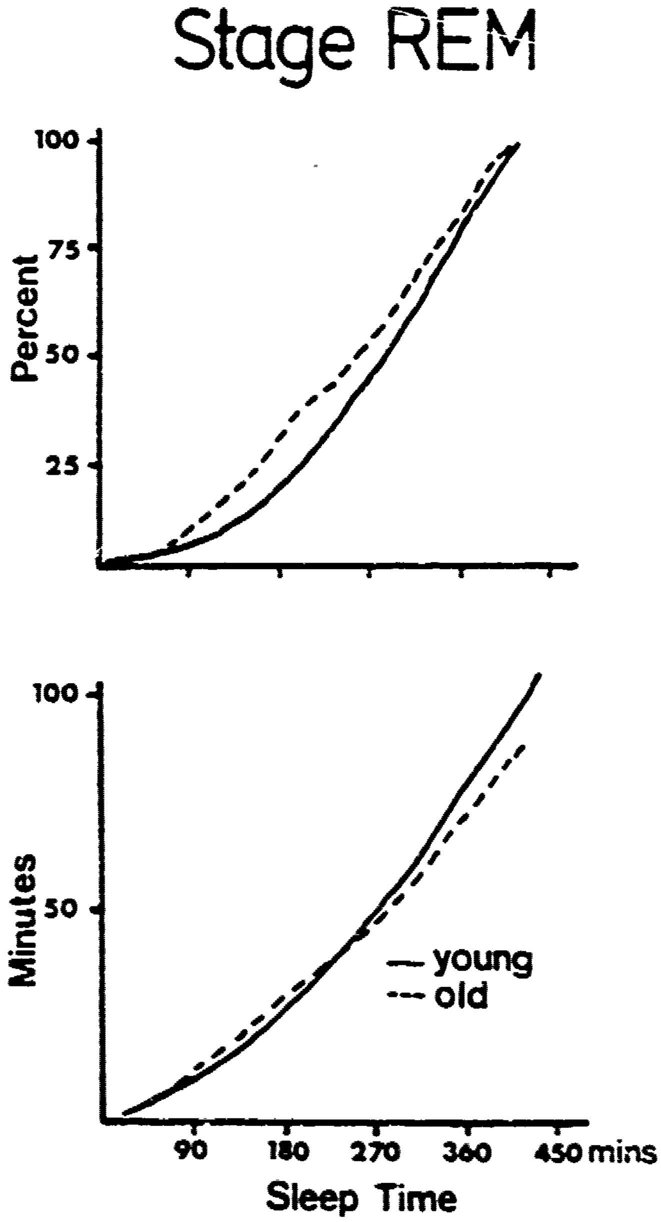

Figure 10. General trend of development of Stage REM sleep for younger and older subjects recorded in the home.

opment is essentially similar. Thus, after 60 minutes, 25% of the total amount of Stage 2 has been accumulated; after approximately 4 hours (228 minutes) 50%, and just after the 6 hour mark (330 minutes), 75% has been accumulated. There are some differences between these figures and those of Gaillard (1977a) which may be due to his subjects' longer nights of sleep. The non-linear trend for Stage 2 is also a departure from Gaillard's findings although more recently (1979), he has described a very similar trend of evolution. There was an acceleration late in the night in his data, which of course could not be observed in our data due to the shorter sleep times.

The most interesting findings for the study of aging are those with respect to Stages 3 and 4. The well replicated finding of a decrease in slow wave sleep (Feinberg, 1974) can be observed in the bottom part of Figure 9. When the data are placed on a relative base, however, (upper portion), the development of Stages 3 and 4 manifests no age effect. For both groups, 25, 50, and 75% of the total amount of SWS occurs after 50, 120, and 240 minutes. Thus, Stages 3 and 4 develop rapidly early in the night and then decelerates so that only a further 25% of this type of sleep is gained in the last half of the evening. The very rapid emergence of SWS as opposed to Stages 2 or REM suggests an immediate and intense "need" (Tissot, 1966) for the former. Our data furthermore indicate that while the quantity of SWS is not as great in older subjects, for whatever reason, qualitatively, the general pattern of its emergence is constant throughout life.

Stage REM (Figure 10) takes on an antagonistic appearance to Stages 3 and 4. Whereas the latter emerges rapidly, REM emerges much more slowly but accelerates towards the end of the evening. Components of higher order related to ultradian variation located in the background circadian trend are only slightly visible. This probably is a function of the large sample size: cyclic variations tend to disappear due to inter- and intra-subject phase and periodicity differences.

Experimental manipulation of noise has typically pointed to a decrease in SWS as noise level increases. In the natural environment a most common source of noise is heavy traffic. Traffic levels are not constant throughout the night; early in the evening they are of moderate to heavy intensity, dropping off significantly in the early hours of the morning and reaching peak levels at around 0600 hr. From a preliminary analysis of subjects in very noisy areas of London (Figure 11), a hint of an actual shift in the development of SWS has been manifested. On noisy nights as compared to quiet ones (noise level 10 dB lower due to the installation of sound insulating windows), after about 2 hrs of sleep and continuing for another 2 1/2-3 hrs, an acceleration in the evolution of SWS can be noted. The period of acceleration corresponds to the times when traffic volume is at a minimum. Hence, if noise does indeed disturb the development of SWS, in spite of the apparent need to attain this type of sleep early in the evening, its "fulfillment" may be moved to periods when environmental conditions are more favourable. The major problem associated with such forms of trend analysis is determining when differences actually become significant. Hence while there may be an apparent dissimilarity in the development of Stages 3 and 4 over noisy and quiet nights, it is quite difficult to determine if this effect is statistically significant.

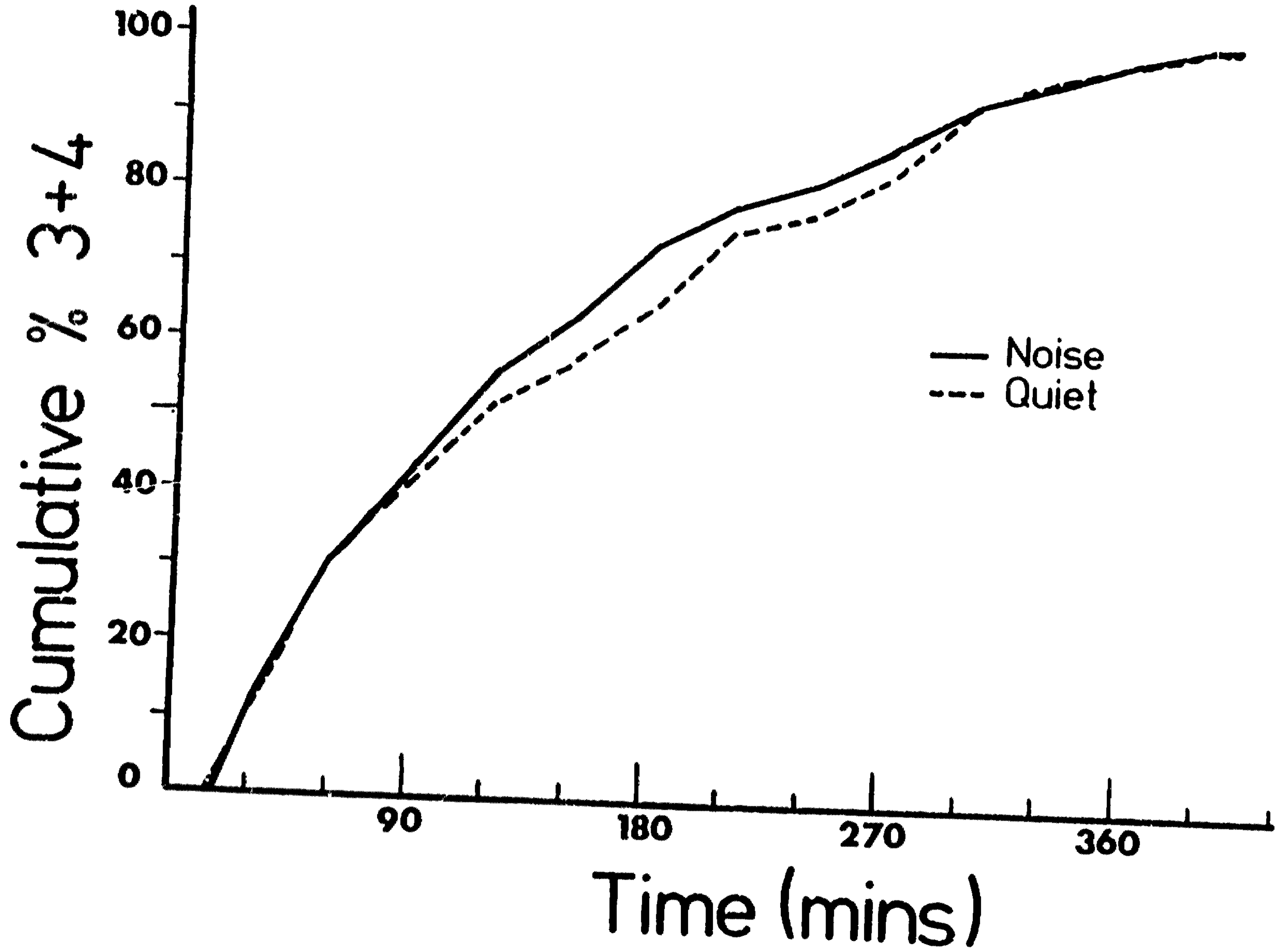

Figure 11. General trend of development of Stages 3 and 4 under noisy and quiet conditions. Note that after about 2 hours of sleep, Stage 3 and 4 evolves at a faster rate in noisy conditions than in quiet ones, then slows down later in the night, when comparatively the latter accelerates. The slowing down later in the night corresponds to a period of intense environmental noise.

Beyond Staging

It has long been recognized that the level or stage of sleep attributed to an EEG record at a given time is a classification schema based on a set of arbitrary human rules, established to put some order in what seemed to be a chaotic mass of data. With the advent of modern computers, in some sense it might have been expected that the arbitrary procedure of staging would have been abandoned. In fact, as with other fields in the neurosciences, once a standard procedure becomes rooted, it very rarely is dislodged. For purposes of inter-laboratory comparison, we continue with the traditional scoring procedures. Beyond these, however, further in-depth investigations have commenced.

Figure 12 depicts what now has become a routine analyzing format. The upper portion of the figure represents the stage profile of one night's sleep of a subject recorded in her natural environment. Because the preprocessor was strobed 128 times per 30 sec epoch (real-time), the classification summary in the form of a single stage amounts to a considerable loss of data, convenient for the human scorer who is unable to cope with more, but quite a limited usage of a computer's capabilities. It was thus decided to investigate the level of activity of each EEG event in each of these 128 samples across the entire recording session. The night was broken down into 15 minute intervals and the number of seconds of alpha, spindle, delta, and REM activity accumulated. Note that there is no concern whatsoever about arbitrary stages in this analysis. The 3 lower illustrations of Figure 12 point out intriguing trends that are entirely overlooked by simpler forms of analysis. The units (secs of activity) of course are quite variant. Thus, in this subject's record, up to 750 seconds of a 15 min interval could be occupied with delta activity, while the maximum figures for REM and spindles were 40 and 25 secs, respectively. The latter, properly speaking, are transients. Thus, only one spindle of 0.5 sec duration is enough for an EEG 30 sec epoch to be classified as Stage 2 sleep, while the same epoch would require 15 sec of delta to be classified as Stage 4. The first feature of interest is that the peaks of the respective waveforms are very predictive of particular stages of sleep. There are other features that make this form of analysis much more exciting. All three waveforms display distinctive ultradian oscillations. It is well known that Stage REM is on an approximately 90 minute cycle. Both REM and spindle activity increase in number as the night progresses, but are, however, almost exactly out of phase. When one is at a maximum the other is at a minimum and vice versa. If REM and spindle activity increase as the night progresses, some other waveform might be expected to do the opposite. This is, as suggested by Figure 9, delta. Not only does it take on a characteristic decaying oscillatory behaviour, it is, like spindles, out of phase with REM. In fact, it is the mirror image of spindle activity or from another point of view, the mirror image of the inverted REM picture.

The rhythmic nature of all three waveforms is not obvious from plots of the various stages. Gaillard (1979) thus, concludes that Stage 2 has greater rhymicity than Stages 3 or 4. The data employed in the tracings of Figure 12 are quite consistent within and between subjects and suggest that Gaillard's conclusion may not be true.

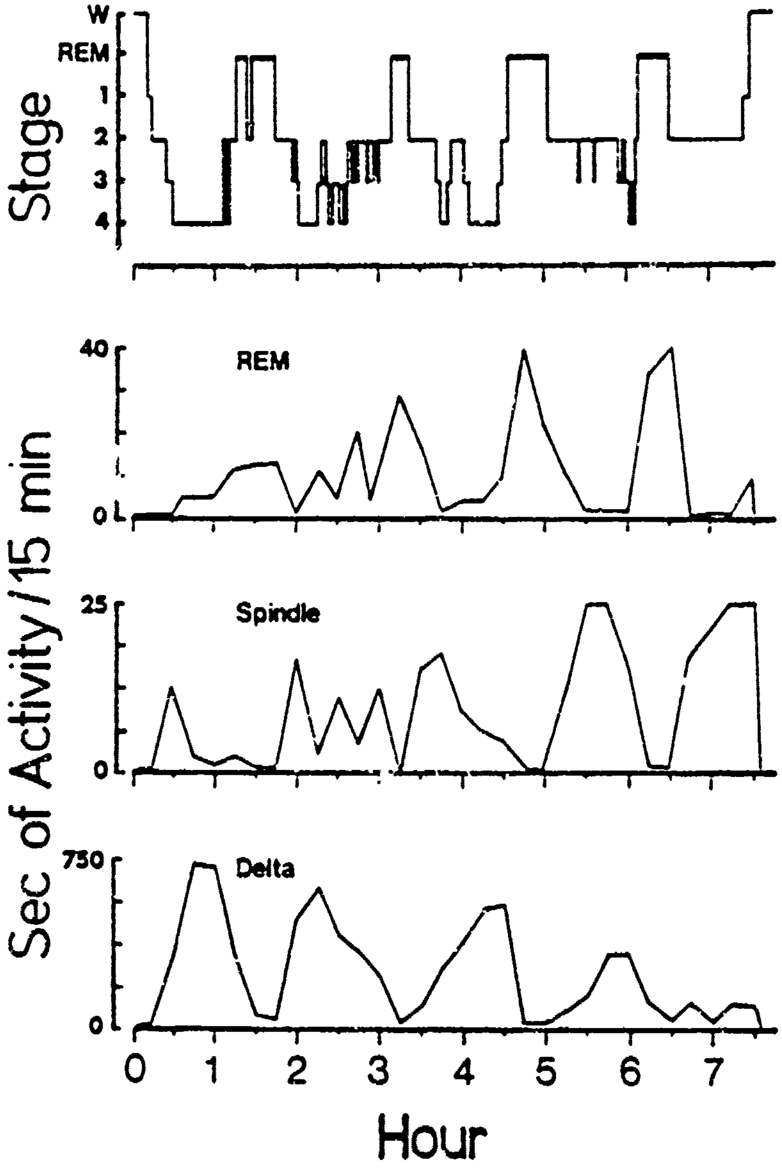

Figure 12. Computer classification of home recorded sleep into stages (upper portion) and in seconds of activity per 15 minute interval with respect to rapid eye movements, spindle transients and delta activity.

Delta activity does exhibit well-defined cyclic rhymicity, even if its quantity is limited late in the sleep period, to the extent that the threshold for Stage 3 or 4 definition is not reached. By restricting himself to stage classifications, Gaillard has overlooked slow wave activity whose total accumulation fails to reach an arbitrarily established level.

Performance Tests

Over the past two decades, it has been found that certain performance tests are sensitive indices of the effects of the quality of sleep and manipulation of the sleep-wake cycle as seen, for example, in shift work. Wilkinson (1970) in a review of such measures, has indicated that their sensitivity is dependent on a number of properties inherent in the nature of the task. Such features include: the duration of the test, level of complexity, interest value and the degree to which knowledge of results is available.

As was the case with the physiological instruments, it was quite impractical to transport the bulky, main voltage supplied psychological battery into the field setting. Two frequently used tests (Four Choice Serial Reaction Time) and the (Unprepared Simple Reaction Time) were completely redesigned while two others (Short Term Memory and the Wilkinson Vigilance Test) were modified for field situations.

Both the Four Choice Reaction Time (4CH) and the Unprepared Simple Reaction Time (USRT) tests were housed in portable battery-operated cassette recorders, enabling a significant reduction in size, weight and cost of the laboratory-based equipment. The recorders are designed to perform the triple function of housing the display and response apparatus, generating a random program of stimuli and recording the response data on the magnetic tape cassette. Back in the laboratory, the tapes are replayed, decoded and analyzed by digital computer.

Four Choice Reaction Time

The 4CH, illustrated in Figure 13 consists of a four light (light emitting diodes or LEDs) display in the form of a square. Close to these are mounted four push buttons corresponding to each of the LEDs. At the start of the test one of the LEDs is illuminated, the subject pressing the button corresponding to its position. The light is then extinguished and, after 120 msec, either the same LED or one of the other three comes on, according to a random program. The subject again makes the appropriate response and, thus, brings on the next light in the sequence and so forth. He or she continues to respond in this way as quickly and as accurately as possible for the duration of the test. Usually this is 10 minutes, although this may be optionally altered to the user's needs.

The 4CH, unlike other performance tests in our battery is self-paced--the LEDs come on at a rate corresponding to the subject's reaction time. There is of course, the possibility of error. A correct response is recorded onto the cassette as a 2 kHz tone, an error by a 4 kHz tone, each of 120 msec duration. In the laboratory, a frequency decoder is employed to reconstruct the original events and to send an appropriate TTI compatible signal to the digital interface of the computer. Because the onset of the stimulus occurs at a fixed 120

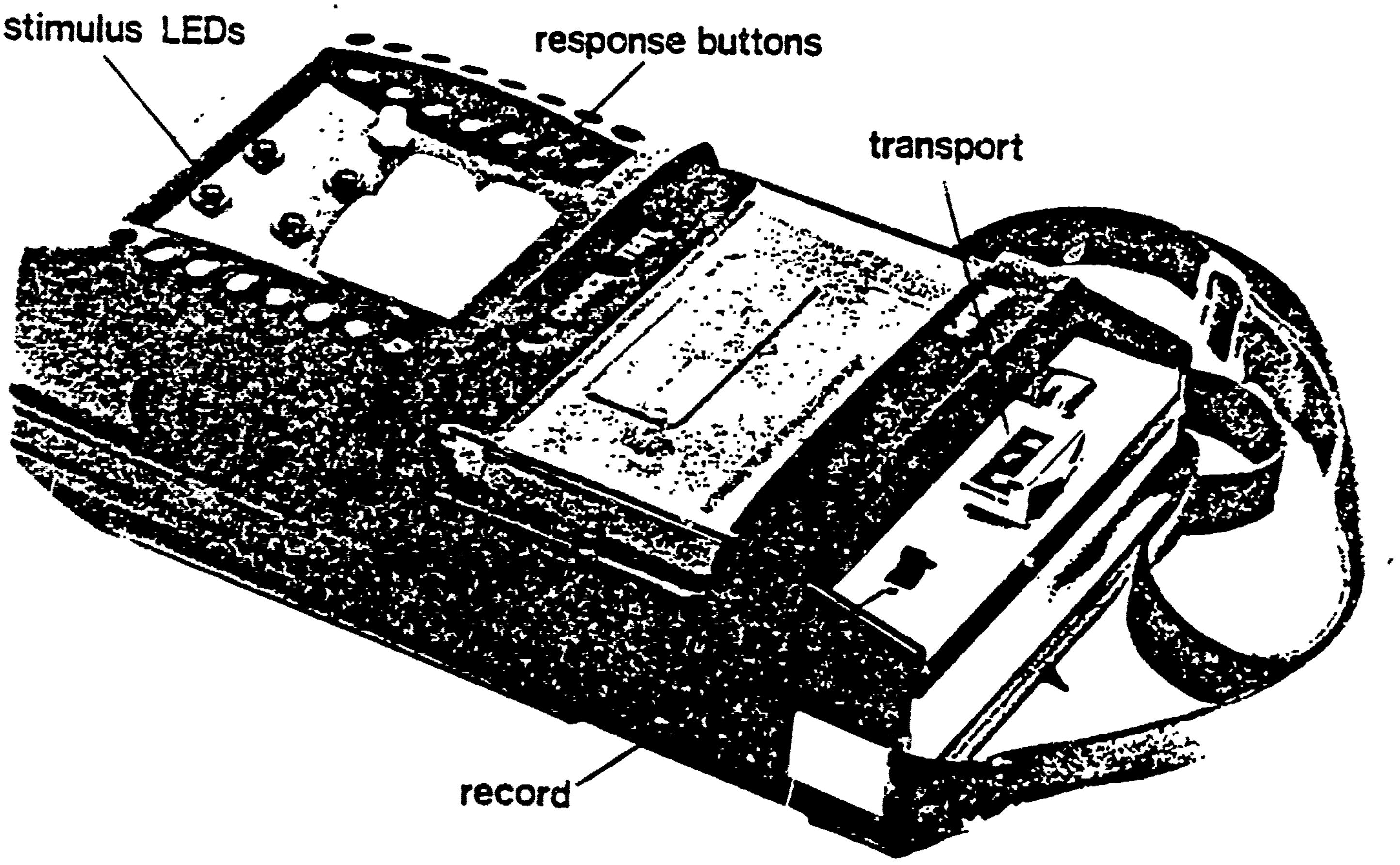

Figure 13. The portable Four Choice Reaction Time test for use in the field. One of four LEDs is illuminated, the subjects task being to respond as quickly as possible by pushing the appropriate button. Correct and error responses are coded on the cassette by 2 and 4 kHz tones.

msec after the response (corresponding to the duration of the coded tone), there is no necessity to encode it on the cassette. Thus, the reaction time for a particular correct or error response corresponds to the time between the previous response and the response in question minus 120 msec. Specific details of the circuitry and function of the test can be found in Wilkinson and Houghton (1975).

The test, because of its relative complexity, has been found to be affected by practice. The subject's performance typically improves over the first 2 or 3 sessions before leveling off. The stimulus must first be encoded, the appropriate response retrieved from memory and then the actual motor response made as quickly as possible.

Glenville and Wilkinson (1979) have described the utility of this as a measure of the effects of shift work on performance. Eleven computer operators working day, evening, and night shifts were tested over a nine week period encompassing three replications of each of the shifts. Testing took place on the first night and day shift. The subjects were examined between 0400 and 0500 hours for the night shift and 0800 and 0900 hours for the day shift. It should be noted that subjects starting the night shift had already been awake for the entire day and evening period. Thus by the end of the shift, they had been awake for approximately 24 hours. Overall, the results indicated that reaction times were significantly longer on the night than on the day shift, the effect being particularly dramatic on the second and third occurrences of each shift. While an improvement in performance was noted over the replications during the day shift, none occurred during the night shift. Moreover, performance deteriorated in the second half of the 10 minute session uring the night shift as might be expected when the level of arousal declines.

With respect to specific studies on the manipulation of sleep parameters, the 4CH has been shown to be sensitive to the specific effects of 24 hour sleep deprivation (Glenville, Broughton, Wing, & Wilkinson, 1978) but less so to the minor effects of noise at night (Wilkinson et al., in press).

Unprepared Serial Reaction Time

The USRT is illustrated in Figure 14. The subject watches the window for the onset of a 000 LED display which immediately begins to count up in msec. A button is pressed as quickly as possible and the arrested display shows the reaction time. The display is then extinguished and after an interval which may randomly vary from 1 to 10 seconds, the cycle is repeated.

The reaction time is coded as a train of 1 msec pulses onto the cassette tape, the total number of which is equivalent to the reaction time (Wilkison & Houghton, in preparation). The USRT is, thus, an uncomplicated index of performance, providing knowledge of results to the subject. Because of its simplicity, it requires only a short practice session before baseline levels are attained. In most instances, a 10 minute trial is run although this can, of course, be increased or shortened depending on time available.

In the Glenville and Wilkinson (1979) study of the effects of shift work, again as in the 4CH, mean reaction time was significantly longer on the night

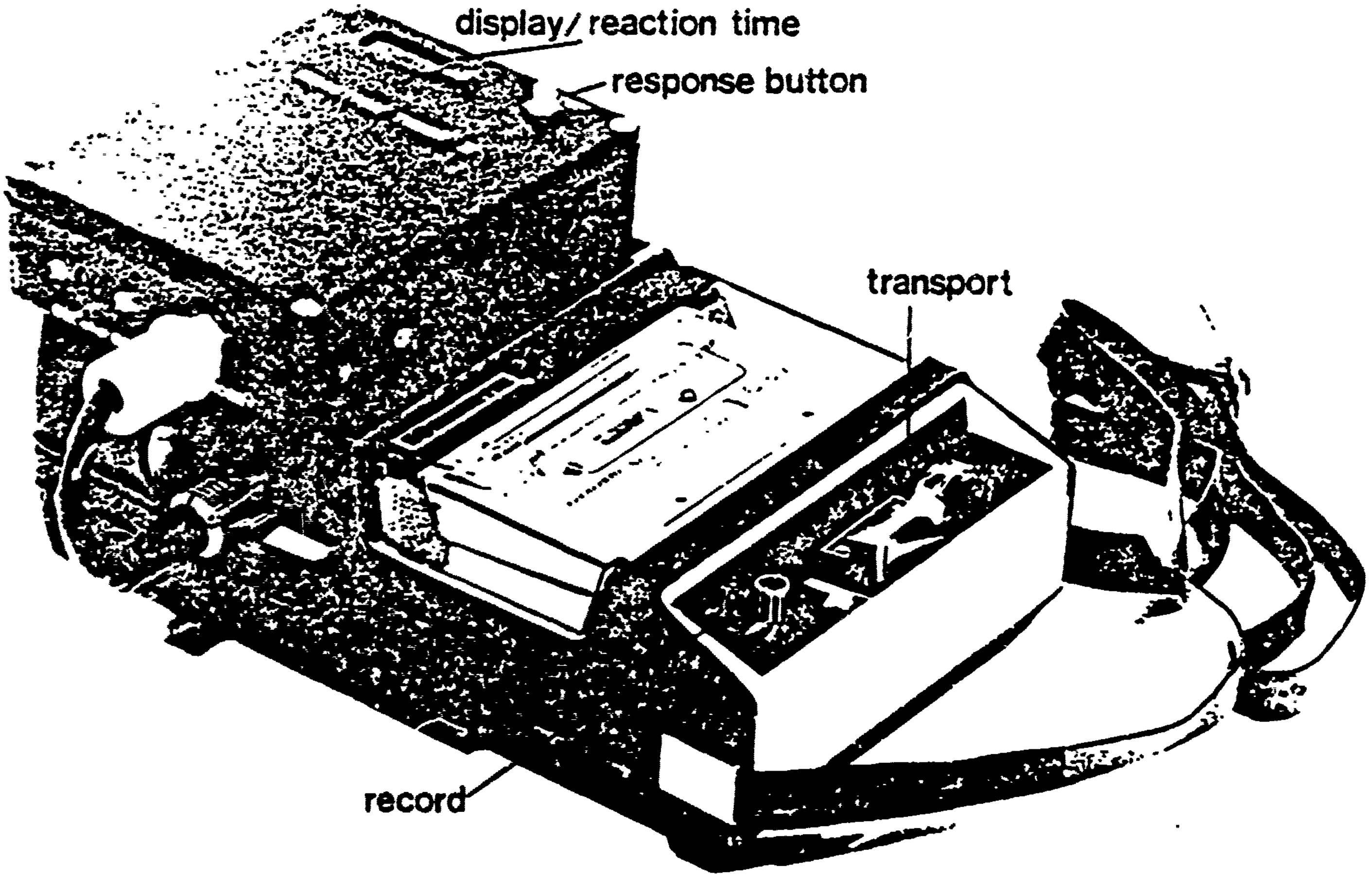

Figure 14. The portable Unprepared Simple Reaction Time test for use in the field. Subjects watch for the onset of the display and push the response button as soon as possible. The reaction time is indicated on the display and recorded as a series of pulses on the cassette tape.

than on the day shift. Moreover, during the course of the experiment the subjects become increasingly slow during the night shift but not on the day shift. Also during the former, the difference between the first and second halves of the test increased with each successive replication whereas during the latter, the difference decreased.

The results found with the portable tests are strikingly similar to the adverse effects of sleep deprivation noted by Wilkinson (1961). It was also apparent that had only an initial test been made of the effects of shift work, no significant differences would have emerged.

The USRT has also been employed in more direct investigations of sleep quality. Glenville et al. (1978) found that reduction of the number of hours of sleep resulted in a slowing of reaction times, while Wilkinson et al. (in press) noted that even relatively minor sleep disturbances, as brought about by environmental noise influences, were sufficient to alter USRT results the following day.

Short Term Memory

A process that appears to be little affected by disorders of sleep is short term memory (STM) (Hamilton et al., 1972). Indeed, some authors (see, for example, Folkard et al., 1976 for a review) claim that STM may be performed better when arousal is low than when it is high since it is complex enough to provide a high level of stimulation to the central nervous system merely as a result of carrying out the task.

In the field, the subject hears a list of digits played back from a cassette recorder at a rate of 2 digits/sec. Each list contains 8 digits randomly drawn from the set 1 through 9, but with no repetitions within the list. After each list, an interval of 6 seconds is allowed during which the subject attempts to write down the sequence he has just heard in the correct order of presentation. The test duration is again 10 minutes during which time 60 such lists are presented for recall. Errors can be one of three types: omissions, in which a digit or digits cannot be recalled; commissions, in which a digit is correctly recalled but not in its correct order of occurrence; and intrusions, in which a digit that was not in the list is falsely recalled.

The Wilkinson Vigilance Test

This test (Wilkinson, 1970) has been used quite widely in studies of sleep deprivation and other states in which arousal may vary. Of the tests mentioned, it has proven to be the most sensitive to disorders of sleep (Glenville et al., 1978). The subject listens through headphones to a cassette recording of a repetitive series of tone pips. 500 msec in duration with a regular inter-stimulus interval of 1.5 seconds, occurring in a background of "grey" noise. Occassionally and at unpredictable intervals, one of the tone pips is slightly shorter in duration than the rest (approximately 400 msec). The subject's task is to detect these signals and report them by an appropriate hand indication to the experimenter sitting out of sight of the subject. Ideally, the test continues for one hour, but can be shortened to 30 minutes depending on the time available to the subject. Performance is analysed in terms of the number of signals correctly detected (Hits) and the number of standards incorrectly identified as signals (False Alarms). From these measures, indices of the subject's discrimination level of sensitivity (d') and willingness to respond (β) can be calculated (Tanner & Swets, 1954).

Subjective Questionnaire

While the computer profile of the subject's sleep provides an "objective" index of various parameters, a number of reports in the literature have pointed out that few of these are actually highly correlated with the subject's own impression of the quality of their sleep. Two questionnaires are therefore administered: The Stanford Sleepiness Scale (SSS) (Hoddes et al., 1973) and a locally designed scale.

The SSS is completed just prior to the subject's going to bed and immediately upon their awakening. Subjects are asked to write a number from 1 to 7 corresponding to their self-assessed level of sleepiness or fatigue.

The second questionnaire was designed to assess the subject's rating of their quality of sleep, quantity of dreams, awakenings during the night, the duration of such awakenings, and latency to the commencement of sleep. This questionnaire, which takes no more than a minute to complete, is administered in the morning.

Conclusions

The development of a sleep recording protocol in the laboratory often takes a number of years of dedicated effort before results begin to appear. The transfer of the laboratory to the natural environment has only very recently been attempted. The barriers are prodigious. Only with the advent of modern electronic trends towards miniaturization has it become feasible for progress to be made towards this end. At the same time, advances in computer technology have enabled the high-speed analysis of the vast volume of data that rapidly accumulates in the field. Automatic analysis also allows for the types of microanalyses that the human is quite incapable of carrying out.

The shift from the behavioural laboratory to the field setting may be accelerated by the methodological trends described in this article. The relatively short duration of many of the performance tests offers the possibility of an inexpensive and completely portable means of assessment for screening purposes. The research that has been conducted to date has by necessity been limited to normal samples. The application of these procedures to the patient population is an obvious "next step", but far from the only one.

Finally, the development of research tools never really ends as such. At the moment, amongst other innovations, we are investigating the feasibility of on-line analysis of sleep patterns in the home through specially constructed microprocessors.

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SHIFTWORK DISCUSSION AND CONCLUSION

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At the end of the Symposium, the participants were divided into six small, interdisciplinary working groups for discussion of the issues and findings in the area covered by the meeting. The groups were asked to produce a consensus response to each of the following questions:

1. Having now gathered a significant volume of data, what facts about work-sleep schedules are clearly evident and require no further research?
2. With regard to future research on variations in work-sleep schedules, what are the most important problems to be investigated in the near future?
3. Given experience to date, what are the most significant methodological problems to be avoided in future work-sleep research and application?

The following is a summary of the responses given to these questions.

Question 1: Known Facts

Variations in sleep-work schdeules, mainly occasioned by night duty in shift work, are widely prevalent in our society. There is good evidence that the incidence of shiftwork had increased dramatically in the recent past. Although there is some doubt as to whether this increase is continuing, it is clear that shiftwork cannot be abolished, and thus that its potential effects on health and performance cannot be ignored. There is a considerable range of shiftwork schedules, and the economic, physiological, medical and social effects associated with these different schedules vary in their nature; thus it follows that research in this area must have an interdisciplinary approach.

There is no doubt that people working on night shifts sleep less, and report poorer sleep quality, during their daytime sleep periods. This is the most obvious effect arising from the disruptions of circadian rhythms occasioned by night work. The existence of such rhythms, the majority of which have been proved to be endogenous in nature, has been firmly established in laboratory research; they have been clearly demonstrated in a variety of physiological and biochemical systems in addition to sleep; and also in task performance, and in subjective measures of sleepiness and mood.

These biological rhythmic systems are highly interactive, some masking, and some setting and/or driving other systems. Certain of these interactions have been relatively well described, e.g., the depressive effect of sleep on temperature, and the dependence (a) of the length of self-selected sleep and (b) of the degree of subjective sleepiness, on the phase of the temperature rhythm.

It is also clear that, in all systems, there is substantial intra- and inter-subject variability. Because of the latter, there are considerable individual differences in adaptability to shiftwork. Where ability to adapt is poor, digestive disorders occur; and there is definite evidence that changed work/sleep schedules create difficulties for some people by interfering with their participation in social and leisure activities, including their family life. It follows that there is no single shift-system that is equally desirable for all workers.

Regarding methodology, it must now be accepted that no study in this area can afford to leave out of consideration time of day, time of year, and geographical location (with regard both to latitude and climate). It is recognized that research on variations in sleep-wake cycles and on shiftwork is not only costly, but, as one group pointed out (not altogether flippantly), that it can present a danger to the observers because, by necessity, they are exposing themselves to the same hazards as the subjects they are studying.

The "known facts" summarized above represent a total of 16 separate responses to the question. However, there was little unanimity between the six working groups about these facts, only 5 of them (all concerned with circadian rhythms or sleep) being mentioned more than once. One group pointed out that although it is clear that variations in work-sleep schedules disrupt circadian rhythms, definite evidence that such disruptions have any direct effects on health and performance is at present lacking.

Question 2: Future Research Problems

A total of some 36 responses were obtained to this question. These responses covered a wide range, and, as with Questions 1, there was little unanimity between the groups. Only 9 of the problems were mentioned by more than one group: 4 problems being listed by four of the six groups, and 5 by two or three groups.

The objective health of shiftworkers was the problem most frequently referred to, in one way or another, as requiring urgent investigation. While one group opined that true impairment of health in shiftworkers (if it occurs) could well be a secondary effect arising from reduced well-being, rather than the direct result of circadian disruption, several groups emphasized that, in any case, there was a pressing need for longitudinal and epidemiological studies to determine the mortality and morbidity rates associated with exposure to shiftwork, and their relation to different shift schedules. Specific aspects mentioned in this contest included the pathophysiology of the gastrointestinal disorders typically associated with shiftwork, and the interaction of different shifts with the presence of mutagens and carcinogens. The need for the development of complex models and their testing in prospective studies was emphasized, as was the establishment of acceptable criteria of risk.

Subjective health, or well-being, was also considered an important research area. While, again, one group questioned whether it had been established that decreases in well-being were directly associated with disruption of circadian rhythms, it was thought important to try to establish the precise relationship between changes in work-sleep schedules and the nature and incidence of non-clinical symptomatology, and whether the extent of lowered well-being can be reduced by the judicious choice of particular shift systems and/or forms of compensation, including non-financial ones. Since it would seem that, at least in part, loss of well-being is a sociopsychological problem, it was thought necessary to determine, by time-budget studies, the impact of varying work/sleep schedules not only on the shiftworker himself, but also on members of his family and on social groups to which he belongs.

If the disruption of the circadian system proves to be important in the aetiology of subjective and objective ill-health, it will then be necessary to determine what degree of rhythm adjustment (i.e., non-, partial, or complete) is optimal in terms of minimizing undesirable side effects; and to find out how to ensure it. For the latter, basic research on the phase-controlling properties of the various Zeitgeber will be required; these include not only the light/dark and sleep/wake cycles, but also the timing of meals, and the wide range of social signals to which the human system is known to respond. In this endeavour, account will have to be taken of periodicities other than the circadian, including both ultradian and infradian (e.g., circannual) rhythms, and the ways in which these integrate with the basic daily cycle.

A better understanding of the concomitants of inter- and intra-individual differences in both "normal" circadian characteristics, and in ability to adapt to altered work-sleep schedules, was felt by a majority of the groups to be highly important. Age, personality, and sex were considered the most relevant variables here; others mentioned were life-style, sleep habits, and motivational level. The attempt should be made to establish predictive relationships between identifiable individual characteristics and various indicators of adaptation or non-adaptation such as: rate and level of adjustment of circadian functions; long-term tolerance of shiftworking; susceptibility to disease; and sensitization to stress.

Stress was also frequently mentioned in the context of its impact on the adjustment process. Research was badly needed on the ways in which various "stressors" interact or synergize with the intrinsic stress of working at unusual hours. "Environmental" factors mentioned here were noise, ambient temperature, lighting, radiation, the composition of the atmosphere at the workplace (including toxic substances), and sleeping conditions in the shiftworker's home. The "socio-environmental" factor of general nutrition, particularly in relation to the frequency and timing of meals, was considered another potential interactive stressor, as was the use of drugs, both in the short- and long-term. "Psychosocial" stresses arising from the shiftworker's home and family situation, and from his relationships with his wider circle of friends, were also thought to be relevant in this respect. It was considered that, in order to assess the impact of at least some of these stressors, more use should be made of the "ambulatory monitoring" techniques now available to record variations in such measures as heart-rate, temperature, and EMG.

It was agreed by most of the groups that the ultimate aim of the research mentioned above was the optimization of shift-schedules with respect to the timing of shifts, the type and speed of rotation, and the kind of work performed. Both experimental and field studies were required here, in order to answer such questions as whether long periods of work on "permanent" nights (as compared, say, to rapid rotation of shifts) were really beneficial to the individual (and to society) in terms both of adjustment of circadian functions, and of adaptation in the more general sense, including the maintenance of good health. "Intervention" studies were considered by one group to be a fruitful way of tackling such questions, the answers to which should eventually lead to a set of physiological, psychological, and social criteria for evaluation existing shift-systems, or establishing new ones.

More than one group felt that more attention should be paid to prophylactic measures, including counselling or education, to reduce potential ill-effects from particular shift-assignments. Thus the efficacy of various countermeasures should be investigated: these would include training for both relaxation and sleep - particularly for "anchor" sleep; the judicious use of hyponotics and stimulants as appropriate; control of dietary intake with respect to both content and timing; and the encouragement of "hygienic" behavioural practices such as taking regular exercise. For these purposes the existing medical coverage of shiftworkers would need to be considerably extended.

Perhaps surprisingly, sleep itself was rarely mentioned as a primary area of research need in the near future. One group felt it essential to develop adequate methods for assessing the recovery function of sleep, since only then would it be possible to determine when people should sleep on different shift assignments, and whether the "necessary" duration of sleep varies with the time at which it is taken. Whereas one group considered that it is important to determine what sleep measures predict waking performance, including responses to emergencies in the context of industrial safety, another felt that it still remained to be established whether the latter was in fact a real problem in shiftwork, and, if so, whether this was due to the disruption of the circadian system. If this proved to be the case, it might well be that the dangers could only be alleviated by first improving our understanding of the changes in information processing functions that are known to exhibit a circadian pattern even in the "normal" situation.

The suggestion was made by one group that a possible way to prevent, or alleviate, performance decrements associated with shiftwork was to study the way in which the latter affects the group dynamics of the workers involved, with a view to, perhaps, modifying the traditional structure of teams in such a manner as to improve their overall efficiency. Since the team leader is the key figure in the social structure of a working group, particular attention should be paid to him; it might be, for example, that a simple ensurance of adequate rest for this person could have substantially beneficial effects on the whole team.

Recommendations

A number of responses given in the discussion were not so much suggestions for future research as recommendations for action, administrative or otherwise. Thus one group felt that it was necessary to achieve a better definition of the criteria and the "costs" of shiftwork, and also to devise better methods of "translating" the findings from research into practical guidelines for action, and for implementing these in the field.

The first of these needs might be met if the proposals of another group were adopted: these were the establishment in each country of a shiftwork registry, and the development of an international classificatory system. It was suggested that recommendations for these steps to be taken should by made to international organizations such as WHO and ILO, perhaps by the Chairman of the Scientific Committee on Shiftwork of the Permanent Commission and International Association of Occupational Health. An additional advantage of such international arrangements would be that research would be enabled to proceed on a more comparable basis than at present.

The need for a means of facilitating the practical application of research findings might be met by another proposal which was made by one of the groups (and also by the present writer in his closing remarks to the meeting). This was the setting-up of national institutes for shiftwork (on the lines of the Japanese and Swedish examples), jointly financed by both management and labour organizations, possibly with some additional State support. A prime function of such institutes would be to act as a two-way bridge between the researchers in Universities and elsewhere, and the potential "users" on the shop-floor: disseminating the results of basic research to management and labour organizations, and encouraging their application; and monitoring present and future problems arising in the work-place in order to ensure that the laboratory research is appropriately oriented. With or without their own research staff, such institutes would be in an ideal position to facilitate the field studies which are clearly needed for validating new findings.

Question 3: Methodological Problems

The variety of the responses to this question was also considerable. Of some 20 different problems that were mentioned, only five were listed by more than one group; however, there was a degree of overlap in some of the responses.

Four of the six groups thought that one of the most important things to avoid was generalizing from the results of laboratory studies without checking the validity of the research findings in the field. Apart from the fairly obvious necessity of having a sound theoretical basis for designing any laboratory investigation, and ensuring that it is of a kind which would reasonably be expected to lead to practical recommendations, several specific aspects of this problem were mentioned. These included the appropriate selection and motivation of subjects (for instance, avoiding the study of non-representative populations such as teenagers/students); the use of appropriately validated dependent variables (e.g. responses in routine simulations are not necessarily predictive of emergency-stress performance) and the ensurance that these variables are not confounded by uncontrolled factors; making certain that the frequency and length of data collection is adequate to test the hypotheses; and being particularly cautious in interpreting the results of studies on other than human subjects.

With regard to circadian rhythm research, one group warned that it should not be assumed that the problems of shiftwork have <u>anything</u> to do with disruptions of the circadian system until such a relationship has been clearly established. However, even assuming that there <u>is</u> such a relationship, it is important that estimates of the adjustment of the system to variations in sleep-waking cycles should not be derived simply from changes in the <u>shape</u> of any particular rhythm, or from only two parameters. Similarly, it is necessary to have a better definition of the norms and transients in any rhythm in order to be able to identify "adjustment" or "adaptation", and to take into account the degree of internal synchrony or de-synchrony which would in any case be encountered in the "normal" situation.

Apart from the need to employ technical methods which bridge both laboratory and field studies (e.g. unobtrusive, portable measuring devices), several groups were exercised by the more general problem of developing appropriate "tools of the trade" that can be used by different workers in different situations to produce results which can be directly compared. The need for standardizing both the independent and dependent variables studied was stressed, and the importance of giving exact descriptions of these variables in reports emphasized; one group suggested the adoption of a standard classificatory system analogous to the International Classification of Diseases. Precise description was also seen as vital when reporting the details of the shift systems studied, such as the times of stopping and starting each shift, the direction and frequency of change of the rota, the nature of the actual tasks being carried out by the workers, and the physical and social characteristics of the working environment.

Concern was expressed by several groups that proper attention should be paid to the dangers involved in studying populations of shiftworkers without careful control for the "self-selection" that is known to operate in this area. It was pointed out that this selection occurs at both ends of the system, i.e., that not only do a sizeable number of erstwhile shiftworkers "drop out" of shiftwork for various reasons, but that, even on entry, there are factors operating which tend to guide certain individuals into day or shiftwork, and, in the latter, into particular shifts or shift-systems rather than others. Apart from anything else, such self-selection often mades the use of "day" workers as control subjects unjustified.

Much research in the field is carried out by means of questionnaires, and several groups expressed a degree of dissatisfaction with the present "state of the art" in the construction and use of these instruments. One group called for a better handling of the "demand" characteristics presented by the questions; another for a substantial improvement in their degree of objectivity and quantificatory potential; and a third warned against simplistic and unreflective interpretation of data gathered not only by quentionnaires, but by all "subjective" methods of a like kind.

The general point was made that biological data relevant to variations in sleep-waking schedules must, as in any other situation, be carefully analyzed in relation to individual versus group characteristics; there is little value in reporting a mean without also giving its standard deviation (an omission which, unfortunately, is not uncommon). Finally, one group questioned the use of a particular and popular type of biological measure, namely the EEG, since there would not seem to be sufficient evidence of its validity for describing the effectiveness of sleep, despite the fact that all agree that reported disturbance of sleep "quality" is one of the few established facts known about the effects of shiftwork.

Conclusions

Although the low degree of consensus in the responses given to the questions was in some respects unexpected. it is perhaps understandable when it is considered that the present area of research has a relatively short history, and that work in this field is currently experiencing a great burgeoning of effort in response to the recent growth in the magnitude of the real-life problem, and in public awareness of its potential implications both for the individual, and for society in general. It is perhaps no coincidence that this increased awareness has come at a time when there is a widespread awakening of consciousness about all those aspects of modern technology which must inevitably pose a threat to what is commonly referred to as the "quality of life".

The great variety of the responses made in the discussion should thus be taken as evidence of the complexity of the problem area on the one hand, and of the degree of concern felt about it on the other. The wide range of the points raised, when considered together with the equally wide range of topics covered by the presented papers, is, in the present writer's opinion, indicative of a healthy state of interest in the effects of variations in work-sleep schedules, an interest which was focussed by this symposium, from which the participants departed with a determination to continue their research efforts on the many, various and complicated issues in the field with renewed vigour.