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THE OPERATIONAL CONSEQUENCES OF SLEEP
DEPRIVATION AND SLEEP DEFICIT

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THE OPERATIONAL CONSEQUENCES OF SLEEP DEPRIVATION
AND SLEEP DEFICIT

by

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SUMMARY

Effects of total sleep loss, partial sleep loss, and sleep stage deprivation are reviewed with particular attention to performance decrement and operational consequences. Within the 36-48 hour range of total sleep loss most likely to be experienced by aircrew personnel, no consistent or uniform performance decrement has been found in operational studies even though laboratory studies have found decrement on certain types of tasks. Of major importance are the type of task, the setting in which the task is to be performed, and the individual. Physiological changes are minimal during moderate sleep loss, but mood changes are clearly noticeable. The most likely sleep problems for aircrew members are those associated with disruption of sleep-wakefulness cycles and partial sleep loss. Consistent performance decrement is difficult to find, but marked increase in fatigue is a common problem. Sleep loss, both total and partial, tends to potentiate the circadian influence on performance and interact with other stressors to enhance the stress-induced physiological responses. Deprivation of sleep stage REM or sleep stage 4 produces no behavioral changes supportive of earlier beliefs that these two stages, especially stage REM, were necessary for effective waking behavior.

INTRODUCTION

The primary purpose of this AGARDograph is to summarize the relevant findings on total and partial sleep loss, sleep stage deprivation, and changes in sleep cycles, with particular attention to those aspects of sleep disturbance which might give rise to impairment of the operational efficiency of flying and ground personnel. Hopefully, the material in this AGARDograph will be of assistance in the development of a more scientific basis for the scheduling of rest and duty cycles for those involved in the various aspects of flight operations. As the reader progresses through these pages, he will soon realize that determining the effects of going without sleep is as complex a problem as is that of unraveling the functions of sleep. The reader may conclude that the only thing we know for certain about sleep-loss effects is that going without sleep makes one sleepy and, when sleep occurs, there is a decrement in performance. Perhaps of most importance for operational planning are the more subtle and perhaps potentiating effects of sleep loss on circadian rhythms, physiological and biochemical responses to stress, and on subjective feelings of mood and fatigue. It will also be readily apparent that the common difficulty of obtaining good operational or field studies' data and the ever-present problem of generalizing from laboratory studies have not been resolved by sleep-loss researchers.

Statement of the Problem

The readily apparent physiological and psychological difficulties encountered when one jets from one side of the world to the other demonstrate that effective functioning is related to the many biological rhythms of roughly a 24-hour period. One of these circadian rhythms is the sleep-wakefulness cycle which is synchronized for most to the dark-light cycle of each day. When the sleep-wakefulness cycle is disrupted, a sleep deficit usually occurs. As the duty schedules of some require frequent disruptions of the usual sleep-wakefulness cycle, sleep deficit is often a problem for these workers.

Of particular interest for this report are the sleep disruptions and deficits incurred during flight operations in both air and ground flight personnel. The importance of obtaining an adequate amount of sleep and of maintaining a stable sleep-wakefulness cycle is clearly demonstrated by the findings of many recent studies. Benson,¹ in his summary of a conference on rest and activity cycles for the maintenance of efficiency of personnel concerned with military flight operations, noted that "Although no paper dealt specifically with the performance decrement associated with sleep loss, this topic was a recurring theme in many of the presentations. The opinion was expressed that loss of sleep, brought about either by disruptive duty cycles (e.g. 4 hr duty, 4 hr rest) or by adaptation to a new time zone, was probably a more potent cause of impaired performance than the inherent circadian variation." Though being mostly concerned with the influence of time-zone changes on performance, workers at the Aerospace Medical Institute, DFVLR, Bonn-Bad Godesberg, Germany,² made the same observation after studying the circadian rhythm of pilots' efficiency and effects of multiple time-zone travel: "The most significant measure to reduce the negative effects of transmeridian trips, we think, is to prevent sleep loss as far as possible [p.131]."

Extensive research efforts by the Royal Air Force Institute of Aviation Medicine, Farnborough, Hampshire, United Kingdom, by A. N. Nicholson and his colleagues,³⁻⁹ as well as those by Bryce Hartman and his associates¹⁰⁻¹⁹ at the United States School of Aerospace Medicine, have added new impetus to the search for duty schedules that do not result in sleep deficit. The work of both groups will be detailed later.

In one of the few studies of sleep during combat conditions, sleep of carrier pilots was recorded while on duty stations off Vietnam.²⁰ While total sleep time of the 27 aviators was found to be similar to 28 nonflying personnel, the aviators' sleep-wakefulness cycle was significantly different. The aviators had a far more variable intersleep interval than nonaviators. The more variable a pilot's intersleep interval, the more likely he was to make a landing error.

Concern over sleep loss is not confined to military air operations. Commercial airlines with world-wide routes have similar problems, and sleep problems are not left behind with the escape from earth into space.²¹⁻²⁵ Rapid transit of multiple time zones by Boeing 707 pilots of the BOAC was found to produce disruption of normal sleep patterns, leading the BEA/BOAC Medical Services Investigators²¹ to state that sleep disruption is probably one of the greatest problems facing airline pilots.

Irregular menstrual cycles have also been reported by stewardesses flying world-wide routes,²³ but Cameron,²⁶ in a study for Swissair, found no menstrual irregularity.

Problems of finding adequate work-rest schedules and a satisfactory sleep-wakefulness cycle have been noted during American Mercury, Gemini, and Apollo space flights^{24,25} even though Nicholson⁸ notes few complaints from Russian cosmonauts. Crew members on early space flights had trouble adjusting to the shifts in sleep-wakefulness cycles and generally reported fragmented poor sleep. When sleep on later Apollo flights was scheduled to correspond with Cape Kennedy nighttime and all crew members slept at the same time, sleep improved. The sleep of the Skylab astronauts, however, has been found to be adequate and comparable to that obtained on earth with respect to both total amount and type.²⁷ While the total sleep duration in both Skylabs I and II decreased from the 7 hours obtained on earth to 6 - 6.5 during Skylab, the reduction was due to the duty schedule restriction of the time available for sleep and not to sleep-onset problems or spontaneous awakenings. The better sleep on Skylab missions was felt to be due to the more spacious and comfortable Skylab quarters, when compared to the Mercury, Gemini, and Apollo capsules.

Sleep loss and, more often, disruption of the sleep-wakefulness cycle thus are potential problems for any flight operation that extends beyond a single day. The problem intensifies, perhaps in a logarithmic fashion, as the duration of the flight is prolonged. Of importance, therefore, are the consequences of sleep loss and sleep deficits.²⁸⁻³⁵ In evaluating the effect of sleep loss, most attention has been on the ability to carry out assigned duties. If there are no significant performance decrements, the "cost" is reported as minimal. Performance decrement following total sleep loss, even that of extended duration, however, is often absent for many tasks. Decrement following partial sleep loss is even more difficult to obtain, especially in operational situations. The absence of easily defined performance decrement following sleep loss has led many individuals, and those responsible for work schedules, to view sleep as a relatively unimportant variable. This feeling has been quite well expressed by Pai³⁶ in his account of people in England during World War II:

"For nearly six years in Greater London with a population of eight million and in many of the larger cities, the sleep of the vast majority of the population was disturbed almost nightly--either by the frequent sounding of the siren announcing the approach of enemy aircraft or by air-raids often followed by bomb explosions.

"Undisturbed sleep was almost unknown for personnel engaged in air and land warfare. Survivors of ships torpedoed at sea who clung to life-boats or wreckage were also deprived of sleep for prolonged periods.

"Hospital in-patients suffering from organic illnesses--both medical and surgical--as well as those afflicted with psychoses and neurosis were frequently awakened at night on account of air-raids and sent to air-raid shelters for safety.

"Nevertheless neither clinical, statistical nor other evidence has been forthcoming to show that even an appreciable number of normal people have suffered any physical or mental disability which could be attributed to the direct effects of insufficient sleep.... One of the lessons of the war is to emphasize that most normal people can manage on as few as six or

five or less hours of sleep without any serious detriment to their health [p.7]."

Pai's view becomes less tenable, however, when factors other than performance are taken into account and examined in some detail. Recent studies have revealed that performance degradation following sleep loss might remain small not because sleep deficit has only a minor influence on task performance, but because task performance is kept at a high level by greater compensatory efforts. As shown in the various studies by Hale and his associates,^{11,16-19} sleep-deprived subjects mobilize and expend a considerable amount of biochemical, physiological, and behavioral resources to maintain their presleep-loss level of performance. "Physiological cost," not performance decrement, is viewed by Hale and his associates as an operationally more meaningful measure of sleep-deficit effect. Expressed in terms of an analogy offered by Teichner,³⁷ task performance would be similar to rectal temperature with respect to its relative constancy, in that rectal temperature does not show a large change even under exposure to an ambient temperature of 100°F. This is not because body temperature is insensitive to high ambient temperature, but because of its being placed under the control of other body temperature-controlling activities, such as an increased sweat rate, a raised skin temperature, and an increased peripheral blood flow. As the relative constancy of body-core temperature is achieved by compensatory physiological activities, so is the relatively high level of task performance achieved by compensatory expenditure of biochemical, physiological, and behavioral resources. More attention, therefore, must be given to the physiological cost of sleep deficit. Levi³⁸ has recently suggested that repeated exposures to sleep loss and stress effects might ultimately result in the disease of stress.

To maintain operational effectiveness, how will the cost of sleep deficit be paid? How long can missions be and how often can they be repeated? There are few studies on the possible cumulative effects of repeated exposure to sleep loss. While laboratory studies of sleep loss usually record recovery sleep and performance, these recovery measures seldom extend beyond a day or two and are limited to one sleep-loss experience. The importance of determining the effects of "cumulative fatigue" is emphasized by the studies by Hale *et al.* at the U. S. Air Force School of Aerospace Medicine, and by Morgan and his staff at the Human Performance Laboratory, University of Louisville.³⁹

The relative lack of research activities demonstrating operational consequences of sleep deficit and recovery functions should not be interpreted as reflecting a total neglect of "sleep logistics." Harold Williams, when a Lieutenant Colonel in the U. S. Army, emphasized that sleep logistics were an important variable in planning for any military operation.⁴⁰ Williams advised that a dangerous shortage of sleep can develop without obvious warnings from the body... "the sleep starved man often acts like the pilot suffering from lack of oxygen, or the nitrogen-poisoned diver experiencing 'rapture of the depths,' or the happy drunk. He feels competent, 'on top of everything,' wonders why others seem concerned about his efficiency and may fly into a rage if it is suggested that he is no longer able to judge his own performance [p.13]." More recently, several reviews and conferences have detailed the importance of sleep-deprivation research in human factors, behavior, and performance.^{31,32,41-43} The effects of sleep loss on human performance and military capability have been a major area of concern for Australian, Canadian, English, and United States representatives on the Technical Panel U-2 of the Technical Cooperation Program.

One of the best-known written examples of the effect of sleep deficit and fatigue was given by S. L. A. Marshall⁴⁴ in his description of paratroopers in the 1944 Normandy operation:

"They were dull-eyed, bodily worn and too tired to think connectedly. Even a 30 minute flop on the turf with the stars for a blanket would have doubled the power of this body and quickened the minds of its leaders to ideas which they had blanked out. But no one thought to take that precaution. The United States Army is indifferent toward common-sense rules by which the energy of men may be conserved in combat.... Said Captain Patch of his people on the far right, 'They were so beat that they could not understand words even if an order was clearly expressed. I was too tired to talk straight. Nothing I heard made a firm impression on me. I spoke jerkily in phrases because I could not remember the thoughts which had preceded what I said' [p.323]."

The task accepted by the present authors is not unlike that accepted by William Harris and James O'Hanlon from the U. S. Army Human Engineering Laboratory, Aberdeen Research and Development Center, Aberdeen Proving Ground, Maryland.⁴⁵ For the Army, the goal was to determine the length of time (hours, days, weeks) a unit (or individual) can perform its (his) primary mission effectively before it (he) must be relieved, plus the length of time it (he) must rest before it (he) is operationally ready for commitment again. The main purpose for the Harris-O'Hanlon

review was to find what was known about the recovery of men from the effects of exposure to certain adverse conditions; sleep deprivation headed the list of their adverse conditions.

In their review, they found, as did we, that fatigue was a concept that appeared in studies from all areas and served as a unifying, though over-simplified, concept. Fatigue is an inevitable consequence of sleep loss. The physical activity necessary to maintain wakefulness during periods of prolonged sleep loss eventually makes it difficult to determine whether failure to respond is due to sleep loss or fatigue. Perhaps when that point is reached, sleep loss and fatigue effects are inseparable and differentiating between the two as causes for performance decrement is not meaningful.

Klein, Brüner, Ruff, and Wegmann,⁴⁶ in discussing the importance of fatigue, emphasized that terms like workload and stress should not be used as synonyms for fatigue. For them, stress is part of a workload, and workload is a cause of fatigue; hence, fatigue is the consequence of stress and workload. They emphasize that this discrimination is not only of academic interest but leads to different approaches for measuring effects of long-duration flights. The presence of environmental and situational stressors such as those present in flying, combined with disturbed sleep-wakefulness cycles or disruption in circadian rhythms, undoubtedly will affect both the rate and the ultimate level of fatigue. The rate of recovery of a degraded function will also depend, though probably not in a simple linear fashion, upon the rate of development and final level of fatigue.

In the next sections of this AGARDograph, relevant research findings following total sleep loss, partial sleep loss, deprivation of selective stages of sleep, and use of drugs to alleviate sleep problems will be presented. In the final chapter, some conclusions and recommendations will be offered. Stages of sleep, and whether one type of sleep is more important than another, have not been mentioned so far in this introduction as a potential sleep problem.* Considering the number of studies detailing the serious negative consequences of reduced dreaming sleep, rapid eye movement (REM) sleep, or the failure to go into deep sleep (stage 4), the reader may wonder at this neglect. In the section concerned with differential sleep deprivation, studies will be reviewed indicating that the early ideas as to serious consequences of not obtaining adequate dreaming (REM) sleep or stage 4 sleep have not stood the test of laboratory scrutiny and clinical observations.

Total Sleep Loss

Total sleep loss occurs when sleep is absent for more than 24 hours. Custom has counted the total awake time since last awakening as the period of sleep loss. This custom will be followed in this AGARDograph. If the period of wakefulness began one morning at 0700 hours and continued until 2300 hours of the following day, 40 hours of sleep loss are recorded even though only one sleep period of, say, 8 hours has been missed if sleep usually occurs from 2300 hours to 0700 hours.

Total sleep deprivation obviously implies complete absence of any sleep. There is some conceptual ambiguity as to the completeness of sleep loss and whether total sleep loss even occurs, especially under field conditions. Sleep is a dynamic state, and it is not a "thing" that can be cleanly excised. Polygraphic analysis has shown that after 72 or more hours of prolonged wakefulness, it is impossible to prevent subjects from obtaining brief "microsleeps." Polygraphically, these microsleeps are periods of drowsiness identified in the Sleep Manual as stage 1.⁴⁷ If the subject is not immediately aroused, these microsleeps rapidly progress into sleep stages 2 and 3. As the duration of the vigil increases, microsleeps increase in frequency. Based upon the occurrence of microsleep, Dement⁴⁸ states: "the notion of total sleep deprivation could be somewhat illusory, and could result merely in a redistribution of activity in sleep and arousal systems in which NREMS [stages 1, 2, 3, and 4] would occur in the form of hundreds of microsleeps [p.337]." According to Dement, total sleep deprivation can be likened to a denial of food at usual mealtimes. Though prohibited from obtaining food at usual mealtimes, substantial amounts of food can be eaten by numerous quick bites between regularly scheduled meals. Three leisurely meals can, therefore, be replaced with hundreds of "snacks" if they become necessary to overcome hunger. In short, three periods of meal activities can be redistributed into many short episodes of eating. Similarly, substantial amounts of sleep can be accumulated by redistributing one long sleep period (which is prohibited under total sleep-loss conditions) into hundreds of microsleeps to be snatched quickly now and then.

Dement's point is well taken, but there is no evidence to indicate that these brief periods of microsleep serve to mitigate the performance decrement and

*Criteria for EEG-EOG definitions of sleep stages and examples of EEG and EOG activity are presented in Appendix 1. An illustration of the cycles of sleep stages during a night of sleep is presented in Appendix 2.

physiological changes during sustained wakefulness. Subjects exposed to more than 200 hours of wakefulness continued their decline in all areas as sleep loss progressed, in spite of the increasing frequency of microsleeper periods.^{49,50} The lack of recuperative value from these periods of stage 1 supports those who believe that the drowsy stage 1 periods should not be viewed as physiological sleep but, rather, as a transition period between awake and asleep. Computer analysis⁵¹ of the EEG activity during awake and asleep has indicated that the bursts of 12-14 Hz spindle activity, referred to as sleep spindles,⁵² first occur during what is classified as stage 2 sleep. Based upon these data, the appearance of the first sleep spindle would be used to define sleep onset, and this criterion has been recommended.^{43,53,54} On the first night of recovery sleep following 264 hours of wakefulness, the physiological indices of the severe loss of sleep were dramatically reversed when the subject entered stage 2 sleep.⁴⁹ No physiological changes were seen during stage 1.

The rapidity with which periods of microsleeper can progress into sleep stages 2, 3, and 4 indicates why field studies of prolonged sleep loss are not feasible. Sleep-starved men rapidly go into sleep and remain asleep unless aroused, even when under strict instruction to stay fully awake. In laboratory studies where successful prevention of all sleep has been achieved and an effective testing program maintained, a characteristic pattern of performance decrement and physiological changes occurs. A brief review of laboratory studies of sleep loss will be followed by more recent studies oriented toward the goal of determining the limits for continuous performance.

Laboratory Studies

Most of the early total sleep-loss studies failed to discover predictable and consistently detrimental effects of total sleep loss on performance. Indeed, the only reliable changes, as a result of total sleep loss, were those in appearance and in mood. This lack of total sleep-loss effects on performance was surprising, considering how sleepy the subjects were outside the testing room.

Before sleep-deprivation studies were able to produce consistent and replicable sets of results, major refinements in the methods of handling performance data were necessary. The absence of responses, not the emitted responses, became the major target of research. In contrast to the earlier hypothesis which emphasized accuracy of performance, this new approach stressed that the ever-increasing number of absences or pauses in a subject's responses was the major behavioral symptom of sleep deprivation. Each brief episode of "no response" constituted performance decrement due to sleep loss. This approach recognized that, even after extended sleep deprivation, there would always be periods during which the sleep-deprived subjects would perform accurately, though these periods would become briefer and more intermittent as the hours of sleep deprivation accumulated. Broadbent,⁵⁵ in his description of this type behavior, stated: "Crudely speaking, a man is not like a child's mechanical toy which goes slower as it runs down. Nor is he like a car engine which continues normally until its fuel is exhausted and then stops dead. He is like a motor which after much use misfires, runs normally for awhile, then falters again and so on [p.2]." Performance measures (e.g., accuracy) which could not pinpoint these brief periods of "misfiring" would be less sensitive indicators of the effects of sleep deprivation.

Investigators at Walter Reed Army Institute of Research were instrumental in pointing out the importance of this lack of response.⁵⁶ Hence, this new approach was labeled "Walter Reed Lapse Hypothesis." The use of "lapse" as a measure of performance degradation was not, however, originated by this group. Patrick and Gilbert⁵⁶ described the failure of one of their subjects to memorize the digits because of his inability to focus attention. They called such failure a "kind of mental lapse." Bills⁵⁷ noted that blocks occurred in mental task performances. Bills also found that the frequency and duration of these blocks increased with fatigue and that errors tended to occur at the time of these blocks. He concluded, after detailed studies of these blocks or lapses, that they were involuntary rest periods which delayed the start of fatigue.

In a sleep-loss study of two nights, Bjerner⁵⁸ obtained, simultaneously with each subject's performance on a self-paced serial reaction test, electroencephalograms (EEGs) and electrocardiograms (ECGs). Those responses which had more than twice the average reaction time were accompanied by a transient fall in pulse rate and a decrease in EEG alpha activity. When the reaction time was 5 seconds or longer, the EEG alpha activity was replaced by delta, sleep spindles, and K-complexes, all indicative of sleep. An example of the physiological changes associated with a lapse and failure to respond is presented in Figure 1.

In 1956, the Walter Reed group undertook a series of studies on sleep loss and performance designed to evaluate tests for their sensitivity to sleep loss, and to construct tests that would be resistant to sleep loss.⁵⁹ The blending of their results and previous studies of fatigue and total sleep loss led to four predictions

Auditory Vigilance

D2:MH

44min

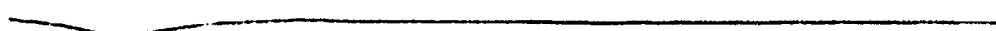
Cz-A2

50 μ v L
1 sec

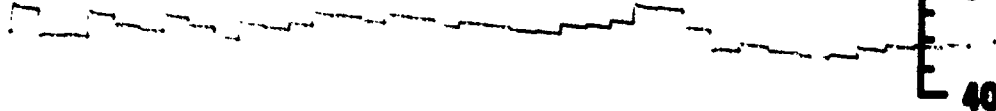
O1-A2



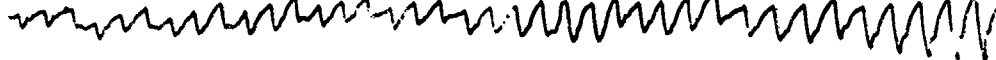
SP



HR



FP



Resp



TASK



CLICK



Fig. 1. Auditory vigilance and continuous task performance 44 minutes after task onset following two nights of sleep loss. Note as the counting task is stopped, started, and not resumed, there is an increase in EEG slow waves and vertex sharp waves as sleep nears, a decrease in HR, an increase in finger pulse amplitude, and the respiration becomes shallow. Abbreviations: Cz-A₂, O₁-A₂, central and occipital EEG placements referenced to right ear according to 10-20 System; SP, skin potential; HR, heart rate; FP, finger pulse, RESP, respiration; Task, serial counting; Click, auditory signal marker.

which became the core of the Walter Reed Lapse Hypothesis. They are:

- (1) Sleep-deprived subjects show brief intermittent lapses. These lapses increase in frequency and duration as hours of sleep loss increase.
- (2) Certain factors in a test situation tend to alert the subject, thus preventing or shortening these lapses. Some examples of the alerting factors would be (a) the massive sensory stimulation caused by physical exercise, electric shock, loud noise, adrenergic drugs, etc., (b) feedback of information upon the quality of performance, and (c) task change.
- (3) Automatic response sequences are relatively resistant to sleep loss.

(4) Many, but not all, tests will be affected by diurnal rhythm. Sleep loss will increase the magnitude of the drop in performance during early morning hours.

While the lapse hypothesis explains most performance decrements following sleep loss, especially vigilance-type tasks or tasks that require motor performance, it does not adequately account for all types of performance decrement, especially that seen in tasks that involve memory. In their exploration of memory deficits following sleep loss, Williams, Gieseeking, and Lubin⁵⁹ studied immediate recall of word lists. Since the subject was required to write down each word immediately after its presentation, they concluded the deficit was not due to failure of sensory registration that would occur during a lapse. Sleep loss appears to cause difficulties in formation of the memory trace. This hypothesis was tested and supported in a subsequent study.⁶⁰

Buck and Gibbs⁶¹ have also questioned whether the lapse hypothesis is adequate to explain sleep loss performance decrement in tasks with a high degree of uncertainty as posited by Williams, Kearney, and Lubin.⁶² Buck and Gibbs prefer to emphasize change in information processing capability rather than the tendency to take periods of microsleep though they admit the two explanations are not necessarily incompatible.

Continuous Operations and Sleep Loss

In contrast to laboratory studies where performance testing was usually done before and after predetermined periods of wakefulness, in continuous-performance studies the subjects perform their regularly assigned task during the entire period of wakefulness. In non-operational studies, the subjects perform a schedule of laboratory tasks throughout the period of wakefulness. The term "sustained performance" is preferred by some, since the performance is disrupted for meals and personal needs, but both continuous and sustained performance infer maintenance of effective performance without the usual interruptions for rest and sleep. These continuous-performance studies have more meaning for aircrew operations than do the earlier laboratory studies with their more intermittent testing program. Performance studies with sleep-loss periods of 24, 36, 40, and 48 hours also are vigils more likely to be endured by air operations personnel.

Laboratory studies: Drucker and his colleagues⁶³ studied 122 young adult enlisted tank crewmen to determine the effects of total sleep loss incurred during 48 hours of continuous operation on simulated driving and target recognition tasks. Their performances were compared with a control group of 20 enlisted men who worked on the same tasks as the experimental group but who were permitted to sleep from 0200-0700 on the first night, and from 0200-0515 on the second night. Tasks were assigned so that between-group comparisons would yield not only information about sleep-loss effects, but to what degree circadian cycle and job rotation modified the effects of total sleep loss.

The results of the 90-minute simulated driving task showed that the control group stayed on the "road" for an average of 87 of the 90-minute test (with the largest standard deviation (SD) a mere 5 minutes), whereas the continuous-performance groups showed degraded capacities to stay on the road. During the 0345-0515 time period of the second night of continuous performance, the experimental group stayed on the road for only 28.1 minutes, near the minimal possible score of 25, with a large between-subject variation as reflected by the SD of 27.8 minutes. Similarly, the capacity to detect a briefly shown signal declined over the period of continuous operation. The control group averaged scores of 8.7 target detections (SD of 2.5) or better out of the maximal score of 15, whereas the continuous-performance subjects averaged only 0.5 detections (SD of 0.9) during the 0200-0330 period of the second night of continuous performance.

Both task performances showed large circadian effects, and it should be noted that the control group was never tested during the early morning hours since they were allowed sleep during these hours. Task performance deteriorated during 0400-0700 hours on the second night of continuous performance when the effects of total sleep loss interacted with the trough of circadian cycle. Daytime performance was always much improved over these early morning scores, in spite of continued accumulation of hours of work. The authors state: "The sharp differences in performance level that occurred between day and night hours suggests that it is somewhat misleading to speak of the relationship between sleep deprivation and performance. After the same number of hours of sleep deprivation, performance may be at a relatively high level, or at a relatively low level, depending upon the time of day in question [p. 23]." Performance deterioration during daylight hours, however, was large enough to prompt the conclusion that "It therefore appears that there is relatively little gain in total productivity as a result of working for 48 hours without sleep, compared to working a shorter period with time off for sleep. Performance during the second night of the experiment was so poor that the subjects... might as well have been allowed to leave the experimental situation to sleep [p. 23]." Job rotation helped to improve task performance slightly, but the job

changes were not sufficient to overcome the enhanced sleep-loss effects during night performance. The authors suggested that fatigue could be reduced by limiting the continuous performance from 48 hours to 36-40 hours if the continuous task performances were started in the morning.

Morgan and his colleagues⁶⁴ used the Multiple Task Performance Battery (MTPB) to determine the effects of 48 hours of continuous performance. The MTPB consists of six tasks: three monitoring tasks, arithmetic computations, code-lock solving, and target identifications. Altogether, 13 scores can be obtained from these six tasks. These scores can be individually evaluated over the experimental periods, or can be combined to yield an index of general performance. Since these six tasks can be run simultaneously to force human operators to time-share their capacity or to increase or decrease workload, the MTPB is said to represent real-life work situations better than simple addition or vigilance tasks.⁽⁵⁻⁶⁷⁾

After 48 hours of practice on the MTPB, the 10 young adult subjects were placed on a work-rest schedule of 4 hours on-duty, 4 hours off-duty, 4 on and 12 off (4-4-4-12), for two days before the 48-hour period. The 48 hours of continuous performance were followed by one full day of rest and recovery, and then two more days of the 4-4-4-12 work-rest schedule. To measure subjective changes associated with fatigue and stress of continuous operation, subjects completed an adjective check list and a subjective stress scale. Data on muscular output were also measured with a strain-gauge hand-grip dynamometer.

Morgan and his associates found, as had Drucker *et. al.*, that even though performance did not always follow the diurnal cycle during normal work periods, it was likely to do so during periods of continuous operations. With respect to the index of general performance, the subjects were able to maintain their performance near 100% of baseline for approximately 18 hours before it dropped to nearly 81% of baseline during the last 8 hours of the first 24-hour period of continuous operation. This period happened to be near the end of the first night. Performance improved during the second day of work to above 80% efficiency for approximately 38 hours before falling to a low point of approximately 67% of baseline during the night of the second 24 hours of continuous work.

Muscular strength and endurance did not show any change due to sleep loss or fatigue. The daily group averages of all 10 subjects on the adjective check list yielded significant correlations: -0.50, -0.40, and -0.52 between daily averaged performance scores and daily averaged anxiety, depression, and hostility scores, respectively, and -0.45 between daily averaged performance scores and the daily averaged subjective stress scale scores. The depression score was higher on the second day of continuous performance.

In one of the few studies with other than young adult subjects, 31 officers and corporals (mean age of 29, with a range of 20-44) and 32 senior officers (mean age 56, with a range of 49-64) were examined to determine the effects of 72 hours of continuous performance on performance, biochemistry, and subjective ratings.⁶⁵ A work-rest schedule of 2.75 hours on-duty/0.25 hours off-duty was used. "Rest" periods were spent answering questionnaires about fatigue and distress, voiding urine for analysis of adrenalin and noradrenalin, and ingesting a standard sandwich meal. For the younger group of officers and corporals, the task was electronic rifle firing. For the 32 senior officers, the 2.75-hour period of rifle firing was alternated with a 2.75-hour period of performing "intellectual tasks" involving simulated military staff work with registration of tape-recorded data, interpretation of these data on a map, extraction and reproduction of requested information based on the data in question, and some paper-and-pencil tests.

Only the younger group of officers and corporals showed performance decrements for both the number of total shots fired and the number of hits achieved. The shooting performance of these younger officers and corporals declined nightly during the 2400-0800 period. During the first night of continuous performance, the number of shots was reduced from a baseline of 1200 by 100. Their performance improved during the day, but only to drop precipitously to 600 shots during 2300-0800 on the second night. In spite of the continuing accumulation of sleep loss, performance improved somewhat during the following day and they fired 900 shots, but the number of shots declined again to a low level of 600 on the third and last night of the continuous operation. The rifle firing performance by the older senior officers, who had alternate tasks, did not decline over the 3-day span of this experiment. The senior officers resisted the effects of sleep loss, not by maintenance of high work output throughout the period of continuous operation but by starting at a low level of firing and maintaining that low level. At the start of the continuous operation, the senior officers paced themselves by shooting only 1/6 of the 1200 shots fired by the younger group.

Both groups showed increasingly higher self-ratings of fatigue on which circadian fluctuations were superimposed. Self-ratings of fatigue were higher for the younger group than for the group of senior officers. Fatigue ratings peaked at

about 0300-0500 hours. The peak of fatigue on the second night was much higher than that observed at the corresponding time on the first night, while the peak fatigue rating on the third night was at approximately the same level as on the second night, suggesting a flattening of fatigue level after it reached its maximal value during the latter part of the second night. Stress ratings showed a similar pattern, but the increase was minor over the 3-day span.

Field studies: The difficulty of generalizing laboratory findings to operational settings is clearly illustrated in the attempt by Haggard⁶⁹ to replicate the laboratory study by Drucker *et al.*, cited on page 7, that sleep-deprived tank crewmen performed less well on a driving task than a non-sleep-deprived control group. Like Drucker *et al.*, Haggard had one group of tank crewmen on a 48-hour continuous field exercise with no provisions for rest or sleep. The control crewmen performed the exercise on a 12/24 work-rest schedule. Performance tasks included gunnery, surveillance, communications, driving, and maintenance tasks administered at 12-hour intervals. The results of the field test did not confirm those found in the laboratory, as there were no performance decrements that could be attributed to fatigue as a result of the continuous exercise. From these results, Haggard concluded, "it would appear that the usual laboratory situation requiring continuous performance of a single task does not sufficiently duplicate the job situation where many tasks must be performed, any one of which occurs only periodically. Thus we might well question the continuing use of standard tasks in present laboratory situations to predict job performance in real-life situations [p.8-9]."

The conclusions from other field studies involving continuous performance are similar to those of Haggard. Soldiers tested intermittently during 44 hours of "continuous" operations showed no decrement on target detection with night vision devices, live rifle fire, and grenade tossing, between the first and second day of the operation.⁷⁰ Like Haggard, Banks *et al.*⁷⁰ concluded, "When properly motivated, soldiers can perform at a stable level with no loss in efficiency on important combat-related tasks during a 44-hour period of continuous military operations [p.7]."
Unfortunately, this study had no control group for comparison with the sleep-deprived subjects.

In another armored tank crew study,⁷¹ 40 young adult enlisted men were designated as the control group, and 80 worked continuously for 48 hours. Tasks covered the areas of communication, driving, surveillance, gunnery, and maintenance. The overall conclusion of Ainsworth and Bishop on driving tanks continuously over 48 hours was that "an extended period of activity results in significant, but relatively minor decrements in the performance.... [p.26]."

To determine the effects of sleep loss on auto driving, 11 male university students, ages 20-25, were asked to drive under three conditions: (1) daylight (driving started at 0800-0900), (2) darkness (driving started at 2000-2100), and (3) daylight, after one night of total sleep loss.⁷² The driving course consisted of 38 km on national roads (about 30 minutes), four laps of 56 km on a motor way (about 3 hours), and the 38 km back to the starting point--a total of 300 km. The maximum speed was set at 90 km/hour, and the driving lasted for about 4 hours. Since subjects underwent all three driving conditions, care was taken to interpose at least 48 hours of recovery period before the subjects drove the next experimental tour. While driving, the subjects intermittently received a 90 dB 1 KHz tone which was to be terminated as quickly as possible by pressing with the left foot a microswitch situated between the brake and clutch pedals.

The results indicated that "a night without sleep, relative to a night with sleep, does not necessarily deteriorate subsequent driving performance [p.340]."
However, two out of the 11 subjects showed increased reaction time in turning off the tone. One of those two subjects had to be taken out of the experimental driving tour at the midpoint. Noting the large variability in performance from subject to subject, Lisper and his associates raised the question of individual difference in susceptibility to sleep loss or to monotonous test conditions.

It should be noted that Lisper and his colleagues tested driving after one night of total sleep loss only during the day. The effect of total sleep loss on nighttime driving when the circadian cycle would interact with the effects of sleep loss was not investigated.

Factors that modify sleep-loss effects: Why are some tasks more sensitive to total sleep loss? What factors are responsible for making these tasks sensitive to total sleep loss? Do these factors help explain some of the differences found between laboratory and field studies? Seven factors have been identified.

(1) Duration of task

The longer the task, the more sensitive it is to total sleep loss. Total sleep loss of 50 hours causes impairment after only 3 minutes of a visual vigilance task. Seventy hours of total sleep loss cause decrement on a vigilance task after

2 minutes.²⁹ Total sleep loss of one night had no appreciable effect on task performances during the first 5 minutes on a 5-choice test of serial reaction, vigilance, and addition, but clear-cut performance deterioration emerged when performance was evaluated after 15-minute task sessions.^{73,74} Following one night without sleep, the number of additions attempted on the Wilkinson addition test decreased significantly from baseline level after 10 minutes of testing.⁷⁵ Following two nights without sleep, the number of additions attempted was clearly decreased after only 6 minutes. Fifty minutes of testing were required to detect a significant decrease in accuracy after one day of sleep loss, while only 10 minutes were required the second day.

(2) Knowledge of results

By immediately feeding back to the subject information as to how well he had performed each task, total sleep loss of 30 hours did not appear to impair performance on 1-hour 5-choice serial reaction and vigilance tests.⁷³ Immediate feedback of quality of task performance, thus, minimizes the effects of total sleep loss.

(3) Difficulty of task

Performance on difficult tasks is more sensitive to total sleep loss. A simple task, such as addition, can be made very difficult by asking the subject to add quickly. Mental addition at a rate of one addition per 2 seconds did not reveal the effects of two nights of sleep loss, but by increasing the speed of addition to one addition every 1.25 seconds, i.e., a 38% speed increase, the effects of sleep loss of two nights were detected.⁷⁶

(4) Task pacing

Self-paced tasks resist sleep-loss effects much better than work-paced tasks. In self-paced tasks, even though lapses could prevent the completion of a task by causing the subject to lose his place, as soon as the lapse ends, the task is resumed. The effects of total sleep loss show up in the increased time needed to complete the self-paced tasks, although there are fewer errors of omission and performance accuracy is high.

(5) Proficiency in task performance

Newly acquired skills, such as those involved in driving a car by a person who has just passed his driver's test for the first time, are more affected by loss of total sleep than those skills which have become almost automatic or second nature.

(6) Task complexity

The more complex the task is, with respect to sequence of mental operations and/or the orderly execution of complex muscular activities, the more likely it is to be sensitive to sleep loss.^{77,78}

(7) Memory requirements

Any task which requires a short-term memory chain will be affected by sleep loss.^{59,60}

In summary, the long, work-paced, complex tasks with high attention and vigilance requirements and which do not provide information to the subject on how well he is performing can be expected to show higher sensitivity to total sleep loss.

There are two major classes of non-task factors which also influence the outcome of total sleep loss on performance. They are:

(1) Psychological factors

(a) High interest. Ax and his colleagues⁷⁹ suggested that interesting tasks resist the effects of loss of total sleep. The battle game was found to be so interesting that sailors could work on the game for one hour without showing the effects of over 50 hours of total sleep loss.⁷⁸

(b) Motivation. While tasks of high interest usually have high motivational value, a distinction between high interest and motivation should be made. For example, a serial learning task which may have little interest to the subject can become highly motivating if his performance is monitored by his supervisor. High motivation tasks showed no significant performance decrements after one night of sleep loss, but most of the low motivating tasks resulted in poor performances. In general, high motivation will counteract the effects of total sleep loss, but there is a point beyond which the sheer need for sleep will overwhelm even the

subject's willingness to work.

(c) Personality. The role that personality factors play in determining sleep-loss effects is unclear. No relationship was found between scores on a psychological test of introversion-extroversion and neuroticism and the degree of performance after total sleep loss of one night,⁸⁰ but, in another study,⁸¹ extroverts were affected more than introverts by loss of 60 hours of sleep, as measured by a pursuit tracking task.

(d) Repeated experiences of sleep loss. Repeated exposures to total sleep loss increased the effects of such sleep loss on task performance.^{39,73}

(e) Behavioral periodicity. The severity of the effects of total sleep loss depends, in part, on the time of day that measures of performance are obtained. Sleep-deprived subjects may appear quite normal and perform very well in the early afternoon when most have peak behavioral efficiency, but the same subjects will show a marked deterioration in their performance in the early morning when sleep-loss effects combine with unusually low behavioral efficiency. Ignorance of behavioral periodicity was a factor in some of the studies reporting no significant effects of total sleep deprivation. Measures of performance taken at different times of the day reflect behavioral periodicity as well as the effects of increasing sleep debt. Klein and his associates⁸² have stressed the interaction of sleep loss and circadian rhythms and the need to establish a single time in the 24-hour period as a point of reference. They prefer to use the lowest level in the early morning.

(2) Situational factors

(a) Physical exercises. Physical exercises just prior to performing tasks helped reduce performance decrement caused by total sleep loss.⁷⁴

(b) Noise. White noise, 90 to 100 dB, in an open field lessened the effects of total sleep loss on auditory vigilance performance and on the 5-choice test of serial reaction.^{83,84}

(c) Temperature. A moderate ambient temperature of 30.5°C does not increase the effects of total sleep loss. There are no conclusive data on the interactions of extreme heat or cold on effects of total sleep deprivation on performances. Occasional cold stresses, e.g., immersing the face in ice-cold water and/or alcohol rubs with an electric fan blowing air onto the subject, help combat spells of extreme sleepiness.

(d) Drugs. Amphetamine appears to be the only effective drug which has been widely used in combating the effects of total sleep loss.⁸⁵⁻⁸⁷ Oral intakes of 15 mg dextro-amphetamine almost halved the behavioral impairment caused by 68 hours without sleep on a work-paced vigilance task.⁸⁶ Dextro-amphetamine was effective in completely eliminating small effects of sleep loss which occurred in self-paced tasks. Depending upon the dosage, alcohol was found to counteract the effect of moderate amounts of total sleep loss.⁸⁸

(e) Breathing atmosphere. Hypoxia and inert gas narcosis (especially nitrogen narcosis) produce performance degradations which are similar to the effects of total sleep loss. Hypoxia and inert gas narcosis may potentiate the effects of total sleep loss on performance, although this contention has not yet been studied experimentally.

The above factors alleviate the effects of sleep loss and may explain why it is difficult to detect sleep-loss effects in field studies. In addition to the problem of insuring that total sleep loss actually occurs, the types of tasks, the subject's motivation, and the environmental setting all mitigate against marked sleep-loss decrements. To show sleep-loss effects for less than 48 hours of wakefulness, the tasks must be long, repetitive, boring, with no feedback as to accuracy, and preferably work-paced. It is these types of tasks, which are most sensitive to lapses, that have been used by laboratories with positive sleep-loss results and which are least likely to be part of operational duties.

Other Effects of Total Sleep Loss

Mood and Behavioral Changes

The most often reported changes are increased feelings of fatigue, irritability, transient feelings of persecution, inability to concentrate, and periods of misperception and disorientation. These feelings can appear after one night of sleep loss and are present, to some degree, in all subjects following two nights without sleep. Illusions and hallucinations, when present, are primarily visual and tactile in contrast to the primary auditory hallucinations of the schizophrenic. As was found for performance decrement, these changes become more intense as the

period of sleep loss progresses and are generally more pronounced in the early morning hours. The subject appears to be able to reconstitute his energies during the afternoon and early evening hours with a resultant increase in his feeling of well-being and in his performance. It is of interest that this behavioral cycle of decreasing and increasing effectiveness follows very closely the decreased and increased presence of 8 to 12 Hz (alpha) activity in the EEG over a 24-hour period.^{29,89} Based on the studies at Walter Reed Army Institute of Research, scales were developed by which changes in visual perception, temporal disorientation, and cognitive disorganization could be quantified.⁹⁰ These perceptual changes are not as common as the changes in feelings noted earlier and usually do not appear before 60-72 hours of wakefulness.

Noting that mood changes often preceded clearly defined performance decrement, the Navy research group in San Diego constructed a mood scale which is sensitive to changes in subjective state following one night of sleep loss.⁹¹ This scale, with scoring instruction, is presented in Appendix 3. After sleep loss, subjects describe themselves as less active, alert, carefree, able to concentrate, etc. Assuming accurate and honest reporting, the use of this simple and rapid measure of feelings could be used as a means of detecting sleep-loss effects before they become obvious in performance decrement.

Earlier views^{92,93} that prolonged sleep deprivation results in a psychotic state that persists after deprivation have not been supported by the follow-up studies of subjects deprived of more than 200 hours of sleep.^{31,94} In studies where florid psychotic behavior accompanied sleep deprivation, some predisposition of the subject seemed evident. Each subject's response to sleep loss depends upon his age, physical condition, the stability of his mental health, expectations of those around him, whether drugs or stimulants are used to maintain wakefulness, and the support he receives from his environment.

Neurological Changes

While the behavioral and cognitive changes after prolonged sleep loss are often pronounced, the neurological changes are generally minimal. A mild but quite fleeting nystagmus and a mild tremor were noted in the upper extremities, primarily in the hand-extended posture after 205 hours.⁹⁵ Intermittent mild slurring of speech was evident from the seventh day and mild drooping of the lids (ptosis) from the third day in all subjects. After 264 hours, dysconjugate gaze, a coarse, clockwise, rotary nystagmus on looking up to the right, a marked ptosis, sluggish corneal reflexes, expressionless face, possible impairment in taste, a hyperactive gag reflex, hyperactive deep tendon reflexes, and an increased sensitivity to pain were evident.⁹⁶ The rotary nystagmus was not observed by the University of California, Los Angeles, researchers;⁹⁵ instead of hyperactive reflexes, their subjects' reflexes tended to be diminished. In neither study were motor, sensory, or coordination dysfunctions reported. Hand tremor was a prominent feature of the examinations in both studies. No definitive explanation for the ocular muscle dysfunction or hand tremor was offered by either group. After 60 hours of sleep loss, a marked loss (20-40%) in neck flexion strength and a general increase in hand tremor were observed.⁹⁷ Three of these nine young adult sailors experienced lateral nystagmus, and four experienced clumsiness and lack of serial coordination in fine adjustive hand movements. None showed any impairment of visual acuity or general muscular strength, although four showed increased sensitivity to pain.

Where done, values of routine clinical laboratory studies have been within normal limits following sleep loss.

Electroencephalographic (EEG) Changes

Following total sleep loss, there is invariably a decrease in percent of waking alpha activity and an increase in percent of delta and theta. In a detailed quantitative analysis of EEG spectra during 205 hours of wakefulness, alpha occupied 60-70% of total EEG activity; delta 14-20%; theta 11-14%; and a small amount of beta up to 60 hours of wakefulness.⁹⁸ Beyond 100 hours of sleep loss, delta increased to 31-44%; theta to 20-33%, with a concomitant decrease in percent alpha. There was virtually no change in EEG beta activity during the 205 hours of sleep loss. The decrease in alpha abundance tended to stabilize after the 100-hour period and, with additional sleep loss, the four subjects tended to regain some alpha but its abundance never approached the pre-sleep-loss level. The decrease in alpha associated with increase in bursts of delta activity was usually associated with periods of brief sleep.

After about 115 hours of sleep loss, closing of the eyes failed to generate alpha activity.⁸⁹ In a single subject, after 249 hours of sleep loss there was no EEG response to eyes opening and closing and external stimuli did not produce alpha enhancement.⁴⁹

Another EEG response that decreases and finally disappears with sleep loss is

the surface-negative slow potential (CNV) associated with an expectancy to respond.⁹⁹ A 4.5-second period between the warning stimulus S_1 and the imperative stimulus S_2 was used to study the CNV under baseline, total sleep deprivation, and recovery conditions in 8 subjects. The S_1 (warning stimulus) was a click; the S_2 (imperative stimulus) was a set of photo-flashes. During baseline, all subjects developed the CNV between S_1 and S_2 . One night of sleep loss decreased CNV amplitude, and two nights of sleep loss abolished the CNV. Figure 2 illustrates the response from a single subject. All 8 subjects showed the decrease in CNV following sleep loss. Only those CNV trials with a background EEG indicating a waking state and with a reaction time of less than a second were used in this analysis. The results were not due to sleepiness but rather to sleep loss and appeared to reflect the performing of the routine, well-learned task without the usual cortical involvement. After one night of recovery sleep, however, the CNV returned while performing the same well-learned task.

SLEEP LOSS & CNV

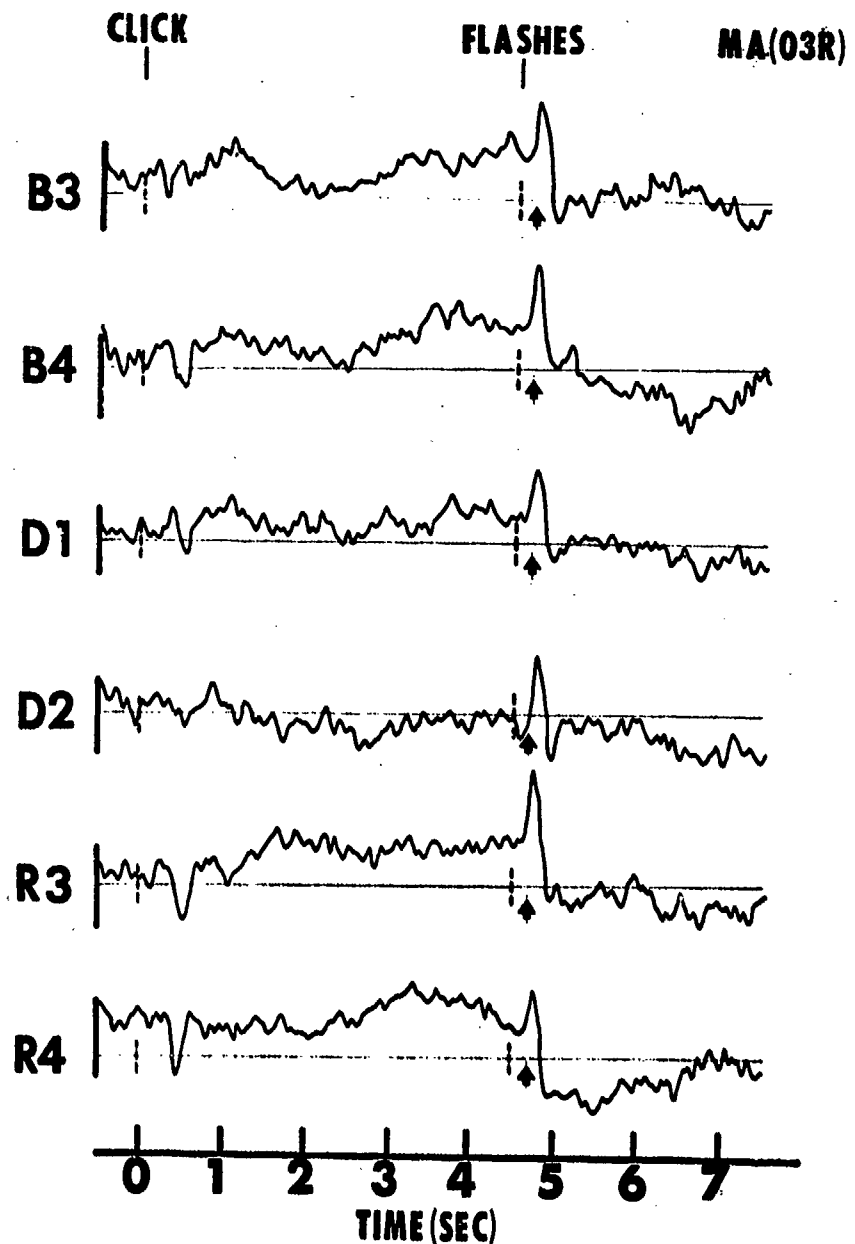


Fig. 2. Disappearance of CNV for single subject during baseline (B₃ & B₄) following one (D₁) and two (D₂) nights with sleep and after the third (R₃) and fourth (R₄) nights of recovery sleep. Average reaction time to stimulus flash is shown by arrow.

Of particular interest to aircrew operations is that sleep deprivation is a well-known activating technique often used in EEG laboratories to induce EEG seizure discharges.¹⁰⁰ Sleep deprivation and fatigue were major precipitating factors in 80 adult patients admitted to the San Diego Naval Hospital with a first seizure and with a provisional diagnosis of epilepsy.¹⁰¹ Grand mal seizures following sleep deprivation in aircrew personnel have also been reported by Bennett.¹⁰² In another study,¹⁰³ 41% of 114 seizure patients with normal or borderline interictal electroencephalographic tracings had unequivocal abnormalities after 24 to 26 hours without sleep. Thus while the neurological changes and changes in the EEG following prolonged sleep deprivation are minimal in healthy young adults, for those with seizure disorders or those susceptible to convulsions, sleep deprivation can be a highly activating stress.

Biochemical Changes

The physiology of sleep deprivation is unclear. It was initially expected that sleep deprivation, like many other stresses, would result in activation of the pituitary-adrenal cortical axis or in a disruption of its circadian pattern. Conflicting results have been reported. Tyler, Marx, and Goodman¹⁰⁴ found that the urinary excretion of 17-ketosteroids was little affected by 112 hours of wakefulness and the change they did report was a slight decrease rather than an increase. Although changes were apparent during 205 hours of deprivation in both the amount of catecholamine output and in the circadian pattern, these changes were not of sufficient magnitude in each of 4 subjects to yield statistically significant differences when compared with the predeprivation levels.¹⁰⁵ A definite increase in 17-hydroxycorticosteroids, however, was found during the second half of the 205-hour vigil. Similar insignificant findings have been reported following 86 hours of sleep loss with respect to the catecholamine output.¹⁰⁶ Not only was there no change in urinary excretion patterns in the 6 young men but the ability to regulate body temperature was not impaired by the loss of sleep. It was concluded that, despite gross psychomotor impairment during sleep deprivation, physiological regulating systems are relatively unaffected by sleep loss. The demands on production of energy in the efforts of staying awake stimulated high-energy turnover in the red cell while depleting levels of adenine phosphates following more than 40 hours without sleep.⁹² Despite continued efforts to maintain arousal, however, the mechanisms associated with energy production began to fail after only 48 to 96 hours of sleep deprivation, possibly because there were inadequate amounts of adenine phosphates to operate the ATP cycle. Unfortunately, this study of the energy transfer system has not been repeated. Also, the relation between the biochemistry of the red cell and that of the neuron is open to question, and the changes that have been reported may be simply a manifestation of muscular exertion.

The importance of circadian variations in biochemical changes and their relation to fatigue and performance have been detailed in two 75-hour sleep-deprivation studies involving 63 subjects.⁶⁹ Catecholamine excretion, psychomotor performance, as well as psychological ratings were measured every 3 hours. The psychomotor performance was a rifle shooting task reviewed earlier under field studies.

All biochemical variables, as well as fatigue and distress ratings, exhibited circadian rhythms even though care had been taken to insure uniform activity, ingestion of food and fluid, body posture, and in spite of minimal cues as to actual time of day. Adrenalin had its maximum values in the afternoon and its minimum values in the early morning, while noradrenalin and urine flow peaked during the morning hours. Fatigue ratings were lowest at about the same time as the adrenalin maximum. Adrenalin excretion thus was highly positively correlated with performance and negatively correlated with fatigue ratings. The reverse was true for noradrenalin excretion. Though performance deteriorated and fatigue ratings increased over time, with changes most noticeable during early morning hours, there were no marked changes from day to day in catecholamine excretion or diuresis.

An important question in the types of psychophysiological correlations reported in this study is how much of the progressive changes noted was due to sleep loss *per se*. Assuming that the effects of sleep loss were approximately linear (a questionable assumption), partial correlations were used to control for sleep loss. The results indicated that the negative correlation between adrenalin values and fatigue ratings was still significant and thus not due to sleep loss. Partial correlations between noradrenalin and performance and fatigue, however, were not significant, indicating that sleep loss was an important factor in the positive relationship of noradrenalin to performance and fatigue.

Autonomic Nervous System Changes

The autonomic system shows no gross impairment in its ability to regulate and maintain the homeostatic balance of systems under its control during moderate sleep loss. As with the biochemical findings, where changes have occurred, they have been conflicting, and, like the data from the EEG, the results have been interpreted as indicating both an increase and a decrease in arousal level.¹⁰⁷ The varying

length of deprivation, the different units of measurement, and conditions during which the measurements were made, all contribute to the varying results. After 120 hours without sleep, 4 subjects showed no change from predeprivation basal levels in heart rate, respiration rate, skin resistance, finger pulse volume, body temperature, or blood pressure.¹⁰⁸ Even after 264 hours without sleep, the changes in heart rate, respiratory rate, blood pressure, and oral temperature were not remarkable.⁴⁹ There were, however, significant decreases in basal skin resistance and in finger-skin temperature, and marked vasoconstriction in the fingers. All of these findings appear to reflect a peripheral vascular response to stress.

The most dramatic finding in the subject who was without sleep for 264 hours was the almost total absence of all autonomic responses to external stimuli.⁴⁹ Naitoh *et al.*⁸⁹ reported a similar failure of the evoked electrodermal response, but the autonomic responses of the other autonomic measures, while variable, were not exaggerated as their subjects approached the 200-hour mark.

The studies to date, however, indicate that sleep loss up to at least 130 hours, well beyond the limits of most continuous operations, can be endured without marked changes in the autonomic nervous system.

Recovery

After sleep deprivation, how long will a person sleep, and is the recovery sleep time linearly related to the length of deprivation? The answer to the last question is no. The amount of recovery sleep reported following sleep loss varies between 12 and 15 hours. After 264 hours without sleep, a young adult male slept only 14 hours and 45 minutes before awakening.⁴⁹ Generally, after one night of 8 or more hours of unrestricted recovery sleep, there is a dramatic reversal of the acute sleep-loss pattern of behavior and decrement of performance. Subjects deprived of 2 to 4 nights of sleep returned to 90% in performance after one night of recovery sleep, but feelings of fatigue often persisted for 2 to 3 days and the EEG often did not show the predeprivation alpha percent before 3 days.²⁹

In the most systematic and detailed study of the recovery sleep and its relation to length of prior sleep loss, 10 subjects, ranging in age from 17-21, were exposed to multiple periods of sleep loss.³⁹ For the 5 subjects in Group A, the first experimental condition consisted of 2 days of 4-4-4-12 work-rest schedule, 44 hours of continuous work, followed by 4 hours of sleep, and then 2 days of 4-4-4-12 work-rest schedule. Group A subjects were permitted to recover for 8 days before they started 36 hours of continuous work on a 4-4-4-12 work-rest schedule, followed by 4 hours of sleep, and then 2 days of 4-4-4-12 work-rest schedule. Again the subjects were permitted to rest for one week before they repeated the cycle, but, this time after the continuous work period, they were allowed only 3 hours of sleep. During the next and last cycle, the subjects were allowed 2 hours of sleep after the 36 hours of continuous performance. The 5 subjects in Group B differed from Group A in the sequence of allotted recovery sleep. Group B experienced 4 hours of sleep after the first continuous work period, then they followed the identical schedule of Group A, until the last session when Group B had 44 hours of continuous work followed by 4 hours of sleep. All subjects in Group B, as in Group A, experienced a "performance/recovery" cycle of 6-day performance/8-day recovery.

The index of general performance on the MTPB remained at approximately 100% for the first 16 hours in the 44-hour continuous performance. Then the task performance level declined to 86% of the baseline during the early morning hours of the first night period. During the following day, task performance improved to baseline levels, only to dip to 82% of the baseline during the early morning hours of the second and last night periods. The only significant performance decrement during both the 36 and 44 hours of continuous performance was during the night. Daytime performance showed no decrement. During baseline testing, the nighttime performance was similar to daytime levels.

Recuperative effectiveness of sleep was evaluated by the percent of recovery immediately following sleep from the observed maximum nighttime decrement during continuous performance. After 44 hours of continuous performance, 4 hours of sleep resulted in an immediate recovery of 39%. Four hours of sleep resulted in 75% recovery following 36 hours, but 3 hours of sleep resulted in only 56%, and 2 hours of sleep resulted in 76% recovery. After 12 hours of sleep, 100% recovery was seen. From their results, it was concluded that the minimum amount of sleep required for the recovery of performance after 36 hours of continuous work is between 6 and 8 hours.

Morgan *et al.*³⁹ were comparing recovery against the maximum decrement found at night, but they did not report the time that recovery testing occurred. Failure to control for time of testing may explain the seemingly incongruous better 76% recovery following 2 hours of recovery sleep when compared with the 56% after 3 hours of sleep. Current studies are designed to control for circadian influences.

Though there may be some question as to the recovery percent, this study again showed the importance of the circadian cycle in continuous work, even when performance was insensitive to circadian effects during normal work schedules. During sleep loss, performance decrements began to occur after midnight and reached a maximum during the 0200 to 0600 hours.

This study also demonstrated another crucial modifier of total sleep-loss effects on task performances: repeated exposures to total sleep loss. All subjects were exposed to conditions of continuous work 4 times in a 10-week period. The results suggested that "if subjects are required to work several successive continuous-work-and-recovery cycles..., their performance likely will be significantly poorer during successive work sessions and greater amounts of sleep will have to be provided during successive recovery periods in order for full recovery to occur [p.30]."

In addition to how much recovery sleep is necessary, the question often asked is: Is recovery sleep different and does one type of sleep have more recuperative value than another? On the first recovery night after sleep loss, there is invariably an increase in slow-wave sleep (stages 3 and 4) over that present before deprivation.¹⁰⁸⁻¹¹⁰ REM sleep usually stays at pre-sleep-loss levels or decreases on the first recovery night. If an increase in REM sleep occurs, it is usually seen on the second recovery night. Quantitative analysis shows that the increase in slow-wave sleep (SWS) is due to both an earlier entry into SWS and longer duration of the SWS periods (see Figure 3). Most of the increase in SWS occurs during the first 4 hours of sleep with no marked changes in the delta cycles.

As part of an extensive research program on the function of sleep stages, the relative recuperative value of stage REM and stage 4 sleep following sleep loss has been examined.¹¹¹ Performance measures on addition, memory, and vigilance tasks, measures of affect and mood, and indices of autonomic and central nervous system activity were obtained from 12 Navy enlisted men, ages 17 to 21. Following two nights of sleep loss, 4 subjects were allowed four nights of uninterrupted sleep, 4 subjects were denied stage REM sleep for two nights and then allowed two nights of uninterrupted sleep, and 4 subjects were denied stage 4 sleep for two nights before obtaining uninterrupted sleep.

All sleep-deprived subjects improved after the first night of recovery sleep and there was no significant difference in the amount of performance recovery for the three kinds of sleep. Subjects deprived of REM sleep or stage 4 sleep showed the same degree of recovery as those subjects with uninterrupted sleep. Performance on the Auditory Vigilance Task presented in Figure 4 is representative of all the tasks. As with the performance tasks, the return to the predeprivation psychological states was the same regardless of the type of recovery sleep. Measures of autonomic and central nervous system activity also showed no significant differences between the REM- and stage 4-deprived groups.

The findings offered no support for the belief that stage REM or stage 4 has unique recuperative values. Following sleep loss, the amount, rather than the type, of sleep appears to be the most important factor.

In summary, total sleep loss of greater than 60 hours may be expected to produce some neurological, physiological, biochemical, performance, behavioral, and mood changes. The degree of change depends upon the individual but, as sleep loss progresses beyond 60 hours, changes will eventually be evident in all areas. Sleep loss up to 264 hours has been endured with complete recovery after 3 nights of recovery sleep. Such prolonged sleep loss, however, is not anticipated as a result of most flight schedules. Total sleep loss of 40-48 hours would probably be the upper limit with loss of 30-36 hours more likely. These amounts of sleep loss can be tolerated without debilitating changes in the physiological system. If any effects are noted, they will, in most instances, first be evident by changes in mood. Performance changes will be minimal if the tasks are brief, self-paced, highly motivating, and feedback is given as to adequacy of response. Tasks that require sustained vigilance and attention, use of newly acquired skills, retention of new information, and which necessitate long periods to complete are more likely to show sleep-loss effects. Most of the decrement will occur during periods of brief sleep. These effects are more likely to occur during the early morning hours when body temperature is low. Performance workload should be reduced during hours when sleep would normally occur, regardless of actual time of day.

Partial Sleep Loss

Most crew members will be able to obtain some sleep even during long missions. Other crew members can take over for short periods or awaken the sleeping member if his skills are required. In most long flights, rest stops and crew changes are scheduled. The work by Nicholson, Preston, Hartman, and Britson, cited in the introduction, noted that reduction in the usual amount of sleep and disruption of established sleep-wakefulness cycles were the most frequently observed sleep

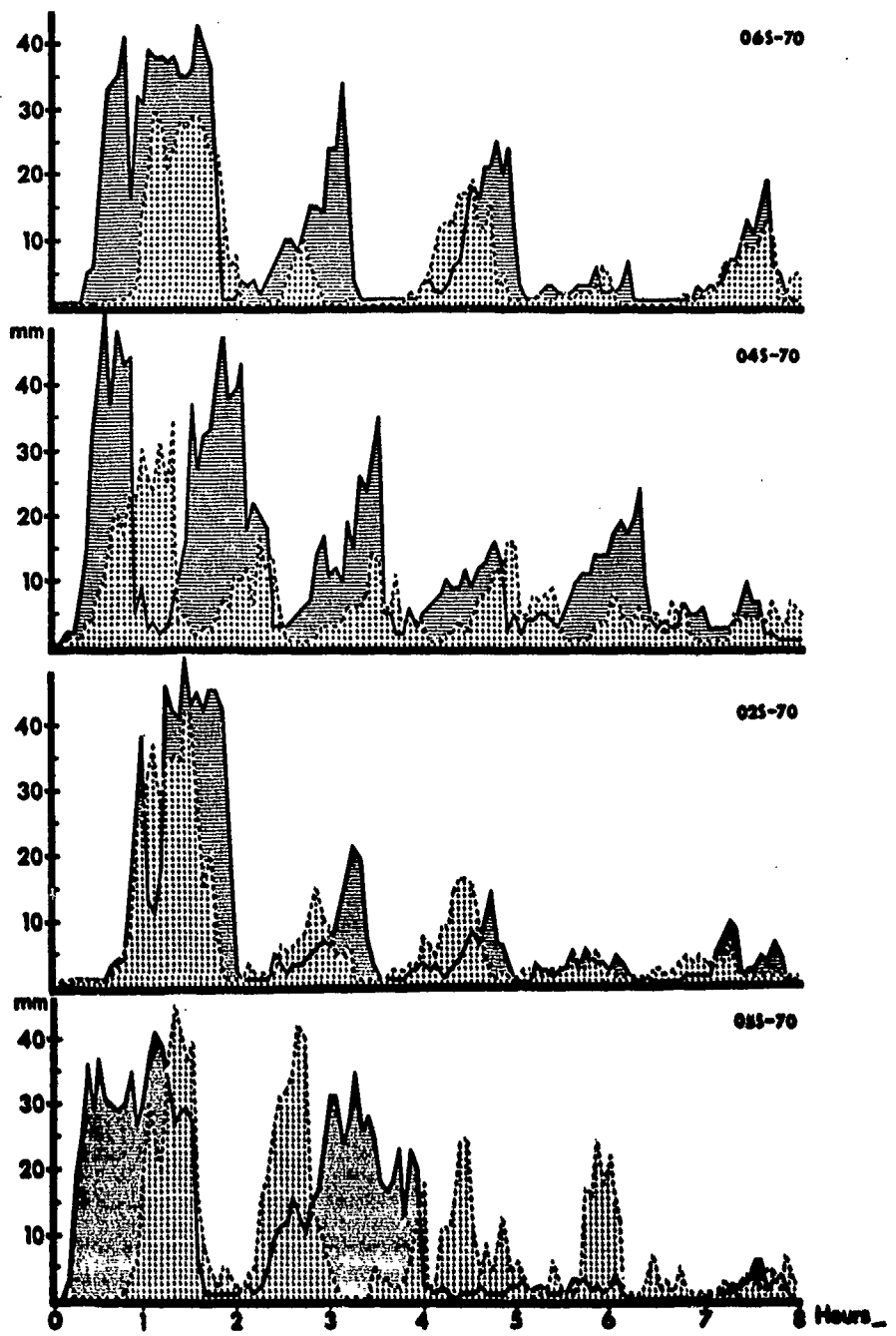


Fig. 3. Analog computer analysis of delta activity (1-3 Hz) for four subjects before sleep loss, dotted histograms, and that following 60 hours of wakefulness plus two additional nights of stage 4 deprivation. The same type of delta profiles were found for subjects deprived of REM sleep for two nights following total sleep loss.

problems. Prolonged loss of all sleep was, by comparison, a relatively minor problem. When total sleep loss was reported, it was seldom beyond 30 hours. Double crews have been used when continuous flight operations beyond this time were required. Partial sleep loss, then, deserves greater attention with respect to possible operational consequences than does prolonged total sleep loss.

Partial sleep loss is both easy and difficult to define. Going to bed later than usual but getting up at the same time results in acute loss of usual sleep time. Or the reverse, going to bed at the same time but getting up earlier, reduces sleep. Partial sleep loss may occur if one sleeps 2 hours, gets up, and then sleeps 3 hours, gets up, etc.; the fragmented sleep may not equal his usual total sleep

AUDITORY VIGILANCE

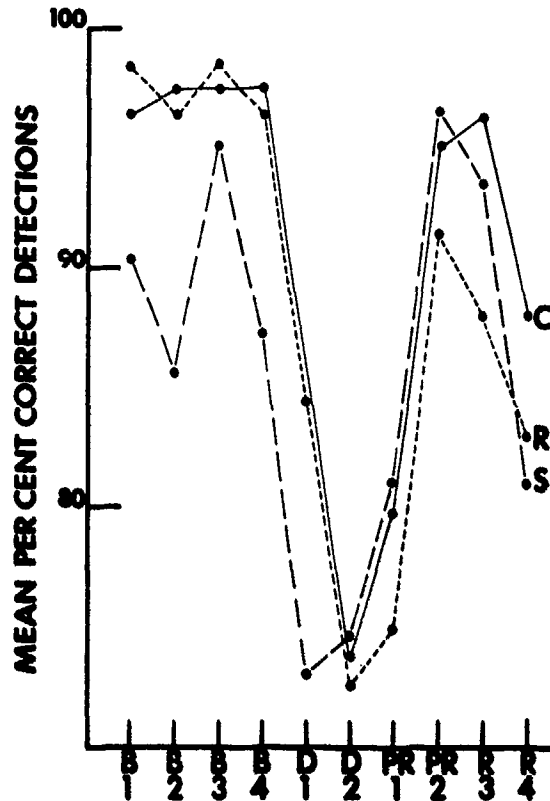


Fig. 4. Performance on the Auditory Vigilance Task during four baseline days (B₁, B₂, B₃, B₄), during total sleep deprivation (D₁ & D₂), during deprivation of stage REM for R group, stage 4 for S group (PR₁ & PR₂), and during uninterrupted recovery sleep (R₃ & R₄). The control group (C) was not sleep-stage deprived.

time. Also, does this fragmented sleep, even when equal to usual total sleep time, have the same recuperative value as uninterrupted sleep? Simply stated, partial sleep loss occurs when there is a reduction of the usual amounts of sleep obtained in 24 hours.

But is a person who sleeps only 4 hours in 24 necessarily suffering from partial sleep loss? Is there a fixed amount of sleep that must be obtained if a sleep debt is to be avoided? The answers appear to be no. There are wide individual differences as to amounts of sleep required. Two men who slept only about 3 hours in each 24 hours reported no sleep-loss complaints.¹¹² A more extreme example is the report of a 70-year-old lady who slept on the average of one hour each night with no daytime naps and was reported to be alert, competent, with no need or desire for more sleep.¹¹³

Though the above are extreme examples of short sleep, there are many who sleep 5 to 6 hours a night. How did these short sleepers achieve their restricted sleep regimen? There are no data on the problems, if any, they encountered in achieving their sleep reduction or the time period required before their reduced sleep time became stabilized. Short sleepers have been found to differ¹¹⁴ and not differ¹¹⁵ in life styles and psychological traits from long sleepers. Hartmann et al.¹¹⁶ found short sleepers efficient, hard-working, and somewhat hypomanic. Individual differences in total sleep times will, of course, be of operational consequence when time for sleep is restricted. Obviously, a schedule which permits only 6 hours for sleep would be less of a problem for a group of "natural short" sleepers. Later (page 20), there will be a description of a current joint research program by Drs. Globus and Friedmann of the University of California, Irvine, and the staff of the Navy Medical Neuropsychiatric Research Unit, whose goal is to see if customary total sleep times can be reduced and maintained without decrement in waking activities.

In addition to individual differences in sleep duration, there are also differences as to when people prefer to obtain their sleep. These are usually classified into two types: "morning larks" and "night owls." A bedtime of 0200 with wake up at 0700 would have probably little effect on the "owl's" nighttime performance, but he would probably not be at his peak at the "early" 0700 hours. The same sleep regimen would mean changes in the life style of the "morning lark" who usually retires well before midnight. His evening performance would be his most vulnerable time. The question of individual variation in pattern of habitual sleep, thus, becomes more important in partial sleep-loss studies.

Unlike total sleep loss, there are infinite variations in possible patterns of sleep reduction. Consequently, a number of critical decisions must be made before a study of partial sleep loss occurs. How many hours of sleep will be allowed? Will the reduction be abrupt or gradual? At what time will sleep occur in the 24-hour period? Will all sleep be allowed in a single stretch (non-fractionated sleep), or partialled out in short pieces (fractionated sleep or "naps")?

Relative to total sleep loss, there are few studies on partial sleep loss. It is difficult to find a study reporting consistent performance decrement during short sleep. All of the factors involved in determining the effects of total sleep loss, type of task, time of day, individual differences, etc., contribute to the variance in partial sleep-loss studies.

As for total sleep loss, one of the most important sources of variance in partial sleep-loss studies is the circadian effect. Whether sleep is shortened by going to bed later, getting up earlier, or by fragmentation of sleep, there is an alteration in the timing of the usual sleep-wakefulness cycle. Because this alteration occurs, it is difficult to know whether the observed changes after partial sleep loss were indeed the result of short sleep, or merely of the imposition of wakefulness (or sleep) on an unaccustomed segment of the circadian cycle. Following changes in both sleep times and sleep-wakefulness cycles, disruption of the circadian cycle was felt to be a more important determiner of performance and subjective mood changes than the shortened hours of sleep per se.¹¹⁶

The effect of partial sleep loss on task performances is also confounded by the inherent organization of the pattern of sleep stages during sleep. Though the unique significance of sleep stages is still unknown, shortening sleep changes the type of sleep obtained. Normally, stages 2, 3, and 4, especially stages 3 and 4 (SWS), dominate the early part of sleep, while stage REM sleep shares the last half of the night with stage 2. This differential distribution of SWS and REM sleep is firmly fixed for adults, regardless of when sleep onset occurs as long as 6-8 hours of waking precede sleep onset.¹¹⁷ If sleep is obtained in the morning shortly after awakening, REM sleep is likely to dominate; but if sleep is delayed until the late afternoon, the sleep pattern will be more like night sleep with stages 3 and 4 most likely to dominate the first hour than is REM. Because of this organization of sleep stages, partial sleep loss generally involves some reduction in sleep stage REM. But more on sleep stages later.

Following the format for total sleep loss, a review of some recent laboratory studies will be presented first, followed by a more detailed presentation of the studies concerned with sleep deficit in aircrew personnel.

Abrupt Sleep Reduction

Interest in effects of sleep length on cognitive and motor responses, especially memory, dates back to the early 1900s. The results of these early studies varied and no consistent effects of reduced sleep on performance could be inferred. With the resurgence of sleep research based upon EEG monitoring of sleep stages, there has been renewed interest in the effects of partial sleep loss.¹¹⁸⁻¹²¹ In the various studies, sleep has been restricted to 3 hours per day over 8 days;¹²⁰ to 5.5 hours for 60 days;¹²¹ reduced to either 1, 2, 3, 4, or 5 hours over 2 days;¹¹⁸ or 7-1/2, 6, or 4 hours were permitted for 4 consecutive days.¹¹⁹

Even though most of these post-1960 studies have carefully monitored EEG indices of sleep, used a larger variety of tasks and a larger number of subjects for longer periods of time, the effects of partial sleep loss on performance have been no more consistent from study to study than the pre-1960 studies.

No uniform or consistent changes were found in 8 subjects when allowed only 3 hours of sleep per day for 8 consecutive days.¹²⁰ Only after the 7th and 8th days were decrements noticed on a paced addition test, on a vigilance task in which the subject listened to tape-recorded letters and pressed a button each time he heard an x, and on a vigilance task in which the subject pressed a signal button each time a red light was flashed on one of the five positions in a pentagon.

In their recent study, Webb and Agnew¹²¹ curtailed the daily sleep time of 16 young adults from 7-1/2 - 8 hours to 5.5 hours for 60 days. Performance tests used

were the Williams Word Memory Test, the Wilkinson Addition Test, and the Wilkinson Auditory Vigilance Task. The only significant decrease in performance was a slight but steady decline in correct detections on the Auditory Vigilance Task. Webb and Agnew attributed this decrement to a decline in willingness to perform on the task rather than to a decline in the subjects' vigilance due to sleep loss. The subjects' sleep onset latencies decreased during the first week, then stabilized. Getting up in the morning was reported to be difficult during the entire 60 days though the greatest difficulty was during the first week. Feelings of drowsiness also were most frequently reported during the first week. There were no significant changes in mood or affect during the study.

Employing the Wilkinson Vigilance and Addition Tasks, 6 subjects were required to work a full day for 2 successive days in each of 6 successive weeks.¹¹⁸ On each of the nights before the 2 test days, the subjects were allowed 0, 1, 2, 3, 5, or 7-1/2 hours of sleep, varying according to the week of testing. Five hours of sleep resulted in a decrement on the second reduced-sleep day but not on the first. Less than 5 hours of sleep on a single night impaired vigilance performance; when sleep was reduced to less than 3 hours, performance on the addition task was impaired.

In an extension of the above study,¹¹⁸ performance was examined following 7-1/2, 6, and 4 hours of sleep per night for 4 days.¹¹⁹ The vigilance and addition tasks were again used plus a digit span test. There was a significant decrease in correct detections and number of sums completed when sleep was reduced to 4 hours. The effect of partial sleep loss was found to be cumulative over the 4-day period. In contrast, the subjects' performance on the digit span test was above baseline values when allowed only 4 hours of sleep.

Wilkinson believes that negative results from partial sleep-loss studies are due to the use of tests which are too short and by not using an experimental paradigm where the tests are scheduled as a part of a workday. Taking a more positive view, Webb and Agnew conclude that stable sleepers with 7-8 hours per night can maintain 5-6 hours of sleep per night for as much as 2 months' time, with little or no decrement from such reduced sleep.

Gradual Sleep Reduction

Though most subjects continue to function with minimal impairment during an abruptly induced restricted sleep regimen, when the imposition is removed they return to their usual sleep schedule. They do not adapt to, nor do they prefer to continue, their restricted sleep diet longer than necessary.

To see if sleep length could be decreased without the usual sleep-loss effects and whether this shorter sleep regimen would be preferred once achieved, a gradual sleep-reduction study was carried out for 2 subjects.¹²² Drs. Gordon Globus and Joyce Friedmann, University of California, Irvine, in collaboration with the Navy Medical Neuropsychiatric Research Unit, have reduced sleep gradually for 4 subjects with 7.5 - 8-hour baseline sleep regimens.

In the Johnson and MacLeod study,¹²² 2 young adults, 1 male and 1 female, reduced their total sleep time by 30 minutes every 2 weeks from an initial 7.5 hours to 4 hours. The 4-hour regimen was maintained for 3 weeks and then *ad lib.* sleep was permitted. A third subject resigned from the study during the 4.5-hour regimen, finding it too difficult to force himself to get up after his summer job terminated and there was nothing to do. The daily sleep and nap logs from the other 2 subjects reflected similar difficulty in maintaining the restricted sleep schedule after the 6-hour schedule. Mood and performance showed changes beginning at 5.5 hours, but these changes were not marked or consistent. An 8-month follow-up report indicated that both subjects had maintained a sleep schedule 1 to 2 hours below their previous baseline.

Based upon the Johnson and MacLeod findings, couples were chosen for the Irvine-San Diego study to insure that there would be support available during the shorter sleep periods; so they could apply the electrodes to each other for all-night EEG recordings; and to provide at least one other person willing to stay up. In addition to measuring mood and performance changes during each sleep regimen, EEG sleep recordings were obtained 3 nights a week in the subjects' homes. These data were obtained by means of a small tape-recording unit. One EEG and two ECG channels were recorded from all subjects on 1/4" tape for later re-recording on a strip chart and on FM tape for sleep-stage scoring and computer analysis.

The performance data included the Wilkinson Auditory Vigilance and Addition Tasks plus a modified Williams Word Memory Task. Daily sleep logs, nap logs, and the Stanford Sleepiness Scale¹²³ were completed upon awakening. The Profile of Mood States (POMS)¹²⁴ was completed on the evenings of the EEG recording. These data were collected during a baseline month, during gradual sleep reduction, and during a 6-month *ad lib.* sleep follow-up period.

More details will be published by Globus *et al.* when all the *ad lib.* sleep data on these 4 subjects are obtained and after another year of data collection on 4 more subjects is completed. The results discussed here, therefore, must be viewed as preliminary.

Over a period of 7 months, the two married subjects (BS and SS) reduced their sleep from 8 hours to an average of 5 hours while the second, the unmarried, couple (JP and PM) reduced their sleep from 8 hours to 4-1/2 hours over an 8-month period. Like the subjects studied by Johnson and MacLeod, these subjects reduced their sleep time by going to bed later. Time of getting up remained constant.

Sleep times were obtained from the daily sleep log cards in addition to the EEG recordings. In other studies, total sleep times from the EEG and sleep logs were shown to be comparable.^{125,126} In Figure 5 are the sleep times from the EEG data for the 4 subjects during sleep reduction and from sleep log data for the first 4 months of *ad lib.* sleep. While all 4 subjects' *ad lib.* sleep was less than 8 hours, the initial amount of *ad lib.* sleep differed for each subject. Subjects BS and SS initially required more *ad lib.* sleep than JP and PM, probably reflecting the greater difficulties BS and SS had during the sleep-reduction period. Their fatigue ratings were higher, they felt less rested, and discontinued sleep reduction before JP and PM. (At the 6-month follow-up, the *ad lib.* sleep times for BS and SS were near 6 hours.) If the below-baseline total sleep times of these 4 subjects persist, these data support the observations by Johnson and MacLeod that gradual sleep reduction does enable the subject to adapt to a shorter sleep time.

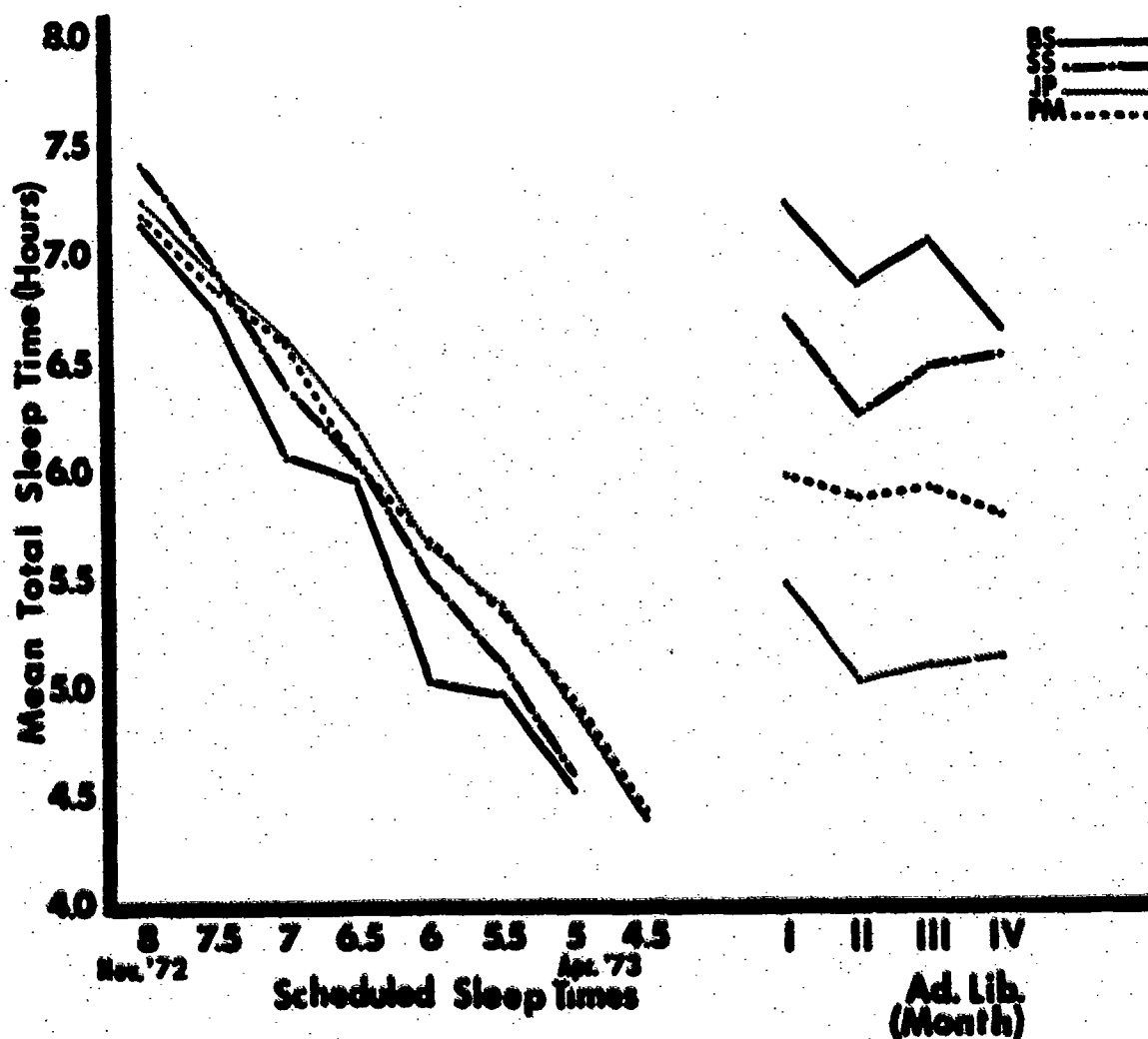


Fig. 5. Total sleep times during gradual sleep reduction and *ad lib.* sleep. During gradual sleep reduction, sleep times were computed from EEG recordings. *Ad lib.* sleep times were obtained from sleep logs.

All of the subjects reported they discontinued reducing their sleep time because they felt more fatigued, had less vigor, did not feel rested in the morning (see Figure 6), and the feeling of need for more sleep became too intense. Feelings of fatigue and need for more sleep began to increase when sleep time was reduced by 1-1/2 hours. Neither of the male subjects reported significant changes in their graduate course work (BS and JP) nor did the two women (SS and PM) feel that the sleep loss caused problems in their jobs. Performance on the Wilkinson Addition Test and Williams Word Memory Test did not show any decrement. There was some decrement on the Wilkinson Auditory Vigilance task, but the analysis of this task is incomplete. The POMS scales showed no consistent changes over the sleep-reduction period in confusion, anxiety, tension, depression, and anger, but there was an increase in the fatigue scale score with a decrease in the vigor scale score.

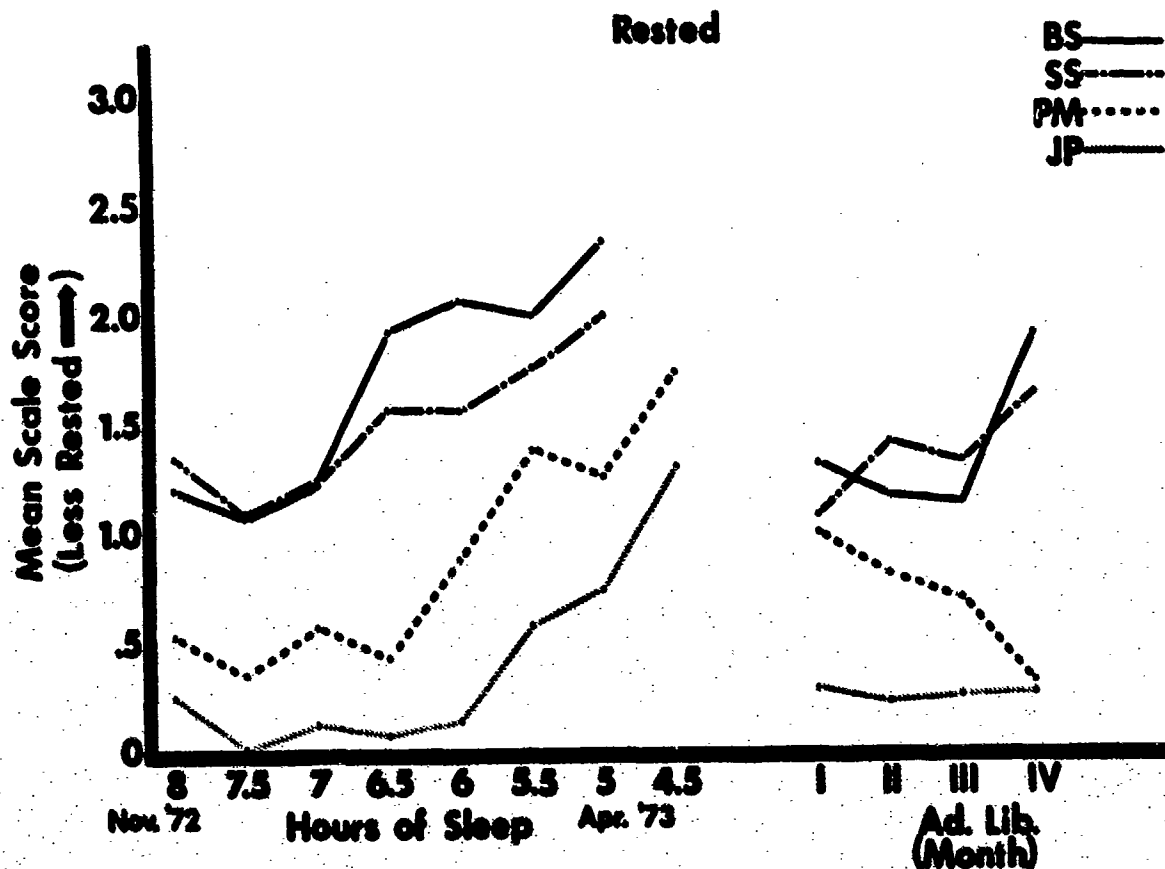


Fig. 6. Ratings as to feeling of being rested after morning awakening during gradual sleep reduction and *ad lib.* sleep.

It was not obvious performance decrement but feelings of fatigue that appeared to set the lower limits for their sleep time. The fatigue was probably due, in part, to the extra effort necessary to maintain an effective level of performance.

BEG Sleep Changes During Sleep Reduction

The sleep changes during gradual sleep reduction for these 4 subjects were very similar to those reported for 3-hour sleepers,¹¹² for 5-hour sleepers,¹³¹ and those previously noted during gradual sleep reduction.¹²² As sleep decreased from 8 to 5 hours, the minutes spent in stage 1 and stage 3 did not change, there was an increase in minutes of stage 4 as the sleep decreased from 7.5 to 6.5 hours, then no further increase; time in stage REM decreased during the entire period as did the minutes spent in stage 2 (see Figure 7). Of all the stages, the largest decrease was for time spent in stage 2. When time spent in each stage was converted to percent of total sleep time, the pattern was the same for all stages but REM. REM percent showed essentially no change during sleep reduction. The stability of REM percent was due to the progressively earlier onset of the first REM period as sleep time was reduced. The latencies to the other sleep stages did not consistently change with sleep reduction.

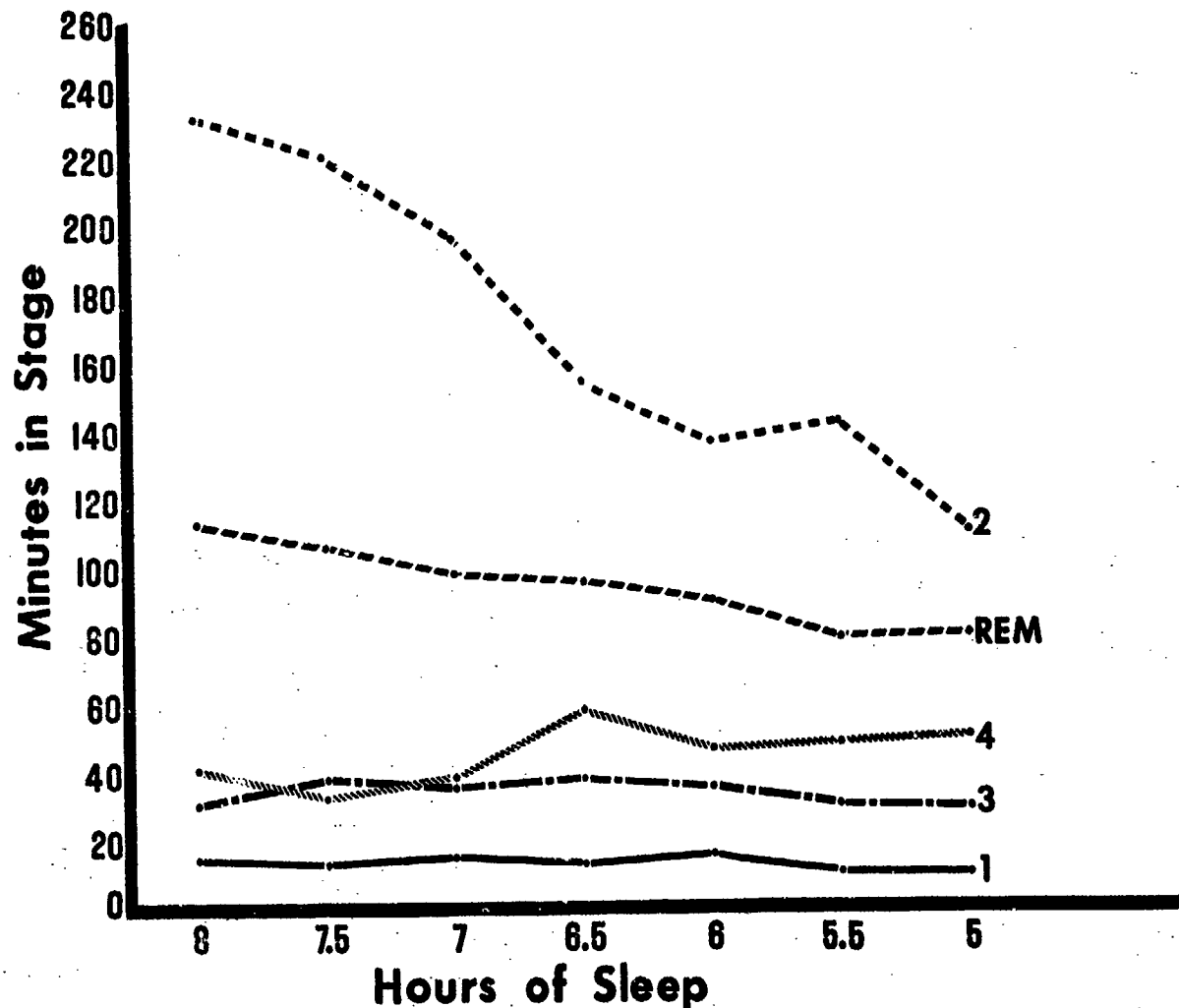


Fig. 7. Average time spent in stages 1, 2, 3, 4, and REM by 4 subjects during gradual sleep reduction.

This study joins a growing list indicating that slow-wave sleep will not be denied.^{109,122,127} Whether total sleep time is decreased abruptly through imposition of a curtailed sleep regimen, reduced gradually over months, or shortened by self-selection, the amount of stage 4 does not decrease. To the contrary, if the reduction is severe (e.g., total sleep time is 3-4 hours), stage 4 time may increase. REM sleep time in all instances decreases.

Hartmann *et al.*,¹¹⁴ in their report on self-selected long and short sleepers, advance the hypothesis that there is a relatively constant requirement for SWS and a requirement for D sleep (REM sleep) that is related to the individual's personality and life style. For Hartmann *et al.*, the sleep regimen one selects is related to his need for REM sleep. The results of the several sleep-reduction studies suggest that a decrease in REM sleep is a result of, not the cause of, shortened sleep. In all instances, regardless of how total sleep time is reduced, there is a reduction of REM sleep time.

The nature of sleep patterns offers a more parsimonious explanation than difference in psychological factors. As noted earlier, the biologically determined cycles of sleep insure the appearance of SWS before REM. When sleep is reduced, REM sleep will be chopped off. Webb and Friel¹¹⁵ draw the obvious conclusion that there is a point at which shortening of the total time available for sleep will result in REM deprivation. The type of sleep one gets is determined primarily by the length of sleep.

Non-aircrew Operational Studies of Partial Sleep Loss

The sleep of 10 electric train drivers, ranging in age from 27.5 - 49, as measured by sleep charts, was found to be 6 hours 22 minutes on working days, and

7 hours 59 minutes on rest days.¹²⁸ Sleep, however, occurred at almost a random function of the clock. Regardless of time of going to bed, the train drivers woke up about noon. The importance of social activities, the noon meal in this instance, was a crucial causal factor in the degree of partial sleep loss. The importance of circadian effects was also demonstrated by the finding that the most difficult time to remain alert was between 0400 and 0500, whether they had been on the job for months or years. All the drivers mentioned dozing while driving. They reported they had at times felt so sleepy and tired that their social relations and activities with their families suffered.

During a 3-month training cruise, the watchkeeping of 12 young adult cadets rotated on a 3-day cycle; from 2400 to 0400 on the first night, from 2000 to 2400 on the second, and from 0400 to 0800 on the third.¹²⁹ In addition to the watch, they were engaged with daily training from 0700 to 1700. To evaluate the effects of partial sleep loss, the cadets performed a task consisting of 5 colored signals to which they responded with particular fingers, except for the fifth color to which no response was required. Each task session was brief (4 minutes long), and 40 signals were presented. The measure of task performance was mean reaction time. Oral temperature, pulse rate, and excretion of water, sodium, potassium, and calcium in urine were also evaluated.

The mean sleep duration of the cadets before the voyage was 7 hours 7 minutes. During the voyage, the amount of sleep was dependent on the watch schedule. On the 2400-0400 watch, sleep was usually divided into two parts; the first period of sleep lasting 2-1/2 hours and the second approximately 2 hours, with a mean total sleep of 4 hours 52 minutes. The sleep duration on the 2000-2400 watch averaged 6 hours 4 minutes, and on the 0400-0800 watch sleep was reduced to 4 hours 38 minutes. Average sleep duration over the entire voyage was 5 hours 10 minutes, or approximately 2 hours of sleep curtailment over the 3-month period. This chronic partial sleep loss did not, however, change the task reaction time. When the cadets were exposed to tropical heat, reaction time was lengthened but returned quickly to the baseline when the ship moved to relatively cooler climate. The authors concluded: "the reduction in mean sleep duration to about 5 hours had no effect on mean reaction time [p.221]."

Stolgitis¹³⁰ compared the operational advantages of the 6/12 work-rest cycle with the 4/8 work-rest cycle. In his computed average of daily work-rest activities, Stolgitis noted that the "rest" period was not necessarily used for resting, naps, or recreation because it included meal time, time for personal hygiene, and for miscellaneous work required for ship upkeep. Stolgitis established that the average time spent on daily watch and work duties was 12.33 hours for the 4/8 schedule, and 11.67 hours for the 6/12 schedule; thus, the two schedules produced almost equal work output. On the average, 5.82 hours of sleep were available out of the 8.67 hours for rest-recreation under the 4/8 schedule, while 8.66 hours for sleep were available out of the 9.67 hours for rest-recreation under the 6/12 schedule. By dividing the average potential daily sleep periods in hours by the average daily rest and recreation periods in hours, Stolgitis obtained an index of Sleep Cycle Efficiency (SCE). If all the available rest and recreation times were used for sleeping, the maximal SCE would be 1, whereas the SCE would be 0 if no sleep was obtained during the 24-hour period, even if time is taken for eating and wakeful resting. For the 4/8 schedule, Stolgitis found an SCE of 0.67. In other words, 67% of the daily rest-recreation periods was used for sleeping. A higher SCE of 0.89 was found for the 6/12 schedule. Stolgitis did not report any cross-validation studies or performance changes supporting the usefulness of the SCE in evaluating work-rest cycles. In support of the higher SCE for the 6/12 work-rest cycle, however, is the observation that crews in some nuclear submarines preferred the 6/12 schedule to the traditional 4/8 cycle as they found the 6/12 schedule more comfortable. A particularly desirable feature of the 6/12 schedule is that once in every three nights, the crew has a chance to get an uninterrupted stretch of free time of approximately 10 hours 30 minutes; time enough for long uninterrupted sleep if desired.

In a study directly related to the disruption of the sleep-wakefulness cycle, 6 adult subjects, 19-32 years, were evaluated during a 7-day baseline period followed by a 14-day exposure to a random sleep-wakefulness schedule.¹³¹ The schedules were such that each 24-hour day contained four 2-hour periods in bed in a quiet, darkened room, and eight 2-hour periods out of bed in natural daylight or commercial fluorescent lighting; all periods occurring in random sequence. Three meals were served each day at random intervals during the periods out of bed. Out-of-bed activities included self-selected reading, watching television, or receiving visitors.

While the schedule and activities are not similar to most aircrew operations, the findings are consistent with observations made from operational aircrew studies. There were no major psychological or performance changes on adjective check lists, California Psychological Inventory, Rorschach responses, the Raven's progressive matrices, paired associate learning, digit span, or on the Watson-Glaser critical

thinking test. The authors concluded, "The results furnish no evidence that a regular synchronizer schedule is essential to normal mental function. Regularity does appear to provide the advantage of better sleep, but the degree of advantage is variable.... [p.321]."

Subjects' reports indicated that there was considerable individual variation in the ability to fall asleep at irregular times, and it was suggested by the authors that these differences might be related to personality factors. One subject was able to fall asleep easily regardless of time and was judged as usually cheerful and alert. Another subject had considerable difficulty in adapting to the random schedule, lying awake 30-40% of the time in bed, and he was frequently judged to be tired and irritable. These observations were confirmed by self-report. The remaining 4 subjects formed a continuum between these two. Sleep was most difficult for all subjects when the time in bed occurred during daytime hours. Transient feelings of irritability and fatigue, and reduced alertness, when present, usually occurred following long periods of waking. All subjects reported maximum fatigue when they were awake between 0500 and 0700 regardless of how recently or how long they had slept. The random sleep-wakefulness schedule appeared to have little effect on other circadian rhythms as the early morning awake low periods were present during the entire 14 days. It was unfortunate the authors did not present body temperature and other biological data detailing other cycles.

Aircrew Operation Studies and Partial Sleep Loss

Hartman¹⁵ analyzed the workload and rest of approximately 100 aircraft commanders in C-141 aircraft for 90 flight missions to Southeast Asia and 10 flight missions to Europe from Charleston Air Force Base, South Carolina. The commanders reported work and rest periods around the clock starting with the period of pre-mission rest to the end of post-mission crew rest. The total time of "away on the mission" was 160.8 hours. During the mission, sleep duration increased to 7.5 hours (with a range of 7.2 - 7.8 hours) from the 6.8 hours obtained in the pre-mission resting phase. Greatest increases in total sleep time were found, however, during the recovery days after the flight missions. The aircraft commanders slept an average of 9.9 hours on the first night after the mission, 9.2 hours on the second night, and 8.9 hours on the third, suggesting "a cumulative physiological cost incurred during the mission [p.820]" to be paid later with the physiological currency of prolonged sleep. On the first recovery night, 32% of the sleep periods of all crew members were longer than 12 hours, and on the second and third recovery nights, 13% and 6% of the sleep periods were longer than 12 hours respectively. Before the mission, only 2% of the sleep periods of all crew members were longer than 12 hours.

The use of double crews to reduce the effects of flying C-141 jet aircraft on performance, subjective fatigue, and sleep has been investigated.¹⁴ Two aircraft commanders, 2 co-pilots, 2 navigators, and 2 flight engineers were studied over 6 experimental transport missions. Each flight mission was conducted under one of two work-rest cycles (4/4 or 16/16) in combination with one of three flight "profiles," A, B, or C. Each flight profile varied with respect to workload. For example, profile C, flying "Europe-reverse route," had shorter legs with concomitant increased frequency in number of take-offs and landings. The crew completed a subjective fatigue checklist and sleep survey forms. In addition to the sleep survey, the EEGs during sleep were recorded on 2 navigators during three of the six flight missions. Crew performance was rated by one of three flight examiners on a rotating schedule.

During flight, the sleep survey results indicated an average sleep time of 6 hours. Post-mission sleep duration increased to approximately 10 hours on the first day, 9 hours on the second, and 7 hours on the third.

EEG sleep records from the 2 navigators indicated that sleep duration during the mission was similar to the pre-mission resting period, but the quality of sleep differed. During the mission, there were more awakenings; 1/2 the amount of slow-wave sleep, and 1/4 the amount of REM sleep. The decrease in slow-wave sleep and REM sleep occurred for both navigators regardless of the work-rest cycle or whether they took the first or the second shift in flying the aircraft.

The aircraft commanders and navigators gave the highest fatigue ratings; the flight engineers the least. The level of flight workload showed some effects on the ratings of fatigue; e.g., profile C was rated as significantly more tiring than the other profiles, but the profiles showed no sleep differences. Despite the reported fatigue, performance did not show any degradation. The authors stressed that the increased hours of sleep after the mission were a direct result of the cumulative depletion of physical reserves which occurred during the flight missions.

In addition to the C-141 missions, 7 additional missions in the C-5, with its more elegant crew rest facilities, involving 15 crewmen and 75-hour missions, were also evaluated.¹⁶ These C-5 crewmen were formed into two crews matched for

experience for the C-141 crews. The crew positions included aircraft commander, co-pilot, navigator, and flight engineer. The double crews in the C-5 flew multiple experimental transport missions under a short work-rest cycle (4/4 or 5/5) or a long cycle (12/12 or 14/14) in combination with one of three flight profiles. Crew performance was rated by an onboard flight examiner. Urine samples, oral temperature, and self-reports of fatigue and sleep were collected every 4 hours. A battery of urinary analysis techniques was applied to urine samples to measure norepinephrine, epinephrine, 17-OHCS, potassium, sodium, urea, and a ratio of Na/K.

As in the C-141 flights, the C-5 crewmen obtained approximately 6 hours of sleep in the aircraft during each of the 3-day-long missions; a possible partial sleep loss of 2 to 3 hours per day. The reduced sleep, however, had no effect on crew performance. The investigators felt the sustained level of performance by the crew was maintained at some physiological cost as revealed by (1) a relative hypothermia which is described by Selye as a response to acute stress, (2) increased subjective ratings of fatigue, (3) increased duration of sleep after the mission, and (4) increased quantities of urinary catecholamines and 17-OHCS. The aircraft commanders paid the highest physiological cost: they showed 169%, 158%, and 122% of the control values with respect to epinephrine, norepinephrine, and 17-OHCS. All other crewmen tended to show significant (but to a lesser extent than the aircraft commanders) increases in urinary catecholamines and 17-OHCS during the flight missions. Epinephrine was found to be most responsive to the stress of flying, while the adrenocortical activation due to flight was always less, ranging from 100 (the control value) to 122. This relatively low value of 17-OHCS during the flight missions was interpreted as a reflection of the high "physiological reserves" of the crewmen.

The sensitivity of urinary measures as indices of physiological cost was shown by the comparison of an aborted flight, due to excessive fatigue, against normal flight missions. In the C-5 aborted flight mission, extreme fatigue developed for unknown reasons despite the same double crew flying the same itineraries as the other flights. After 26 hours in the abnormal flight, the crew as a group showed very high values of urinary catecholamines, up to 2.5 times of the control values. There was a decline of epinephrine (from 258% at 26 hours to 102% at 34 hours) and norepinephrine (from 199% at 26 hours to 108% at 34 hours), a pattern of neuroendocrine response suggestive of exhaustion. This decline in catecholamines was accompanied by an increase of urinary 17-OHCS to 152%, reflecting the exorbitant cost incurred during 34 hours of this mission and a possible loss of physiological reserves. Hartman and Hale maintained that degraded sleep in flight and partial sleep loss contributed to the physiological cost.

In summary, the concept of "physiological cost" emphasized by Hale and his co-workers highlights the coping mechanism of the body to unusual conditions. While "cost" implies these physiological responses are detrimental, there are little data to indicate that the changes reported by Hale and his associates have long-term detrimental effects. Though it may still be too early and too complex to accomplish, it would be of help in evaluating the physiological cost of missions if Hartman and his colleagues could develop a numerical scale for labeling a stress response as "mild," "moderate," or "severe," depending on the excretion rates of catecholamines and 17-OHCS. Another question that needs attention is that of determining what part of the "cost" is due to the usual stressors of flight, that due to sleep deficit, and that resulting from the interaction of the two. It should also be remembered that consistent physiological and biochemical changes from this amount of sleep loss *per se* have been difficult to find. The attempts by Froberg *et al.*⁶⁸ to partial out sleep-loss effects from those due to circadian rhythms were noted on page 8.

Preston and his co-workers^{21-23,132-135} have focused their efforts on determining the effects of flying across time zones, on world-wide schedules, on sleep and subjective feelings. A sleep log was used to record times of arising, times of retiring, estimated duration of sleep, and times of on and off duty, from pilots of BOAC's Boeing 707 flights on "Round the World Service" tours.²¹ Subjective ratings of fatigue were obtained twice daily; on getting up and on going to bed. The subjects were three captains, two observers, and one first officer on four "tours," including one east-to-west (westbound) and another west-to-east (eastbound) Round-the-World flights.

All the pilots, the observers, and the first officer incurred some partial sleep loss as their sleep duration during the tours was reduced by 1 to 2-3/4 hours on the average everyday for the entire period of the tours. Subjective assessments of fatigue showed a parallel increase as sleep debt accumulated. Once the subjects were back home, the crew members quickly returned to customary sleep times and duration but the number of days required was not given. Despite the partial sleep loss and consequent fatigue, "At no time did we consider the sleep disruption introduced any hazard to the operating situation [p.1411]."

In a subsequent study,²² sleep loss was found to cumulate as the air tour progressed away from the home base and the degree of sleep loss seemed to be related to the number of night flights at local time per tour and not to time-zone changes. It was also found that reaction time and short-term memory declined in airline stewardesses subjected to multiple crossings of time zones. Accordingly, Preston *et al.* stressed the importance of preservation of sleep for pilots and other personnel on a long-haul airline by providing adequate and acceptable hotel accommodation for crews at "slip stations," and possibly by providing a suitable short-acting hypnotic for crews.

In 1970, Nicholson⁵ reported on the workload and sleep of a Boeing 707 captain of the BOAC at the fifth decade of his life, who had kept a diary for 18 months. In this diary, the captain recorded his sleep, duty periods, and subjective evaluation of well-being upon getting up and on going to bed. The diary included a period of approximately one month of non-flying status in Europe.

The captain reported an average sleep duration of 6 hours 52 minutes, with a range from 6 hours 15 minutes to 7 hours 25 minutes during non-flying duty. During the several periods of route flying, his average duration of sleep remained at roughly the same, 6 hours 57 minutes, but with an increase in range; *i.e.*, 5 hours to 8 hours 35 minutes. Nicholson also noticed an irregularity in the interval between sleep periods which varied from 2 to 24 hours. Accordingly, Nicholson concluded that the problem of sleep in airline pilots operating scheduled routes of the type studied in this paper was predominantly that of disturbed pattern of sleep rather than loss of sleep.

In the same year, two continuous flying operations with double crews involving two types of aircraft, the Belfast and the VC-10, were evaluated.⁶ In the Belfast mission, each flight crew alternated duties with another crew, using a work-rest cycle of 10 hours on/10 hours off. The Belfast mission consisted of 8 arduous flights of approximately 9 hours' duration each, totaling a planned 72 hours, but actually it took 112 hours due to delays. The crew slept on bunks in a compartment situated forward in the freight hold. Altogether 9 airmen were involved in this study, including 1 non-flying commander, 2 pilots, 2 co-pilots, 2 navigators, and 2 engineers.

The VC-10 mission involved 8 crewmen, 5 flights with flight durations ranging from 7.5 to 9 hours, totaling 45 hours. The crew maintained a 24-hour day schedule under a different work-rest schedule than that used for the Belfast. The first crew took 3 watch periods, while the second crew took 2 watches, 2130-0614 and 1535-0015. The VC-10 aircraft was equipped with stretcher bunks at the rear of the aircraft for sleep and resting. In both missions, the meals were served on a GMT schedule. The crew kept a sleep diary one month before the start of each exercise, throughout the flight, and for about a week following the completion of the missions. The aircrew also evaluated their well-being by checking how refreshed or tired they were upon awakening and retiring. To evaluate sleep, first the baseline range of total sleep duration was established for each crewman, using sleep time averages over 3-day baseline periods. The minimum sleep times over a 3-day period during baseline were taken as the acceptable level of sleep, and any sleep shorter than this baseline minimum was regarded as a sleep deficit.

The minimum baseline sleep for the Belfast crew ranged from 4.5 hours for the engineer in crew 1, to 7 hours for the co-pilot in crew 1. On the first day of the flight, all crewmen slept longer than the minimum baseline sleep duration. From the second day of the flight, the crewmen showed wide individual differences in reduction of sleep time ranging from 1/4 to 2-1/2 hours, with the pilots generally having shorter sleep. Almost all crewmen had experienced some sleep deficiency by day 4 of the mission, but after that some crewmen started to sleep longer than the baseline minimum. The navigator of crew 1 was the only exception, in that he slept as much during the entire flight as during baseline.

The eight VC-10 crewmen's minimum sleep during baseline ranged from 5 to 7.5 hours. On the second day of the VC-10 mission, six crewmen, and on the third day, when duty was scheduled during normal sleep time, all eight crewmen experienced sleep reductions ranging from 1/4 hour to 3 hours. Normal sleep was re-established in six crewmen after 2 days, and for the two remaining crewmen after 3 days after completion of the flight. For the Belfast exercise, recovery of the crewmen to normal sleep patterns was complete in 5 days.

In the VC-10 mission, there was a remarkable absence of subjective feelings of tiredness, but the Belfast operation was felt to be the upper limit for continuous operation of aircraft. Based on the sleep patterns, the authors concluded that the missions of 2 days of continuous flying may be optimal in terms of the crewmen, providing at the same time a world-wide capability for air transport.

Nicholson^{3,5,7} has also published data on two airline pilots operating world-wide east-west routes, both in the 5th decade of life. Based on the data from

these two pilots, he has proposed a theoretical model which describes the relation between workload and sleep duration, and the relation between days on route and cumulated duty hours. The acceptable sleep pattern of Nicholson is based on the minimum total sleep duration observed over 3 nights during a baseline period. Nicholson defines "workload" as the cumulated duty hours on route at completion of each flight divided by the number of days on route plus 1. The additional day in the denominator is an adjustment for the fact that pilots prepare for the initial flight from the base during the 24 hours preceding the commencement of the schedule. The workload is "low or optimum" if sleep difficulties are unlikely to occur, while it is "high or maximum" when work schedules make it impossible to adhere to an acceptable sleep pattern. When these concepts of an acceptable sleep pattern and workload were applied to the data of the BOAC captain, Nicholson was able to see that "the workload compatible with an acceptable sleep pattern reduces, possibly in a logarithmic manner, as the number of days of the schedule increases [p.140]." Accordingly, the longer the flight schedule, the less workload the crewmen can handle if the effects of partial sleep loss and subsequent fatigue are to be avoided. Nicholson further stated: "within reason the most critical parameter determining an acceptable sleep pattern may not be the duration of each duty period but the total duty hours in relation to the progress of the [flight] schedule [p.140]."

An important contribution of this paper was a graphic model showing the relationship between the days on route and the cumulated duty hours on the X-Y coordinates (Figure 8). This graph illustrates that the workload can be high at the beginning of the flight and that 26 duty hours can be completed during the first two days without reducing sleep below an acceptable level in the second day of the flight. But extension of the flight time by 24 hours to 72 hours on route adds only 6 useful hours to the duty hours. If Nicholson's optimal workload is to be maintained, workload at this rate during the first three days of a schedule would require 38 hours of rest before a further duty period of 10 hours. The penalty of a high initial workload is less frequent duty periods as the schedule proceeds. Nicholson advises that planning an operation for the workload to remain in the optimal zone has the advantage of maintaining aircrews in the most satisfactory condition to cope with unforeseen emergencies with their extra workload.

What are the consequences of working at the high workload or at the level of workload which interferes with obtaining an acceptable sleep pattern? In his 1970 review paper in the proceedings of a conference for the NATO Advisory Group for Aerospace Research and Development (AGARD), Nicholson indicated that there was at present no conclusive evidence from the aeromedical literature showing that limited sleep deficits, which may be experienced with workloads just above the zone, would lead to decrement in performance during flying.

Individual Differences

In most partial sleep-loss studies, little emphasis is placed on the question of the individual susceptibility or tolerance to the effects of partial sleep loss. Wilkinson³³ noted the importance of individual differences when he referred to the power of his 6-week long experimental design to detect individual differences in susceptibility to partial sleep loss. Recently, pupillography has been used to determine individual differences to sleep loss as reflected in size of pupil diameter, in 50 veteran commercial pilots.¹³⁶ The test involves measurement of pupil diameter with infrared pupillography. A large and stable pupil is representative of an alert state. Initially, 32 well-rested pilots were studied. The pilots were seated in darkness for 15 minutes, and their pupils measured at the 1st, 8th, and 15th minute for 30 seconds each. On the basis of the pupillographic test, the pilots were classified into superior, average, marginal, or unsatisfactory categories. Three of the pilots showed a pupillographic response less than expected. One 59-year-old pilot's pupils remained large for 2 minutes before they became smaller and began to show pupillary waves. By the middle of the test, his pupil diameter was reduced to 3/4 of his alert state, and at the end of the test the pupil diameter was further reduced to one-half that of an alert state. At this time, he experienced major difficulties in keeping his eyes open due to sleepiness.

Yoss and his colleagues have also examined 18 pilots who had inadequate rest the night before pupillographic testing. For this group of 18 poorly rested pilots, the pupil response of only one pilot behaved in a superior manner characteristic of an alert state. Eight pilots showed an average pupillographic performance, 6 pilots showed marginal performance, and for 3 pilots the pupils behaved unsatisfactorily during the test. The worst pupillographic response was by a 48-year-old pilot who obtained only 6 hours of sleep instead of his ideal sleep duration of 8 hours. Sleep was also of poor quality, and he blamed his poor sleep upon time-zone crossings, since he had just completed a transoceanic flight the day before the pupillographic test.

In each instance where a marginal or unsatisfactory pupillographic response was obtained, it was associated with a pilot's report of difficulty in maintaining alertness while flying. No direct correlation between the pupillographic results

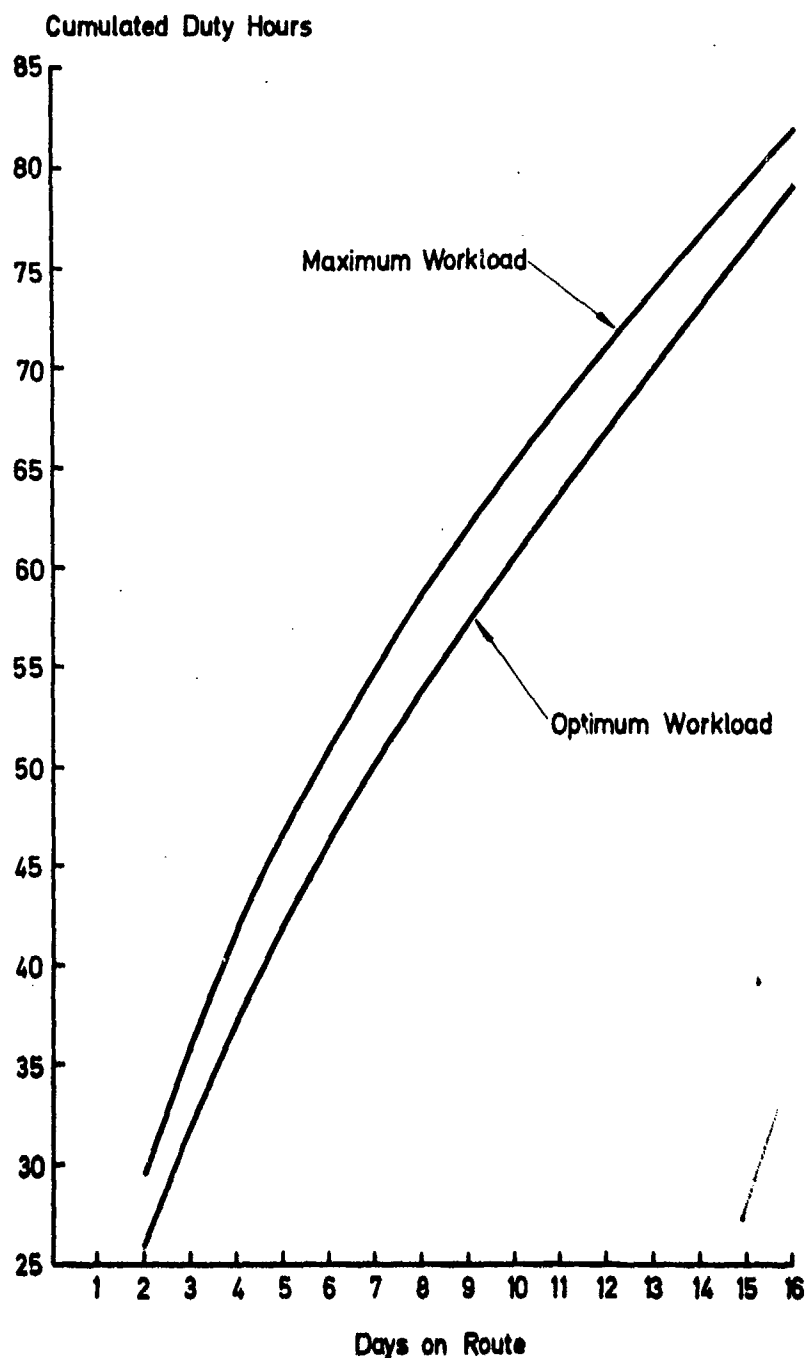


Fig. 8. Cumulated duty hours for days on route. Optimum workload for 2 days on route 26; 3 days 32; 4 days 37-1/2, etc. Workload is given by number of days on route +1 X average hours of duty per day.³

and actual flight observations and performance has been reported, but their findings emphasize the importance of evaluating individual dispositional differences in susceptibility to the effects of partial sleep loss and suggest a relatively simple measuring technique.

Recovery from Partial Sleep Loss

The problem of adequate recovery function studies following sleep loss has been discussed. The problem is even more acute for partial sleep loss. Most researchers have stressed the need for adequate rest and sleep before beginning another mission, but few have presented data to support specific recommendations.

In planning long-duration flights, Klein *et al.*⁴⁶ note that while reactivation from fatigue is possible and reactivation often happens in a tired crew, for instance during approach or landing, it should be remembered that the energy expended in the reactivation from fatigue is directly related to the level of fatigue. They advise that flight effects might persist for more than one or two days after duty times of 12-20 hours respectively.

After double crew missions, it took some crewmen 3 days before their normal sleep patterns reappeared, and physiological indices of flight after-effects from C-5 double crew missions were still present on the second and third days post-flight. The "cost" of double crew continuous flying was felt by Nicholson³ to require 2 days for the crew to regain their normal sleep after 48-hour long operations and 7 days for the return of usual sleep if continuous double crew flying was demanded for 4-5 days. Article 47 of the British Air Navigation Order¹³⁷ states that crews are to be scheduled so that they have at least 36 hours, including two "at home" nights, at least once in any 7-day period.

Wilkinson⁷³ and Morgan *et al.*³⁹ have both reported that repeated loss of sleep increased the effects of such sleep loss on performance and questioned whether one could build up a tolerance to repeated experiences of sleep loss. The observations from flight crews suggest that repeated disruption of the sleep-wakefulness cycle and partial sleep loss are also cumulative, though conclusive data are not available.

In summary, partial sleep loss appears to be a part of most aircrew operations, especially those involving time-zone crossings. Of far more significance than the actual amount of sleep loss is the disruption of the usual sleep-wakefulness cycle. Sleep appears to be fragmented and often scheduled for unusual hours. Flights during usual sleep periods tend to be associated with a greater accumulation of sleep deficits. While performance decrement does not appear to be a major problem, sleep disruption and sleep deficit raise the "cost" of the mission both in terms of increased physiological stress-related responses and by higher levels of fatigue. Subjective feelings of fatigue are the major findings whether sleep reduction occurs in a laboratory or in an operational setting. Double crews help to reduce sleep loss and permit sustained flights of two or more days, but these flights appear to have an optimal period of about 48 hours. Short work-rest cycles such as 4 work/4 rest lead to sleep deficit and should be replaced by cycles that allow for uninterrupted sleep periods of 6 or more hours.

Sleep Stage Deprivation

The ability to track a night of sleep by means of electroencephalographic recordings not only made possible the dividing of sleep into stages 2, 3, 4, and REM, but it also provided the means by which a particular type of sleep could be excised. By arousing the sleeping subject when the EEG signs of the type of sleep to be denied appear, it is possible to deny any or all of a particular stage of sleep. Sleep stage REM and sleep stage 4 are the two stages most frequently denied. In addition to EEG signs, the EOG signs of rapid eye movements are required before REM sleep arousals are made.

In 1960, Dement¹³⁸ reported that when subjects were prevented from staying in REM sleep there were, with each successive night of deprivation, earlier and more frequent attempts to enter REM sleep. Also, he found an increase or rebound in REM sleep during recovery sleep. This "pressure" to achieve REM sleep was compatible with the belief that dreaming was necessary. It was later found, however, that attempts to enter stage 4 also increased with each successive night of stage 4 deprivation and that, like REM, there was a stage 4 rebound when deprivation ended.¹³⁹ For both REM and stage 4 deprivation, the number of arousals necessary to prevent the deprived sleep stage from occurring often tripled from the first deprivation night to the fifth deprivation night. These results were interpreted as indicating a need for both REM sleep and stage 4 sleep.

In his 1960 paper, Dement¹³⁸ reported that five nights of REM deprivation resulted in "Psychological disturbances such as anxiety, irritability, and difficulty in concentrating... [p.1707]." In 1963, Fisher and Dement¹⁴⁰ warned that REM deprivation, and thus dream deprivation, would lead to "a great intensification of the pressure of instinctual drives toward discharge, eventual eruption of the dream cycle into the waking state and the development of hallucinations, delusions and other psychotic symptoms [p.1164]." But in 1965, Dement¹⁴¹ stated that he no longer believed that REM sleep occurs in order to satisfy a need for the experience of dreaming. The first two statements reflect the initial enthusiasm and belief that REM sleep provided a unique psychological function closely related to dreaming, while the last statement reflects the failure of subsequent research to support these expectations of REM sleep.¹⁴²⁻¹⁴⁵ It was in response to these early REM reports that led Nicholson,⁷ Pegram *et al.*,¹⁴⁶ and Preston and Bateman²¹ to express concern that sleep disruption, especially the shortening of sleep, would result in a REM deficit.

From the beginning, there have been fewer expectations that nonREM sleep, stages 2, 3, and 4, would prove important for waking behavior. The fact that no consistent significant performance differences were found between REM-deprived and stage 4-deprived subjects was not helpful to those wishing to push studies of stage 4 sleep.¹²¹

It is now known that dreaming occurs in some form in all stages of sleep and that REM deprivation does not prevent dreams or cause marked changes in awake behavior. What functions are served by the different sleep stages, however, are still unknown and the question of whether each sleep stage meets a unique need is still unanswered. Though each new study offers little support for a unique need hypothesis, many sleep researchers still believe that there is a functional difference between stage 4 and stage REM sleep.

In a major research effort, the Navy Medical Neuropsychiatric Research Unit, San Diego, has attempted to determine if sleep stage 4 and stage REM were uniquely related to various aspects of waking behavior. Instead of continuing to search for psychological correlates of stage deprivation, however, the Navy's research program has focused on the recuperative value of these two sleep stages. One of these studies¹¹¹ was presented earlier in the discussion of recovery from total sleep loss (page 16). That study asked, What were the relative recuperative values of REM and stage 4 sleep after total sleep deprivation? In a second study, the procedure was reversed to determine whether deprivation of REM or stage 4 sleep before total sleep loss would potentiate the sleep-loss effects.^{147,148}

Fourteen Navy enlisted men, ages 18 to 21, participated in the Johnson *et al.* study.¹⁴⁸ After three nights of baseline sleep, 7 subjects were deprived of REM sleep and 7 were deprived of stage 4 sleep for three nights. Both groups were next deprived of total sleep for one night and then allowed two nights of recovery sleep. Sleep-stage deprivation was produced by arousing the subjects when the EEG and EOG signs of the stage to be denied appeared.

Performance on the Wilkinson Addition Test and Auditory Vigilance Task, a continuous counting task, measures of both long-term and short-term memory, measures of reading speed and comprehension, and subjective ratings of affect for feelings of happiness, anger, fear, depression, and arousal were obtained daily at the same time of day from all subjects. A Rorschach measure of conceptual consistency, conformity, and looseness was also included.¹⁴⁹

Three nights of REM and stage 4 deprivation produced minimal changes, and what changes were present were similar for both groups. Following the night of total sleep loss, the expected test decrement was evident, but this decrement was significant from baseline for only the continuous counting task. The decrement was associated with breaks in the counting task due to brief lapses. The decrement in all tasks was the same for both stage 4- and REM-deprived subjects. Prior deprivation of stage REM or of stage 4 did not potentiate the effect of total sleep loss. There were no differences between the stage 4- and REM-deprived subjects with respect to mood or changes in autonomic activity to repetitive stimuli. Johnson⁴³ has discussed the changing attitudes toward the earlier-held views that stages of sleep were unique physiological states and served discrete functions.

In summary, for this AGARDograph, the most appropriate conclusion at this time appears to be that the amount of deprivation of any sleep stage that would likely occur in present aircrew operations does not pose an operational problem.

Use of Drugs to Alleviate Sleep Deficit

Since some sleep disruption and sleep deficit often occur, the question of drug usage to maintain alertness or as an aid in obtaining sleep continues to be raised. Because of concern over drug effects on performance and hangover effects, the Federal Aviation Agency's guide to drug usage states that for short-acting barbiturates, airmen's duties are contraindicated for 24 hours after usual dosage.¹⁵⁰ Hartman and McKenzie¹⁵¹ found secobarbital hangover effects and degraded performance on a simulated flying task in 64 subjects administered 3.0 gr doses the previous evening, 10 hours prior to the "flight." No degradation of performance was obtained with a dose of 1.5 gr.

Recently, however, there have been reports indicating that hypnotics may not produce performance decrement,¹⁵²⁻¹⁵⁴ and it has been suggested that, to prevent sleep irregularities, sleeping drugs should be used.² Preston¹⁵⁴ also stresses the need for a suitable and safe short-acting hypnotic which can be prescribed to pilots.

Since this AGARDograph is oriented toward sleep-loss effects and not on the effects of drugs on performance, this brief discussion of drugs will concentrate on recent findings with respect to their effect on sleep. Both the acute and chronic effects of drug usage on sleep should be considered before drugs are prescribed to

prevent or promote sleep.

While amphetamine has long been used as a drug that promotes wakefulness and prevents sleep, the first study on the effect of amphetamine on sleep by means of EEG and EOG recordings was reported in 1964.¹⁵⁵ After taking 10 or 15 mg of the drug before bedtime, sleep did not come easily. In addition to delayed sleep onset, frequent body movements and awakenings were noted. Only 8 of the 10 subjects got sufficient sleep to reach the minimal criterion of 75 minutes without an awakening lasting more than 5 minutes. There was a significant increase in the delay between sleep onset and the first REM period, REM latency, with a suppression of total REM sleep time.

Oswald and his associates^{156,157} have detailed the effect of amphetamine addiction on sleep. With chronic use, a tolerance to the drug develops and the sleep pattern is not disturbed. When the drug is withdrawn, however, sleep becomes abnormal. The withdrawn patient slept much longer; REM sleep began abnormally early and was greatly increased in amount, especially at the beginning of the night. Restoration of the drug restored sleep to the regular pattern, but the disturbed sleep appeared again when the drug was again withdrawn. Based upon the time required after withdrawal before the sleep pattern became normal, Oswald¹⁵⁷ concluded: "These changes show that, when a person tries to do without amphetamine-type drugs, once tolerance has developed, a couple of months may be needed for his brain physiology to return to normal, even though the drugs themselves are eliminated from the body within a few days [p.319]."

To see if hypnotics, another drug on which dependence may be quickly developed, would produce a response similar to that of amphetamine, Oswald and Priest¹⁵⁶ gave volunteers sodium amobarbital nightly for 18 nights, and to others nitrazepam (a benzodiazepine hypnotic) nightly for 10 nights. In these subjects, withdrawal provoked sleep abnormalities similar to those seen after amphetamine withdrawal, and these continued for up to 6 weeks. During the withdrawal period, Oswald and Priest noted an increase in unpleasant dreams, insomnia, and the general feeling of having slept poorly.

Intensive and extensive studies of the physiological and biochemical changes following use and withdrawal of hypnotics have been conducted by Anthony Kales and his colleagues.^{158,159} This comparison has included both barbiturate and nonbarbiturate hypnotics: pentobarbital (Nembutal), secobarbital (Seconal), glutethimide (Doriden), methyprylon (Noludar), methaqualone (Quaalude), chloral hydrate (Noctec), and flurazepam (Dalmane), as well as several antihistaminic agents reported to have side effects of sleepiness: diphenhydramine (Benadryl), chlorpheniramine maleate (Chlor-Trimeton), and promethazine (Phenergan), a phenothiazine-type drug. Dosage level was also studied in some of the drugs.

To investigate effects of short-term use of hypnotics, the study included three placebo nights for baseline, three drug nights, followed by two more placebo nights to determine possible effects of drug withdrawal. With the exception of chloral hydrate (500 and 1,000 mg), flurazepam (30 mg), and methaqualone (150 mg), on the first drug night all drugs produced an increase in time to first REM, and a moderate to marked decrease in REM sleep time. By the third drug night, REM time had returned to near baseline levels. Glutethimide caused the greatest REM suppression over all three nights. REM increase during withdrawal was greatest for those drugs with the greatest REM suppression during drug nights.

Flurazepam, glutethimide, and pentobarbital produced a significant decrease in stage 4 sleep. Decrease in stage 4 was most pronounced for flurazepam, and there was little recovery on the two withdrawal nights. During the withdrawal nights, even after three nights, there was a report of increased dream intensity and, although still infrequent, more nightmares were reported during withdrawal than during baseline sleep.

With chronic use of hypnotics, Kales et al. found that tolerance quickly develops to the drugs so that initial dose levels may no longer be effective. REM time gradually returns to predrug levels during chronic use. Withdrawal of hypnotics from chronic users often produced the same sleep problems noted by Oswald; increased REM, intense dreams often becoming nightmares, and reports of "poor sleep" coupled with the psychological apprehension of inability to go to sleep. This withdrawal pattern is often of such concern to the patient that there is a return to the hypnotic to avoid another night of disturbed sleep. When this point is reached, drug dependency is well established. As Kales et al.¹⁵⁸ noted, "However, it does appear that in some individuals short-term drug use and in most individuals long-term drug use result not only in altered sleep patterns but also in associated changes in dream intensity, which may be a factor in the development of drug dependency [p.340]."

The acute and chronic effects of alcohol are similar to that found for hypnotics. Acute intake of alcohol will depress REM sleep. Chronic alcoholics usually

show only moderate depression of REM sleep but there is a marked reduction of stage 4, with frequent awakenings and frequent stage changes.¹⁶⁰ Delirium tremens of withdrawal are associated with a dramatic increase in REM sleep.¹⁶¹

When obtaining adequate amounts of each stage of sleep was thought to be necessary, the REM or stage 4 suppression was felt to be potentially the most harmful drug side-effect. But, as indicated in the section on sleep stage deprivation, the early belief that REM deprivation led to gross psychological changes is no longer supported and, at this time, it would not be correct to say that either REM sleep, stage 4, or stage 3 is necessary. (Stage 2 sleep is necessary or total sleep loss would occur.) Kales and Kales¹⁵⁹ now believe that "Drug Withdrawal Insomnia," which results from both psychological and physiological changes involved in drug withdrawal, is the most potential harmful effect of hypnotics. They believe that "Drug Withdrawal Insomnia" is why most patients continue the use of hypnotics long after they become ineffective. Kales and Kales,¹⁵⁹ however, do implicate the increased REM sleep time during withdrawal as a contributing factor to the increase in dream intensity and nightmares.

The inevitable disruption of the rhythmicity of sleep cycles has not received much attention by those studying drug effects. Recent work by Johnson⁶³ has stressed the relation between goodness of sleep and regularity of the 90-100 minute REM-nonREM cycle. When REM latency is increased or decreased, or when the REM cycle is missed completely, the usual REM-nonREM cycle is disrupted. Based upon observations that sleep-cycle rhythmicity in chronic alcoholics was more closely related to severity of the withdrawal syndrome and to recovery during withdrawal than amounts of stage REM or stage 4 sleep, Johnson has urged that more attention be given to sleep-cycle rhythmicity as an index of goodness of sleep. To aid in the study of this sleep measure, computer technology has been developed for the measurement of EEG delta activity during sleep as an ultradian rhythm,¹⁶² and for the extraction of an ultradian cycle in sleep from manually-scored sleep stages.¹⁶³

CONCLUSIONS AND RECOMMENDATIONS

What are the operational consequences of sleep loss and sleep deficit? Short of prolonged sleep loss of greater than 60-72 hours, it is difficult to categorically state what the effects of sleep loss on performance will be. Whether a performance decrement will occur during sleep loss depends upon a complex interaction of task, situational and personal factors. The nature of the task and its meaning to the subject, particularly its survival value, are of primary importance in the type of sleep-deprivation effects which occur. In the majority of instances, performance decrement occurs when the subject becomes sleepy. If the subject can be motivated to remain alert, performance decrement is difficult to detect. The conclusion by the Tufts¹⁶⁴ group at the end of their 1949 review is still appropriate to state at the end of this review. "Subjective attitude (mood, appearance, and behavior) is the primary factor seriously affected by sleep loss." There have been no studies that have conclusively demonstrated consistent performance decrements as a result of partial sleep loss, even though numerous illustrations of sleep disruption and sleep deficits have been presented.

The paucity of data indicating a clear performance decrement might cause some to conclude that sleep logistics should be relegated to a minor position in mission planning. Such a conclusion would be a mistake. The importance of adequate sleep has been emphasized by all researchers as the most important factor in alleviating the problems from repeated time-zone crossings and as a means of reducing the physiological cost of air operations. Preston¹³⁴ perhaps summarized the view of those who have closely observed sleep problems of aircrew members: "There is no doubt that sleep deprivation affects performance but in the sophisticated problems of flying a large jet aircraft decrement of performance is difficult to measure with accuracy....What is urgently required at the moment is a statistically reliable method of measuring performance decrement in the actual operating situation [p.78]. That reliable performance measure is still needed.

A potentially useful alternative to the search for performance decrement is the concept of "physiological cost." While there are no specific physiological responses that clearly separate sleep loss from other stressors, and it is even difficult to establish a pattern of physiological changes related to sleep loss *per se*, it was obvious to Hale and his colleagues at the U. S. Air Force School of Aviation Medicine that sleep loss potentiated the usual physiological changes associated with routine flight missions. What is needed at this time are more data on the long-term effects of these physiological changes and whether these changes are cumulative with repeated exposure. In addition to information pertinent to the general adaptation syndrome, data on the reactions of the musculo-skeletal, renal, hepatic, gastrointestinal, and infection-combating systems to the stressors of long-duration missions and repeated exposure to sleep loss are needed. Harris and O'Hanlon⁶⁵ list other areas requiring further research, in their study of recovery functions in man, and they also offer several suggestions for physiological studies that should be considered by those concerned with the operational consequence of sleep loss.

Klein and his staff at the West German Institute of Aviation Medicine have also stressed the interaction of the various stressors, the difficulty of obtaining an absolute measure of fatigue, and the problem of establishing the relative weights to assign to the various factors contributing to the fatigue. What is needed are more data on the relative contributions of varying amounts of sleep deficit to fatigue and its physiological correlates. Such data will be difficult to obtain and, as Klein and his colleagues have so ably stated, the unraveling of cumulative fatigue into its component parts is extremely complex. To help obtain a constant reference point to measure changes during prolonged air operations, Klein and his co-workers have used the "normal night minimum of activation point" as a reference level. Consistent reference to this "standard" or "dead point," obtained usually in the early morning hours, permits comparison of measures obtained at different times of day and during various parts of a mission. Performance, psychological, and behavioral data can all be referenced to this same point. Future work in this area would be more comparable from study to study if the "standard" reference point of Klein *et al.* was accepted.

Klein and his associates chose this "standard" or "dead point" to help control for the circadian influence on physiological functions and performance. The importance of circadian cycles was often cited as an important factor in the effects of sleep loss. Sleep loss potentiates the usual performance decrement seen during these early morning hours and quantity of alpha activity is at its lowest level. Comparison within sleep-deprived groups or between sleep-deprived and non-sleep-deprived groups must be made at the same time of day. If men are kept awake and required to perform when ordinarily they would be asleep, their performance will suffer. The effects of circadian periodicity and the course of adaptation to time displacement thus are important factors in mission planning. Where possible, sleep should be permitted during the low periods of the circadian cycle regardless of local time if the aircrew member is keeping his cycle on his home base day-night cycle. Except in space flights where social and other environmental influences are controlled, maintenance of the home base cycle is probably not practical. When this is true, the schedules should permit as much night sleep as possible with reference to local day-night cycles. Adequate sleep is more difficult to obtain during daylight hours. Scheduling without reference to local times may result in some aircrew member always arriving at his rest station during daylight hours and leaving during night hours. It should be remembered, however, that even though the sleep-wakefulness cycle may be on local time, other circadian biological rhythms may remain for some time on their home base schedule. The home base early morning "dead point" may still exert its influence, resulting in unanticipated episodes of increased fatigue and reduced effectiveness.

A crucial factor in preventing sleep loss is adequate work-rest scheduling. Work-rest schedules such as 4 hours work, 4 hours rest (4/4) do not allow time for a reasonable period of uninterrupted sleep and should be avoided. The preferred schedule appears to be nearer 10/10. The cumulative effect of duty hours during long-duration missions may result in a logarithmic rise in workload rather than a simple arithmetic increase. In planning flight schedules, the most important parameter in maintaining an effective sleep-wakefulness pattern may not be the duration of each duty period but the total number of duty hours in relation to the mission duration. A quantitative approach to scheduling has been developed by Wing Commander A. N. Nicholson of the Royal Air Force.^{5,7} From his observation on transport crews, a graphic model has been developed which permits a rapid determination of optimal duty hours for each day of a planned mission (see Figure 8, p.29). Though developed on transport crews, this approach to scheduling and to sleep patterns has been found to apply to fighter pilots, tanker crews, and ground personnel in a long range air-to-air refueling mission.¹⁶⁵ The work by Nicholson and his colleagues is the most extensive and the most objective approach thus far developed as a guide for flight schedules. While there is no information as to the behavioral changes or performance decrement incurred by a "maximal workload" schedule, the data by Nicholson offer an approach by which the influences of operational scheduling can be obtained.

Fatigue is a universal result of sleep deprivation, sleep disruption, and sleep deficit. The complexity of this term has been noted. The effects of sleep loss are to potentiate the effects of other fatigue-inducing factors that might already be present. It is the complaint of fatigue that may be the first indicator of a sleep deficit. Increased ratings as to level of fatigue will, in most instances, precede performance decrement. Though their use may not be readily accepted and the willingness of aircrew personnel to answer them honestly is a problem, the use of brief fatigue questionnaires such as that developed by the Navy Medical Neuropsychiatric Research Unit deserves more study. To be successful, accurate reporting as to level of fatigue should have no punitive aspects. Admission of fatigue is better than having it become known through a performance error.

There is still a paucity of data on individual susceptibility to sleep-loss effects and techniques to measure these individual differences, but there is increased interest in the individual differences in patterns of sleep as illustrated

by the studies of natural long and short sleepers. It is clear that there are short sleepers, those who sleep 6 hours or less, and long sleepers, those who sleep more than 9 hours. Whether there are personality and behavioral differences between these two groups is still a matter of controversy, but when it is known that reduced sleep will be inevitable, short sleepers may perform better than natural long sleepers.

Of potential significance is the early finding that, by means of gradual sleep reduction, total sleep time may be reduced. Whether all subjects can reduce their total sleep time, by what amount, and how long this shortened sleep regimen can be maintained awaits more data. The present findings, however, suggest that gradual sleep reduction might be considered for special assignments where reduced sleep is an important aspect of the mission and enough lead time is available to permit the subject to gradually achieve the desired sleep regimen.

Sleep patterns and preferences should be a part of any crew member's profile sheet, and these should be included along with other factors in mission assignments. Whether an individual is a night person (*i.e.*, prefers to go to sleep late at night) or a morning person (prefers to awaken early) may be of some value in the scheduling of late night or early morning missions.

During the early 1960s, the type of sleep was thought to be of crucial significance. Subsequent research has questioned many of the early assertions that fixed amounts of each sleep stage, and in particular REM sleep, were necessary for effective waking behavior. At this time, the amount of time spent in each sleep stage does not appear to have important operational consequences. The amount of sleep and whether the sleep is broken into several segments over the 24-hour period are more important.

The use of drugs to overcome sleep loss and to insure rapid sleep onset is being given more attention. Amphetamines can be used to maintain alertness, and nonbarbiturate hypnotics can be used to insure rapid sleep onset at unusual times of day and in difficult settings. Recent studies have indicated that there may be minimal drug-related performance impairment, and, with some of the new hypnotics, hangover effects may be negligible. Before these drugs are freely prescribed, however, attention should be given to the possible sleep disruption during drug nights and withdrawal. The drug withdrawal insomnia syndrome and the risk of long-term drug dependence should be carefully weighed against the operational consequences of a sleep deficit of limited duration.

Perhaps the most important question is the one for which there are little data; *i.e.*, Following missions that result in sleep deficits and the cumulative build-up of fatigue, what is the necessary recovery period? The little data available suggest that the recovery period is related to the duration of the mission. A 4-day mission will require a longer recovery period than a 2-day mission. Whether the recovery period following 4-day missions needs to be twice as long as those for 2-day flights is unknown and probably will be related to the final level of fatigue and to the coping ability of the individual crewman. To determine probable time necessary for recovery following long flights, a formula involving travel time, time zones crossed, and departure and arrival times has been devised for use by air travelers.¹⁵⁵ While the factors in this formula may be relevant, the relative weightings may not be appropriate for flight crews where the stressors added by their inflight duties and responsibilities must be considered. Further, the ICAO formula by Buley¹⁵⁶ was devised for personnel who were going to remain several days or weeks and thus had to adapt to local times. Such is not the case for most civil and military flight personnel. Until a formula with factors and weights specific to aircrew personnel can be developed, one measure of recoverability that has been used is the time taken to return to pre-mission sleep schedules. In the absence of more easily accessible data with a higher correlation with feelings of well being, perhaps the time taken for stabilization of sleep should be used as a criterion of recovery.

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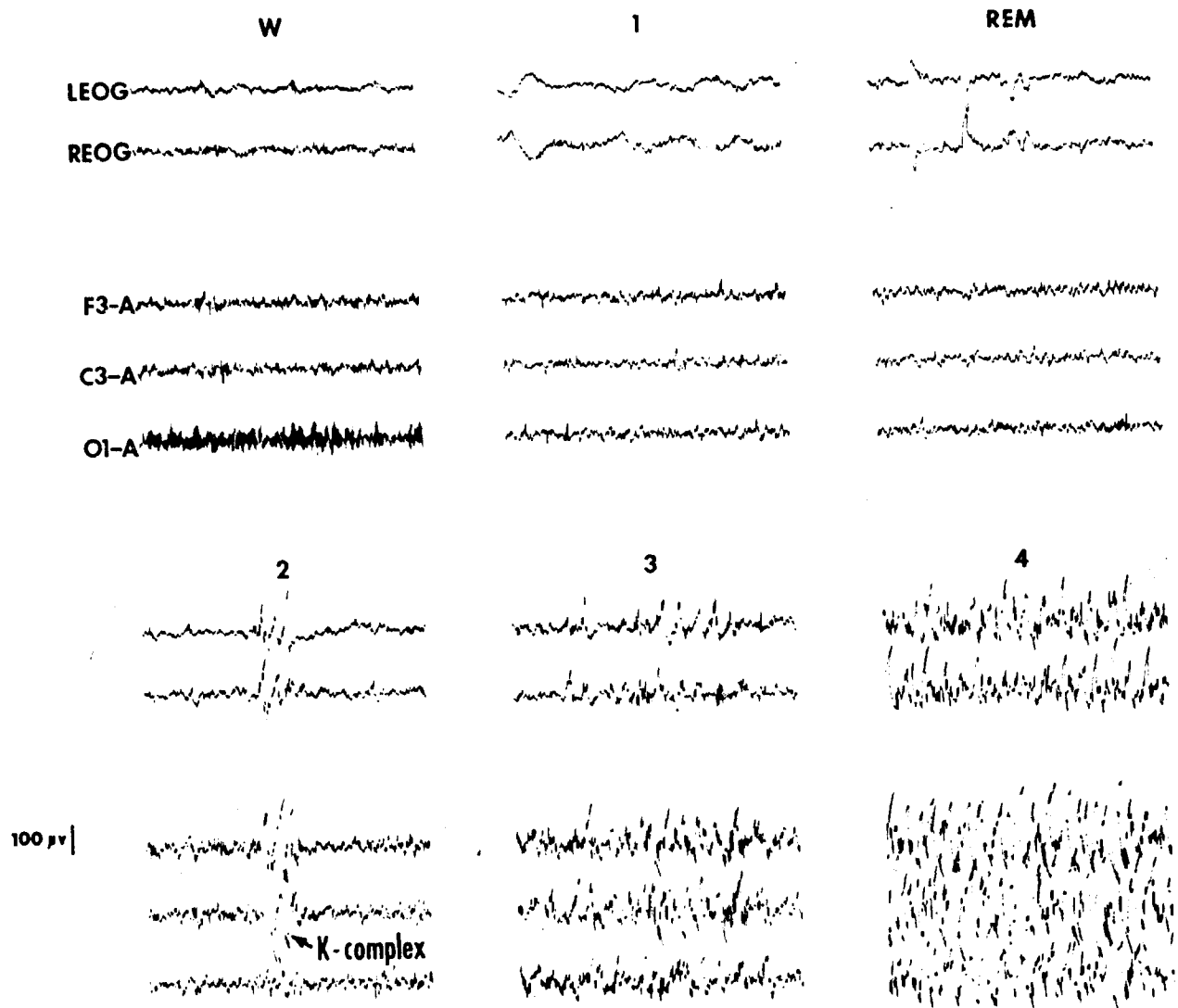
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APPENDIX 1

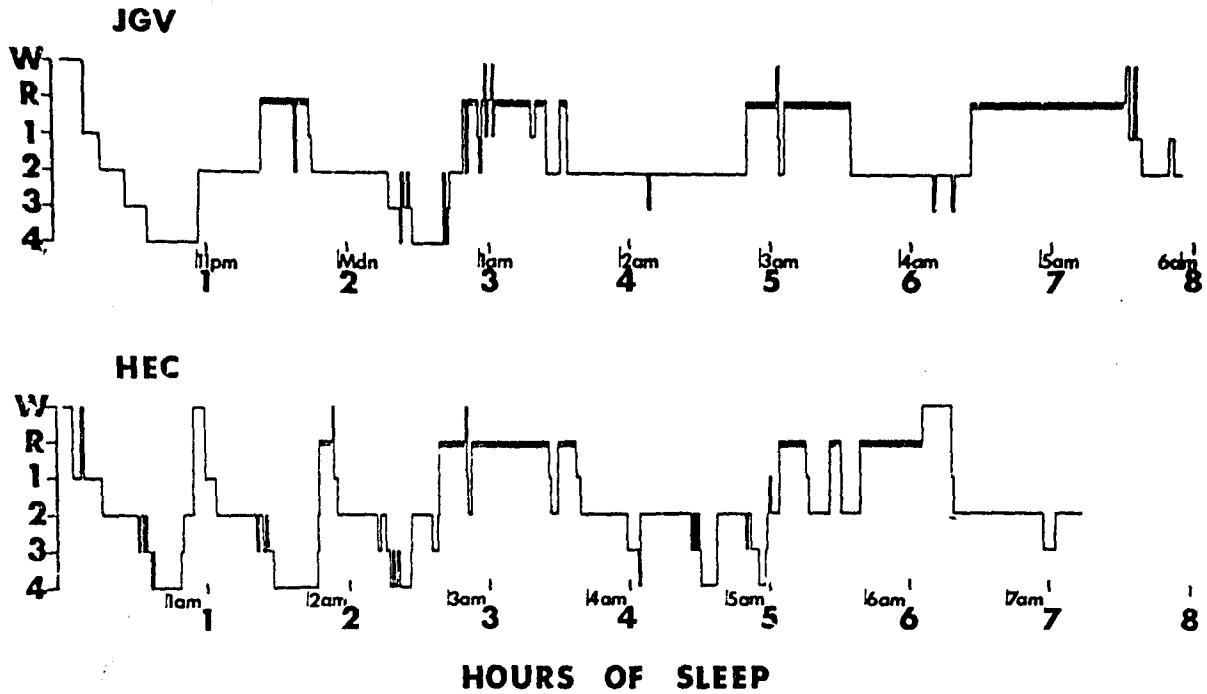


EEG stages of sleep following the revised scoring criteria of Rechtschaffen and Kales.⁴⁷ The record length for each stage is 20 seconds. Briefly, the stage descriptions are:

- Stage W (wakefulness) - The EEG contains alpha activity and/or low-voltage, mixed-frequency activity.
- Stage 1 - A relatively low-voltage, mixed-frequency EEG without rapid eye movements (REMs).
- Stage 2 - 12-14 Hz sleep spindles and K-complexes on a background of relatively low-voltage, mixed-frequency EEG activity.
- Stage 3 - Moderate amounts of high-amplitude, slow-wave activity.
- Stage 4 - Large amounts of high-amplitude, slow-wave activity.
- Stage NREM (nonREM) - Stages 1, 2, 3, and 4 combined.
- Stage REM - A relatively low-voltage, mixed-frequency EEG in conjunction with episodic REMs and low-amplitude electromyogram (EMG).

APPENDIX 2

SLEEP CYCLES



Two all-night sleep profiles, illustrating sleep cycles for two young adult males. Sleep onset was 2200 hours for the upper profile and near midnight for the lower one.

APPENDIX 3

NPRU MOOD SCALE
11ND-COM 4250 2 (5-73)

Instructions: For each item, choose one of the four answers that best describes how you feel now. Then put an "X" in that box.

NAME					AGE	SEX	DATE		
ITEM	NOT AT ALL	A LITTLE	QUITE A BIT	EXTREMELY	ITEM	NOT AT ALL	A LITTLE	QUITE A BIT	EXTREMELY
ACTIVE					GOOD-NATURED				
ALERT					GROUCHY				
ANNOYED					HAPPY				
CAREFREE					JITTERY				
CHEERFUL					KIND				
ABLE TO CONCENTRATE					LIVELY				
CONSIDERATE					PLEASANT				
DEFIANT					RELAXED				
DEPENDABLE					SATISFIED				
DROWSY					SLEEPY				
DULL					SLUGGISH				
EFFICIENT					TENSE				
FRIENDLY					ABLE TO THINK CLEARLY				
FULL OF PEP					TIRED				
DO NOT FILL IN SCORES:	N	P			ABLE TO WORK HARD				

Scoring Instructions: Each of the four possible response categories is assigned a weight: "not at all," 0; "a little," 1; "quite a bit," 2; "extremely," 3. The sum of 19 positive items (active, alert, carefree, cheerful, able to concentrate, considerate, dependable, efficient, friendly, full of pep, good-natured, happy, kind, lively, pleasant, relaxed, satisfied, able to think clearly, able to work hard) is the P score. The positive items reflect feelings and behavior that generally decrease following sleep loss, i.e., feel less active, alert, efficient, etc. P scores range from 0 (extremely sleepy) to 57 (extremely active and alert). The sum of the responses to the 10 negative items (annoyed, defiant, drowsy, dull, grouchy, jittery, sleepy, sluggish, tense, tired) is tabulated in the same way to obtain the N score. The negative items usually increase following sleep loss. Negative scores range from 0 (extremely active and alert) to 30 (extremely sleepy). The two scales were included because it was found that certain subjects, such as those in the military, were reluctant to admit negative feelings and behavior while being more willing to admit to change in more positive-type feelings. College students, on the other hand, were more willing to admit to negative feelings such as increased feelings of fatigue, tension, and defiance. The P score has been found to be the most sensitive to sleep loss, and it is recommended that the two scales not be combined.

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