A REVIEW OF CIRCADIAN EFFECTS ON SELECTED HUMAN INFORMATION PROCESSING TASKS

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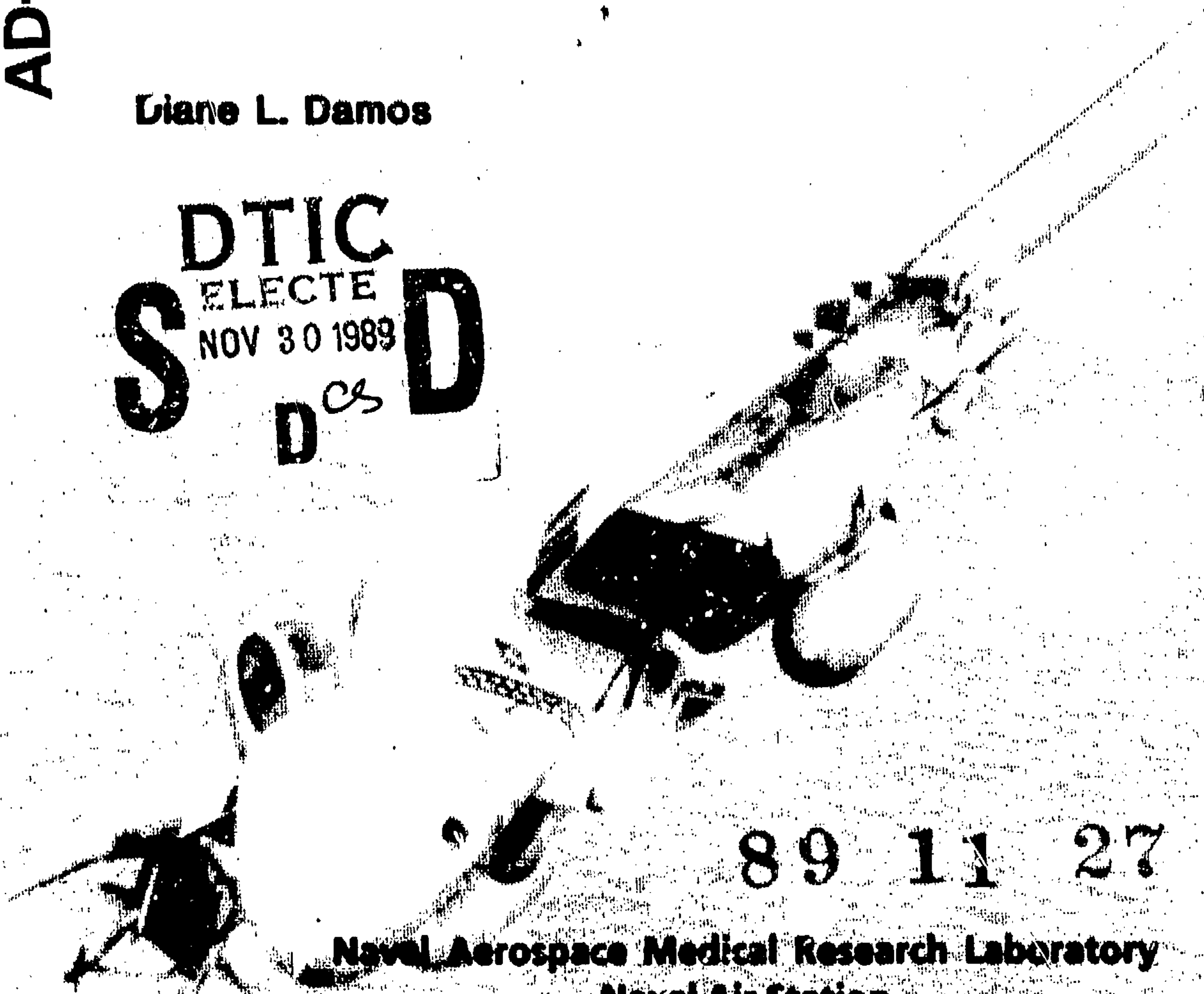

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Approximately half of the statistical tests conducted to detect circadian effects were nonsignificant. The majority of circadian effects, regardless of their statistical significance, showed less than a 10% difference between mean performance and either the maximum or minimum performance.

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ABSTRACT

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Approximately half of the statistical tests conducted to detect circadian effects were nonsignificant. The majority of circadian effects, regardless of their statistical significance, showed less than an 10% difference between mean performance and either the maximum or minimum performance.

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1. INTRODUCTION

The primary purpose of this report is to describe the magnitude of the circadian effect on selected human information processing tasks. The results of experiments examining the circadian effect are presented in the literature review (chapter 4), where the experiments are grouped according to task. Each study is described briefly, and then a summary indicating the magnitude of the effects and the time at which the minimum and maximum performance occurred is given. The studies included in the literature review represent a sample of those available rather than an exhaustive review.

Determining the magnitude of the circadian effect on human information processing is particularly difficult for at least two reasons. First, the study of the circadian effect on information processing has all the hallmarks of a young discipline: developing theories, methodologies, and data analysis techniques. Consequently, "established" experimental designs and analysis techniques may suddenly be recognized as seriously flawed, calling into question many "facts." The literature concerning the magnitude of the circadian effect on information processing clearly shows a pattern of theory, disproof, and new theory that is common in rapidly developing areas.

Second, many methodological and mathematical problems involved in assessing the circadian effect are unusual or unique to this research area (see chapters 2 and 3). No large, easily accessible literature discusses these problems, and little debate has been conducted in the journals. A novice investigator, therefore, must spend a great deal of time "discovering" these problems and their solutions. To make matters worse, sophisticated mathematical techniques may be required to overcome some of these problems. Such techniques are even less well known to most investigators than those required to analyze more routine situations.

This report presents only what might be considered "baseline" data. That is, only studies examining the magnitude of the circadian effect on information processing without confounding variables, such as transmeridian flight, varying work/rest cycles, or sleep deprivation are reviewed. Chapters 2 and 3 discuss the data analysis and methodological problems of assessing the circadian effect. These discussions apply only to the investigation of human information processing in repeated-measures situations. Indeed, many of the problems do not pertain to the study of the circadian effect on physiological variables. The actual literature review is presented in chapter 4. Chapter 5 is a summary and critical evaluation of the data. A glossary of related terms is provided in appendix A.

2. DATA ANALYSIS

Three basic methods can be used to determine the magnitude of the circadian effect: interpretation of graphs, analysis of variance (ANOVA), and identification of periodicities. All of the studies presented in the literature review (chapter 4) are concerned with determining the effect of the circadian cycle on information processing. Surprisingly, all of the studies reviewed analyzed their data either by interpreting graphs or conducting ANOVAs, rather than identifying the periodicities, which would be more informative. One reason for not using periodicity analyses is that data obtained from human information processing tasks often cannot satisfy the assumptions of these analyses. Problems associated with satisfying the assumptions and appropriate techniques are discussed elsewhere (1). The discussion immediately following describes some of the common problems associated with determining the effect of the circadian cycle on human information processing data.

DATA AVERAGING

One common data analysis problem relates to averaging across subjects. The major question in chronobiology studies is not if, but when, to average. The problems associated with averaging across subjects may be demonstrated in Fig. 1. Assume that each line in Fig. 1 represents one subject's diurnal temperature after they have undergone a phase shift such as a transmeridian flight. The average of the three lines is presented in Fig. 2, which clearly shows a decrease in amplitude compared to the graphs in Fig. 1. Such averaging techniques could be the cause of some purported chronobiological phenomenon, such as temperature flattening (see 2 for a discussion) during unusual shiftwork cycles or after transmeridian flights. This does not imply that all decreases in the amplitude of dependent variables are caused by inappropriate averaging; clearly, this is not the case. Averaging can, however, distort the results. An interesting example concerns the effects of averaging on the amplitude of simulator performance curves (3). Most, but not all, of the apparent flattening of the curves was caused by averaging. Another excellent discussion of the distortion caused by averaging across subjects is given in Klein et al. (4).

The example above demonstrates that relatively innocuous mathematical techniques can cause large distortions when applied to periodic data. The best guideline for handling averaging problems may be to perform as much of the analysis as possible on individual subject's data and delay averaging across subjects until as late as possible. For example, assume the best-fitting equation for an experiment must be obtained. In most cases, it would be preferable to fit each subject's data and then average the parameters of the individual equations to obtain a general equation rather than first averaging across subjects at each testing time and then fitting an equation to the averages.

DATA SMOOTHING

Another problem concerns smoothing (averaging across successive time periods). Some investigators smooth their data because they believe that the raw data are too irregular to be interpretable. Such smoothing creates several problems for the reader. First, usually no raw data are given.

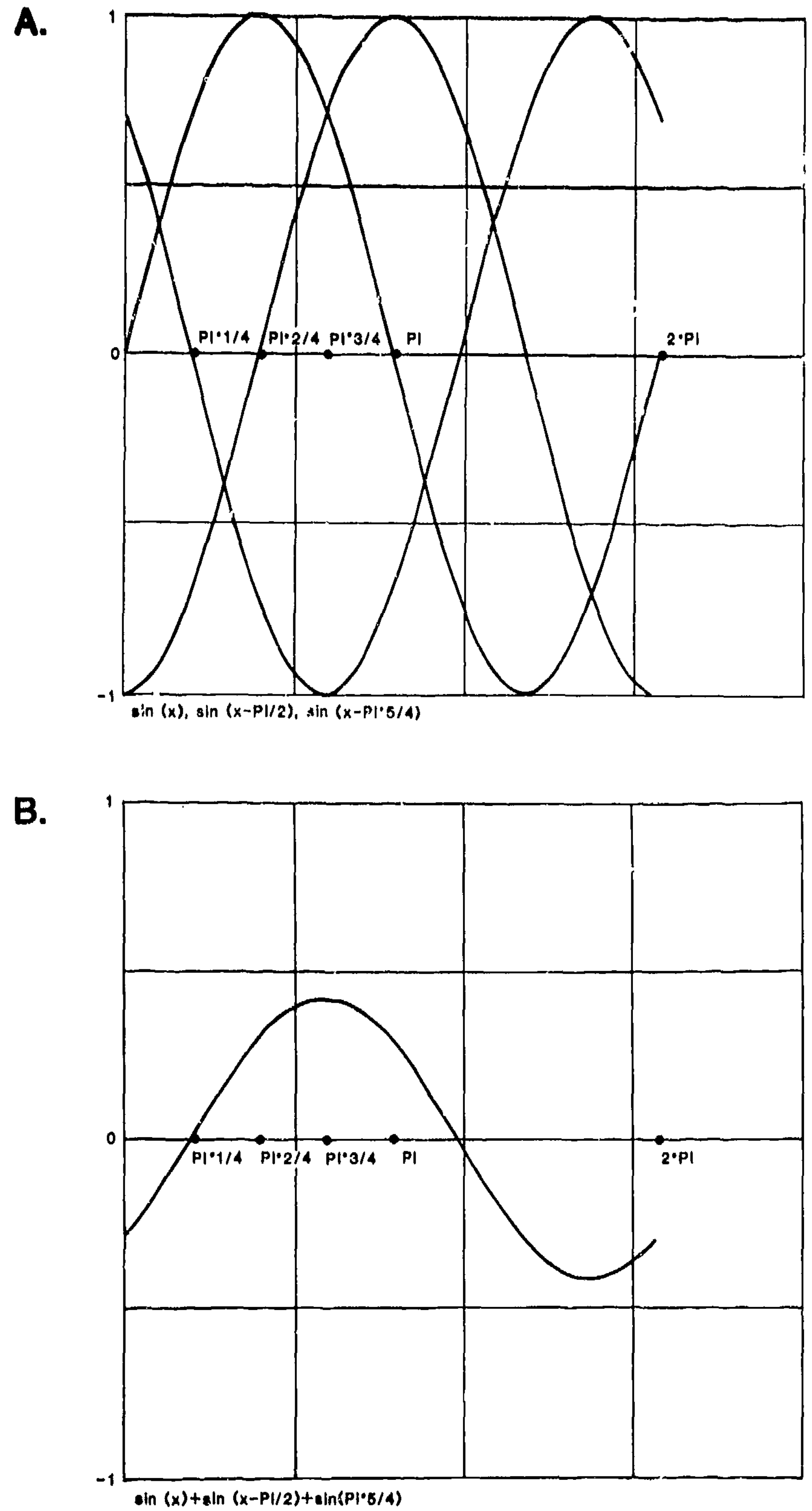

Figure 1. Three hypothetical curves and their average. Diagram A shows three hypothetical curves. Each curve represents one subject's performance curve. Diagram B represents the average of the three subjects' performance curves and is flatter than any of the individual curves.

The reader, therefore, cannot determine how much the data from individual testing sessions differ from the smoothed data. If the raw data are extremely variable, then smoothed data may not provide a representative picture of the raw data. Second, analyses may or may not be conducted on the smoothed data. Again, depending on the variability of the raw data, analyses conducted on the raw and the smoothed data may give conflicting results.

3. METHODOLOGICAL PROBLEMS

Studies examining the effect of the circadian cycle on information processing often have serious methodological shortcomings. Three of these are common enough to warrant detailed discussion.

Probably the most common methodological shortcoming concerns practice. A surprising number of investigators provide little or no practice on the experimental task(s) before collecting data. Practice effects then occur in the experiment and may be confounded with time-of-day effects.[1] For example, if all the subjects begin the experiment at the same time of day, 0800 for example, the practice effects are completely confounded with the time-of-day effects, and no unbiased estimate of the circadian effect can be made.

The situation becomes more complicated if different subjects begin the experiment at different times. Many investigators have relied on a Latin square design to balance time-of-day effects with trial (practice) effects. Superficially at least, this is a reasonable approach. Latin square designs assume, however, no interaction between any of the experimental factors (5). The investigator must know, therefore, a priori that time-of-day effects do not interact with trial (practice) effects. In most cases, this assumption appears unwarranted, and the investigator should verify this assumption carefully. If the subjects receive no practice before beginning the experiment, the three-way interaction between trial, the time at which the test is conducted, and subjects (or groups) may be significant. Such an interaction again will violate the assumptions of the Latin square design.

To eliminate confounds associated with practice effects and simplify the experimental design, all subjects should receive sufficient practice before beginning the experiment. This raises the question "What is sufficient practice?" The traditional answer to this question is practice to an asymptote. The problem with this approach is that asymptotes are subjectively determined by the investigator. In some cases, the investigator may simply "eyeball" the data and determine if the rate of change has become satisfactorily slow. In other cases, the investigator may use some "objective" criteria, such as "A change of less than 3% on the last five trials." In either case, practice to asymptote is fundamentally a subjective evaluation of performance with many pitfalls. Bradley (6) gives an excellent brief account of some of these problems.

A second method for evaluating practice effects is differential stability (7,8). This approach has been discussed in detail elsewhere (9), and its mechanics will not be described here. Briefly, practice to differential stability has two major advantages compared to practice to asymptote. First, differential stability takes into account changes in the variance of the data and the rank order of the subjects as well as changes

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[1] The term "circadian effect" and "time-of-day effect" are not synonymous. "Circadian effect" refers to the effect the 24-h cycle has on some variable. "Time-of-day effect" indicates that statistical tests show significant differences between performances obtained at different times of the day.

in the mean. Second, differential stability relies on a statistical test to determine when practice effects become minimal. Thus, the only subjective judgment the investigator must make concerns the p value for the statistical test.

The second common methodological problem concerns assumptions about the subjects' circadian cycle. Many investigators assume that all subjects have the same circadian schedule, for example, everyone goes to bed around 2200 and gets up about 0700. This assumption is questionable, particularly when the subjects are college students, who have a great deal of flexibility in their daily schedule.

Some investigators have attempted to deal with the problem of different daily schedules by having the subjects sleep in a controlled environment at least one night before the start of the experiment. Typically, the subjects must report to these facilities and be in bed at a specified time. The investigator then awakens the subjects at the desired time. Such procedures almost certainly decrease the between-subject variance although the amount of time required to synchronize a given subject to a given schedule may be excessive and, consequently, impractical.

The third problem associated with studies of the circadian effect concerns meals and mealtimes. The "post-lunch dip" is a well-documented phenomenon (see 10 for a review), which is distinguished by a general drop in performance following lunch. The most widely held explanation for the post-lunch dip is that people tend to be sleepy after a meal, which affects their performance. Surprisingly, almost none of the experiments described in this monograph attempted to control either the subjects' mealtimes or the content of their meals.

Problems associated with practice, individual differences in the sleep/wake cycle, and meals and mealtimes are pointed out for each experiment in the Literature Review. Other less common methodological problems are discussed in chapter 4 when appropriate.

4. LITERATURE REVIEW

The data described in this section are presented in two different ways. A brief synopsis of each study is given in the table of appendix B. The reader may consult this table to determine the tasks used in a specific study, the type and number of subjects, the magnitude of the circadian effect, the frequency of the data sampling, and comments or criticisms about the study. The rest of this section presents information on the magnitude of the circadian effect by task. All of the studies that used a specific task are discussed under one heading, allowing a direct comparison of the magnitude of the effect across different experiments. To allow a more general evaluation of the effect of circadian rhythms on performance, the magnitude of all effects is described in terms of a percentage change from mean performance.

Several criteria were used to select studies for this section. Only studies examining the performance of two or more adults (individuals at least 16 years old) on information processing (cognitive) tests or on simulations of real-world tasks were included. Only studies sampling performance at least every 6 h with four testing sessions are discussed. In a few studies, the data were not presented in a manner that allowed the circadian effect to be described as a percentage of the mean. These studies are not reviewed. Data collected when the subjects were in a sleep-deprived state are not reported although data obtained by awakening the subjects during sleep periods are included. Finally, only studies published after 1949 are included. Excellent reviews of the earlier experiments are available (11,12), and the reader is referred to these articles. No attempt was made to include articles associating individual differences, such as "morningness" and "eveningness," with the magnitude of the circadian effect.

Many of the experiments discussed below used several different tasks to examine the circadian effect. The results of the experiment are discussed on a task-by-task basis in the appropriate sections. Methodological details of the experiment are only provided for the first discussion of the study.

SIMPLE REACTION TIME

Simple reaction time tasks cannot actually be considered information processing tasks. They have been included because they are commonly used in assessing performance decrements and because they can provide a criterion for judging the magnitude of the circadian effect on choice reaction time tasks.

Blake (13) had 25 naval enlisted men perform a manual response to the extinction of a light. The article describing this experiment is very abbreviated. Consequently, most of the procedural details reported below are from Blake (14).[2] Apparently, meals, mealtimes, physical activity

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[2] All Blake results should be viewed with extreme caution because apparently none of the training on the various tasks was sufficient to eliminate a practice effect. Only raw, uncorrected scores are discussed in this monograph.

immediately preceding testing, and the sleep schedule were not controlled during the experiment. Each subject was tested once a day at one of five preselected testing times between 0800 and 2100. Thus, each subject required 5 days to complete this experiment, and only one estimate of performance was obtained for each time. The order of testing for each subject was determined by a Latin square design. This should allow time of testing to remain unconfounded with practice effects. During each testing session, the subjects made 75 responses, which were measured to an accuracy of 10 ms. Testing time was 20 min. All subjects were given one practice trial before the experiment began. Body temperatures were obtained by averaging readings obtained 3 min immediately before the test and immediately after the test from a thermometer inserted sublingually. An ANOVA performed on the average reaction time obtained in each testing session revealed no significant time-of-day effect. Performance varied from -2.2% to 2.8% over the testing time with the slowest reaction times occurring at 1300 and the fastest, at 2100.

Klein et al. (15) had 17 members of a laboratory staff perform a simple reaction time task. This task reportedly used both visual and auditory stimuli, but no description of the task is provided to indicate the number of stimuli presented in each modality. Additionally, no testing procedures are given. Subjects were tested every 3 h from 0900 to 0000 on 1 day and from 2100 to 1200 on a following day. Thus, half of the testing times (0900, 2100, and 0000) were replicated once; half were never replicated. Data obtained during the replicated periods were averaged on a subject-by-subject basis. Reaction time data were collected after a 15-min rest in the supine position. This rest period provided some control for the subject's activity level proceeding data collection. Mealtimes were left to the subject's discretion. Standardized meals may have been provided although the report is not clear on this point. The subjects' sleep periods apparently were not controlled.

The fastest reaction times occurred at 1500 (-4.2%), whereas the slowest occurred at 0300 (4.8%). Because the testing procedures are not given, the number of responses used to calculate these averages is not known. Additionally, although some statistical tests were conducted, their description is vague, and the significance of the time-of-day effect cannot be determined. Data are also given on individual ranges in performance and group ranges. The description of the calculation of these values is confusing and, with the lack of procedural information, make the values difficult to interpret.

Klein et al. (3) had 12 experienced jet pilots perform what appears to be a simple visual reaction time task. Most of the procedural aspects of this experiment are given in Klein et al. (16). Neither article, however, describes the apparatus or the data collection procedures, except that the subject made 15 responses in each testing session. No information is provided about meals, mealtimes, or the subjects' physical activity during the experiment. Data were collected every 2 h over a period of 25 h. Two of these 25-h assessment sessions were conducted and were separated by 24 h. The authors never state if the subjects were kept awake all night to perform the task or if they were awakened at the appropriate times. No raw data are presented (all information is given as deviations from the mean), and all performance information was extrapolated from graphs. The best performance (-6.0%) occurred at 1300; the worst (8.0%) at 0500.

Klein et al. (4) had eight college students perform a simple reaction time task involving a manual response to a visual stimulus. Subjects were tested every 3 h for 3 days. The experimental description does not indicate if the testing was conducted on consecutive days or if some rest period separated the days. Subjects performed the test every 3 h for a 24-hour period beginning at 0900. Each test consisted of 15 responses to the stimulus. Subjects were awakened for the tests conducted at 0300 and 0600. On test days the subjects' physical activity, as well as the sleep/wake cycle, apparently were controlled. No mention, however, is made of mealtime and meals. Subjects received between 30 and 35 h of practice on this task as well as two other described in the Symbol Cancellation and Arithmetic Sections before data collection began. Additionally, all data obtained during the first 24-h testing period was discarded to ensure no practice effects would affect the results. The slowest reaction times were recorded at 0600 (14.0%); the fastest at 1800 (-7.1%). An ANOVA indicated a significant time-of-day effect.

Summary

These studies show little consistency in identifying the time of day at which either the fastest or the slowest reaction times occur. Generally, the magnitude of the circadian effect appears rather small, from approximately -2% to 14% of the average performance. Only Klein et al. (4) demonstrated a significant time-of-day effect. Generally, the slowest reaction times occurred during the early morning, from 0300 to 0600. The studies show little consistency in the time at which the fastest reactions occurred, with estimates ranging from 1300 to 2100. The circadian cycle, therefore, has a relatively small effect on simple reaction time.

CHOICE REACTION TIME

Blake (13,14) had 30 naval enlisted men perform a 5-alternative choice reaction time task. Subjects pressed one of five keys in response to the illumination of the corresponding light (see Simple Reaction Time above for methodological details). Subjects received one practice session before data collection began. Each testing session required 30 min. An ANOVA performed on the average correct reaction time for each testing session revealed a significant time-of-day effect for correct reaction time and gaps (periods of 1.5 s or more between responses) but no effect for the number of errors. Correct reaction times varied from -2.0% of the mean to 1.8% over the testing period (0800 to 2100). The best performance was obtained at 2100; the worst at 1300. The number of gaps varied from 39.9% to -7.0% of the mean, with the fewest gaps occurring at 2100 and the most at 1300. The number of errors ranged from -7.0% at 2100 to 17.2% at 1300, indicating again the best performance at 2100 and the worst at 1300.

Rutenfranz et al. (17) examined a five-alternative choice reaction time task that used colored lights as stimuli. Twelve military cadets responded to four of the lights by pressing a key and made no response to the fifth light. Subjects performed the task 4 min/day for 7 weekdays. During each testing session, 30 signals were presented. Apparently, no attempt was made to control the subjects' meals, mealtimes, and physical activity immediately preceding testing. Subjects were tested six times per day beginning at 0800. Subjects were awakened 15 min before data collection for the 0000 and the 0400 testing sessions. The subjects appear not to have had any prior practice on the task before data collection began. No error data are given and all quantitative values had to be interpolated from graphs provided in the report. Only a small circadian effect is present between 0800 and 2000. This effect is manifested primarily as a slow reaction time at 0000 and 0400 (8.1%) relative to the reaction time obtained at 2000 (-4.8%). These data should be interpreted with caution; although large practice effects are evident in the daily data, the summary curves used to perform the calculations are based on averages for all 7 days.

Summary

Again, the magnitude of the circadian effect does not appear to be particularly large, ranging from approximately -2% to 8%. Although the studies do not agree on the time of slowest response, the fastest reaction times appear to occur around 2100.

TIME ESTIMATION

Blake (13,14) had 30 naval enlisted men produce intervals of 10, 20, 30, 60, and 120 s (see Simple Reaction Time above for methodological details). Subjects produced two estimates of each interval during each testing session. Each testing session required about 20 min. The subjects apparently received one training session before data collection began. An ANOVA performed on the data revealed no significant time-of-day effects for any time interval. Raw data are presented only for the 10- and 120-s intervals. The greatest underestimation of the 10-s interval occurred at 1530 (-7.5%). The greatest overestimation occurred at 2100 (5.7%). For the 120-s interval, the greatest underestimation also occurred 1530 (-8.6%); the greatest overestimation at 0800 (11.8%).

Pfaff (18) had 10 male undergraduates perform 2 types of time estimation tasks during 5 testing sessions conducted between 0700 and 2000 on 1 day. All subjects were asked to refrain from strenuous exercise, alcohol, and beverages containing caffeine during the experiment. Apparently, no attempt was made to control the subjects' sleep/wake cycle, mealtimes, or meals. All subjects received 1 h of practice making time judgments using both methods on the day preceding the experiment. The time production task had subjects produce 15-, 30-, and 60-s intervals. For the time estimation task, the subjects estimated the duration of 10-, 20-, and 30-s intervals. Subjects made five estimations and five productions of each of the intervals during each testing session. Estimates and productions were scored as a percentage of the correct period. Temperature was recorded sublingually three times during each session and then averaged. Two testing orders were used; any residual practice effects are not, therefore, completely confounded with time-of-day effects.

No statistical tests of the time-of-day effect are reported. For both the method of production and the method of estimation, the greatest overestimation of time relative to the mean occurred at 1600, with a 15.8% and a 13.8% overestimation, respectively. Similarly, both methods showed the greatest underestimation at 0700 with the method of production showing a -9.1% underestimation and the method of estimation -10.6%. Body temperature appeared to follow the performance curves closely.

Poppel and Giedke (19) did a series of six experiments examining time estimation. The first two studies will be reviewed here. Both of these experiments required the estimation of 10-s intervals using the production method. In the first experiment, the subject produced the intervals without counting; in the second, all subjects were required to count. In the first experiment, the time of assessment is confounded with practice effects; all subjects received their first assessment at 0800 and were tested every 2 h until 2000. The testing sequence for the second experiment is unclear. The authors state that all subjects received their first assessment at noon but then mention that the starting times were staggered to avoid confounds. In either case, the subjects were tested every 3 h during a 24-h period. During Experiment 1, subjects performed their normal activities and, apparently, no aspect of their behavior was controlled. In Experiment 2, the subjects lived in an isolated experimental chamber. Thus, their activities and meals probably were controlled. Subjects in Experiment 2 were awakened 15 min prior to data collection for the 0000, 0300, and 0600 testing sessions. The subjects produced five 10-s intervals during each assessment session in Experiment 2; the number produced in Experiment 1 is not recorded. No description of the type of subjects is given in either experiment.

The results of the two experiments differ somewhat. Experiment 1 shows a U-shaped curve, with the shortest time estimates occurring at 1400 (-6.7%) and the longest at 2000 (9.7%). Estimates obtained at 0800 are also relatively long (5.4%). The time-of-day effect was significant in this experiment, as it was in Experiment 2. Results from Experiment 2 also show a function that is primarily U-shaped, with the greatest overestimation of 10 s occurring at 0300 (12.1%) and the greatest underestimation occurring at 1500 (-21.7%). Between 0900 and 2100, the function for Experiment 2 is much more erratic than that for Experiment 1. All of the estimates obtained between 0900 and 2100 in Experiment 2 are less than 10 s. In contrast, only those estimates in Experiment 1 from the testing sessions at 1200, 1400, and 1600 have estimates below 10 s.

<u>Summary</u>

The results of these three studies can be viewed from different perspectives. Only one study (18) examined both the production and the estimation methods. The results of this study were encouraging in terms of its internal consistency: the times at which both the maximum under- and overestimations occurred were identical, and the magnitude of the circadian effect was similar. The other studies (13,14,19) do not show much internal consistency and do not agree well with each other or with Pfaff. Determining the time of maximum under- and overestimation from these three studies is, therefore, difficult. The magnitude of the circadian effect appears larger than for simple and choice reaction time, with estimates ranging from -21.7% to 15.8%. Significant time-of-day effects are reported only in Poppel.

ARITHMETIC

Blake (13,14) had 25 naval enlisted men perform a mental arithmetic task that required the subject to sum five 2-digit numbers. (See Simple Reaction Time above for methodological details.) The subjects had practiced this task for several hours on each of 15 preceding days. Thus, no practice effects should have occurred. An ANOVA conducted on the number of calculations attempted showed a significant time-of-day effect although a comparable analysis performed on the percentage of errors showed no significant effect. The most calculations were attempted at 2100 (8.6%); the fewest (-4.7%) at 0800. The most errors occurred at 1030 (10.4%); the fewest at 1530 (-11.2%). A speed/accuracy tradeoff is not apparent from these data.

Colquhoun et al. (20) had 11 naval enlisted men perform an arithmetic task 4 times on each of 12 consecutive days. Unlike most of the experiments described in this monograph, this study simulated an industrial or military work shift. Thus, the subjects worked continuously from 0800 to 1600, with time taken only for tea breaks and lunch. Thus, physical activity and mealtimes were strictly controlled during the experiment, but no mention is made of any regulation of the sleep/wake cycle.

The task required the subjects to add five two-digit numbers and enter the sum on a report sheet for 50 min. Testing sessions occurred at 0850, 1040, 1320, and 1510. The fewest sums were attempted at 0850 (-6.2%); the most at 1040 (3.0%). The lowest error rate occurred at 0850 (-3.2%), with the highest at 1320 (6.3%). These data imply that subjects were working very slowly during the first testing session. No statistical analyses are reported.

Adam et al. (21) had 40 enlisted men perform a mental arithmetic task. The task required the subjects to add columns of five two-digit numbers as rapidly as possible and required 30 min. Subjects were tested at 0630, 1030, 1430, and 2000 on alternate days during a 10-day period. Subjects lay supine for 20 min before each testing session. No stimulants or alcohol were allowed during the assessment days, and subjects were kept as sedentary as possible.

Data from the first day were considered as practice and were not analyzed. Thus, four performance estimates were obtained for each testing time. Only the average number of sums attempted showed a significant time-of-day effect. The average number of sums attempted varied from 7.0% at 2000 to -7.0% at 0630. The error rate varied from 8.0% at 1030 to -7.0% at 2000. Oral temperature appeared to be positively related to the percentage difference from mean performance for the number of sums attempted and negatively related to the error rate, but no correlations are given.

Klein et al. (4) had eight college students perform a digit addition task (see Simple Reaction Time above for methodological details). Two-digit numbers were arranged in 10 lines on a sheet of paper. The subject had to add five consecutive numbers horizontally and write the answer on the sheet. The dependent variables were the number of errors and the time to complete the sheet. An ANOVA did not show a significant time-of-day effect for the time to complete the task. Subjects required the most time to complete the task at 0600 (10.9%) and the least time at 1800 (-7.1%). No data or results are given for the number of errors.

Hughes and Folkard (22) performed a study on six members of a survey team during a winter project in Antarctica. The subjects performed the same arithmetic used by Blake (13). Although the authors indicate that all subjects received prior practice on the task, the amount of practice and the terminal levels of performance are not discussed. The subjects apparently engaged in their normal activities during the experiment. The meals, mealtimes, and sleep/wake cycle appear not to have been controlled although the environment may have restricted the variability. The subjects performed the arithmetic task every 4 h for 16 h from the time they arose. Thus, this study determined testing times according to "time from awakening" rather than clock time. The dependent variable is not stated but appears to have been the number of problems attempted. The best performance (3.8%) occurred 12 h after awakening; the poorest (-7.0%) on awakening. No statistical tests are reported.

<u>Summary</u>

For arithmetic tasks, the dependent measure of primary interest is arguably the time to complete a problem, which is usually measured by the number of problems attempted in a given period or the time to complete a given number of problems. The studies described above show a very consistent performance pattern: subjects always required the most time to complete a problem during the first testing session. Generally, subjects performed the calculations most quickly during the early evening. The only study described in this monograph to use time for awakening rather than clock time showed a consistent pattern of results, with the slowest performance occurring at awakening and the fastest 12 h later. The magnitude of the circadian effect again appeared moderate, ranging from -10.9% to 8.6%.

Only three of the five studies in this section reported the error rate. The magnitude of the circadian effect ranged from -11.2% to 10.4%. The highest percentage of errors occurred in the late morning or early afternoon. The studies show no consistency concerning the time at which the lowest error rate occurred.

VIGILANCE

Blake (13,14) had 25 naval enlisted men perform a 53-min auditory vigilance task (see Simple Reaction Time above for methodological details). Every 3 s during this task, the subject heard a tone. Most of the tones were 600-ms long. Twenty-four tones were 670-ms long and were the signals to be detected. All subjects were given 5 h of practice before any data were collected. The ANOVAs performed on the percentage of signals detected and on the number of false alarms revealed only a significant time-of-day effect for percentage of signals detected. The highest percentage of signals, 68.2%, was detected at 2100. This value corresponds to 10.9% of the mean. The lowest percentage, 56.0%, was detected at 0800. This value was -8.9% below the mean. The greatest number (18.9%) of false alarms occurred at 2100; the fewest (-15.8%) at 1030.

The probability of detection declined with time on task at all testing times except 2100. No analyses were conducted to determine if this decrease was the result of an increasingly strict response bias (beta) or a decrease in perceptual sensitivity (d').

Colquhoun et al. (20) had 11 naval enlisted men perform an auditory vigilance task. (See the Arithmetic section above for details. Other details of this study are reported in Craig et al. (23). The description of this experiment is based on both sources.) Subjects were required to detected a 900-cps tone with a duration of 1 s that was presented in a background of white noise. Each session lasted 50 min and contained 36 signals. Subjects performed this task at 0800, 0950, 1230, and 1420 on 12 consecutive days. Subjects received 1 week of practice before data collection.

An ANOVA performed on the percentage of correct detections revealed a significant time-of-day effect, with the poorest detection performance occurring at 0800 (-6.2%) and the best at 1230 (2.8%). A comparable analysis on the number of false alarms again showed a significant time-of-day effect. The most false alarms occurred at both 1230 and 1420 (8.5%). The fewest occurred at 0800 (-19.1%). The authors interpret this pattern of data as a change in the subjects' willingness to respond (beta) rather than a change in their ability to detect a target (d'). Generally, performance deteriorated with time on task regardless of the time of day.

Adam et al. (21) had 12 subjects perform an auditory vigilance task that required 30 min (see Arithmetic above for methodological details). Signal stimuli were 680-ms tones; noise stimuli were 600-ms tones. Stimuli were presented every 3 s, and 30 signals were presented in each testing session. The percentage of signals detected ranged from -5.0% at 0630 to 8.0% at 2000. Although the report is not entirely clear, apparently the time-of-day effect was not significant. The false-alarm rate varied from -7.0% at 0630 to 7.0% at 2000, which reflected a nonsignificant time-of-day effect. The authors assumed that the subject's performance could be analyzed using the Signal Detection Theory (24).[3] Consequently, the signal-detection rate and the false-alarm rate were used to calculate d'. This measure varied from -4.0% at 0630 to 6.0% at 2000. Again, the report is unclear about the results of the statistical test performed on d', but apparently the test was nonsignificant. The authors also obtained measures of response latency. This measure varied from -10.0% at 2000 to 12.0% at 0630 and did reflect a statistically significant circadian effect.

Overall, these parameters indicate that the subjects had a low response rate at 0630, which resulted in low false-alarm and detection rates and a depressed d'. Additionally, subjects were relatively slow to respond at 0630. Oral temperature appears related to all four of these measures such that higher temperatures are associated with better performance. No correlations, however, are given.

Bonnet and Webb (25) had 18 college students perform an auditory vigilance task. No description of the task is given, but it appears to be the same task used by Blake (13). The experiment required 2 assessment sessions that were 1 week apart. Subjects were tested 10 times on the vigilance task during each session. Each vigilance task trial required 25 min and was followed by a 25-min break. One assessment session began at 0900; the other began at 0000. The subjects' physical activity was

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[3] This assumption may not be justified because the subjects apparently did not know the a priori probability of a signal nor the cost and benefits associated with correct detections and false alarms. Such information is usually considered necessary for the use of the Signal Detection Theory.

controlled during the assessment sessions but apparently no attempt was made to control activity immediately preceding the experiment. Subjects could eat or sleep during the breaks and no attempt appears to have been made to control any aspect of the subjects' sleep/wake cycle. All subjects received at least 2 h of practice on the task and were required to detect at least 75% of the targets before beginning data collection.

Two dependent measure were used: the percentage of targets detected and the total number of responses. The data analysis does not lead to a straightforward time-of-day effect. Both the percentage of targets detected and the total number of responses decreased significantly with time on task, regardless of the time at which the assessment session began. The greatest percentage of targets (29.3%) and the greatest total number of responses (36.6%) occurred at 0000. Similarly, the lowest percentage of targets (-32.2%) was detected at 0530. The fewest responses (-35.0%) also were emitted at this time.

In a review article, Craig et al. (23, Set 2) discuss a study in which 25 naval enlisted men performed a complex vigilance task. This experiment reportedly used the same procedure as Blake (13,14). Consequently, the reader may refer to Simple Reaction Time above for methodological details. This task simulated four-channel acoustic sonar. Subjects detected a 200-ms increase in energy against a background of a continuous, amplitude-modulated tone. The task required 1 h. During this time, 24 signals were presented on randomly selected channels. Subjects were tested every 2.5 h between 0800 and 1530 and again at 2100. Before beginning the experiment, each subject was given five practice sessions. Testing was conducted on 5 consecutive days, with each subject tested once each day. The order of testing was determined using a Latin square design. The ANOVAs performed on the percentage of hits and the number of false alarms showed no significant time-of-day effects although both measures tended to increase with the testing time. The fewest false alarms (-32.1%) and the lowest percentage of hits (-10.3%) occurred at 0800. The greatest number of false alarms and the highest percentage of signals detected occurred at 2100 (14.1% and 5.3%, respectively) although the 1530 testing time also showed the same percentage of signals detected.

In the same review article, the authors report two sets (Sets 4 and 5) of previously unpublished data from a study by Wilkinson et al. (26). The data in these two sets are from the same experiment and differ only in the number of testing sessions the subjects received on each of 2 consecutive days. In Set 4, 13 naval enlisted men were tested 5 times each day; in Set 5, 11 men were tested 4 times each day. The task required the subjects to monitor 500-ms tones that occurred every 2 s for 1 h. Signals were 375 ms. During each session, 1760-noise and 40-signal stimuli were presented. All subjects had received a minimum of 2 h of practice on the task before the experiment began. No information is given on meals, mealtimes, physical activity, or the sleep/wake schedule.

The Set 4 data showed no significant time-of-day effects. The lowest percentage of signals detected (-3.5%) and percentage of false alarms (-14.3) occurred during the first testing session, 0745. At this time, beta was at its maximum (2.6%), indicating the strictest decision criterion. During the second testing session, 1105, d' was at its maximum (1.9%), as was the percentage of signals detected (2.6%). The greatest number of false alarms (39.3%) occurred during the last testing session, which was conducted at 2135. During this session, d' and beta were also at their lowest values (-0.6% and -3.4%, respectively).

The Set 5 data showed considerably different trends from those of Set 4. For d', the Set 5 data showed almost exactly the opposite pattern as Set 4; the smallest d' value (-3.5%) occurred during the first testing session at 0855. The largest value (4.6%) occurred during the last testing session at 2030. The only Set 5 measure to show significant time-of-day effects was d'. The lowest percentage of signals detected (-4.0%) again occurred during the first session but, unlike the Set 4 data, the highest percentage of false alarms (20.3%) also occurred during this session. The data from the last testing session showed the greatest percentage of signals detected (5.4%), the smallest percentage of false alarms (-13.0%), and the greatest (strictest) beta (3.8%). The lowest value (-7.3%) of beta occurred in the immediately preceding session, which was conducted at 1815.

Summary

Some caution is necessary in interpreting vigilance data; d' and beta are dependent on the percentage of signals detected and the false-alarm rates. This discussion will, consequently, be limited to discussing the percentage of signals detected and the false-alarm rate. The studies described above almost exclusively show the lowest percentage of signals detected and false-alarm rates during the first testing sessions, which was in the early morning. The times at which the percentage of signals detected and the false-alarm rates were highest varies somewhat, but generally appears to be in the late evening (2000 to 2200). Some caution must be exercised in interpreting the magnitude of the circadian effect, particularly for the false-alarm rate. Typically, the false-alarm rate was very low, with subjects emitting one or two false alarms per testing session. An increase of one false alarm per session could, therefore, represent a change of 50%, even though statistical analyses revealed that change to be nonsignificant. The same problem occurs in interpreting percentage of signals detected; some of the experiments employed very rare signals. Again, a chance fluctuation in the number of signals detected could appear to be a large change in the percentage.

The conclusions that can be drawn from the studies above are limited in a fashion that has not yet been discussed. Recently, several investigators (27) have distinguished between vigilance tasks requiring successive discrimination and those requiring simultaneous discrimination. In simultaneous discrimination tasks both the signal and the noise stimuli are presented concurrently. Thus, the subject must compare the stimuli and select the signal. This type of vigilance task is assumed to place little or no load on working memory. Successive discrimination tasks present the signal and the noise stimuli successively. Subjects must, therefore, identify the signal from memory. This type of vigilance task is assumed to involve working memory.

Craig et al. (27) recently have proposed that simultaneous discrimination tasks often result in a more stringent response criterion (beta) with time on task, whereas successive discrimination tasks result in a decrease in sensitivity (d'). More importantly, Craig et al. have proposed that time-of-day effects differ for the two types of tasks. No examples of simultaneous discrimination could be found for this monograph. Consequently, any conclusions drawn from the studies presented above are limited to the successive discrimination paradigm.

SYMBOL CANCELLATION

Twenty-five naval enlisted men (13,14) canceled the letter "e" from a short story. They performed this task for 30 min during each testing session and were given one practice session before data were collected (see Simple Reaction Time above for methodological details). Two performance measures were obtained: the total number of "e" letters the subject would have marked, assuming no omissions, and the percentage of missed "e" letters. The ANOVAs performed on these two measures revealed only a significant time-of-day effect for the first measure. The best performance occurred at 2100 (4.5%); the worst, at 0800 (-7.2%). The smallest number of "e" letters was missed at 1030 (-7.3%); the greatest (10.6%) at 1300.

Klein et al. (4) used abstract, dot patterns rather than letters or numbers in their task (see Simple Reaction Time above for methodological details). Three-, four-, and five-dot patterns were drawn on a sheet of paper. Eight college students were required to cancel all the four-dot configurations. An ANOVA conducted on the time to complete a page revealed a significant time-of-day effect. Subjects required the greatest amount of time to complete the task at 0600 (14.3%) and the least at 1800 (-6.7%).

Craig and Condon (28) had 48 college students perform a letter cancellation task. During each testing session, subjects searched through 6 blocks consisting of 15 rows of 30 letters for the letter "e." Each time they detected an "e," they marked it with a pencil. The time to complete the six blocks and the percentage of correct detections were the dependent measures. Subjects received some training on this task although the amount and the terminal level of performance are not specified. No discussion is given about meals, mealtimes, physical activity, or sleep/wake schedules. Each subject performed this task once per day at a different time each day on 6 successive days. This design was a variation of the standard Latin square design. The first testing session began at 0800; the last at 2300.

Only the time to complete the task showed a significant time-of-day effect. The longest time (4.1%) occurred during the earliest testing session, 0800. This session was also associated with the lowest percentage of correct detections, -0.3%. This pattern may indicate that the subjects used a slow-but-accurate tradeoff strategy during the earliest testing session. The fastest time to complete the task occurred at 2000 (-3.2%). This testing time was also associated with the highest accuracy (0.4%). Thus, in this testing session, subjects appeared to be both fast and accurate.

Summary

Because of the different dependent measures used by these three experiments, their results are difficult to compare. Generally, the poorest performance appears to have occurred during the first testing session, which was between 0600 and 0800 for these studies. The best performance appears to have occurred in the early evening between 1800 and 2100.

MEMORY TASKS

Digit Span

Blake (13,14) had 30 naval enlisted men perform a digit-span task identical to those included in standard intelligence testing (see Simple Reaction Time above for methodological details). No information on practice is given for this task. An ANOVA performed on the number of digits recalled showed a significant time-of-day effect. The most digits, 7.98, were recalled at 1030. This value corresponds to an increase of 3.9% over the average number of digits recalled. The poorest performance occurred at 2100, when 7.31 digits were recalled. This value corresponds to a decrease of 4.8% from the average number of digits recalled. From 1030 to 2100, the average number of digits recalled decreased monotonically. In contrast, the body temperature monotonically increased.

Delayed Response

In a very abbreviated paper, Ottmann et al. (29) describe an experiment using a delayed digit comparison task. At the beginning of the trial, the subject saw 3 digits, which were displayed for 1 s. After a 1-s break, the subject saw another set of 3 digits. If the second set was identical to the first, the subject made a response; if they were different, the subject did nothing. Apparently, subjects alternated each hour between this task and a visual inspection task. On each of 5 consecutive days, the subjects began the delayed comparison task at 0900 and continued the experiment until 1800. No discussion of training or practice effects is given and the data are averaged over the 5 days. No information on meals, mealtimes, physical activity, or the sleep/rest schedule is provided. The results are based on two subjects, who are not described. Apparently, the number of correct responses was not recorded. Therefore, only reaction-time data are described, but no appropriate analyses are reported. The longest reaction times were obtained at 0900 (3.4%) and the shortest (-3.4%) at 1500. These time-of-day effects may be confounded with practice effects, and the results of this study should be accepted with caution.

Summary

Because so few examples of memory tasks could be located, no conclusions are warranted.

SIMULATED PERFORMANCE

Aircraft

Klein et al. (3) had 12 experienced jet pilots perform a simulator "flight" of 12 min every 2 h for a 25-h period (see Simple Reaction Time above for more detail). The simulator data are also discussed in Klein et al. (16), and the description given here is based on both articles. Neither article gives any information on the amount of practice received before data collection, efforts to control the subjects' sleep on the preceding night, physical activity during the experiment, mealtimes, or meals. The dependent measure was the sum of the deviations of speed, course, and altitude from pre-set values. Performance ranged from 16.0% at 0500 to -12.0% at 1300 and 1500. These values should be interpreted with caution; they may be based on "smoothed" data, that is, data based on running averages. No statistical tests of time-of-day effects apparently were conducted.

Navigation

Craig and Condon (28) had 48 college students perform a task very similar to plotting a ship's course (see Symbol Cancellation above for methodological details). Subjects were required to plot 50 points that represented the course of a ship moving in an easterly direction at a varying speed. Some practice was given on this task, but the amount and the terminal levels of performance are not recorded. Each subject was tested once on each of 6 days. The dependent variable, the time to plot the 50 points, did not show a significant time-of-day effect. Subjects required the most time (2.8%) to plot the points at 0800, the first testing session, and the least time (-2.8%) at 1700.

In the same experiment, the students also performed collision-avoidance calculations. For this task, the subject was given a booklet with 24 diagrams. Each diagram used vectors to depict the speed and bearing of two vessels. The subject was to determine if the two vessels were on a collision course. Again, some practice on this task was provided before data collection began, but the amount and the terminal levels of performance are not given. The time to complete the booklet and the percentage of correct responses were the dependent measures.

Only the time to complete the task showed a significant time-of-day effect. The longest time (8.2%) occurred during the earliest testing session, 0800. This session was also associated with the lowest percentage of correct detections, -1.7%. This pattern may indicate that the subjects used a slow-but-accurate tradeoff strategy during the first testing session. The fastest time to complete the task occurred at 1700(-6.7%). The best accuracy was recorded at 1100 (1.9%).

Although the results from these two navigation tasks are interesting, the subjects were college students, who probably had little if any previous experience with navigation tasks. Consequently, these results should be extrapolated to trained navigators with caution.

Summary

Again, drawing any conclusions from so few studies is difficult. Nevertheless, the poorest performance on these tasks appears to occur during the morning and the best performance occurs during the late afternoon.

5. DISCUSSION

Before drawing any conclusions concerning the magnitude of the circadian effect on the tasks reviewed above, the methodological shortcomings of the work conducted in this area will be described. Three serious methodological problems were distressingly common in the experiments described in chapter 4. These problems relate to meals, the sleep/wake cycle, and practice.

Few of the studies reviewed made any attempt to control the subjects' meals or mealtimes. Given the amount of information on the "post-lunch dip" (see 10 for a review), the lack of control on the subjects' mealtimes and the composition of the meals is puzzling. Either investigators are deliberately ignoring the information on the post-lunch dip, or they are assuming that the phenomenon has little effect on performance. Deciding between these alternatives is impossible. Nonetheless, at least some of the studies reporting the post-lunch dip show a substantial decline in performance. Failing to control the subjects' mealtimes and the composition of the meals appears lax at best.

Surprisingly few investigators controlled the subjects' sleep schedules. In one experiment (25), subjects were even permitted to sleep during the intertask breaks. This lack of control is particularly problematic for college students, who frequently have extremely variable sleep schedules. Again, the failure to control a variable of obvious importance is difficult to explain.

Admittedly, requiring all subjects to sleep in a controlled environment before and during an experiment may be not feasible. Testing subjects according to the individual's rising (awakening) time rather than the clock time appears to be a convenient and effective method for reducing between-subject variance in the sleep/wake cycle. Although this testing scheme has been discussed occasionally, only one example (22) is included in this report.

Practice was a serious methodological shortcoming in many of the studies reviewed. A discouraging number of articles never mentioned practice, even to indicate if the subjects had received prior training on the tasks. Most of the remaining articles indicate that subjects received practice on the tasks before beginning the experiment but never reported the amount or the terminal levels of performance. Neither practice to differential stability nor practice to asymptote was mentioned in any of the articles reviewed. Practice effects may, therefore, be confounded with time-of-day effects in many of these studies.

Drawing conclusions about the magnitude of the circadian effect on information processing tasks is difficult because of the methodological shortcomings of many of the studies. Nevertheless, approximately half of the statistical tests conducted to detect the circadian effect were nonsignificant. The majority of circadian effects, regardless of their statistical significance, showed less than a 10% difference between mean performance and either the maximum or minimum performance. The overall impression is, therefore, that for the types of tasks reviewed in this monograph, the circadian effect does not exert a major influence on performance.

Future research on the effects of the circadian cycle on information processing should use standard information processing tasks; despite approximately 20 years of research on circadian rhythms in human performance, surprisingly few data are available on standard information processing tasks. For example, the Sternberg Memory Search Task (30) is arguably the most widely used information processing task for both applied and basic research. Yet, no research investigating the magnitude of the circadian effect on this task was found. The choice reaction time task, which has been used in psychological research for over 100 years, has also been studied relatively infrequently. As noted earlier, no research on vigilance using the simultaneous discrimination paradigm was found. Because these types of tasks are commonly used in both basic and applied research, estimates of the magnitude of the circadian effect on their performance would be valuable.

Data on complex laboratory tasks, particularly those that require timesharing, are conspicuously absent.[4] Tasks that require the concurrent performance of two or more tasks represent an important step between the performance of common information processing tasks and the performance of simulations of real-world tasks, such as those investigated by Klein et al. (3) and Craig and Condon (28). Future investigations of task combinations should determine the magnitude of the circadian effect on each on the tasks performed alone as well as on the combination. By examining each task individually, the magnitude of the circadian effect on timesharing may be evident.

In conclusion, the effect of the circadian cycle on human information processing tasks is difficult to determine because of the many methodological shortcomings of the experiments. The effect does not appear large but may be masked by the shortcomings previously discussed.

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[4] Alluisi and his colleagues (31) have conducted an extensive series of investigations using the multiple-task performance battery (MTB). This battery consists of six tasks and requires the concurrent performance of three to five of the tasks. The data from this series are not included in this monograph for two reasons. First, performance on all of the task combinations was combined to produce one dependent variable. Thus, it is not possible to determine the magnitude of circadian effects separately on each task. Second, the majority of the studies using the MTB investigated the effects of different shiftwork schedules. Few included the baseline conditions appropriate to this monograph.

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APPENDIX A. GLOSSARY

Acrophase. Peak.

Amplitude. The maximum absolute value obtained by a quantity that varies periodically. Amplitudes are measured from the mesor (mean value).

Autocorrelation. A technique used to detect cyclic activity in a complex signal.

Entrainment. "The process whereby rhythms become tuned from their inherent personal cycle length to a consistent pattern determined by natural and social clues in the external environment (32, p. 14).

Fourier analysis. The study of convergence of Fourier series and when and how a function is approximated by its Fourier series or transform.

Free-running experiment. A paradigm in which the subject determines the timing of sleep, activity, and meals.

Frequency. The number of cycles completed by a periodic quantity in a unit time.

Latin square. An n x n square array of n different symbols, each symbol appearing once in each row and once in each column; the symbols are useful in ordering the observations of an experiment.

Oscillator. Any device which, in the absence of external forces, can have a periodic back-and-forth motion, the frequency determined by the properties of the oscillator.

Period. The time required to complete one cycle of a rhythm.

Phase. The fractional part of a period through which the variable of a periodic quantity has moved, as measured at any point in time from an arbitrary time origin.

Signal detection theory. A normative decision model that can be applied in situations where the subject must decide between two stimuli that cannot be easily distinguished. The primary advantage of the theory is that it separates the subject's ability (sensitivity) to detect a signal from the person's willingness to respond. A subject's ability to detect a signal is measured by d', whereas the person's willingness to respond is measured by beta.

Zeitgaber. Environmental time cue; synonymous with synchronizer and entraining agent.

APPENDIX B

TABLE 1

AUTHORS	SUBJECTS	NUMBER	TASKS	MAGNITUDE OF CIRCADIAN EFFECTS	COMMENTS	FREQUENCY OF SAMPLING
Rutenfranz, Aschoff, and Mann (1972)	Military cadets	12	Choice RT	RT: +8.1% to -4.8% (N.R.)	a,b	Every 4 h from 0800 to 2000 for 7 nonconsecutive days
Klein, Bruner, Gunther, Jovy, Mertens, Rimpler, Wegmann (1972)	Experienced jet pilots	12	Flying a simulator	+16.0% to -12.0% (N.S.) for total deviation from assigned parameters	b,c,d	Every 2 h for a 25-h period for 2 nonconsecutive days
			Simple RT	RT: +8.0% to -6.0% (N.R.)		
Adam, Brown, Colquhoun, Hamilton, Orsborn Thomas, and Worsley (1972)	Military enlisted men	40	Arithmetic	# Attempted: +7.0% to -7.0% (S.) % Errors: +8.0% to -7.0% (N.S.)	b	At 0630, 1030, 1430, and 2000 on 4 alternate days
			Vigilance	% Detections: +8.0% to -5.0% (N.S.) % False alarms: +7.0% to -7.0% (N.S.) d': +6.0% to -4.0% (N.S.) RT: +12.0% to -10.0% (S.)	b	

(S.) significant difference reported
(N.S.) nonsignificant difference reported
(N.R.) no results reported

AUTHORS	SUBJECTS	NUMBER	TASKS	MAGNITUDE OF CIRCADIAN EFFECTS	COMMENTS	FREQUENCY OF SAMPLING
Poppel and Giedke (1970)						
Experiment 1	?	12	Time estimation	+9.7% to -6.7% (S.) deviation from estimated value	b,e,f,g	Every 2 h from 0800 to 2000 for 3 consecutive days
Experiment 2	?	4	Time estimation	+12.1% to -21.7% (S.) deviation from estimated value	b,e,g	Every 3 h beginning at noon for 1 day
Pfaff (1968)	Male college students	10	Time estimation			
			Production method	+15.8% to -9.1% (N.R) deviation from estimated value	b,d,f,h	At 0700, 1000, 1300, 1600, and 2000 on 1 day
			Estimation method	+13.8% to -10.6% (N.R) deviation from estimated value		
Ottman, Plett, Knauth, Gallwey, Craig, and Rutenfranz (1986)	?	2	Delayed digit comparison	RT: +3.4% to -3.4% (N.R.)	b,c	Every 2 h from 0700 to 1800 over 5 consecutive days

AUTHORS	SUBJECTS	NUMBER	TASKS	MAGNITUDE OF CIRCADIAN EFFECTS	COMMENTS	FREQUENCY OF SAMPLING
Blake (1967)	Navy enlisted	25	Simple RT	RT: +2.8% to -2.2% (N.S.)	d,g,h	AT 0800, 1030, 1300, 1530, and 2100. Subjects tested once/day on 5 days
	Navy enlisted	30	Choice RT	Correct RT: +1.8% to -2.0% (S.) # Errors: +17.2% to -7.0% (N.S) Gaps: +39.9% to -7.0% (S.)	"	" " " "
	Navy enlisted	25	Vigilance	% Correct detections: +10.9% to -8.9% (S.) False alarms: +18.9% to -15.8% (N.S)	"	" " " "
	Navy enlisted	25	Letter cancellation	# Completed: +4.5% to -7.2% (S.) % Errors: +10.6% to -7.3% (N.S.)	"	" " " "
	Navy enlisted	30	Time estimation	10 S: +5.7% to -7.5% (N.S.) (deviation from estimated value) 20 S: +11.8% to -8.6% (N.S.) (deviation from estimated value)	"	" " " "
	Navy enlisted	30	Digit span	# Recalled: +3.9% to 4.8% (S.)	"	" " " "
	Navy enlisted	25	Arithmetic	# Attempted: +8.6% to -4.7% (S.) # Errors: +10.4% to -11.2% (N.S.)		

AUTHORS	SUBJECTS	NUMBER	TASKS	MAGNITUDE OF CIRCADIAN EFFECTS	COMMENTS	FREQUENCY OF SAMPLING
Colquhoun, Blake, and Edwards (1968)	Navy enlisted men	11	Vigilance	# False alarms: +8.5% to -19.1% (S.) % Detections: +2.8% to -6.2% (S.)	b,g,h	At 0800, 0950, 1230, and 1420 on 12 consecutive days
			Arithmetic	# Attempted: +3.0% to -6.2% (N.R.) % Errors +6.3% to -3.2% (N.R.)	b,h	At 0850, 1040, 1320, and 1510 on 12 consecutive days
Craig, Wilkinson, and Colquhoun (1981)						
SET 2	Navy enlisted men	25	Vigilance	# False alarms: +14.1% to -32.1% (N.S.) % Detection: +5.3% to -10.3% (N.S.)	g,h	At 0800, 1030, 1300, 1530, and 2100. Subjects tested once/day on 5 consecutive days
SET 4	Navy enlisted men	13	Vigilance	# False alarms: +39.3% to -14.3% (N.S.) % Detection: +2.6% to -3.5%% (N.S.) d': +1.9% to -0.6% (N.S.) ln β : +2.6% to -3.4% (N.S.)	g,h	At 0745, 1105, 1605, 1920, and 2135 on 2 consecutive days
SET 5	Navy enlisted men	13	Vigilance	# False alarms: +20.3% to -13.0% (N.S.) % Detection: +5.4% to -4.0% (N.S.) d': +4.6% to -3.5% (S.) ln β : +3.8% to -7.3%	g,h	At 0855, 1355, 1815, and 2020 on 2 consecutive days

AUTHORS	SUBJECTS	NUMBER	TASKS	MAGNITUDE OF CIRCADIAN EFFECTS	COMMENTS	FREQUENCY OF SAMPLING
Craig and Condon (1984)	College students	48	Letter cancellation	Time to complete task: +4.1% to -3.2% (S.)	d,g,h	Every 3 h from 0800 to 2300. Subjects tested once/day on 6 days
				% Correct: +0.4% to -0.3%		
			Course plotting	Time to complete task: +2.8% to -2.8% (N.S.)		
			Collision course calculation	Time to complete task: +8.2% to - 6.7% (S.)		
				% Correct: +1.9% to -1.7% (N.S.)		
Klein, Wegmann, and Bruner, (1968)	Technical staff	17	Simple RT	RT: +4.8% to -4.2% (N.R.)	c,d	Every 3 h for 15 h on 2 nonconsecutive days
Klein, Wegmann, and Hunt (1972)	College students	8	Simple RT	RT: +14.0% to -7.1% (N.R.)	b,g	Every 3 h for 3 days
			Symbol cancel-lation	Time to complete task: +14.3% to - 6.7% (S.)		
			Arithmetic	Time to complete task: +10.9% to -7.1% (N.S.)		

AUTHORS	SUBJECTS	NUMBER	TASKS	MAGNITUDE OF CIRCADIAN EFFECTS	COMMENTS	FREQUENCY OF SAMPLING
Bonnet and Webb (1978)	College students	18	Vigilance	% Detection: +29.3 to -32.2 (N.R.) Total responses: +36.6% to 35.0% (N.R.)	b,d	Every 50 min from 0900 to 1700 on one day and from 0000 to 0800 7 days later
Hughes and Folkard (1976)	Members of an Antarctica survey team	6	Arithmetic	# Attempted (?): +3.8% to -7.0% (N.R.)	a,b,h	Every 4 h from time of awakening for 16 h on 2 consecutive days

a. Learning effects apparent in the task(s) data.
b. Data obtained by extrapolating from graphs.
c. No information on any practice effects given.
d. Sleep/wake cycle not controlled.
e. No practice given prior to data collection.
f. Data obtained while subjects performed their routine daily activities.
g. Data analyzed using ANOVA.
h. Subjects received prior practice on the task(s) but no information given on the amount of practice or terminal levels of performance.

Other Related NAMRL Publications*

Damos, D.L., Some Considerations in the Design of a Computerized Human Information Processing Battery, NAMRL Monograph 35, Naval Aerospace Medical Research Laboratory, Pensacola, FL, December 1987. (AD A199 491)

Damos, D., Identifying the Circadian Cycle in Human Information Processing Data Using Periodicity Analysis: A Synopsis, NAMRL Technical Memorandum 89-1, Naval Medical Research Laboratory, Pensacola, FL, April 1989.

* These publications are available from DTIC, Cameron Station, Alexandria, VA 22314 (Phone: (C) 202/274-7633 or (AV) 284-7633). Use the AD number when requesting reports from DTIC. Reports listed without AD numbers may be requested from the NAMRL author or Code 00B2, NAMRL, Bldg. 1953, NAS, Pensacola, FL 32508-5700.