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The Effects of exposure to bright light on cognitive performance

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The effects of exposure to bright light on cognitive performance

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THE EFFECTS OF EXPOSURE TO BRIGHT LIGHT ON COGNITIVE PERFORMANCE

A Thesis

Presented to

the Faculty of the Department of Psychology

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

by

Elizabeth E. Keller

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Abstract

Male astronaut analogs were subjected to two, eleven-day stays in a time-isolated laboratory. Subjects were confined to bedrest throughout the laboratory portion of the study and inclined at a 6-degree head-down-tilt. A 12-hour phase reversal was accomplished in two nights by phase-advancing the laboratory "clock" 6 hours a night. Subjects were then exposed to 10,000 lux lamps at specified times during their circadian rhythms. Physiological recordings were taken and cognitive performance tests were administered throughout both phases of the study. Design of the study was a cross-over double blind, such that each of the fours subjects served as his own control. There were statistically significant diurnal patterns in performance on the SRT test, as well as on the LogRes test. However, the overall pattern of results for all the performance tests did not demonstrate reliable time-of-day effects. The exposure to the bright lights did not improve the subjects' performance after the phase-shift. There was an effect of the phase-shift on the subjects' performance from which they were not able to recover throughout the rest of the study.

The Effects of Exposure to Bright Light on Cognitive Performance

The number of people traveling across multiple time-zones is on the rise as more businesses expand into the international market. Unfortunately, the associated effects of high-speed jet travel, commonly known as "jet-lag," can be substantial. Most significantly affected by transmeridian travel are flight crews who must continually subject themselves to changes in their "internal clocks" (Gander, Myhre, Graeber, Anderson, & Lauber, 1985). Also affected by a continually altered body clock are space travelers, who are additionally subjected to shift-work and extended duty schedules (Wegmann, Gundel, Klein, & Samel, 1987). The extent to which people must work in environments with continually changing time cues poses practical problems for planning work-rest schedules. The goal in planning such schedules is to obtain maximum efficiency from an individual, while reducing errors which can sometimes cost human lives.

A number of attempts have been made to remedy the effects of jet-lag, ranging from diet (Graeber, Gatty, Halberg, & Levine, 1978; Levine, Halberg, Halberg, Thompson, Graeber, Thompson, & Jacobs, 1977), to drugs (Simpson, Bellamy, Bohlen, & Halberg, 1973), to hormones (Arendt, Aldhous, English, Marks, Marks, & Folkard, 1987). The most promising countermeasure so far has been exposure to bright light (Czeisler, Kronauer, Allan, Duffy, Jewett, Brown, & Ronda, 1989; Wever, Polasek, & Wildgruber, 1983). It has been suggested that bright light may be used as a practical means of counteracting the effects of jet-lag, or more generally circadian desynchronization, because it is assumed to reset the body's internal clock. To date, studies investigating the effectiveness of light exposure on manipulating the body's "pacemaker" have focused primarily on physiological functions. It is of practical significance to determine the extent to which bright light exposure will help influence psychological functions, particularly cognitive performance.

First, the literature on human circadian rhythms will be reviewed as a general orientation to the problem. The focus of the current investigation will be on cognitive performance rhythms. Consequently, a review of the literature on cognitive performance will be presented, including reaction time tests, memory and search tasks, and tests of logical reasoning. Selected literature on sleep deprivation and phase-shifting of the circadian timing system will also be examined. Finally, presentation of the current research using bright light exposure as a countermeasure for circadian desynchronization will be reviewed.

Human Circadian Rhythms

The existence of daily fluctuations in behavior has been observed in both humans and animals and has been the subject of rigorous scientific investigation since the early part of this century. Daily cycles have been observed in the heart-rate, core body temperature, hormonal excretion rates and blood levels, and in rest-activity behaviors (Mills, 1966). These daily oscillations have been labelled "circadian rhythms" meaning "about a day" because of their approximately 24-hour periods in time-free environments. It has been suggested that the circadian rhythm of sleep-wake is driven in part by an endogenous "pacemaker" located in the suprachiasmatic nucleus (SCN) in the hypothalamus (Moore-Ede, Sulzman, & Fuller, 1982). Although circadian rhythmicity is generated within the organism, the "pacemaker" is synchronized by periodic time cues from the environment. The circadian system adjusts only gradually to an abrupt shift in the external time cues (for example, following a transmeridian flight). In addition, different rhythms adjust at different rates. It is during this period of transient internal and external desynchronization that the symptoms of jet-lag are experienced.

What Drives the Circadian Rhythms?

Endogenous Control. Evidence for the endogenous control of circadian rhythms comes from studies of subjects in temporal isolation where their rhythms are allowed to "free-run." Examination of sleep-wake and body temperature rhythms shows that during normal activity in real-life settings, and for the first few days in a laboratory, these rhythms are synchronized with each other. However, in the absence of external time cues, in free running conditions, these circadian rhythms will eventually "break out" of synchronization and run somewhat independently. For example, the body temperature rhythm will maintain roughly a 25-hour period, whereas, the sleep-wake cycle can lengthen its period up to 50 hours. This condition is called internal desynchronization (Wever, 1979). The fact that the different circadian rhythms break out of synchrony, but independently maintain periodicities of varying lengths, indicates that there may be an internal mechanism which regulates the periodicity of each rhythm.

There are currently a number of different models to explain the action of the internal mechanism observed during internal desynchronization. An example of one model, developed by Kronauer and colleagues (Kronauer, Czeisler, Pilato, Moore-Ede, & Weitzman, 1982), asserts that there are two interacting oscillators called the X and Y pacemakers. These pacemakers function somewhat independently of each other and exert influence over the different physiological systems. For example, the thermo-regulatory system may receive a predominant input from the X pacemaker, which determines the body temperature rhythm, but it may also receive a small amount of input from the Y pacemaker which controls the skin temperature rhythm. Kronauer et al. (1982) suggest that there might be a "coupling" mechanism (possibly neural or hormonal) between the two pacemakers which keeps circadian rhythms synchronized. Kronauer's model explains internal desynchronization as the result of a spontaneous drift in the period of one of the oscillators in the absence of external time cues.

External Influences. Internal mechanisms drive the circadian system, but the synchrony of the rhythms is influenced primarily by input from external time cues, otherwise known as zeitgebers. Evidence for the strength of external synchronizers comes from studies where subjects' circadian rhythms have been trained to exhibit a periodicity shorter or longer than 24 hours. Entrainment, as it is called, has been accomplished by introducing a zeitgeber with a periodicity differing from 24 hours as a laboratory "clock." For example, light-dark cycles have been used to entrain the circadian rhythms of body temperature and sleep-wake (Wever, 1979). The range of entrainment, however, varies for each rhythm and is dependent upon the strength of the zeitgeber cycle used. Zeitgebers can be used to "force" (through entrainment) circadian rhythms to desynchronize, but the absence of external time cues (in free-running conditions) can also cause circadian rhythms to "spontaneously" desynchronize.

Whether as a result of spontaneous or forced desynchronization, each of the circadian rhythms adapts to changes in the zeitgebers at different rates, much like phase adjustments after transmeridian flight. Once a stable phase relationship between the zeitgebers and the circadian system is regained, the rhythms will again run in synchrony. If one considers the lability of the circadian system from an evolutionary standpoint, this regained synchrony makes sense, because survival of the organism depends upon its ability to adapt to changes in its environment.

Human Performance Rhythms

The existence of circadian rhythms in physiological systems has unequivocally been established. The literature on psychological rhythms has also demonstrated diurnal patterns in performance. When the literature is reviewed carefully, a theme which emerges consistently is that expression of the rhythm (time of day at which performance peaks) depends on the type of performance being measured.

Many of the early studies measured performance only during waking hours. Thus, the performance curves could only be referred to as diurnal patterns rather than circadian rhythms. Only those measures taken throughout a 24-hour period can truly be considered "circadian." In studies examining circadian patterns, those measures of cognitive performance which have been more successful in demonstrating patterns have been reaction time tests (both simple and choice), and more complex tasks, such as memory tests and tasks involving reasoning abilities. Memory and logical reasoning tasks have consistently shown circadian variation. Until recently, simple reaction time tasks were thought to be insensitive to diurnal variations in central processes because they did not typically exhibit circadian patterns. However, that has recently been repudiated by the work of some diligent psychologists.

Reaction Time Tests. Reaction Time (RT) tests have been applied in both the laboratory (Blake, 1967; Kleitman, 1963; Luce & Green, 1972) and the field (Kleitman & Jackson, 1950; Wilkinson & Houghton, 1982) and have proven to be powerful tools in examining a wide range of behaviors under various conditions. A number of theories for memory retrieval mechanisms have been born out of RT studies (Craik, 1948; Sternberg, 1966, 1969a &b). In essence, RT tests have been used to measure the "central mechanisms" involved in the human response to a signal.

Choice RT tests have been more widely used as measures of cognitive performance because of their greater variety and the presumed complexity of cognitive processing. Simple RT tests have been largely overlooked as a measure of cognitive processes because of their simplicity and the presumption that variance is primarily from the sensory and motor components. However, administered under the right circumstances, even simple RT tests can be used to tap cognitive performance.

For example, another type of performance test that uses RT as a dependent measure is a vigilance test. Vigilance tests typically use dependent measures of detection rate (number of correct detections) and detection latency, otherwise known as reaction time. In fact, RT tasks administered over long periods of time (up to 10 minutes or more) can be considered vigilance tasks. Reaction Time tests administered continuously for long periods of time become vigilance tasks because, according to Mackworth's (1957) definition of vigilance, the subject is required to maintain a "state of readiness to detect and respond to certain specified small changes occurring at random time intervals in the environment" (e.g., presence or absence of some stimuli) (p. 390). The processes involved in a vigilance task (e.g., expectancy, motivation, inhibition, arousal, attention, and attentional filtering) leave little doubt as to whether cognitive abilities are being tapped.

In a classic study of performance rhythms, Kleitman (1963) used both choice and simple RT tests to examine the relationship between temperature and performance. The diurnality of body temperature had been established by that time (Kleitman & Jackson, 1950; Lewis & Lobban, 1957). According to Kleitman, there was a very close relationship between RT performance and temperature rhythm which seemed to indicate diurnality of performance. Unfortunately, infrequent time-sampling throughout the day posed a problem for locating peaks and troughs in performance.

Kleitman's methodological problems were overcome in a study conducted by Blake (1967) where sets of 25 or 30 subjects were tested five times a day on a number of different tasks. Blake found significant time-of-day effects for choice RT tests, but none for simple, visual RT tests. The lack of an effect for simple RT can perhaps be explained in light of a later study which indicated that time-of-day effects (and even those of sleep deprivation) can be overcome on simple tasks by high motivation (Chiles, Alluisi, & Adams, 1968).

Some of the more convincing evidence for the diurnality of cognitive performance comes from the work of Dinges and colleagues (Dinges, Orne, &

Orne, 1984; Dinges, Orne, Whitehouse, & Orne,1987; Dinges & Powell,1988, 1989). Much of their work has focused on investigating the effects of sleep loss and circadian variation on performance. Over the years, these investigators have consistently found that circadian rhythms modulate performance on visual reaction time tasks throughout the 24-hour day. These findings have resulted in a theoretical framework designed by Dinges and colleagues to explain the characteristics of RT performance as a function of sleep loss. Building on the early work of Williams, Kearney, and Lubin (1965), Dinges and colleagues have contributed the notions of optimum response shifts and cognitive slowing as measures of RT performance, in addition to the lapse hypothesis originally developed by Williams' group.

Characteristics of RT Performance. Dinges typically analyzes performance data according to the following theoretical framework because it provides detailed descriptions of the characteristics of interest in RT performance: 1) lapsing, 2) cognitive slowing, and 3) optimum response shifts. This method is a notable departure from the standard practice of using mean RT, which does not typically yield diurnal patterns.

The operational definition of a lapse, originally termed "blocks" by Bills (1931), is "a pause in responses equivalent to the time of two or more average responses" (p. 231). For example, if a subject's average RT is 200 msec, a response lapse would be at least 400 msec or longer. Lapsing is used to describe a subject's inability over time to attend to a memory task due to a kind of "mental lapse" that "undoes the work." In evaluating the lapse domain of a performance test, the number of lapses, as well as the mean duration of the 10 longest (or longest 10% of a trial) RT's can be used to demonstrate response variability.

Cognitive slowing can be described as the "speed/accuracy trade-off" observed during performance decrements (Dinges & Kribbs, in press). For example, when a subject tries to maintain a high level of performance, especially after sleep deprivation, his or her ability to process information may become impaired, resulting in slower RT's and response omissions.

Optimum response shifts explain the gradual overall increase in RT during sleep loss which can't be explained by lapsing. Lapsing assumes that, outside of the lapses, average RT performance throughout the trial remains the same as during baseline. However, it has been shown that there is a small, but measurable increase in the fastest 10% of RT's during sleep deprivation (Dinges & Powell, 1989).

Memory and Search Tasks. A prominent issue in the debate over the existence of circadian rhythms (or even reliable diurnal patterns) in performance involves the notion of the type of task that is used as the performance measure of interest. Some types of performance have been shown to parallel circadian variations in temperature, while others appear to completely oppose the temperature curve. A number of investigators have posited that it is the underlying processes the task probes, as well as the degree to which the task "loads," or stresses, the subject that determines whether circadian patterns will emerge. For example, Hockey and Colquhoun (1972) in a review of the literature, explain that performance on tasks involving more immediate processing - such as simple RT tasks - are more likely to parallel body temperature throughout the day than are tasks involving higher memory "load." Tasks which demand more memory functioning have tended to follow an inverse relationship to the temperature curve. An example of a task that has been used in studies of performance rhythms which has been shown to be sensitive to time-of-day effects is the Memory and Search Task (MAST).

In order to address the issue as to which kinds of performance exhibited circadian patterns, Folkard, Knauth, Monk, and Rutenfrantz (1976) further capitalized on a test first developed in 1966 by Kaplan, Carvellas, and Metlay. Kaplan et al. (1966) had devised a test which tapped visual search and “immediate memory,” upon which Folkard and colleagues expanded. The test Folkard et al. (1976) used was a paper and pencil test in which the experimenters could manipulate the memory load. Each page of the test had four columns of twenty four lines, with twenty uppercase letters in each line. Each line was a random string of letters drawn from the alphabet such that they did not form a pattern, word, or pseudo-word. The object of the test was to search each line on the page for the presence of all the members of a subset of letters given at the top of each page. If a line contained every letter, then the subject was to put a check or tick mark next to the line. Memory load was manipulated by varying the number of letters in the subsets from two, to four, to six letters.

Folkard et al. (1976) used the MAST tests in a study investigating memory load and circadian variation in performance under a shift system. Using only two subjects, these investigators found circadian patterns in performance on the MAST tests. They were able to obtain performance around the clock because the subjects were rotated on a shift system with “duty” times varying from morning to night hours. Using speed of responding (number of lines completed in the time allotted) as the dependent variable, an analysis of variance revealed significant time-of-day effects. Then performance was correlated at each testing time with a significant temperature curve, obtained in the same study, to test for parallelism between the two measures.

Significant positive correlations between speed of performing on the MAST 2 test (MAST test with 2-letter probe) and temperature were found for both subjects. A significant negative correlation was found between speed of performing and temperature for the MAST 6 (MAST test with 6-letter probe), although the other subject had a trend in the same direction, but no significance. No relationship was found between performance on the MAST 4 (MAST test with 4-letter probe) and temperature. These findings followed what Hockey and Colquhoun had predicted in their incisive review in 1972. The reasoning behind the logic was that arousal was in some way affecting performance on tasks involving varying degrees of memory. If arousal is directly related to increases in body temperature, and temperature increases as the day progresses, then it follows that performance on tasks involving higher memory loads which are more sensitive to general arousal (such as the MAST6) would tend to decrease later in the day when arousal is highest.

A later version of the MAST test was generated on a computer for a study conducted at NASA Ames Research Center on the use of theophylline as a countermeasure for circadian desynchronosis (Connell, 1985). The computerized version of the MAST differed from Folkard's paper and pencil test in that presentation of target lines was simultaneous with the subsets, each target line and letter subset being presented alone on the computer screen.

Using mean latency for each testing time, a 5 X 5 factorial ANOVA of time-of-day by day (collapsing across all conditions) yielded significant time-of-day effects for the MAST2, but not the MAST6 test. In addition, there were significant day by time-of-day interactions for both the MAST2 and the MAST6 tests. Unfortunately, the interaction acted as a source of confounding error for the main effects of time-of-day. Connell emphasized that the lack of significant main effects for time-of-day in her investigation may have been due to differences in the test she used from the one Folkard et al. (1976) used. For example, Folkard's paper and pencil test used the same target subset for each page. By the time the subject got to the bottom of the page the subset would have been very well learned. The main effects of time-of-day may have been due to both memory load and a type of learning effect. The computerized version of the MAST tests used by Connell, however, presented a different subset each time, thus preventing a learning effect.

Logical Reasoning Tests. Another type of test which has been widely used to test for circadian patterns in performance is Baddeley's Logical Reasoning Test. The test was first developed by Baddeley (1968) in an attempt to create a measure of "higher mental processes" that was valid, reliable, and sensitive to a number of stresses. The test Baddeley designed was based on grammatical transformations of sentences that varied in levels of syntactic complexity.

The test was composed of a number of sentences which potentially described a pair of letters (always the letters A and B, sometimes in different order) appearing at the end of the line. The statement was to be judged by the subject as to whether it accurately described the letter pair. All of the statements essentially asked which letter appeared first in the pair, but each addressed the pair differently. The complete test was comprised of all 32 possible combinations of five binary factors: 1) Positive or Negative, 2) Active or Passive, 3) True or False, 4) Precedes or Follows, and 5) A or B mentioned first. An example of a true positive statement would be "A follows B-BA," while a true negative statement would be "B is not followed by A-AB." The subjects were to complete as many of the items as they could in three minutes. Baddeley (1968) found the test to be valid (highly correlated with I.Q), reliable, (+.80 between tests), and to have negligible practice effects.

Folkard et al. (1975) were the first to use Baddeley's Logical Reasoning Test to assess diurnal variations in performance. They tested 36 subjects, six times a day, on two tasks of logical reasoning abilities, one of them Baddeley's Logical Reasoning Test. Using measures of speed of responding he found that performance on both tests improved between 0800 hours and 1400 hours and then dropped off over the rest of the waking day. Accuracy did not exhibit a diurnal pattern, but decreased fairly consistently as the day progressed.

A more elegantly controlled study of diurnal variation in performance was conducted by Monk, Fookson, Moline, and Pollak (1985) in a time-isolated environment. Eighteen subjects were tested six times a day for five days while in temporal isolation. The logical reasoning task used as a performance measure in the study was a modified version of Baddeley's test. The target letters used were "M" and "C" instead of "A" and "B" in order to "reduce both visual confusion and the tendency of subjects to stereotype the ordering of the two letters" (p. 188). The study was obviously unconfounded by external sources that might influence performance such as social interaction and awareness of clock time. Unfortunately, Monk et al. (1985) did not find significant time-of-day effects for performance on the test. There did appear to be a diurnal trend, but it did not reach significance. Monk and colleagues attribute the lack of time-of-day effects to individual differences in the heterogeneous sample of subjects used (heterogeneity referring to the differences in their wake/sleep times and perceived difficulty of the test). The modification of Baddeley's test may also have contributed to the lack of significance because the lack of familiarity of the "CM" letter pair could have produced some small learning effect.

Perhaps the most impressive test of Baddeley's Logical Reasoning task as a measure of *circadian* variation in performance was conducted recently (Gillooly, Smolensky, Albright, Hsi, & Thorne, 1990). Twelve subjects were broken into groups of three and tested in rotating "shifts" such that performance on the test was available around the clock. Subjects were tested hourly in 13-hour sleepless blocks. Measures of performance were mean reaction time and SD, slowest and fastest reaction times, accuracy, speed (responses per working minute), and throughput. Since the subjects had been trained on all of the performance tests prior to the investigation, practice effects were not a consideration. Using cosinor analysis, the Logical Reasoning Test was found to have a statistically significant circadian rhythm for all of the measures of performance except for accuracy. However, there were significant individual differences between subjects as to when in the 24-hour period performance was at its peak.

Documentation of cognitive performance rhythms has traditionally been in the form of diurnal patterns, rather than circadian rhythms, because of the tendency to measure only during waking hours. Investigations which require the testing of subjects around the clock are costly to run and can be complicated by the effects of sleep deprivation. However, when cognitive performance has been measured over the entire 24-hour period, the results have been promising.

Sleep Deprivation and Performance. The literature on performance during sleep deprivation is limited primarily to simple reaction time tests. Baddeley's Logical Reasoning Test and the MAST have not been used to investigate the effects of sleep loss; therefore, the review will focus on the work of Dinges and colleagues. As an example of some of their work on the effects of sleep deprivation on performance, Dinges and Powell's 1988 study will be reviewed. In this investigation, simple RT tests were used to describe the impact of prolonged sleep deprivation of 54 hours. The RT test used was a 10-min Visual RT (VRT) task developed by Wilkinson and Houghton (1982).

The stimulus in this task was the onset of a 4-digit millisecond timer (3-mm LED) visually displayed in a window near a built-in response switch. At the start of each trial, the window was dark so the subject needed only to observe when the lighted display appeared. The subject started each 10-minute test by pressing a response button and then stopping the timer as quickly as possible when he or she observed the lighted display. The inter-trial intervals were determined randomly by an internal counter so that the subjects could not anticipate their responses merely by counting between trials.

With this VRT test, Dinges and Powell demonstrated that the slowing of simple RT with time-on-task increased as sleep loss increased. The results of Dinges and Powell's study served to substantiate a previous study which had found the VRT task to be sensitive to as little as 24 hours of sleep deprivation (Glenville, Broughton, Wing, & Wilkinson, 1978).

Phase-shifts and RT Performance. Disruptions in the circadian timing system have also been shown to affect performance. The most commonly experienced source of circadian disruption results from transmeridian flight. In a review of his work on the effects of jet lag, Graeber (1982) makes a distinction between internal desynchronization (experienced in "artificial" settings, such as free-running conditions in a laboratory) and external desynchronization. He defines external desynchronization as the discrepancy between the timing of the internal circadian rhythms and the external zeitgeber cycles that occurs after transmeridian flight. The effects of this discrepancy can lead to a condition known as "internal dissociation." If the circadian rhythms remain in synchrony, but are not in phase with the external zeitgebers the subject experiences external desynchronization. Much of the evidence on phase adjustments after transmeridian flight, however, indicates that circadian rhythms adjust to new time zones at different rates (Wegmann, Klein, Conrad, & Esser, 1983). This leads to internal dissociation of the rhythms until they resynchronize with each other. The effects of internal dissociation and external desynchronization can lead to a variety of undesirable physiological symptoms, as well as impairment in psychomotor and cognitive performance (Graeber, 1982).

In a classic study of the effects of phase-shifts on cognitive performance, Klein and Wegmann (1974) administered a battery of performance tests before and after transmeridian flights. They found that phase adjustments of the performance rhythms took longer after eastbound travel than after westbound travel. Naitoh (1982) explains that the nature of the circadian system is to drift longer. Therefore, it is reset daily to remain in synchrony with the 24-hour clock of the day-night cycle. Apparently, the circadian system's preference for lengthening the day is what allows for easier phase adjustment after a westward flight. Therefore, it can be said that the body adjusts more easily to a phase-delay than a phase-advance of the zeitgebers. In practical terms, it means circadian phase-shifts are more "easily" accomplished by delaying bedtime than by trying to go to bed earlier.

Bright Light as a Chronobiotic

With the possibility of circadian desynchronization adversely affecting performance, whether as a result of transmeridian flight, shift-work, or space travel, it is of practical importance to develop a means for accelerating the body's rate of adjustment to changes in the zeitgebers. In an attempt to address the problem, Czeisler, Kronauer, Allan, Duffy, Jewett, Brown, and Ronda (1989) have shown that bright light is a strong zeitgeber for resetting the human circadian system. Indicators of the diurnal rhythms were physiological measurements, such as body temperature and plasma cortisol levels. Results of their investigations indicated that properly-timed exposure to bright light could reliably induce a phase-shift in the circadian timing system, independent of the sleep-wake cycle. Czeisler et al. (1989) were confident their findings illustrated that the light exposure treatments were driving the "master" circadian pacemaker, as evidenced by the robustness of the shifts of the rhythms measured.

If exposure to bright light can induce such strong changes in human physiological rhythms, then it is reasonable to expect such changes to take place in human performance rhythms. Of the studies undertaken so far using carefully-timed exposure to bright light to phase-shift diurnal rhythms, none have examined the corresponding psychological rhythms, particularly cognitive performance. For humans who are constantly subjected to altered time cues and the resulting effects (such as commercial airline pilots and astronauts) changes in cognitive performance can be of paramount importance. If there is diurnality in performance, then that implies at some time during the 24-hour period there is a decrement in the ability to perform, as compared with other times of the day. If the trough of performance coincides with scheduled duty for someone who is responsible for controlling a large aircraft, or spacecraft, serious consequences might result from impaired performance.

The current investigation examined the effects of exposure to bright light on cognitive performance rhythms. Four cognitive performance tests (simple RT, MAST2, MAST6, and Logical Reasoning) were administered daily, six times a day. The purpose of this design was to investigate a number of theories from previous research:

Diurnal Performance Rhythms. Of interest was whether cognitive performance exhibited diurnal patterns and if the patterns were consistent with the circadian rhythm of body temperature.

Phase-Shift Effects. Also under investigation was whether an experimentally induced phase-shift of the zeitgebers would produce a phase-shift of the diurnal performance rhythms. It was of theoretical interest to determine the waveform of the performance rhythms after the phase-shift. The prediction was that there would be a decrease in strength of the diurnal patterns during and soon after the phase-shift. Of primary interest was whether the shifted diurnal pattern re-established itself within four days after the phase shift.

Sleep Deprivation Effects. Also of interest was whether, during the phase-shift days, the effects of sleep deprivation would produce a measurable change in diurnal performance, independent of the influence of circadian patterns.

Light Exposure Treatments. The primary issue in the current study was whether carefully-timed exposure to bright light would induce a phase-shift of the circadian system. If cognitive performance exhibited circadian patterns, then it was anticipated that the light exposure would have an effect on the expression of those patterns. If the light treatments induced a phase-shift in cognitive performance rhythms, in addition to the experimentally induced phase-shift of the sleep-wake cycle, then this would facilitate adjustment of the cognitive performance rhythm to the zeitgeber ensemble, allowing external synchronization to be rapidly regained. These results would argue for the practical use of bright lights in aiding resynchronization, particularly in situations where cognitive performance needs to be optimized.

Methods

The current investigation used archival data from a study that was much larger in scope. In this section, the entire study will be described with particular attention to detail of those areas which are directly relevant to the focus of this project.

Subjects

Six healthy, male subjects, aged 34 to 41, were used. Bionetics Corporation, a contractor with NASA Ames Research Center, obtained the subjects for the experiment. Subjects were paid wages for their participation in the study by the Bionetics Corporation.

Subjects were selected on the basis of their willingness to remain alcohol and caffeine-free for 30 days and their availability for confinement to a bedrest facility during two experimental periods, each 11 consecutive days in length. Subjects were non-smokers and were determined by questionnaire to have normal sleeping and eating habits. A confidential background questionnaire was administered which included the following measures: Personal Attributes Questionnaire (Spence & Helmreich, 1978), the Work and Family Orientation Questionnaire (Spence & Helmreich, 1978), the Eysenck Personality Inventory (Eysenck & Eysenck, 1968), the Horne and Ostberg Morningness-Eveningness Questionnaire (Horne & Ostberg, 1976), and questions on health, sleep, dietary, and exercise habits. A preliminary health screening exam of the subjects was administered by a physician to rule out any pre-existing medical contraindications, such as hemorrhoids, or a heart condition. All subjects were within a two-hour drive from the bedrest facility, so no time-zone changes were inflicted upon the subjects prior to the study.

Three subjects were assigned to the control condition and three to the experimental condition. Subjects had been advised prior to receiving their consent to participate that they would be able to withdraw from the experiment at any time. During the course of the first phase of the study two of the subjects withdrew from the experiment due to gastrointestinal discomfort. The remaining portion of the study was conducted with four subjects, two in each condition. Treatment of the subjects was in accordance with the ethical standards of the APA and had been approved by NASA's Human Research Review Board.

Apparatus and Materials

Performance Testing. Two Macintosh SE computers were used to administer the performance tests and record each subjects responses. There were four performance tests administered at each testing session and in the following order: 1) two memory and search tasks, MAST2 and MAST6 (Folkard, Knauth, Monk & Rutenfranz, 1976), 2) the Logical Reasoning Test (Baddely, 1968), and 3) a 10-minute serial RT test (Dinges & Powell, 1985). The specific order in which the tests were administered was arbitrary. The decision to maintain the same order across sessions was based on the focus on diurnal patterns within task, rather than a comparison between task. In order to facilitate performance testing, all of the tests were programmed into the Macintosh.

MAST Tests. Since the MAST4 has not reliably exhibited diurnal patterns only the MAST2 and MAST6 were of interest in this investigation. Both of the MAST tests consisted of sequential presentation of 16 random character strings each of twenty letters per string. Strings that formed patterns, words, or pseudo words were excluded. All 16 trials of the MAST2 were presented before the MAST6. In each of the MAST tests, the target letters (2 in the MAST2 and 6 in the MAST6) appeared above the letter string. The response required was for the subject to move the mouse-pointer to the "true"or the "false" "bubble" which appeared on the screen below the statement and depress the button on the mouse to indicate the choice. Both reaction time and accuracy were recorded by the computer.

Logical Reasoning Test. This test involved the sequential presentation of a series of 32 statements that referred to the letter pair "AB" (and not always in that order) which appeared at the center of the screen near the top. The object of the test was for the subject to read the statement and determine if it accurately described the letter pair at the top of the screen. The response required was for the subject to move the mouse-pointer onto either the "true" or the "false" "bubble" which appeared on the screen below the statement and depress the button on the mouse to indicate the choice. Accuracy of the response, as well as the reaction time were recorded by the computer. The complete test was comprised of all 32 possible combinations of five binary factors: 1) Positive or Negative, 2) Active or Passive, 3) True or False, 4) Precedes or Follows, and 5) A or B mentioned first.

Reaction Time Tests. The stimulus in this task was very similar to the one used by Dinges and Powell (1988) and will be described below.

At the start of the test, a blank timer-window appeared on the screen. The location of the timer-window was approximately 4 cm down from the top of the screen and 7.5 cm from the left side of the screen. The average viewing distance for the subjects was approximately half a meter.

The subjects were required to move the mouse-pointer onto the "Stop" icon that appeared below the time-window and leave it there for the duration of the RT test. The response required was to depress the button on the mouse to stop the timer from counting.

The stimulus was the onset of the timer. Subjects were instructed to try to stop the timer as soon as it began counting so that all zeroes appeared in the timer window. When the subject pressed the mouse button, the timer stopped counting and the RT appeared in the timer window. The RT reading remained on the screen until the next trial.

After a randomly determined interval of time passed (1 to 9 s), the RT reading disappeared and then immediately began counting ms starting from zero in 16 2/3 ms intervals until the subject responded. This sequence continued for a fixed interval of time of ten minutes. The number of trials completed within each ten-minute test session depended upon the subject's reaction times within the ten-minute interval (i.e., the longer the RT's, the fewer trials completed).

The performance tests were administered six times a day on "normal days" and eight times a day on the two phase-shift days. Performance tests were administered at the same time every day, starting immediately upon the subjects' arising and commencing every three hours until just before the "lights out" period.

Questionnaires. Each subject kept a daily log provided by NASA in which he recorded 1) type and amount of food intake, 2) fluid intake, 3) subjective mood/fatigue assessment, and 4) subjective sleep quantity and quality. Also, administered every three hours during waking was a questionnaire assessing subjective fatigue, tension, and arousal. This questionnaire was a compilation of several measures: 1) Stanford Sleepiness Scale (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973), 2) Subjective Fatigue Checkard (Pearson & Byars, 1956), and 3) two 10-cm analog scales. The analog scales were measures of tension and arousal and had the following anchors: (tension - low end) "Feeling very relaxed," (high end) "Feeling very tense"; (arousal - low end) "Feeling very drowsy," (high end) "Feeling very alert."

Equipment and Facilities

Physiological Recording A 420 gm ambulatory physiologic monitoring system (PMS-8, Vitalog Corp., Redwood City, CA.) was used to record heart rate, non-dominant wrist activity, and rectal temperature. Subjects wore the "Vitalogs" continuously during baseline recording (at home on the weekend prior to the start of the study) and throughout the duration of the bedrest portion of the study.

To record objective sleep quality and quantity a number of measures were taken with a portable "Medilog" polysomnographic recorder. Polysomnography included continuous EEG, EOG, and EMG recordings during the subjects' "lights out" period. Electrodes were attached to the head of each subject at 10 placement sites. Electrode placements were reapplied only when high impedances were measured before each sleep period.

Bedrest Facility. Subjects were isolated from most of the external time cues of night and day, as there were no windows in the facility. There were two separate rooms in the laboratory such that the control and experimental groups could be isolated from each other. Each room was large enough to contain four beds, although only two were occupied. The beds each had a collapsible room divider which could be closed to offer the subject complete privacy. Individual "emergency" bedlights (68 lux intensity) were next to each bed should a subject need light during the night. Subjects were encouraged not to use them, but to try to remain in total darkness until the "wake-up call."

Treatment Lamps. The lamps used specially engineered bulbs designed to simulate the visible spectrum of the sun's rays, and to emit up to 10,000 lux intensity (Medic-Light, Inc., Lake Hopatcong, NJ). The bulbs were housed in a square box approximately 2' X 2' X 5" and mounted on a non-adjustable stand. The light intensity used for the exposure treatments in the current investigation was 10,000 lux. All light intensities were measured with a "LiteMate/SpotMate"

Photometer (Kollmorgen Corp., Burbank, CA, 1983). The 10,000 lux emitted by the lamps is approximately equal in intensity to outdoor light shortly after sunrise in the springtime.

Procedure

For both phases of the study subjects came to the bedrest facility on the Friday of the weekend prior to the bedrest confinement to receive information and instructions on how the Vitalog monitors operated and when they were to report to the lab for the bedrest portion of the study. They were then "hooked-up" to the Vitalogs and sent home for the weekend to obtain baseline recordings. Subjects were encouraged to adjust their sleep-wake schedule to 2200 to 0700, which would be their schedule during the first few bedrest days.

Experimental Manipulations. When the subjects arrived at the laboratory they were allowed to choose a bed in any room. Thus, control and experimental groups were determined by subject choice, but the choice was based on characteristics unrelated to the experimental variables. The main purpose of the larger investigation was to study the effectiveness of the light exposure treatments on phase-adjusting circadian rhythms for space operations. In order to simulate the physiological effects of weightlessness experienced in space (0g), the subjects were confined to their beds at a 6-degree head-down-tilt. Accurately measuring the amount and periodicity of the circadian rhythms was of paramount importance to determine the effects of the light exposure. Therefore, to avoid the masking effects of activity the subjects were not allowed to get out of bed or sit up at any time during the 11 days of bedrest for both phases of the study. Diet was regulated by a dietician so that potassium and sodium intake could be monitored. All elimination functions were managed by a nursing staff hired by Bionetics Corporation.

To test the phase-shifting effects of the light exposure, a phase-shift was induced. For all subjects, a complete 12-hour reversal was accomplished in two days by delaying the sleep period 6 hours each night beginning on the fourth night of the study in the Human Research Facility. This was done during both phases of the study.

In order to simulate the lighting on the Space Shuttle or Space Station, room light was kept relatively dim (about 500 lux - the intensity of normal indoor lighting) during the day and was less than 68 lux during the sleep periods. Except for the two time-manipulation days, the lighting was maintained on a 16-hours Light to 8-hours Dark (16L:8D) cycle.

All subjects were exposed to the bright lights; however, the control group was given the treatments during the maximum phase of the temperature rhythm, when the light was not expected to induce a phase-shift. The experimental group was given the treatment during the descending phase of the temperature rhythm, when the light was expected to have its strongest phase-setting influence. Temperature maximum and descending phase were determined daily for each individual by inspection of on-line temperature plots.

Both groups were exposed to the lights for five hours at a time on each of the two phase-shift days and the day after for a total of 3 treatments per subject. The exact same treatments took place during the second phase of the study; however, the control and experimental groups were reversed. Adaptation to the environmental time cues outside the bedrest facility took place on the last day of the study.

Experimental Design

This study was designed in an effort to predict changes in performance as a function of time-of-day and shifts in the sleep/wake cycle. Therefore, a number of within-subjects independent variables were used: day, time-of-day, phase of experiment, and pre-shift, shift, and post-shift phases within each phase. To control for individual differences the study was designed as a crossover experiment with each subject serving as his own control for the light treatment factor. The subjects were blind to the hypotheses of this experiment. The exposure to light of the control group at a time when it was not expected to induce a phase-shift served as a placebo. Design of the study, therefore, necessitated within-subjects analyses.

Results

Preliminary Treatment of Data

Upon visual examination of the performance plots of all four tests it appeared that there was a significant practice effect. Examining the raw data revealed that the reaction times for the Simple Reaction Time Test on the very first test were extremely long. It was determined that this was a result of the subjects being unclear as to how the test was to be taken. Subjects D and E did not receive instructions for taking the MAST tests until the eighth session. This was merely an accidental oversight due to the initial confusion in the data collection schedule at the beginning of the investigation. Consequently, the very first session of the SRT test (in phase 1, for all four subjects) was removed from the analyses. The first seven sessions of the MAST tests for subjects D and E were also removed from further analyses.

To test for the possibility of a significant, negative linear trend, a regression was performed across both phases for each subject on four dependent variables; 1) mean reaction time, 2) median reaction time (med), 3) the fastest ten percent of each session (min), and 4) the slowest ten percent of each session (max). There was a significant negative linear trend across phase for both phases, for each subject, for all four performance tests except for subject D in the Simple Reaction Time (SRT) test; subject D, phase 1 (slope=1.6), subject D, phase 2 (slope=-.51). Due to the extreme unreliability of subject D's performance between phases on the SRT test, his SRT scores were dropped from all further analyses. To eliminate the practice effects from the reaction times for all four performance tests, the data were detrended using a linear regression.

Test of Assumptions. Before proceeding with the analyses to test the experimental hypotheses, the data were examined to verify the appropriateness of performing Analysis of Variance. Levene's test for homogeneity of variance indicated that ANOVA was the appropriate statistical technique. This test is the method available in the BMDP statistical software package for testing the homogeneity of variance assumption.

Experimental Periods. In order to test the experimental hypotheses each phase of the experiment was divided into four periods: 1) baseline - session numbers one through 18 on the first four days of the investigation; 2) shift - sessions 19 through 37 on days five and six; 3) resynchronization - sessions 38 through 55 on days seven, eight and nine; and 4) final - sessions 56 through 67 on days ten and eleven. For a schematic diagram of the relationships among experimental time periods see Figure 1.

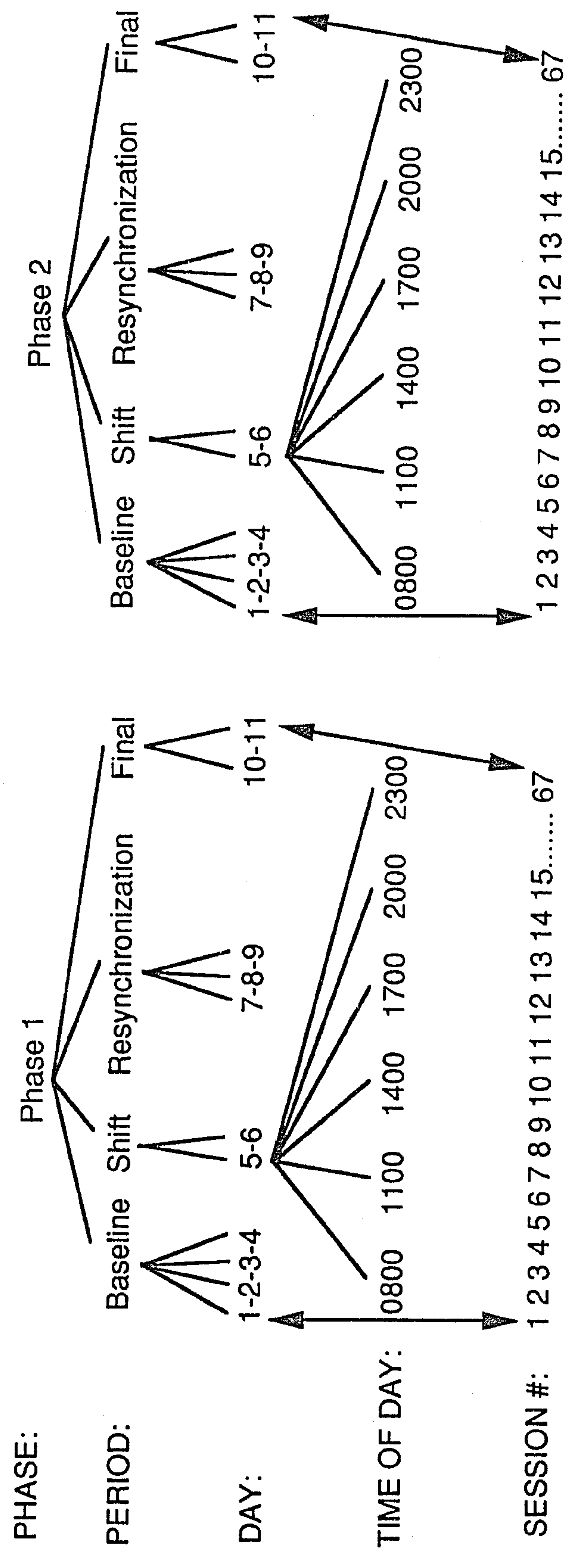

Figure 1. Experimental Time Periods

Hypothesis One: Diurnal Patterns in Performance. Before testing whether performance exhibited diurnal patterns, the two phases were compared with a paired *t*-test to determine if there were significant differences between phases in baseline performance. As there were no significant differences for any of the dependent measures on any of the performance tests, the two phases were combined in the subsequent analyses.

In order to test for diurnal patterns a one-way ANOVA on time-of-day was conducted on *z*-scores of all performance and body temperature data during baseline. *Z*-scores were used to eliminate scale differences between the test types. Results of the ANOVA and the detrended reaction times are displayed in Table 1.

It was anticipated that temperature would show strong time-of-day effects as it is typically used as a reliable circadian index. Only three of the dependent measures of performance exhibited significant time-of-day effects (Mean SRT, Max SRT, and Min LogRes). Those measures are displayed in Table 2 with the temperature data to display the relationship between temperature and performance.

A two-way ANOVA on time-of-day and test type was performed on the *z*-scores for the above performance measures and body temperature. *Z*-scores again were used to eliminate scale differences between the test types and body temperature. The levels of test type were defined as the three performance measures listed in Table 2, plus body temperature. There was a significant time-of-day effect for all dependent measures, as was expected from the previous ANOVA's (F=10.73; p<.001), and a significant interaction between

Table 1. One-way ANOVA on Baseline Period; Detrended Data and Time-of-day Effects.

SRT

DV	0800	1100	1400	1700	2000	2300	F	p
Mean	286	273	292	273	281	280	2.65	.03*
Median	276	266	270	268	272	272	.96	NS
Min	225	222	223	217	224	219	1.38	NS
Max	471	416	522	420	431	440	2.78	.02*
Temp	36.51	36.79	37.00	37.08	37.03	36.94	22.33	.001*

LogRes

DV	0800	1100	1400	1700	2000	2300	F	p
Mean	4486	4285	4102	4640	4306	4175	.44	NS
Median	3585	3462	3467	3607	3785	3728	.40	NS
Min	2118	1881	1376	1766	1975	2015	3.49	.005*
Max	14647	11975	11477	13758	10866	9843	.55	NS
Temp	36.51	36.79	37.00	37.08	37.03	36.94	22.33	.001*

Memory and Search Task 2

DV	0800	1100	1400	1700	2000	2300	F	p
Mean	6459	6559	5841	5775	6479	6499	.76	NS
Median	6126	6117	5354	5616	4845	5855	1.29	NS
Min	2938	2614	2290	2768	2878	2741	1.74	NS
Max	13405	16215	11522	11176	18522	12746	1.59	NS
Temp	36.51	36.79	37.00	37.08	37.03	36.94	22.33	.001*

Table 1. One-way ANOVA on Baseline Period: Detrended Data and Time-of-day Effects (continued).

Memory and Search Task 6

DV	0800	1100	1400	1700	2000	2300	F	p
Mean	12074	12239	11744	11673	10349	11298	.68	NS
Median	12099	11142	10798	11327	11073	10554	.41	NS
Min	6792	6877	5626	5802	6092	6299	.99	NS
Max	18596	25393	21769	20632	17583	22221	1.18	NS
Temp	36.51	36.79	37.00	37.08	37.03	36.94	22.33	.001*

Table 2. Raw Performance and Temperature Data.

Time of Day

Test	0800	1100	1400	1700	2000	2300
SRT Mean	286	(273)	[292]	(273)	281	280
SRT Max	471	(416)	[522]	420	431	440
LogRes Min	[2118]	1881	(1376)	1766	1975	2015
Temperature	(36.513)	36.791	36.996	[37.083]	37.034	36.941

Note: The values enclosed in parentheses in Table 2 are minimum values and those enclosed in brackets are the maximum values.

time-of-day and test type (F=15.7; p<.001). As anticipated, there was no significant main effect for test type.

To further test for a relationship between body temperature and performance on those measures showing significant time-of-day effects, a simple regression was performed between temperature and SRT mean, SRT max, and Logical Reasoning min. Results of all three regressions indicated there was no evidence of a linear relationship between body temperature and performance.

In general, the hypothesis that performance exhibits diurnal patterns was not supported by these data. Although three performance measures did exhibit time-of-day effects, thirteen did not. The three that were significant were not part of a persuasive pattern. For example, SRT mean was significant, but SRT median was not even close (F<1). Additionally, LogRes min was significant, while for SRT it was SRT max that was significant.

Hypotheses 2 and 4: Phase-shift and Light Exposure Effects. In order to test for the effects of the laboratory-induced phase-shift and the effects of exposure to bright light a two-way, repeated measures ANOVA was performed on experimental condition by period. Separate ANOVAs were performed for each dependent measure to examine the overall pattern in the data.

It was expected that any phase-shift effects would be evident in significant differences in performance between periods (e.g., baseline and shift). In only two out of sixteen tests were there any significant differences between periods: for the dependent measure of mean on the Logical Reasoning test (F=3.8; p<.01), and for the dependent measure of mean on the MAST 6 test (F=2.68; p<.05). A planned comparison between baseline and the other periods revealed that performance was significantly better during baseline for the mean on the Logical Reasoning test (F=8.978; p<.003). For the MAST 6 test planned comparisons demonstrated that mean performance was best during the shift period (F=6.06; p<.02). Due to the overall pattern of results for this analysis, it can be said that the hypothesis for the effects of the laboratory-induced phase-shift on performance was not supported.

The two-way repeated measures ANOVA revealed no significant differences between the experimental and control conditions on any of the dependent measures for any of the tests. There were significant period by condition interactions in only two out of sixteen tests; for the dependent measure of max on the SRT test (F=3.002; p<.03), and for the dependent measure of min on the MAST 6 test (F = 4.067; p<.008). In the case of the SRT test it appears that performance was significantly different between the experimental and control groups only during the baseline period (F=6.722; p<.01). On the MAST 6 test the differences between conditions appeared only during resynchronization and final periods. Upon examination of the means in Table 3 it appears that the experimental group performed significantly slower during resynchronization and then went on to perform significantly faster than the controls in the final period. Based on the results of the preceding analyses it can be said that the light exposure treatments did not improve performance for the experimental group after the laboratory-induced phase-shift.

Hypothesis 3: Sleep Deprivation Effects. It has been determined that any effects of sleep deprivation, or more appropriately in this case, delayed sleep, would be extremely difficult to detect with a specific statistical test due to the complexity of the experimental design. The subjects in this study were required to maintain wakefulness for an extended period of only 22 hours. Noticeable

Table 3. ANOVA Summary Table for Test Type by Time-of-Day.

Source	df	Sums of Squares	Mean Square	F	p
Test Type	3	3.697E-32	1.232E-32	1.5E-32	1
Time of Day	5	14.07	2.814	3.446	.005
Interaction	15	80.802	5.387	6.598	.0001
Residual	408	333.128	.816		

Cell Means for
Time-of-Day by Test Type

	RT Max	RT Mean	LR Min	Temp
0800	.202	.264	.320	-1.328
1100	-.278	-.340	-.034	-.536
1400	.674	.553	-.695	.426
1700	-.309	-.438	-.149	.730
2000	-.180	-.034	.244	.566
2300	-.110	-.004	.314	.142

effects of delayed sleep typically do not appear until at least 24-hours of deprivation. Any effects of delayed sleep in this investigation would appear in the results of the analyses performed to determine experimental treatment effects and phase-shift effects. Since the overall pattern of results from the previous analyses suggest no differences in performance between periods for any of the measures, it is logical to assert that there were no detectable effects of delayed sleep on performance.

Discussion

The primary purpose of the larger investigation, from which these performance data were obtained, was to examine the effects of exposure to bright light on phase-shifts of circadian rhythms. The overall pattern of results in the preceding analyses did not demonstrate conclusively that there were reliable diurnal patterns in cognitive performance, or that exposure to bright light had an effect on performance rhythms. The discussion in this section will first focus on the pattern of results found in the analyses conducted to test for time-of-day effects. Then the literature on the effects of extended bedrest and motivation on performance will be reviewed, followed by discussions of sample size in performance testing. Finally, the experimental findings will be briefly examined.

Diurnal Rhythms in Performance

To test the hypotheses for the effects of the phase-shift and light exposure on performance rhythms it was necessary to first test for the existence of diurnal patterns in performance. In the current investigation, the presence of diurnal patterns in performance on simple reaction time, as well as the reaction times for the MAST2, MAST6, and Logical Reasoning tasks, was evaluated statistically with an analysis of variance for time-of-day effects. Significant time-of-day effects were found on some parameters of the SRT test and on the Logical Reasoning test. The overall pattern of results, however, indicated that there was no consistent diurnal pattern in performance. The lack of a statistical relationship between body temperature and performance only reinforced this conclusion.

In his previous work, Dinges did not make any specific predictions about the measures of mean RT, minimum RT, and maximum RT with respect to time-of-day effects, but there are some interesting comparisons between the results of this study and the work of Dinges' group. The dependent measure of maximum RT, referred to by Dinges as a measure of the "lapse domain," is purported to be sensitive to the effects of sleep loss (i.e., as sleep loss increases, so do the maximum RTs). In this investigation, however, significant time-of-day effects were found for maximum RT during the baseline period, when subjects were supposed to have gotten "normal" amounts of sleep. It has been argued that circadian patterns in performance occur because of the body's natural tendency towards sleep at certain times of the day (Rutenfranz & Colquhoun, 1979). Since maximum RT is a performance measure which is sensitive to "sleepiness" (according to the work of Dinges), it follows that maximum RT would exhibit time-of-day effects.

In examining a plot of the detrended maximum RTs for the SRT test during the baseline period (Figure 2), there is a clear decrement in performance in the afternoon at the 1400 hour. Not only does maximum RT exhibit a clear diurnal pattern, but the nadir in performance at the 1400 hour is a classic case of the

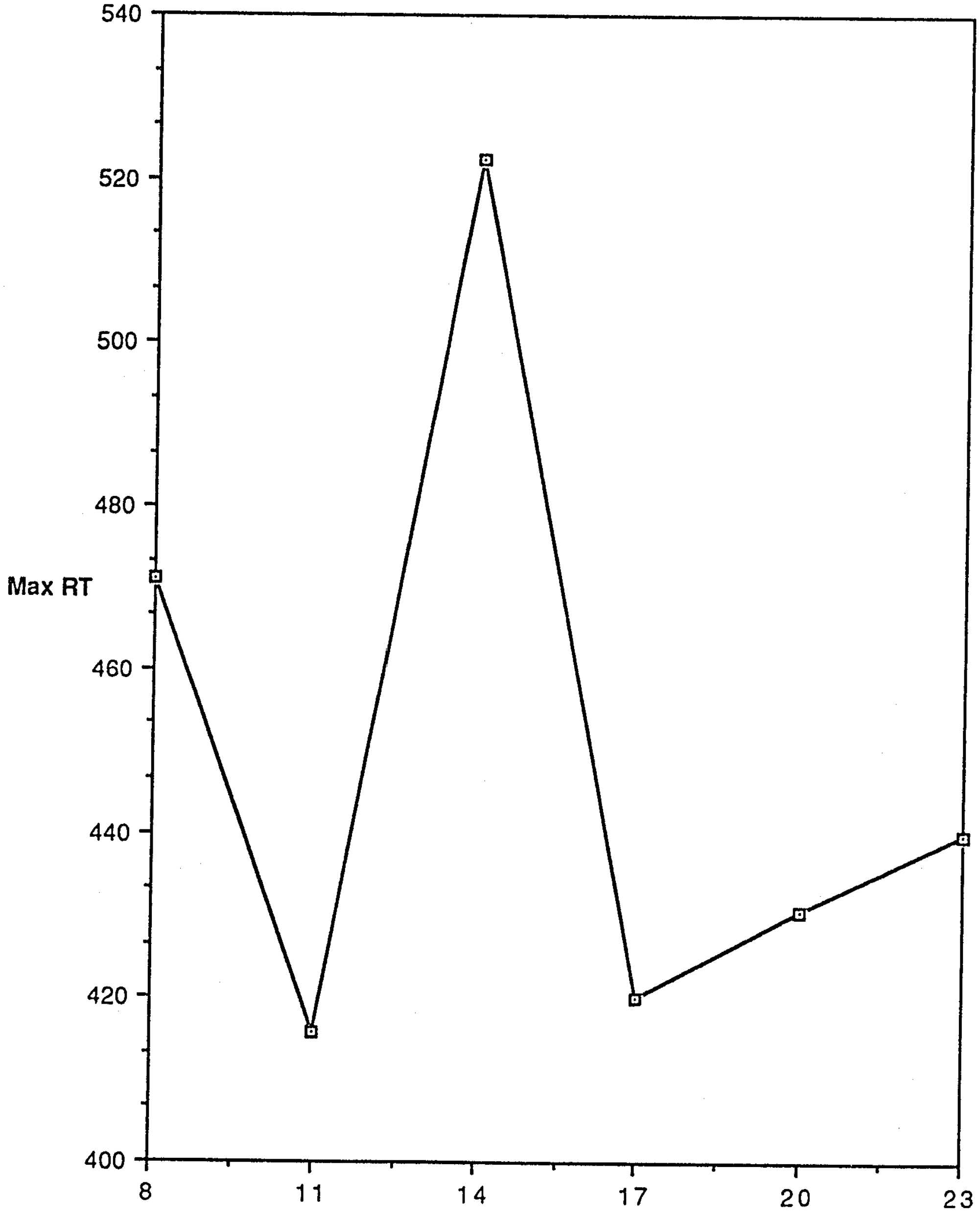

Figure 2. SRT Baseline Max - Detrended Data

"post-lunch dip." The literature on performance and time-of-day is rife with examples of performance following body temperature on immediate information processing tasks, such as simple reaction time (Kleitman, 1963; Folkard, Knauth, Monk, & Rutenfranz, 1976). Although there was no statistically significant relationship between body temperature and performance in this study, comparing the temperature curve in Figure 3 with maximum RT in Figure 2, it appears as though the peak in body temperature coincides with the fastest of the maximum reaction times. As shown in Table 2, the raw reaction times for maximum RT are fastest at 1100 and 1700 hours. Although the fastest of the reaction times occurs at 1100 (RT = 416 ms) there is a difference of only 4 ms between the RT at 1100 and the RT at 1700 (RT = 420 ms). The lack of a statistical relationship between SRT max and body temperature can be attributed to the overall relationship between the two measures throughout the day; the fastest RT actually occurs at the second lowest body temperature and the next fastest RT occurs at the temperature maximum.

Mean RT has been the dependent measure of choice in many previous studies of diurnal patterns in performance. In this study, the pattern in performance for the mean RT (Figure 4) is as clearly diurnal as that for the maximum RT. The significant time-of-day effect follows the same pattern as the literature predicts, particularly the presence of the "post-lunch dip" occurring again at the 1400 hour. As shown in the plot of the mean RTs for the SRT during baseline, the fastest RTs tend to occur earlier in the day, along with the temperature minimums. Again, however, the lack of a statistical relationship between SRT mean and body temperature is due to the fact that the RT

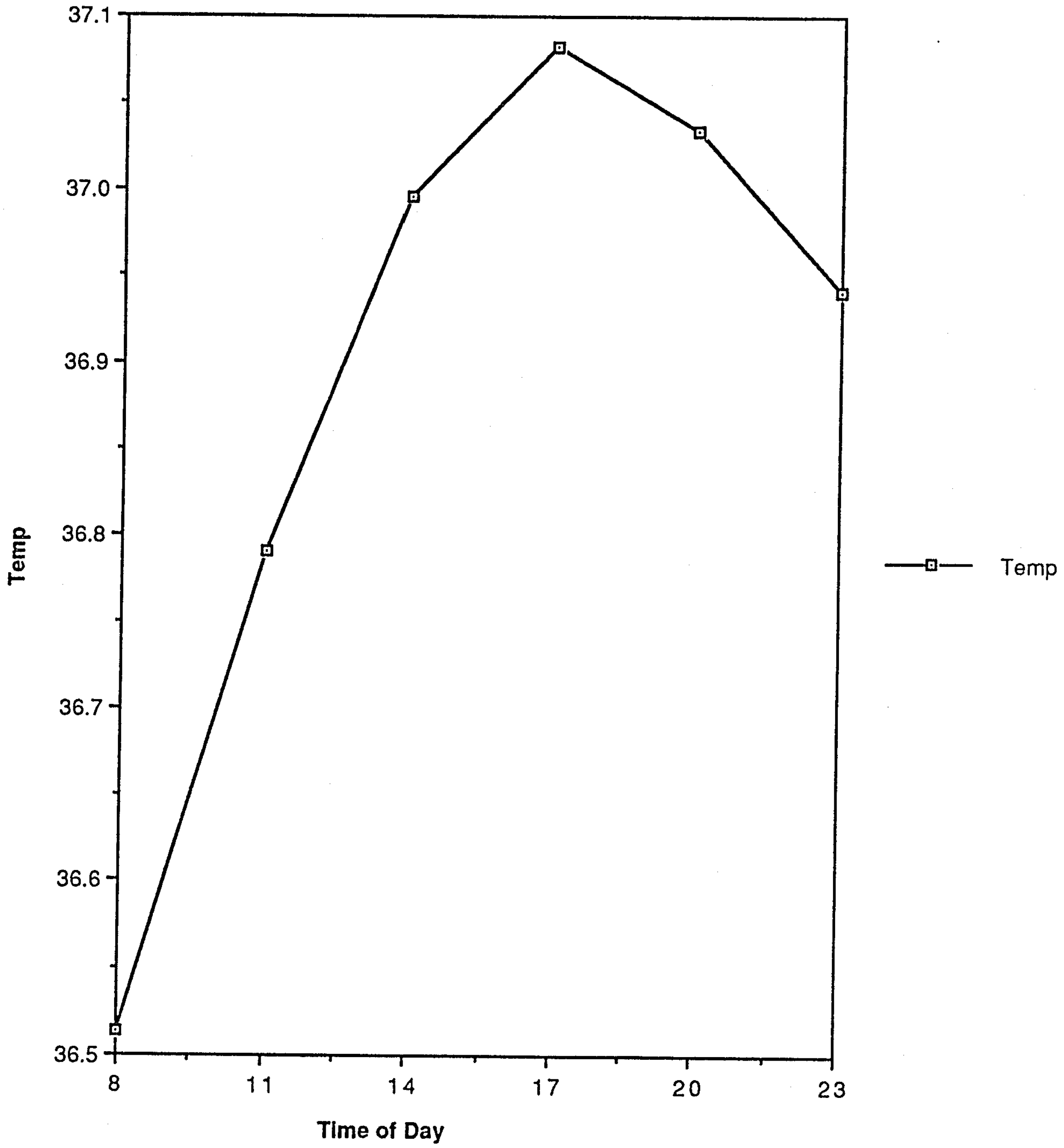

Figure 3. Temperature Data

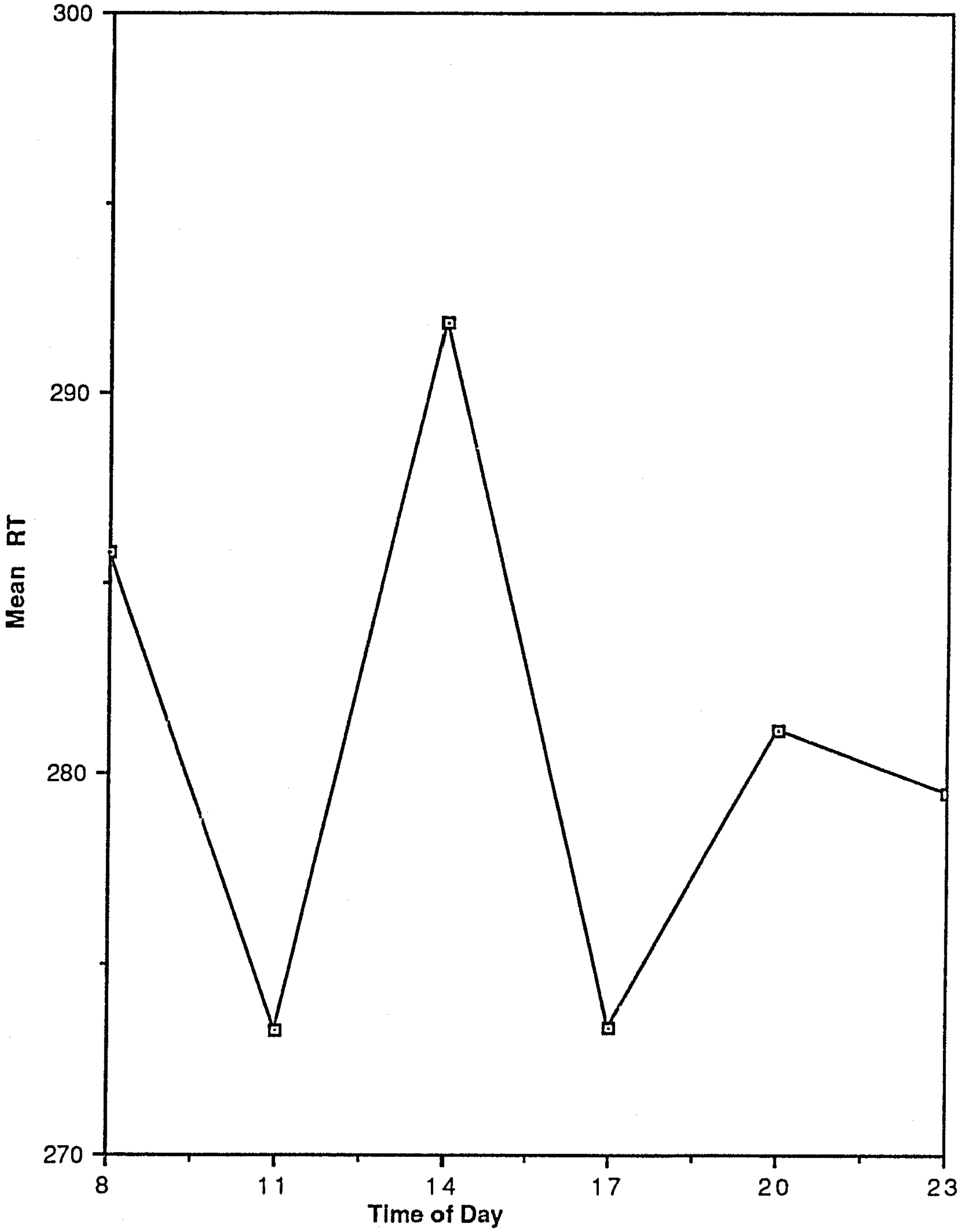

Figure 4. SRT Baseline Mean - Detrended

Data

minimum for the day occurs twice, as shown in Table 2 (RT 1100 = 273 ms; RT 1700 = 273 ms), and in Figure 4.

In order to examine the performance data consistently, and to obtain maximum information from the available test data, the MAST tests and the Logical Reasoning results were analyzed according to the theoretical framework used to analyze the SRT data. The raw reaction times for the three performance tests were reduced to the same dependent measures of mean, median, minimum, and maximum. The only instance where significant time-of-day effects were found for any of the three performance tests was for the minimum RT in the Logical Reasoning Test.

The literature on the Logical Reasoning Test has fairly reliably shown significant time-of-day effects. Folkard et al. (1975) found that speed of responding tended to improve between the hours of 0800 and 1400 and then gradually drop off over the rest of the day. In Figure 5 it is evident that the minimum RT for the Logical Reasoning Test in this investigation clearly followed the same pattern. The definition of speed of responding in Folkard et al.'s study was a function of the number of items attempted and may be compared with the use of minimum RT in this study. According to Dinges and colleagues, minimum RT taps into the "optimum response" domain, which is essentially the fastest overall RTs and is a measure similar to "speed of responding."

The results of the performance on Logical Reasoning in this investigation are consistent with the predictions of Rutenfranz and Colquhoun (1979). It was predicted that performance on more complex tasks involving memory functioning and "higher mental processes" would tend to oppose the temperature curve. By comparing minimum RT in Figure 5 with the temperature

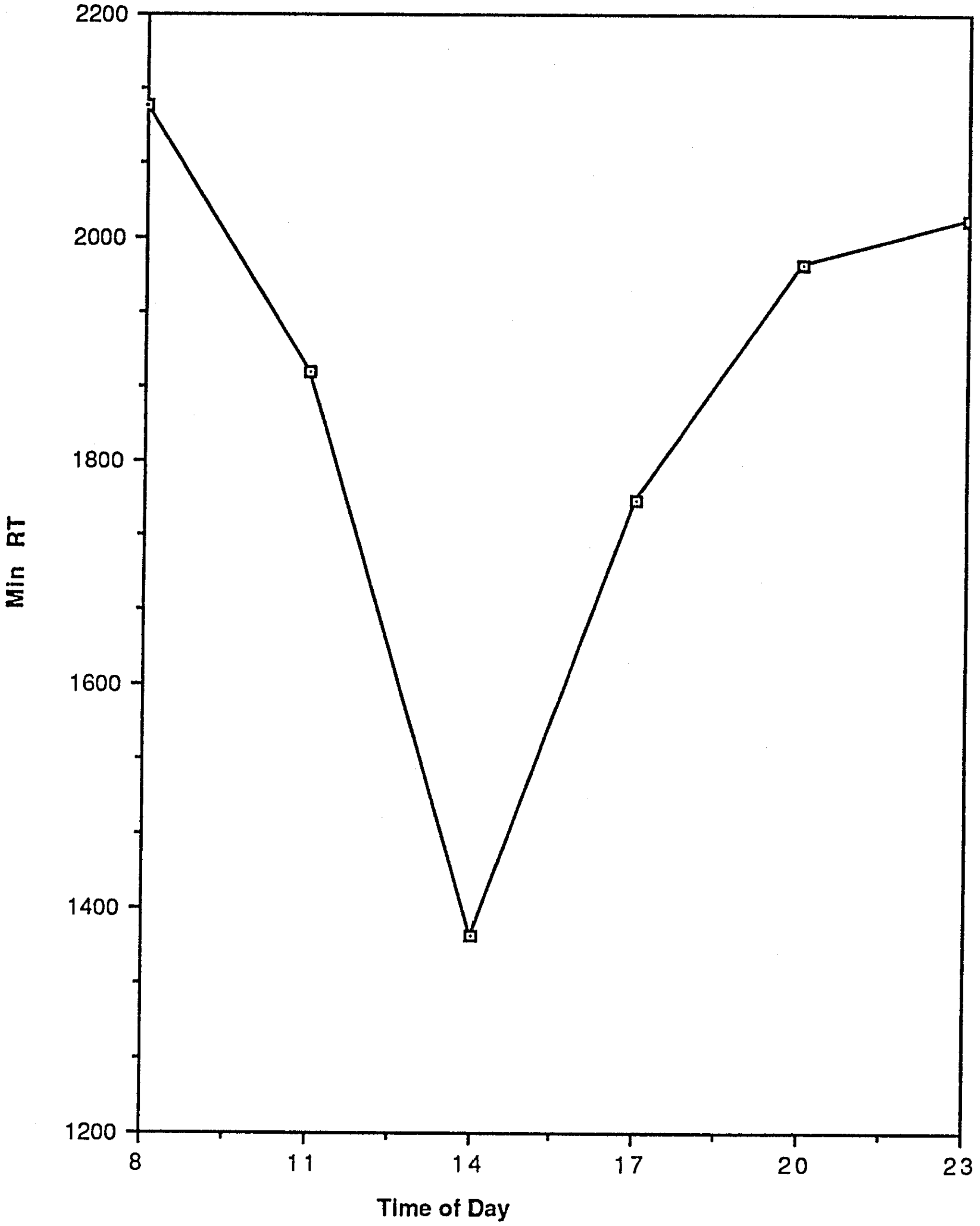

Figure 5. LR Baseline Min - Detrended

Data

curve in Figure 3, the minimum RT curve appears to oppose that of body temperature.

The two-way ANOVA was the preliminary test to determine if there was a relationship between body temperature and performance. As expected, the main effects for time-of-day for the performance measures and temperature were significant. The main effect for type of test was not significant because *z*-scores were used, which, by the nature of *z*-scores and ANOVA, eliminated any differences between test types. However, the interaction between time-of-day and test type was highly significant (see Table 3) and can be attributed to the changing relationship between temperature and performance on the three measures over the course of the day.

For example, by examining the plot in Figure 6 it appears that there is a negative correlation between temperature and all three performance measures from 0800 to 1100, but then performance on the Logical Reasoning test takes a dramatic turn from the other performance measures by showing a marked improvement in performance during the 1400 hour. This phenomenon is very much in contrast to the "post-lunch dip" exhibited by the SRT measures. Then at the 1700 hour, all three performance measures converge once again and exhibit a negative correlation with temperature. It appears that the contrasting relationships between performance and temperature (from negatively correlated, to both positive and negative at 1400, and then to negative again) is what accounts for the significant test type by time-of-day interaction. As mentioned previously, the relationships between temperature and performance on each of the three measures is consistent with the findings in the literature.

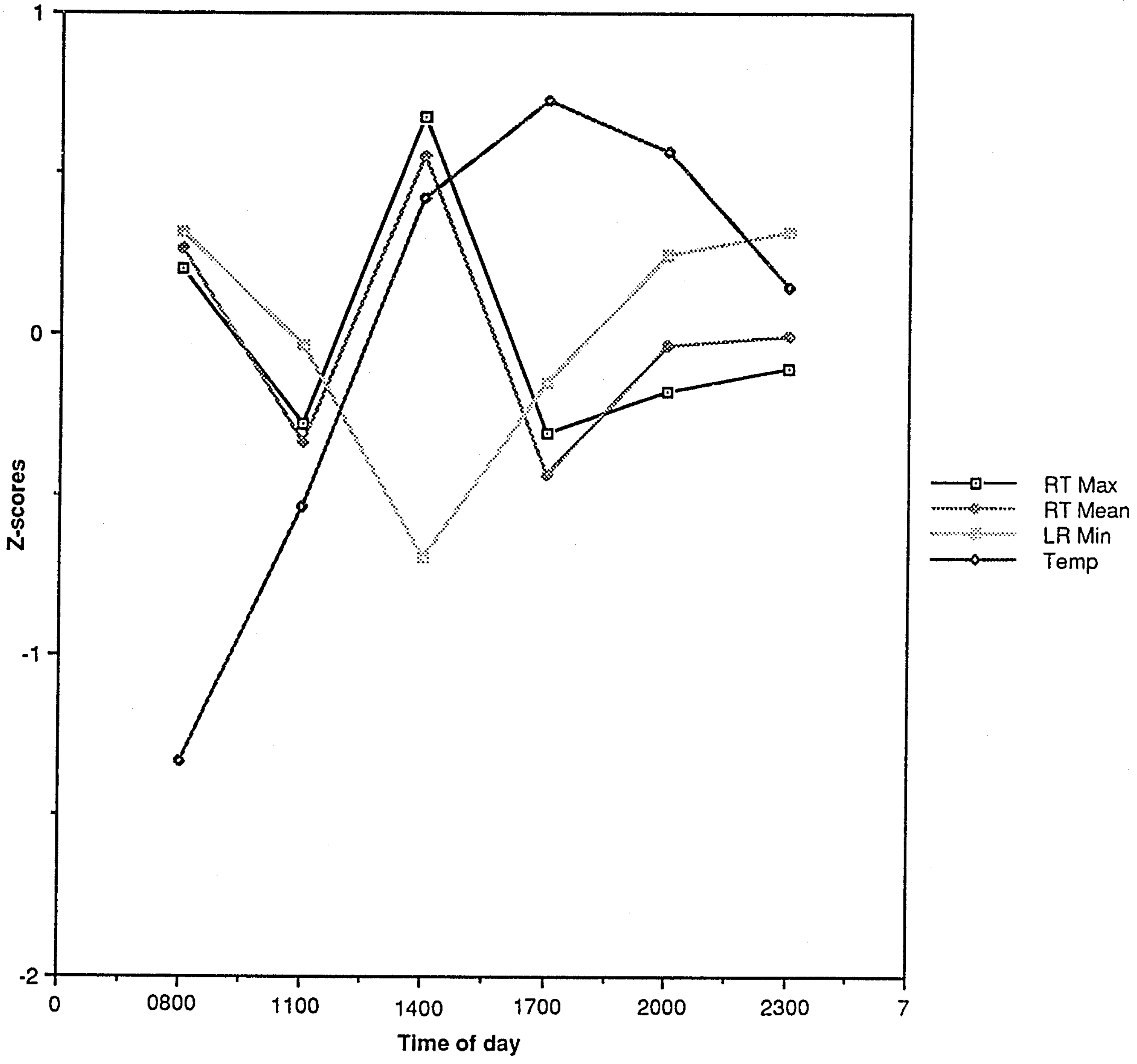

Figure 6. Time-of-day by Test Type

Apart from the three measures of performance previously mentioned, none of the measures on any of the four performance tests (most notably, the MAST tests) exhibited time-of-day effects. Perhaps the lack of significant time-of-day effects can be attributed to the effects of motivation. It has been shown that time-of-day effects can effectively be eliminated on simple tasks by high motivation, or "extra effort" (Chiles, Alluisi, & Adams, 1968).

The investigators worked in shifts to continuously monitor the subjects' behavior and performance during the activity portions of the days and to collect data. Subjects were grouped in two pairs, based on their room assignments, and maintained the same "partners" throughout the course of the experiment. They were tested two at a time because only two computers were available for use throughout the study. Subjects A and B were tested together and then subjects D and E were tested together, always in that order. The investigators administered the tests by placing a cart in front of a subject with the Macintosh computer set up on it. The subjects' progress was monitored by the investigators by occasionally entering the rooms during testing and by verbal exchange with the subjects when the testing was over.

Motivational factors were clearly in effect during the experiment. Two subjects (A and B) were engaged in a contest with each other, and with themselves, as well, to obtain the best (fastest) reaction times possible, regardless of the time of day. The other pair of subjects (D and E) rarely communicated with each other. Subject D complained of boredom with the test and began changing the parameters of the test to keep himself interested. For example, several days into the experiment, subject D began trying to stop the timer at specific intervals, rather than trying to obtain the best reaction times possible. Subject D was also seen several times engaging in other tasks simultaneously with the performance test. Subject E, on the other hand, complained of having difficulty with the Logical Reasoning task and his scores reflected that fact. Subject E's overall performance (in terms of RTs) was clearly slower than any of the other three subjects.

There are several major factors which probably contributed to the overall unreliability in performance throughout the day. The first factor being that none of the previous investigations examining diurnal rhythms in performance have kept subjects confined to a laboratory for such extended periods of time as the subjects in this investigation. Nor have any subjects been subjected to extended bedrest in combination with a 6-degree head-down tilt. Both the extended confinement and the bedrest may have had significant effects on the motivation to perform.

The lack of a significant time-of-day effect in this investigation is consistent with the results of a previous investigation where subjects were confined to bedrest for five days while several physiological and performance measures were taken (Natelson, DeRoshia, Adams, Finnegan, & Levin, 1983). Performance measures were short-term memory (recall) and a task involving eye-hand coordination. Using the statistical technique of principal components, Natelson et al. (1983) found that none of the physiological parameters predicted or covaried with performance.

The lack of reliable time-of-day effects in the performance of the subjects in this investigation can most likely be attributed to an insufficient number of datapoints. Datapoints can be increased by either increasing the number of subjects, or from longer-running studies with more data collected over time.

The existence of diurnal rhythms in cognitive performance has been well documented in the literature (Hockey & Colquhoun, 1972; Klein & Wegmann, 1979; Webb, 1982). The diurnal rhythms in the performance measures used in this investigation, which have been particularly well documented, have used a much larger subject pool, or tested over longer periods of time. Circadian rhythms in performance have been so well established that Aschoff, Giedke, Poppel, and Wever (1972) used tests of simple computation and time estimation to demonstrate that these rhythms are endogenous in the absence of zeitgebers.

In an investigation using 18 subjects, performance on the Logical Reasoning Test varied over the day by as much as 20% of the 24-hour mean (Bugge, Opstad, & Magnus, 1979). Even during baseline and recovery days, subjects' performance exhibited diurnal fluctuations of about 10% of the 24-hour mean.

In another study, significant time-of-day effects were found for a task similar to the SRT test used in this investigation. Buck (1977) exposed 40 subjects to a series of self-administered tests repeated every 4 hours during the waking day over a period of 48 hours. The test unit was designed to record subject response time, as well as errors. The similarity between the stressalyzer in the Buck investigation and the SRT test used in this study was that they were both types of vigilance tasks. Since statistically significant performance rhythms were found in the 1977 study, as well as by Dinges et al. (1989) in their investigations, it appears reasonable to assert that diurnal rhythms exist in tests of simple reaction time, if enough data are obtained.

There are not yet sufficient data to conclude that the MAST2 and MAST6 tests reliably yield significant time-of-day effects. The MAST2 test showed a significant, positive correlation with body temperature in the Folkard et al. (1976) investigation, as well as significant time-of-day effects in the Connell (1985) investigation. However, the MAST6 test has not been shown to exhibit diurnal patterns. Connell emphasized the lack of significant main effects for time-of-day in her investigation may have been due to differences in the test she used from the one Folkard et al. (1976) used. Since the versions of the MAST 2 and MAST6 tests used in this investigation were virtually the same as those used by Connell, the previous explanation for the lack of significant time-of-day effects may hold true in this case, as well. This means that the main effects of time-of-day for the MAST2 test may have been due to both memory load and a type of learning effect. The analyses conducted for this investigation were based on an extant database. Had there been an option for this investigator to select the types of performance measures to be used, the MAST tests would not have been selected because of the unreliability of the findings as documented in the literature.

In this investigation, the significant differences that were found in performance over the day beg the question, "Are the differences in responding meaningful?" When significant time-of-day effects were found, as in the case of SRT mean and maximum, and Logical Reasoning minimum, the range of the daily maximums and minimums on each measure were small enough to be considered meaningless. For example, looking again at Table 2, the difference between the daily maximum and minimum for the SRT mean is only 19 ms. To say that performance on this test varied significantly throughout the day makes sense only from a statistical perspective. When put into practice a change in speed of responding by only 19 ms would be imperceptible, and probably inconsequential. If we were able to correlate a range in speed of responding over the day of 19 ms with a proportionately greater difference in response speed in tasks that we perform every day, then we could conclude that the 19 ms range is meaningful. As seen from the data in Table 2, on a more complex task, such as Logical Reasoning, the range of the daily maximums and minimums is much greater than that for SRT (range = 742 ms). The implications of the observed RT differences for "real-world" task performance is an area that must be investigated.

Effects of Phase-shift, Delayed Sleep, and Light Exposure

In order to appropriately address the remaining three hypotheses (1. phase-shifts, 2. delayed sleep, and 3. light exposure), it was necessary to first establish diurnal patterns in performance. With respect to the effects of sleep deprivation, or more appropriately, delayed sleep, it is a fundamental problem in the field of sleep deprivation research to separate out the effects of sleep deprivation from those of circadian variation. An additional source of variation in this investigation was the laboratory-induced phase shift. It is possible that the subjects experienced fatigue as a result of delayed sleep, but the effects on performance may be negligible. With the complexity of this experiment and the possibility of several factors contributing to the observed variance it is likely that any effects of delayed sleep are obscured by other effects, such as phase-shift and light exposure.

The overall pattern of results in the two-way repeated-measures ANOVA did not support the hypotheses of effects on performance of exposure to bright light and the phase shift. In the case of the dependent measure of minimum (optimum responding) on the Logical Reasoning Test, the fact that performance was significantly better during baseline than any other period (and all other periods combined) suggests that the phase-shift adversely affected optimum performance from which the subjects were not able to recover throughout the rest of the experiment. The fact that performance on the Logical Reasoning task degraded after the experimental manipulations were introduced indicates that at least one, if not more, of the manipulations had an effect on performance. We were unable to attribute the detrimental effects on performance to either the phase-shift or to the delayed sleep, nor have we learned how long of a recovery period the subjects require in order for their performance to return to baseline levels.

The evidence of individual variability in the expression of behavior abounds within the psychological literature. In order to compensate for this variability when measuring human performance, it is customary to sample a large group of subjects to overcome these effects. As cited previously, those investigations which have found diurnal performance rhythms have used large numbers of subjects to detect those patterns. This implies that diurnal patterns in performance would not be found for an individual subject, or for smaller subject pools, as was the case in this investigation. Such an implication points out significant weaknesses in the arguments for detecting and predicting diurnal performance. If we are unable to find patterns in performance until we average over many subjects, then how can we be expected to predict individual performance for an airline pilot, for example? The goal of the science of psychology is to be able to understand human behavior and consequently predict it. In order for us to meet that objective when predicting cognitive performance throughout the day, we must have a measure that is sensitive and reliable enough to exhibit diurnal patterns for an individual subject, as well as for performance averaged over many subjects.

References

Aschoff, J., Giedke, H., Poppel, E., & Wever, R. (1972). The influence of sleep-interruption and of sleep deprivation on circadian rhythms in human performance. In W. Colquhoun (Ed.), Aspects of human efficiency: Diurnal rhythm and loss of sleep (pp. 135-150). London: English Universities Press.

Arendt, J., Aldhous, M., English, J., Marks, V., Marks, M., & Folkard, S. (1987). Some effects of jet-lag and their alleviation by melatonin. Ergonomics, 30, 1370-1383.

Baddeley, A. D. (1968). A three-minute reasoning test based on grammatical transformation. Psychonomic Science, 10, 341-342.

Bills, A.G. (1931). Blocking: A new principle of mental fatigue. American Journal of Psychology, 43, 230-245.

Blake, M.J.F. (1967). Time of day effects on performance in a range of tasks. Psychonomic Science, 9, 349-350.

Buck, L. (1977). Circadian rhythms in step-input pursuit tracking. Ergonomics, 20, 19-31.

Bugge, J., Opstad, P., & Magnus, P. (1979). Changes in the circadian rhythm of performance and mood in healthy young men exposed to prolonged, heavy physical work, sleep deprivation, and caloric deficit. Aviation, Space, and Environmental Medicine, 50, 663-668.

Chiles, W., Alluisi, E., & Adams, O. (1968). Work schedules and performance during confinement. Human Factors, 10, 143-196.

Connell, L. J. (1985). The influence of Theophylline on the circadian sleep-wake cycle, cognitive performance, and core temperature rhythms. Unpublished master's thesis, San Jose State University, San Jose, CA.

Craik, K.J.W. (1948). Theory of the human operator in control systems II. Man as an element in a control system. British Journal of Psychology, 38, 142-148.

Czeisler, C.A., Kronauer, R.E., Allan, J.S., Duffy, J.F., Jewett, M.E., Brown, E.N., & Ronda, J.M. (1989). Bright light induction of strong (Type O) resetting of the human circadian pacemaker. Science, 244, 1328-1333.

Dinges, D.F., & Kribbs, N.B. (in press). Performing while sleepy: Effects of experimentally-induced sleepiness. In T. Monk (Ed.), Sleep, sleepiness, and performance (pp. 1-55). West Sussex: John Wiley & Sons.

Dinges, D.F., Orne, M.T., & Orne, E.C. (1984). Sleepiness during sleep deprivation: The effects of performance demands and circadian phase. Sleep Research, 13, 189.

Dinges, D. F., Orne, M. T., Whitehouse, W. G., & Orne, E. C. (1987). Temporal placement of a nap for alertness: Contributions of circadian phase and prior wakefulness. Sleep, 10(4), 313-329.

Dinges, D., & Powell, J. (1985). Microcomputer analyses of performance on a portable, simple visual RT task during sustained operations. Behavioral Research Methods, Instruments and Computers, 17(6), 652-655.

Dinges, D., & Powell, J. (1988). Sleepiness is more than lapsing. Sleep Research, 17, 84.

Dinges, D., & Powell, J. (1989). Sleepiness impairs optimum response capability. Sleep Research, 18, 366.

Eysenck, H. J., & Eysenck, S. B. G. (1968). Eysenck Personality Inventory. Educational and Industrial Testing Service, San Diego, CA.

Folkard, S., Knauth, P., Monk, T., & Rutenfranz, J. (1976). The effect of memory load on the circadian variation in performance efficiency under a rapidly rotating shift system. Ergonomics, 19, 479-488.

Gander, P. H., Myrhe, G., Graeber, R. C., Anderson, H. A., & Lauber, J. K. (1985). Crew Factors in Flight Operations I: Effects of Nine Hour Time Zone Changes on Fatigue and the Circadian Rhythms of Sleep/Wake and Core Temperature (NASA Technical Memorandum # 88197). Moffett Field, CA: NASA-Ames Research Center.

Gillooly, P., Smolensky, M., Albright, D., Hsi, B., & Thorne, D. (1990). Circadian variation in human performance evaluated by the Walter Reed Performance Assessment Battery. Chronobiology International, 7 (2), 143-153.

Glenville, M., Broughton, R., Wing, A.M., & Wilkinson, R.T. (1978). Effects of sleep deprivation on short duration performance measures compared to the Wilkinson Auditory Vigilance Task. Sleep, 1, 169-176.

Graeber, R. C. (1982). Alterations in performance following rapid transmeridian flight. In F. M. Brown & R. C. Graeber (Eds.), Rhythmic aspects of behavior (pp. 173-212). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Graeber, R. C., Gatty, R., Halberg, F., & Levine, H. (1978). Human Eating Behavior: Preferences, Consumption Patterns, and Biorhythms (Technical Report TR-78-022). Natick Research and Development Command: U.S. Army.

Hockey, G., & Colquhoun, W. (1972). Diurnal variation in human performance: A review. In W. Colquhoun (Ed.), Aspects of human efficiency: Diurnal rhythms and loss of sleep (pp. 1-23). London: English Universities Press.

Hoddes, E., Zarcone, V., Smythe, H., Phillips, R., & Dement, W. C. (1973). Quantification of sleepiness: A new approach. Psychophysiology, 10, 431-436.

Horne, J. A., & Ostberg, O. (1976). A self-assessment questionnaire to determine Morningness-Eveningness in human circadian rhythms. International Journal of Chronobiology, 4, 97-110.

Kaplan, I., Carvellas, T., & Metlay, W. (1966). Visual search and immediate memory. Journal of Experimental Psychology, 71, 488-493.

Klein, K. E., & Wegmann, H. M. (1974). The resynchronization of human circadian rhythms after transmeridian flights as a result of flight direction and mode of activity. In L. E. Scheving, F. Halberg, & J. E. Pauly (Eds.), Chronobiology (pp. 564-570). Stuttgart: Georg Thieme Publishers, 564-570.

Klein, K. E., & Wegmann, H.M. (1979). Circadian rhythms of human performance resistance: Operational aspects. AGARD-AG-105, Godesburg (Germany), NATO-AGARD.

Kleitman, N. (1963). Sleep and Wakefulness. Chicago: Chicago University Press.

Kleitman, N., & Jackson, D.P. (1950). Body temperature and performance under different routines. American Journal of Applied Physiology, 3, 309-328.

Kronauer, R. E., Czeisler, C. H., Pilato, S., Moore-Ede, M. C., & Weitzman, E. D. (1982). Mathematical model of the human circadian system with two interacting oscillators. American Journal of Physiology, 242 (Regulatory Integrative Comp. Physiology II), R3-R17.

Levine, H., Halberg, E., Halberg, F., Thompson, M. E., Graeber, R. C., Thompson, D., & Jacobs, H. L. (1977). Changes in internal timing of heart rate, diastolic blood pressure, and certain aspects of physical and mental performance in presumably healthy subjects on different meal schedules. Proceedings of the XII International Conference of International Social Chronobiology. Milan, Il Ponte.

Lewis, P.R., & Lobban, M.C. (1957). Dissociation of diurnal rhythms in human subjects living on abnormal routines. Quarterly Journal of Experimental Physiology, 42, 371-386.

Luce, R.D., & Green, D.M. (1972). A neural timing theory for response times and the psychophysics of intensity. Psychological Review, 79, 14-57.

Mackworth, N.H. (1957). Vigilance. The Advancement of Science, 53, 389-393.

Mills, J. N. (1966). Human circadian rhythms. Physiological Review, 46, 128-171.

Monk, T., Fookson, J., Moline, M., & Pollack, C. (1985). Diurnal variation in mood and performance in a time-isolated environment. Chronobiology International, 2 (3), 185-193.

Moore-Ede, M. C., Sulzman, F. M., & Fuller, C. A. (1982). The clocks that time us. Cambridge: Harvard University Press.

Naitoh, P. (1982). Chronobiology of performance. In F. Brown & R. C. Graeber (Eds.), Rhythmic aspects of behavior (pp. 42-103). Hillsdale, New Jersey: Lawrence Erlbaum Associated Publishers.

Natelson, B., DeRoshia, C., Adams, J., Finnegan, M., & Levin, B. (1983). Relations between visceral and behavioral function in men at bedrest. Pavlov Journal of Biological Science, 18, 161-168.

Pearson, R. G., & Byars, G. E. (1956). The Development and Validation of a Checklist for Measuring Subjective Fatigue (Report No. 56-115). Randolph AFB, Texas: School of Aviation Medicine, USAF.

Rutenfranz, P., & Colquhoun, W. (1979). Circadian rhythms in performance. Scandinavian Journal of Work and Environmental Health, 5, 167-177.

Simpson, H. M., Bellamy, N., Bohlen, N., & Halberg, F. (1973). Double-blind trial of a possible chronobiotic (Quiadon). International Journal of Chronobiology, 1, 287-311.

Spence, J. T., & Helmreich, R. L. (1978). Masculinity and femininity: Their psychological dimensions, correlates, and antecedents. Austin: University of Texas.

Sternberg, S. (1966). High-speed scanning in human memory. Science, 153, 652-654.

Sternberg, S. (1969a). Memory-scanning: Mental processes revealed by reaction time experiments. American Scientist, 57, 421-457.

Sternberg, S. (1969b). The discovery of processing stages: Extensions of Donders' method. Acta Psychologica, 30, 276-315.

Webb. W. (1982). Sleep and biological rhythms. In W. Webb (Ed.), Biological rhythms, sleep and performance (pp. 87-110). New York: John Wiley.

Wegmann, H. M., Gundel, A., Klein, K. E., & Samel, A. (1987). Implications of Shiftwork in Space for Human Physiology Experiments (SP-271, pp.255-258). European Space Agency.

Wegmann, H.M., Klein, K.E., Conrad, B., & Esser, P. (1983). A model for prediction of resynchronization after time-zone flights. Aviation,Space, and Environmental Medicine, 54, 524-527.

Wever, R. A. (1979). The circadian system of man. Results of experiments under temporal isolation. New York: Springer-Verlag.

Wever, R. A., Polasek, J., & Wildgruber, C. M. (1983). Bright light affects human circadian rhythms. Pflugers Archives, 396, 85-87.

Wilkinson, R.T., & Houghton, D. (1982). Field test of arousal: A portable reaction timer with data storage. Human Factors, 24, 487-493.

Williams, H.L., Kearney, O.F., & Lubin, A. (1965). Signal uncertainty and sleep loss. Journal of Experimental Psychology, 69, 401-407.

APPENDIX A

SJSU SAN JOSE STATE UNIVERSITY

A campus of The California State University

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To: Elizabeth Hackett, Psychology
2611 La Terrace Circle
SAn Jose, CA 95123

From: Charles R. Bolz
Office of Graduate Studies and Research

Date: February 26, 1991

The Human Subjects Institutional Review Board has reviewed and approved your request for exemption from Human Subjects Review for the proposed study entitled:

> "The Effects of Exposure to Bright Light on Cognitive Performance (as amended by request for minor changes dated February 19,1991)"

You may proceed with this study without further review by the Human Subjects Institutional Review Board.

I do caution you that Federal and State statutes and University policy require investigators conducting research under exempt categories to be knowledgeable of and comply with Federal and State regulations for the protection of human subjects in research. This includes providing necessary information to enable people to make an informed decision regarding participation in your study. Further, whenever people participate in your research as human subjects, they should be appropriately protected from risk. This includes the protection of the confidentiality of all data that may be collected from the subjects. If at any time a subject becomes injured or complains of injury, you must notify Dr. Serena Stanford immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

Please also be advised when people participate in your research as human subjects, each subject needs to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate or withdrawal will not affect any services the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact Dr. Stanford or me at (408) 924-2480.