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PHOTIC EFFECTS ON SUSTAINED PERFORMANCE

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ABSTRACT

The advent of space exploration requires attention to the adaptability of human circadian rhythms in the unique environment of space. Circadian disruption, related to altered sleep work cycles and accelerated solar clues, can lead to fatigue that may impede mission success particularly as the duration of space flights increase. Research is described which evaluates manipulating environmental light intensity as a means to attenuate nocturnal fatigue.
A counter-balanced, within subjects design was used to compare 9 male subjects exposed to dim (100 lux) and bright (3000 lux) light conditions. Oral temperature values were greater for the bright light group over the dim light condition. Melatonin levels were suppressed by bright light treatment. Also, the frequency of eye blink rate was less for subjects during bright over dim light exposure. Light exposure was without effect on subjective fatigue. However, irrespective of light condition, significant effects on confusion, fatigue and vigor mood dimensions were found as a result of 30 hr sleep deprivation. The findings suggest that bright lights, may be used to help sustain nocturnal activity otherwise susceptible to fatigue. Such findings may have implications for the lighting arrangements on space flights during the subjective night for astronauts.

Key Words: Light, Temperature, Melatonin, Performance, Eyeblink, Mood

INTRODUCTION

Acclimatization to extraterrestrial environments represents a challenge to human productivity during future space missions. As extended flights become more frequent, a greater demand on the sustained vigilance of the crew increases the likelihood of performance problems associated with cumulative fatigue. Disrupted sleep is reported to be a common difficulty on shuttle flights particularly when dual shifts are required (Santy, et al., 1988). Fatigue problems related to alterations in circadian sleep work cycles and from unfamiliar light and dark solar cues have been known for some time and have been termed desynchronosis (Winget, et al., 1984). Although most astronauts quickly adjust to the demands of new work shifts in space, some never do and become chronically fatigued (Graeber, 1987). It may be that this fatigue results from an inability to resynchronize to the new circadian work rest cycles required in orbit. Light may serve as an adaptive counter measure for pre-shifting astronauts.

The adaptive characteristics of the circadian cycle to the unique environment of space is relatively unknown. Phase shifting of the sleep cycle as a result of travel across time zones on the earth can produce changes in the topography of the normal sleep EEG (Endo, et al., 1985) that may account for the inadequacy of the rest experienced during orbit. The fatigue produced by circadian disruption can be studied on earth albeit in the absence of microgravity. Effective treatment for fatigue related to circadian disruption may improve the potential for a successful mission. The present study evaluated the effects of ambient light as a counter measure to human fatigue degraded performance and may serve as a model of inducing circadian dysrhythmia.

Recent evidence supports a relationship between environmental light and improved nocturnal alertness (Campbell, et al., 1990, French, et al., 1990). The effectiveness of light exposure on performance enhancement is hypothesized to be related to the ability of light to attenuate the normal nocturnal surge of the pineal hormone melatonin. In support of this hypothesis, many studies suggest that melatonin acts as an endogenous sleep enhancing substance. For example, human subjects given relatively low doses (2 mg) of melatonin for three weeks experienced increased fatigue (Arendt, et al., 1984). Similarly,
Lieberman, et al., (1985) using an acute oral dose of

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240 mg of melatonin found reduced vigor, elevated fatigue, increased confusion and slowed reaction time. Additionally, plasma levels of melatonin are greatest during the sleep phase of the human circadian cycle. Orally administered melatonin has also been found to alleviate transcontinental disruption of circadian sleep wake cycles (Petrie, et al., 1989). Further, melatonin has a high affinity for receptor sites in the suprachiasmatic nucleus (SCN) of the hypothalamus where it is purported to trigger hormonal entrainment and regulate circadian and circannual rhythms (Reppert, et al., 1988; Brainard, et al., 1988).

Bright, light acutely suppresses plasma melatonin levels in animals (Benshoff, et al.,1987; Brainard, et al.,1982) including humans (Lewy, et al., 1980). The current study addressed the consequences of melatonin suppression via elevated ambient light intensity on temperature, melatonin levels, cognitive abilities, eye blink rate as measured by the electrooguloqram and subjective mood.

METHODS

A counter-balanced, within subjects analysis of variance design was used to compare 9 male subjects exposed to dim (100 lux) and bright (3000 lux) conditions. Subjects were recruited from non-smoking civilian and military personnel who indicated a normal nocturnal sleep pattern. During both conditions, scores on cognitive performance tests developed for military human performance labs (Hegge, et al., 1985) were obtained every 2 hours throughout the 30 hour testing session. Beginning at 0600, subjects were stabiliized on the performance measures under dim light training conditions. Then at 1800, the light treatment (either dim or bright) began and continued until 0600 the next day. Finally, dim illumination was used until the completion of the experiment at 1200.

Immediately after each performance trial, oral temperature was measured and plasma samples were obtained for later melatonin assays (Brainard, et al., 1991). Monopolar electrodes attached to the bony orbit of the left eye and referenced to the pinna of the left ear were used to determine the blink rate for each subject during a 2 minute recording session, which also followed the performance trial. Blink rate per minute was then visually appraised from 1 minute of artifact free record in a blinded manner. Subjects completed profile of mood surveys (POMS) every 4 hours. They were then allowed 2 weeks before exposure to the second light condition. Subjects were prevented from drinking any caffeinated beverages and were fed the same foods (crackers, chips, sandwiches, fruit, pizza, milk, water, juices) at the same times during each light session.

Five subjects were evaluated at a time during each light session Each subject was assigned to a testing booth that contained a wide spectrum Vita-Light fluorescent lamp (Duro-test Corp., Fairfield, N.J., 07007 Part # 1157030) as the adjustable illumination source and a PC workstation. Each booth was separated from adjacent booths by sound attenuating, frame partitions that restricted the subject's view to their individual workstation. A comfortable chair allowed the subject to sit close to a work table that contained the workstation. The light source was mounted on a wooden frame over the workstation and suspended from an adjustable height to provide directed illuminance within either the dim or the bright treatment ranges. The subjects required to stay in the booth throughout the study with the exception of short (< 10 minute restroom breaks). Social interaction was kept to a minimum between subjects by the experimenter and by the demands of the testing schedule. Dependent measures on the cognitive tasks consisted of response time and accuracy variables. The order that the tests were presented did not vary throughout the study. The 10 performance tests used consisted of the choice reaction time (CRT), column addition and subtraction (CAS), the manikin test (MT), serial addition and subtraction (SAS) and Wilkinson reaction time (WRT). A subjective mood survey was also taken. As well, a tower puzzle (TP), following directions (FD), the numbers (N) and words (W) dual process task and route planning (RP) tests were used.

RESULTS

Oral temperature levels were significantly elevated in the bright light condition compared to the dim light condition at the 2130, 0130 and the 0330 sample points ($p < .05$) as shown in Fig. 1. Subjects in constant dim light had typically low levels of melatonin during daytime and higher levels at night. In contrast, this melatonin rhythm was suppressed by the bright light condition (Figure 2).

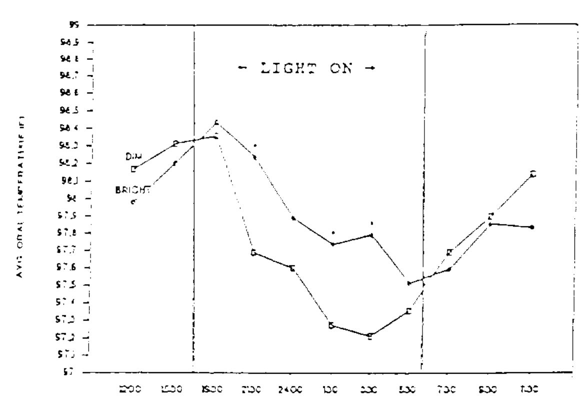

Figure 1. The effect of bright light on oral temperature. The onset of the bright light is indicated and differences from the dim light condition are marked with an *

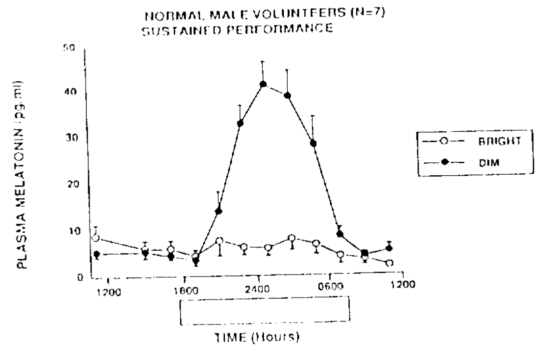

Figure 2. The suppression of normal nocturnal plasma melatonin levels was accomplished by bright light exposure. The open bar beneath the abscissa indicates the light exposure period.

Analyses of performance data indicate that bright light treatment improved response time while reducing the number of errors, particularly at the 2400 through the 0400 sample points. Table 1 shows the number of cognitive tests which were increased or decreased during bright light treatment. As shown in Table 1 the most effective time for bright light exposure to affect the cognitive tests occurred at midnight, 0200 and 0400 hrs. The effectiveness of the bright light exposure on cognitive ability did not extend beyond 0400 and may be detrimental when dim illumination is reinstated after 0600 as indicated in Table 1.

Table 1. The number of cognitive test results either increased or decreased by the application of bright lights at sequential times. A total of 10 performance tests were given at each time. The individual tests are identified (parentheses) at each time point. If response time or accuracy or if both were affected are indicated by a - or + or ±, respectively.

TIME	# OF TESTS INCREASED	# OF TESTS DECREASED
Light on		
1800	1 (CRT+)	0
2000	1 (RP+)	0
2200	1 (SAS-)	0
2400	4 (SAS- N+ W+ FD±)	0
0200	2 (SAS- N+)	0
0400	2 (SAS- N+)	0
0600	0	1 (FD±)
Light off		
0800	0	3 (FD± N+ W+)
1000	1 (SAS-)	1 (FD±)

Seven of the tests (CRT, RP, SAS, N, W, FD and MT) were sensitive to the effects of the illuminance conditions. Light exposure seemed to have beneficial effects on SAS, RP and N tasks as shown in Table 1, whereas the FD task seemed to be the most susceptible to disruption following extended exposure to bright light. Only response time performance variables were improved for the SAS test throughout the test session while the FD and W tasks demonstrated alterations in response time and accuracy variables at the times indicated. Only accuracy variables were susceptible on the N, CRT and the RP tasks. All of these results represent light x time awake interaction effects ($p < .05$). The bright light condition improved an accuracy variable (number of errors) on the MT as a main effect across all time points.

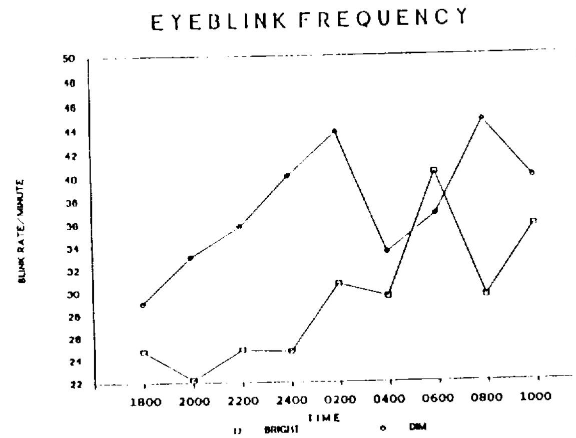

Figure 3. The increase in blink frequency per minute is shown during dim light (1800 - 0600 hrs) compared to the bright light exposure.

The results shown in Figure 3 demonstrates that light treatment was associated with significant differences in eyeblink rate as determined by the EOG. An overall main effect of light on eyeblink frequency was found ($p < .05$) but no interaction of light condition by time was found. However, the EOG differences did not parallel the time course of the melatonin or performance variables sensitive to bright light exposure.

There was no effect on subjective mood as a result of bright light exposure. However, as the duration of the sustained performance task increased 3 mood dimensions were affected as shown in Fig. 4. Subjective impressions of confusion, fatigue and vigor as shown in Fig 4a, 4b and 4c, respectively were affected during the later trials (time) when compared to the earlier trials, independant of light condition. Accordingly, the bright and dim light groups were averaged together in Fig. 4 for each mood state and graphed across hours awake. There was no effect on subjective anger, tension or depression as a result of extended hours awake, as shown in Fig. 4d, 4e and 4f, respectively.

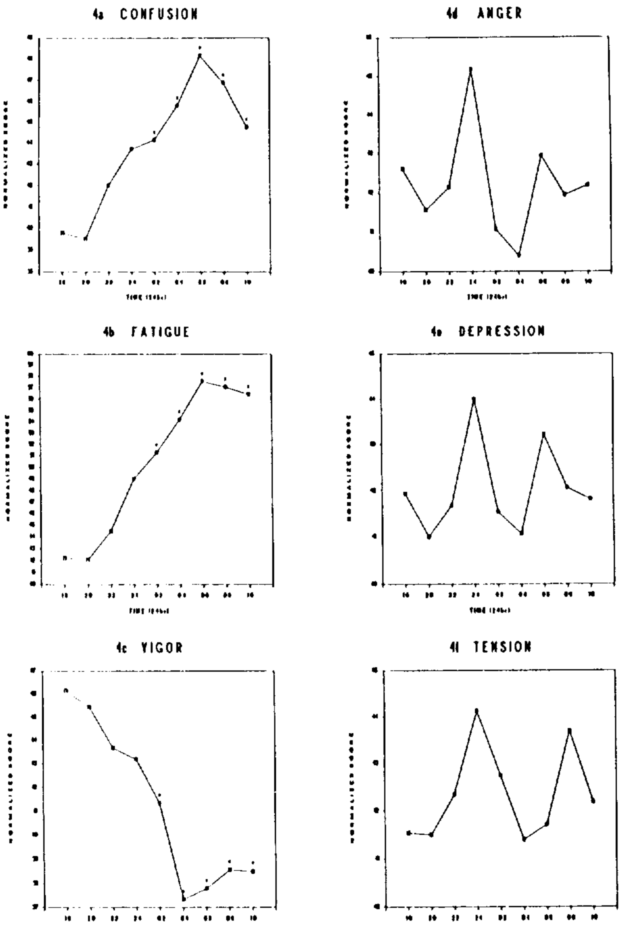

Figure 4. The effect of sustained performance on mood. No effects were found between light exposure conditions. Early trials were significantly different from later trials ($p < .05$) as indicated by an *. Bright and dim light groups were combined due to an absence of a light effect.

DISCUSSION

Exposure to bright light produced effects on oral temperature, melatonin levels and eye blink frequency. Although not sensitive to light condition, specific subjective mood states were responsive to the sustained performance test battery and to sleep deprivation. The times during which bright light exposure improved cognitive performance was similar to the time in which oral temperature was elevated and melatonin was suppressed. The levels of illumination used (3000 lux) were completely effective in suppressing melatonin to daytime levels. Although not excessive, 3000 lux seems to be more than adequate to control the normal nocturnal surge of melatonin.

Bright light exposure may improve performance otherwise susceptible to fatigue. However, it appears that there is no duration of the light effect beyond the exposure period. In fact, since performance begins to degrade somewhat after 10 hours of bright light exposure, the effectiveness of the lights in reducing fatigue degraded performance may have been exceeded. The absence of an interaction between light exposure and mood suggests that bright light did not improve mood state or make the the subjects feel less tired or more vigorous. Although effects on physiological state and cognitive performance were found, subjective mood was more sensitive to the duration of the sleep deprivation inherent in the 30 hour sustained performance test.

CONCLUSIONS

The protocol used may present the opportunity to evaluate adaptation problems, such as determining the optimal conditions for pre-shifting astronauts in earth bound labs. These and other problems associated with cumulative fatigue and shiftwork in the unique habitats and working conditions required in space could be studied with much greater facility in the absence of microgravity and the best solutions could then be applied to space operations. Also, the results may have implications for lighting conditions on board space flights, particularly for shift workers required to work during their subjective nights. Accuracy and response time might be improved by increased light intensity.

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