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Effect of bright light at night on core temperature, subjective alertness and performance as a function of exposure time

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Objectives This simulated night shift study measured the effects of moderate bright light (a 4-hour pulse starting at 2000 or 0400) during the exposure night and subsequent night (dim light).

Methods Eight young males remained confined with little physical activity to a laboratory in groups of 4. After a night of reference, they were active for 24 hours; then after a morning recovery sleep, they were active again for 16 hours.

Results Continuously measured rectal temperature proved to be immediately sensitive to 4 hours of bright light, particularly when given at the end of the night. Self-assessed alertness and also performance on a task with a high requirement for short-term memory were improved by the exposure to bright light. During the subsequent night the subjects were exposed only to dim light. Core temperature, subjective alertness and performance continued to show a time course depending on the preceding bright light exposure.

Conclusions Probably because evening exposure to bright light and morning sleep both had a phase-delaying effect, the effects on the circadian pacemaker were more pronounced. Thus, for practical applications in long night shifts, bright light can be considered to improve mood and alertness immediately but the possibility of modifying the circadian "clock" during subsequent nights should be taken into consideration, in particular after exposure to bright light in the evening.

Key terms circadian phase shift, circadian rhythms, laboratory study, pilot study.

Many studies with different approaches have been devoted to the effects of rotating shift work on circadian rhythm and performance. The extent of disruption due to shift systems has not always been assessed in the same way. For instance, in terms of sleep length, morning shifts resulting in very early rising times were found to be the most detrimental, but, when the efficiency of operators and incident risk were assessed, night periods were the worst (1, 2). Although it has been hypothesized that some serious accidents or catastrophes are related to night hours, the available literature does not report any evidence of decreasing efficiency in modern industrial processes as a function of time of day, contrary to what had been concluded by Folkard & Monk (3) on the basis of earlier field results. The explanation is that processes and work organizations have been especially designed to be insensitive to the circadian decline of individual performance. In contrast, generally speaking, shift workers rate the night shift as the worst when well-being, subjective fatigue, and social life are taken into consideration.

Thus many workers have agreed to trade longer shifts for fewer workdays and particularly fewer work nights. With a workweek of around 35 hours, such a shift often comprises only 3 days or nights. However, as Smith et al (4) put it aptly, are 12-h shifts a solution despite a generally positive response to the introduction of a 3- to 4-day 12-hour rotating shift schedule (4—7)? In addition, although they recognized the rapid spread of the 12-hour shift in the petroleum and chemical industries as early as around 1970, Northrup et al (8) expressed some doubt concerning its generalization because of its negative effects on some older workers and also because of the negative effects in industries in which work is more

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arduous. In fact a 10-hour nightshift system implemented in a French car assembly plant had to be discontinued in spite of productivity increases because of the growing opposition of the workers (9).

Attempts have been made to improve the efficiency and well-being of workers during long night shifts by treating them with bright light. It is well known that circadian regulation, particularly the phase position of most physiological functions, can be modified by bright light, provided it is applied at appropriate times of the night. Several laboratory studies (10—13) and a few studies involving actual shiftwork (14, 15) have shown that appropriately timed bright-light exposure is a promising means of countering the negative effects of night activity. However, several important points still need to be better defined, among them: (i) the best timing of bright light exposure to produce an adequate response to the demands of the night shift, (ii) the extent to which the effects of bright light on temperature are correlated with the effects on alertness and performance, and (iii) the extent to which bright light produces a significant effect during the subsequent night even if there is no bright light exposure (ie, to what extent has the circadian oscillator been phase shifted).

These 3 issues have been investigated in the present study. The subjects were confined in a sleep laboratory and kept awake for 2 nights. During the 1st night, they were exposed to a 4-hour pulse of bright light starting at either 2000 or 0400. During the 2nd night, they received only normal artificial light (≤100 lux at eye level).

Subjects and methods

Eight paid male volunteers aged 19—23 years were studied. They had normal sleeping times and were free of medication and drugs. They did not smoke and had normal psychological profiles, in particular in terms of anxiety (Minnesota Multiphasic Personality Inventory, Cattell Questionnaire, Eysenck Personality Inventory).

In groups of 4, they were confined to a room where they remained seated except for going to the bathroom. Apart from test sessions, electroencephalographic recordings, and blood sampling, they read, played cards and studied. They were prevented from dozing off by the investigator. The 60-hour protocol was performed twice, at 2-week intervals (figure 1), with 2 different light treatments. One group (4 subjects) was studied in March and the other in September to obtain approximately the same photoperiod (0800—1800). The order in which they experienced the 2 conditions was counterbalanced. During the day (0800—2000)), the subjects received natural light through the window. From 2000 to 0800 (1st night called N1), they received either dim light using conventional bulbs (about 50 lux) or a 4-hour pulse of bright light supplied by a ceiling fixture. The bright-light intensity measured at eye level varied between 700 and 1000 lux according to the angle of gaze. With the exception of the light level, environmental conditions were kept as constant as possible: ambient temperature (≅24° C), humidity, noise and contacts with the experimenters. Naps, cigarettes, alcohol, and coffee were not allowed during the entire experiment. During the 2nd night (N2) of both conditions, the measurements were made in identical conditions but with constant dim light.

Rectal temperature was monitored continuously by a portable recorder (MiniMitter with Yellow Springs disposable probes) and recorded every 5 minutes.

Self-rated alertness was assessed using a French shortened version of the Activation/Deactivation Adjective Checklist (16). The ratio of GA (general activation) to DS (deactivation sleepiness) was used as an indication of the alertness level (11). Performance tests were "Search and Memory Tests" (SAM tests) derived from

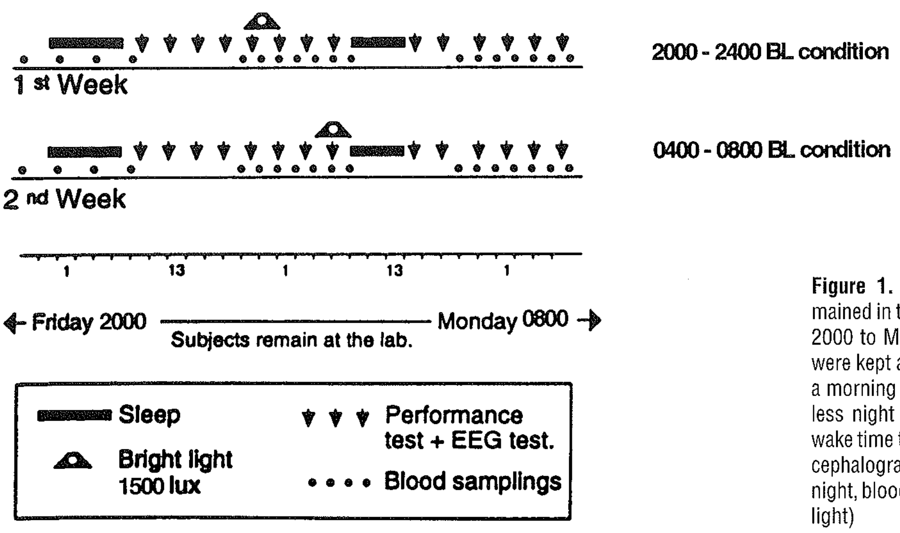

Figure 1. Study protocol — the subjects remained in the laboratory for 60 hours from Friday 2000 to Monday 0800. After 1 sleep night, they were kept awake but sedentary for 24 hours, had a morning recovery sleep, and then a 2nd sleepless night (about 18 hours awake). During the wake time they had performance tests, electroencephalographic tests, meals every 3 hours and, at night, blood sampling every 2nd hour. (BL= bright light)

the Memory and Search Task (MAST) (17) with different memory demands. The subject's task was to memorize 1, 3 or 5 letters, search through a line of 20 letters and indicate the first occurrence of 1 of the targets.

Time courses of the variables were compared using a repeated-measures analysis of variance (ANOVA). The comparisons between light conditions at given times were made by a paired t-test.

Results

The temporal changes in the variables are presented as a function of the bright-light exposure (2000—2400 versus 0400—0800). The results from the 1st night (N1) indicate immediate effects of bright light, or those occurring a few hours after the exposure between 2000 and 2400. Any long-lasting effect of the bright light was estimated from the results of the 2nd night (N2).

Rectal temperature

There was no difference for the mean levels during the first night, but the interaction between the time and the bright light condition was highly significant (df=142, F=1.7, P<0.0001). The 2000—2400 exposure did not result in any clear-cut increase in comparison with the dim light condition, instead there was a prolonged plateau followed by a steep decline after 0100. In the 2nd half of the night, the 0400—0800 bright-light condition corresponded to a higher temperature (slightly significant difference at 0538, df=6, t=2.51 P<0.07) (figure 2).

On the whole the time course of the 2nd night showed the same pattern as during the preceding light-exposure night. There was no difference in the mean level and a strong interaction between time and the bright-light condition (df=142, F= 1.6 P<0.0001). During the 1st half of the night, the temperature was higher between 2000 and 2400 during the bright-light condition (significant at 2230, df=6, P<0.05); during the 2nd half, it was higher during the 0400—0800 bright-light condition (significant at 0540, df=6,t=2.64, P<0.04). Figure 3 suggests a phase delay with the 2000—2400 bright-light and an advance with the 0400—0800 bright light condition. In fact, the mean of the actual individual minimum times was respectively 0516 and 0424 (no significant difference)

Performances

In an attempt to diminish the intersubject variability, performances were presented as the percentage of an individual's mean measured over the whole period. All of the performance variables were analyzed with a repeated measures ANOVA (time × light condition). Neither an effect of time nor a difference between the light condition was found, probably because of the low memory load and thus the facility of the task in the SAM test for 1 letter.

The subject's performance showed a significant time-of-day effect [F(7,98)= 5,17, P<0.001] for the SAM test with 3 letters during the 1st night of the experiment. It was best in the evening (2030) and declined throughout the night (ie, time needed increased). The last test was an exception probably due to the "end-of-the-session" effect. In the 4 night tests (from 2330 to 0730) the interaction between time and the bright-light condition was marginally significant [F(3,42) = 2.2, P<0.1]. Figure 4 shows that performance was improved at 2330 by the

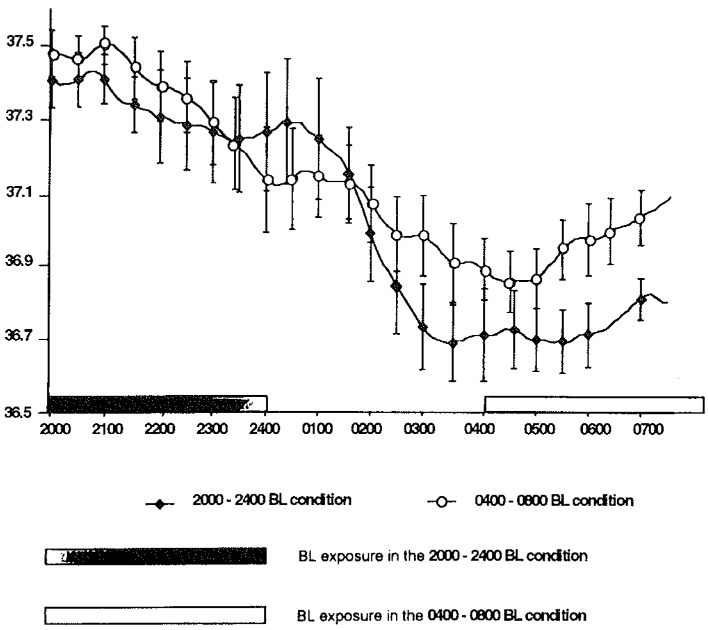

Figure 2. Means and standard errors of the means of the rectal temperature waveforms between 2000 and 0800 during the 1st exposure night in the 2 bright light conditions, one with 2000—2400 exposure and the other with 0400—0800 exposure (BL= bright light).

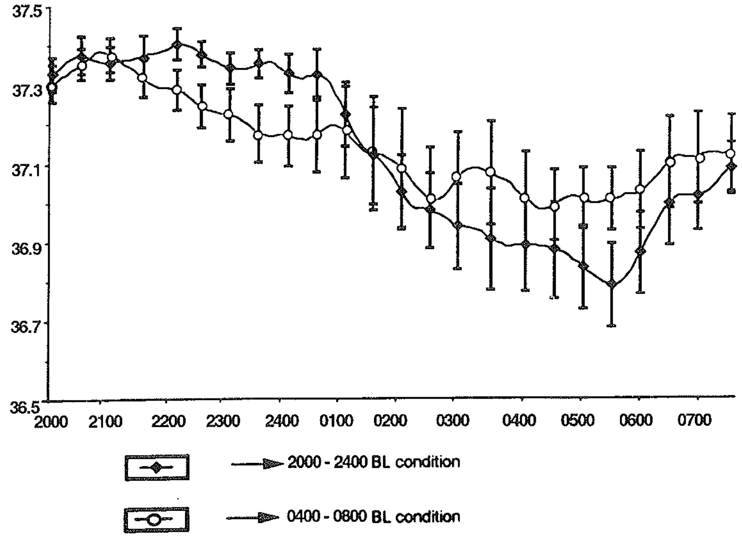

Figure 3. Means and standard errors of the means of the rectal temperature waveforms between 2000 and 0800 during the 2nd night in dim light in the 2 bright light conditions, 1 after 2000—2400 exposure and the other after 0400—0800 exposure.

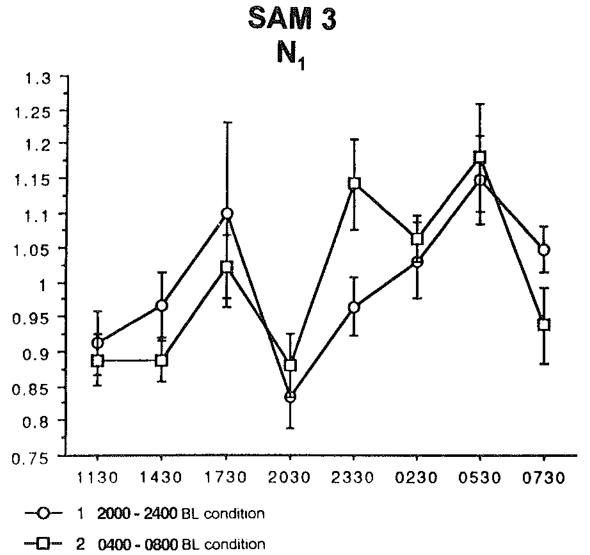

Figure 4. Mean time needed to find 1 memorized letter during the night of bright-light exposure (N1), the higher the value, the worse the performance. The task consisted of memorizing letters (SAM 3 = 3 letters) and finding the 1st occurrence of 1 of them in a row of letters. The values are the means of the percentage of the subjects' mean values measured across the whole experiment.

2000—2400 bright-light condition (t=2.91, P<0.05) and at 0730 by the 0400—0800 bright-light condition (t=2.65, P<0.05)

No significant difference between the bright-light conditions was found for the SAM test performance with 3 letters on the 2nd night.

A decrease in performance was observed throughout the experiment [F(7,98)= 3.4, P<0.003] with the SAM test involving 5 letters on the 1st night. On the 4 night tests between 2330 and 0730, the interaction between time and the bright-light condition showed only a trend [F(3,42)= 2.3, P<0.09] reflecting a better performance on the 0230 test in

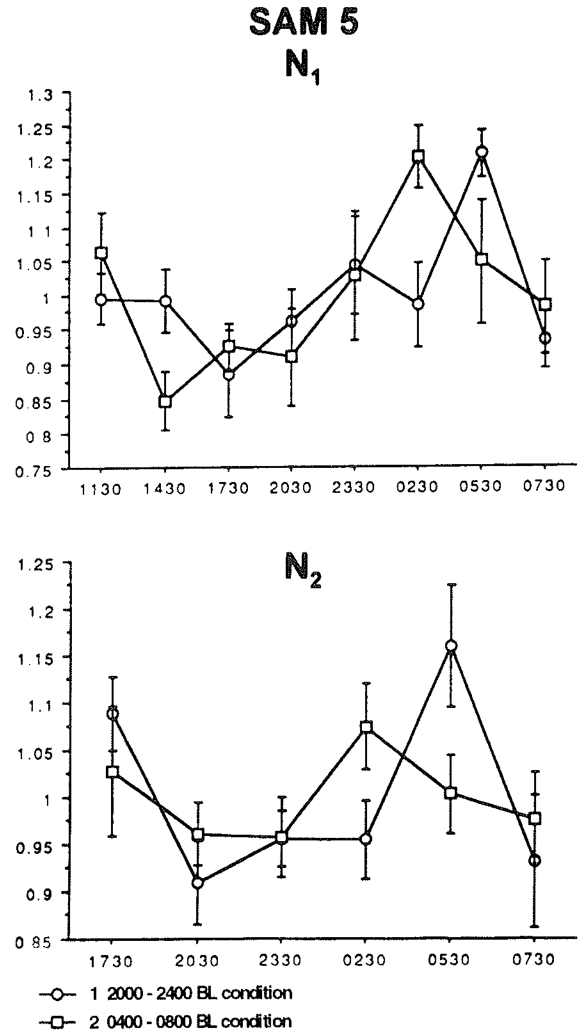

Figure 5. Mean time needed to find 1 memorized letter among 5 letters (SAM 5 = 5 letters) during the night of bright-light (BL) exposure (N1) and the subsequent night (N2).

2000—2400 bright-light exposure ($t=3.24$, $P<0.05$) and on the 0530 test after the 0400—0800 bright light exposure (trend with $t=1.7$, $P<0.13$) (figure 5).

On the 2nd night the time curve of the performance displayed a remarkably similar pattern for both bright-light conditions when compared with the results of the 1st night, though with a somewhat less pronounced time-of-day effect [$F(5,70)= 2.6$, $P<0.05$]. The interaction between time and the bright-light condition for the 4 night tests was marginal [$f(3,42)= 2.3$, $P<0.1$]. Differences were observed at 0230 ($t= 1.94$, trend at $P<0.09$) and at 0530 ($t=2.49$, $P<0.05$) (figure 5).

During both the 1st and the 2nd nights, a steep deterioration in performance was noted on the 0530 test after the end of the 2000—2400 bright-light exposure.

Subjective alertness

The GA/DS for both bright-light conditions continuously decreased throughout the night [time-of-day effect $F(8,112)= 21.23$, $P<0.0001$]. There was a tendency for the 0400—0800 bright-light condition to result in a better alertness when assessed from 2130 to 0800 [$F(4,56)= 2.3$, $P<0.07$) because during the light exposure alertness was significantly improved at 0630 ($t=2.45$, $P<0.05$) and at 0800 ($t=3.93$, $P<0.01$) when compared with the results of the 2000—2400 bright-light exposure. In contrast the 2000—2400 bright-light exposure did not produce the same immediate effect (figure 6).

As on the 1st night, the GA/DS determined on the 2nd night for both bright-light conditions declined throughout the afternoon and night (time-of-day effect $F(5,70)=10.81$ $P<0.001$), but it was higher for the 2000—2400 bright-light condition [$F(1,70)= 2.2$, $P<0.15$ computed across all the tests of the 2nd night] with the most significant difference at 24.30 ($t=2.74$, $P<0.05$).

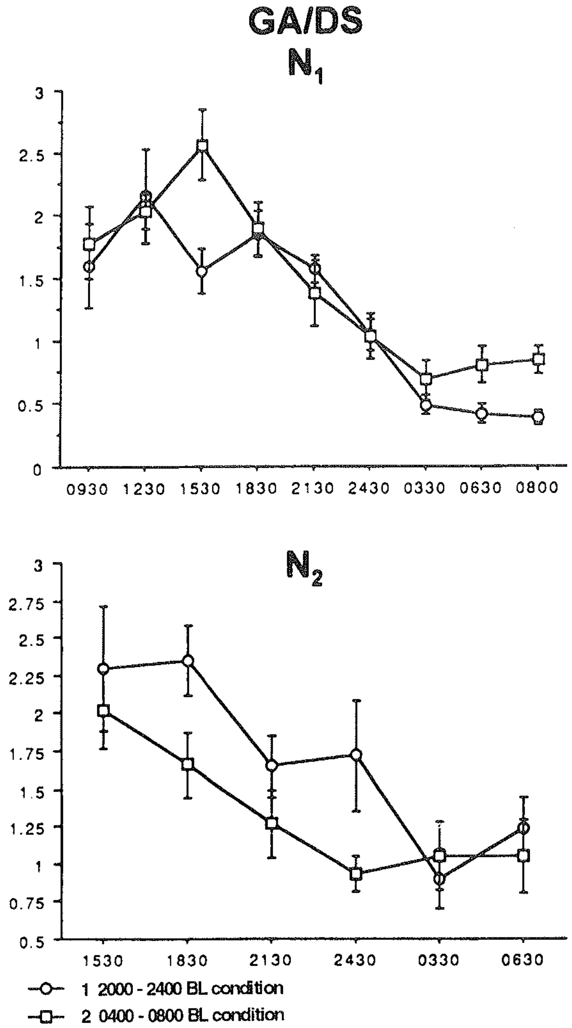

Figure 6. Subjective index of alertness [GA (general activation)/ DS (deactivation sleepiness)] during the night of exposure (N1) and the subsequent night (N2).(BL = bright light).

Discussion

The immediate effect of the 2000—2400 bright-light exposure resulted in an improvement in performance (3-letter SAM at 2330 and 5-letter SAM at 0230) only. No effect was noted on temperature and subjective alertness. The 0400—0800 exposure had a clearer impact since, when compared with the 2000—2400 condition, temperature, subjective alertness, the 3-letter SAM and the 5-letter SAM performance were all better. This finding agrees well with, for instance, the results of Wright et al (18). In addition our results were obtained even though the light intensity was less than the intensities used in some earlier studies on actual shift workers (14, 15). Therefore, subjective alertness appeared to be linked with temperature, but performance at night exhibits a more complex relationship with temperature.

The main result of our study was the fact that there was a large differential effect of the 2 bright-light conditions on temperature, performance, and alertness during the following night, even though the light condition (<100 lux) was the same. The time course of temperature tended to be flatter after the 0400—0800 bright-light exposure than after the 2000—2400 exposure. This effect did not reflect the immediate positive effect obtained in the last hours of the 1st night (better alertness and better performance). During the night following the 2000—2400 bright-light exposure, temperature amplitude was increased and the minimum tended to be delayed. The hypothesis of a phase delay of the circadian oscillator is plausible in that the bright light between 2000 and 2400 before the temperature trough, the delayed sleep onset, and the delayed beginning of the dark period all facilitated phase delay. In contrast a delayed sleep or dark period and a period of bright light between 0400 and 0800 (ie, favoring phase advance) were in conflict. This finding may explain the very limited phase effect during the following night. This result is in good agreement with the results of Mitchell et al (19) and confirms the conclusions of Foret et al (20) that evening exposure is recommended if a circadian phase delay is needed.

In summary, our study demonstrated that a moderately intense and moderately long nocturnal light exposure is sufficient to produce (i) an immediate effect on the well-being of night workers, particularly when given at the end of the night, and (ii) marked physiological and psychological effects on the circadian system during the subsequent night, particularly if the light exposure occurs at the beginning of the preceding night. The results of this preliminary study with a limited number of subjects (N=8) should be confirmed by measurements made on a larger population.

Acknowledgments

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