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Effect of bright light on tolerance to night work

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COSTA G, GHIRLANDA G, MINORS DS, WATERHOUSE JM. Effect of bright light on tolerance to night work. *Scand J Work Environ Health* 1993;19:414–20. Fifteen young (mean age 23.4 years) female nurses engaged in a resuscitation unit and working on a fast rotating shift schedule comprising two consecutive night shifts were exposed to short periods (4 × 20 min) of bright light (2350 lx) during their night duty to test a possible positive effect on their tolerance to night work. Two nights with normal lighting (20–380 lx) and two nights with bright light were compared. The following positive effects of bright light upon psychophysical conditions and performance efficiency were noted: in particular, signs of better physical fitness; less tiredness and sleepiness; a more balanced sleep pattern; and higher performance efficiency (letter cancellation test). This result could not be attributed to shifts of the internal clock although the exact cause remains to be determined. In fact, hormonal excretion and body temperature did not show any effect from bright light. In addition melatonin excretion was not suppressed appreciably by the bright light used.

Key terms: catecholamines, cortisol, masking, melatonin, nurses, oral temperature, performance, purification, shift work.

Night work is a stressful condition which interferes with the normal synchronization of body functions, as well as with social habits. The abnormalities are believed to give rise to negative effects on health and well-being (1–3).

Tolerance to night work may depend on several factors, including the organizational aspects of the work conditions, the psychophysiological characteristics and social conditions of the work force, and the coping strategies developed by the individuals concerned. As a result, several types of compensatory mechanisms have been proposed to help alleviate these difficulties (4–6).

One possibility is the use of bright light during shift work. There are two reasons why this use might be effective. First, it has been shown that bright light (of an intensity of ≥ 2500 lx) can adjust the body clock as inferred from the phase of melatonin (7) and rectal temperature rhythms (8). Second, and in this instance the mechanism of action might not involve an adjustment of rhythms, bright light can reduce the symptoms of seasonal affective disorders (9), and some of the negative effects of night work can be likened to a mild form of endogenous depression (10).

Therefore we have tested whether brief exposures to bright light could be considered a possible tool for

improving tolerance to night work among shift workers. We exposed a group of nurses, engaged in a resuscitation unit, to short periods of bright light during their work shift (insofar as duty allowed) in an attempt to obtain a positive effect on their psychophysical condition and performance.

Subjects and methods

Subjects

Fifteen nurses, all women in good health, were studied. They were aged 21–29 (mean 23.4) years and had 0.5–7 (mean 2.9) years of experience with shift work. All of the subjects were single except two, who were married but without children. Three subjects were smokers.

All of the subjects worked in an intensive care unit for patients who had just been operated on for heart disease, and they worked in teams of five nurses per shift.

The unit had 10 beds divided between three smaller rooms that were separated from the central control area by glass walls. A separate small kitchen was located beside the unit.

Shift schedule

The nurses were engaged in a continuous, fast rotating shift schedule on an 8-d cycle: A-M-M-A-N-N-R-R.

The times of the shifts were 0700–1400: morning (M), 1400–2100: afternoon (A), 2100–0700: night (N). Rest days (R) were lived in the conventional way.

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Work conditions

The nurses were examined on four occasions during the winter season (December 1990–February 1991) while working two consecutive nights under normal light conditions and two consecutive nights under “bright light.”

In order to interfere as little as possible with normal work activity and not to affect the patients, we decided to alter the lighting intensity in the nearby kitchen (where the nurses took their breaks during work) from 100 lx (normal condition) to 2350 lx horizontally at the eye level (“bright light” condition). This level, the highest possible without glare or unnatural sensations, was achieved by three quartz-iodide lamps placed on the ceiling and oriented in such a way as to avoid glare, and three overhead projectors illuminating the wall in front of the table, where the nurses could sit, have a drink, or take a light meal.

The nurses were exposed to bright light for four periods of 20 min before starting work (2030–2100) and then every 2 h during the night duty (between 2300 and 2400, 0130 and 0230, and 0400 and 0500). This timing was dependent on the rest pauses and was not aimed at achieving a phase delay, as such adjustment need not be advantageous in rapidly rotating shift systems (8).

In the intensive care unit the lighting ranged from 20 (“lights off”) to 380 (“lights on”) lx. During the night shift the lights were generally turned off, but the nurses used an additional desk lamp that gave a light intensity of 240 lx.

Two of the teams (5 nurses per team) worked nights with bright light before nights with normal light. The other team had the opposite sequence.

One nurse from the first two teams did not complete the study because of intervening family problems. Therefore 14 nurses were used in the evaluation of the collected data.

Methods

Self-ratings. Subjective evaluations of work load were recorded at the end of the workshift by means of 100-mm visual analogue scales, according to the task load index of the National Aeronautics and Space Administration (NASA) (11).

Subjective evaluations of the psychophysical conditions (20 items) experienced during each workshift were recorded at the end of the workshift by means of 100-mm visual analogue scales, according to Warr (12).

Subjective evaluations of mood and physical fitness, on a seven-point scale according to Halberg et al (13), and of overall fatigue (5 items), according to Grandjean et al (14), were made at the start, middle, and end of each shift. The five items comprising overall fatigue were strong-weak, relaxed-tense, rested-tired, energetic-exhausted, and awake-sleepy.

Behavioral performance measures. A test of simple auditory reaction time (50 tones; 1000 Hz, 25 ms, 70 dB; with a random interval between them) was given at the start, middle, and end of each shift. The mean reaction time to respond to the tone by pressing a switch was recorded.

A search and memory (SAM) test, derived from Folkard et al (15), was given in which the subjects had to cancel one, three, and five target letters, respectively, in three groups of four lines of 30 letters. This test was performed at the start, middle, and end of the shift. The time taken (s) and the percentage of correct answers were recorded. A score was derived by dividing the percentage of correct answers by the square root of the time.

Hormone secretion. For the determination of plasma cortisol ($\text{g} \cdot \text{dl}^{-1}$) 1 ml of blood was collected from nine nurses at the start, middle, and end of the shifts. The serum was stored at -20°C for 7–20 d before the analysis, carried out by means of fluorimetric enzyme immunoassay (Baxter).

The urinary excretion of 6-sulfatoxymelatonin, adrenaline, and noradrenaline was determined. All of the nurses emptied their bladder at the beginning of each shift and then collected their urine at the middle and end of the shift. Volume and concentration were determined for each half of the shift. 6-Sulfatoxymelatonin was determined by radioimmunoassay according to Bojkowski et al (16), and the rate of excretion ($\text{ng} \cdot \text{min}^{-1}$) was calculated. Adrenaline and noradrenaline were determined by high-pressure liquid chromatography (Bio-rad®), and the rates of excretion ($\text{nmol} \cdot \text{min}^{-1}$) were calculated.

Oral temperature and activity logs. The nurses recorded their oral temperature (digital thermometer, 1/20 Celsius) on retiring and rising and approximately every 4 h during the workdays and the two rest days; they also kept a diary in which they reported times of sleep and times of leisure, work and travel to work. A method of “purifying” the data was used (17, 18) to gain an estimate of the endogenous component of oral temperature. Briefly, the method consists of correcting the raw temperature each hour for the fall produced by sleep and the rises produced by leisure, travel, and work. This correction is based upon the main type of activity during the previous hour and is computed for each subject and day. One can then use such purified data to estimate the phase of the endogenous component of the temperature rhythm by calculating the phase shift of a standard set of “normative endogenous” data required to match the purified data set most accurately. As a control, raw (masked) data were assessed by the same technique.

Statistical analysis. The data were analyzed by two-way (light, day) and three-way (light, day, occasion) analyses of variance (ANOVA) with repeated measures, Tukey tests, and paired Student t-tests by means of SYSTAT package (19).

Results

Subjective evaluation of the work load and the psychophysical conditions at the end of the shifts

The subjective evaluation of the work load did not differ at all between the four test nights, while some

differences emerged concerning the psychophysiological conditions perceived during the shifts.

Of the 20 items considered, none of the nine "positive" items (alert, calm, energetic, enthusiastic, good mood, lively, optimistic, relaxed, satisfied) showed any significant effect of bright light exposure, while two of the 11 "negative" items (annoyed, anxious-worried, bored, depressed, demoralized, discouraged, fatigued, restless, tense, tired, wanting in energy) showed a positive effect of the bright light. In particular, the nurses expressed feeling less "anxious-worried" (three-way ANOVA: $F = 5.66$, $P = 0.033$) and of being less "wanting in energy" ($F = 5.64$, $P = 0.034$) during the nights with bright light (figure 1).

Figure 1. Subjective evaluation of work load and psychophysical conditions during the night shifts — mean values (rating scale: 0 = minimum, 100 = maximum).

Subjective evaluation of mood, physical fitness and fatigue during the shifts

No significant differences emerged from a three-way ANOVA for mood, physical fitness, and overall fatigue, both with respect to light exposure and the first versus the second day, while significant differences emerged between the start, middle, and end of all the shifts for physical fitness and overall fatigue, but not for mood, the worst scores occurring at the end of each shift (physical fitness: $F = 23.5$, $P < 0.001$; overall fatigue: $F = 76.99$, $P < 0.001$; mood: $F = 1.39$, not significant) (table 1).

When the components of fatigue were considered separately, they all showed slightly, but not significantly, lower scores at the end of the second night shift with bright light, as compared with the other nights, whereas physical fitness was slightly higher (figure 2).

Table 1. Subjective evaluation of mood, physical fitness, and factors of fatigue during the workshifts (score: 1 = minimum, 7 = maximum).^a

	Mood		Fitness		Weak		Tense		Tired		Exhausted		Sleepy		Fatigue	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bright light																
First night																
Start	4.6	1.7	4.3	1.5	3.0	1.3	3.6	1.5	3.5	1.4	3.1	1.1	2.4	1.3	15.6	4.9
Middle	3.8	1.8	3.1	1.6	4.5	1.3	4.4	1.6	5.1	1.3	4.8	1.0	4.4	1.6	23.2	5.8
End	3.9	1.6	2.4	1.7	5.3	1.3	4.1	1.5	5.9	1.2	5.2	1.0	5.8	1.5	26.4	5.6
Second night																
Start	4.3	1.5	4.4	1.6	3.2	1.1	3.6	1.7	3.4	1.6	3.4	1.3	3.3	1.3	16.9	6.2
Middle	4.4	1.2	3.3	1.4	3.8	0.9	3.5	1.4	4.4	1.3	4.1	1.3	4.3	1.7	20.1	5.5
End	4.2	1.4	2.8	1.7	4.4	1.3	3.8	1.5	5.3	1.2	4.8	1.4	4.9	1.9	23.3	6.2
Normal light																
First night																
Start	4.3	1.6	4.6	1.4	3.3	1.4	3.6	1.8	3.0	1.6	3.3	1.2	2.4	1.3	15.6	6.5
Middle	3.7	1.3	2.8	1.0	3.9	1.2	3.3	1.6	4.6	1.3	4.2	1.2	4.0	1.5	20.1	5.7
End	3.7	1.4	2.1	1.2	4.9	1.4	4.0	1.7	5.8	1.3	5.2	1.2	5.3	1.5	25.3	5.9
Second night																
Start	3.9	1.7	4.1	1.2	3.3	1.0	3.4	1.5	3.2	1.0	3.0	1.0	2.6	1.4	15.6	4.5
Middle	3.9	1.5	3.3	1.5	3.8	1.3	3.5	1.5	4.1	1.4	3.7	1.4	4.0	1.9	19.2	5.7
End	3.9	1.3	2.1	1.3	4.9	1.0	3.6	1.5	5.8	0.9	5.1	1.1	5.3	1.5	24.7	4.5

^a Results of three-way analyses of variance are reported in the text.

A significant positive effect of the bright light exposure emerged concerning the feeling of "restored-tired." The three-way ANOVA showed a significant "light $\times$ occasion" interaction ($F = 3.442$; $P = 0.047$) when all of the occasions of the four shifts were compared. Furthermore, considering the differences between the start and end of each shift, the two-way ANOVA showed a positive effect both for the factor "light" itself ($F = 4.333$; $P = 0.058$) and for the "light $\times$ day" interaction ($F = 3.442$; $P = 0.047$), a finding indicating less tiredness during bright light exposure, particularly during the second night.

As concerns sleepiness ("awake-sleepy") in particular, no significant differences emerged in the three-way ANOVA among the 12 occasions, but the lowest score of sleepiness was recorded at the end of the second night with bright light exposure, in spite of the fact that the group had the highest score of sleepiness before starting the same shift.

Behavioral performance measures

The auditory reaction times showed a progressive and significant increase from the start to the end of each shift (three-way ANOVA: $F = 12.503$, $P < 0.001$) with a slight improvement on the second night, either with or without bright light exposure (three-way ANOVA: $F = 4.132$, $P = 0.077$). On both nights with bright light, the times were slightly, but not significantly, lower (three-way ANOVA: $F = 2.243$, $P = 0.173$) (table 2).

On the other hand, the letter cancellation test (SAM) showed a significantly better performance (higher index) during the two nights with bright light in comparison with the other two nights, particularly at the end of the shifts (three-way ANOVA: $F = 6.869$, $P = 0.021$). No significant difference was found between the first and second nights in either bright or normal light (three-way ANOVA: $F = 2.130$, $P = 0.168$).

Hormone secretion

Plasma cortisol did not show any effect of bright light exposure ($F = 0.673$, $P = 0.459$), but there were significant differences between the concentrations at the start, middle, and end of the shifts ($F = 65.477$, $P < 0.001$), presumably resulting from circadian rhythm. In addition, there was a slight increase in concentration during the second night under both normal and bright light ($F = 11.342$, $P = 0.012$) (table 3).

Urinary excretion of 6-sulfatoxymelatonin showed a clear increase during the second half of every shift (three-way ANOVA: $F = 18.921$, $P < 0.001$), and a slight effect emerged concerning the "light $\times$ day" interaction (three-way ANOVA: $F = 4.53$, $P = 0.053$). However, there was a lack of depression of melatonin excretion during exposure to bright light (figure 3).

Adrenaline and noradrenaline excretion also showed significant differences between the first and

the second halves of the shifts, both having higher levels in the first half (adrenaline: three-way ANOVA $F = 12.431$, $P < 0.01$; noradrenaline: ANOVA $F = 12.807$, $P < 0.01$) in connection with higher work activity, but no differences due to bright light exposure or between the first and second nights were detected.

In all cases, the changes in concentration during the night shifts indicated that the rhythms had not

Figure 2. Subjective evaluation of physical fitness and factors of fatigue at the end of the night shifts — mean values (rating scale: 1 = minimum, 7 = maximum).

Table 2. Simple auditory reaction times and results of the search and memory test (SAM) during the workshifts.^a

	Reaction times (ms)		SAM score ^b	
	Mean	SD	Mean	SD
Bright light				
First night				
Start	171.3	20.3	5.149	0.83
Middle	176.5	19.6	5.274	0.65
End	183.5	18.6	5.489	0.76
Second night				
Start	169.4	17.4	5.156	0.89
Middle	177.2	16.0	5.365	0.86
End	180.0	16.6	5.165	0.68
Normal light				
First night				
Start	179.4	24.6	5.154	0.75
Middle	182.8	26.6	5.529	0.65
End	190.8	22.9	4.742	0.55
Second night				
Start	173.8	19.8	5.068	1.07
Middle	179.6	22.1	4.784	0.95
End	188.0	24.5	4.842	1.11

^a Results of the three-way analyses of variance are reported in the text.

^b Percentage of correct answers divided by the square root of the time.

Table 3. Plasma levels of cortisol and the urinary excretion rate of 6-sulphatoxymelatonin, adrenaline, and noradrenaline during the workshifts.^a

	Plasma cortisol ($\mu\text{g} \cdot \text{dl}^{-1}$)		Urinary excretion					
			6-Sulphatoxy-melatonin ($\text{ng} \cdot \text{min}^{-1}$)		Adrenaline ($\text{nmol} \cdot \text{min}^{-1}$)		Noradrenaline ($\text{nmol} \cdot \text{min}^{-1}$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bright light								
First night								
Start	8.5	2.3	.	.	.	.	.	.
Middle	4.6	1.7	4.7	3.2	4.2	1.7	24.9	7.7
End	18.4	5.2	12.1	10.6	2.9	1.2	21.8	6.4
Second night								
Start	9.9	2.3	.	.	.	.	.	.
Middle	8.0	1.7	3.7	3.3	4.3	2.6	27.1	14.5
End	17.4	5.2	14.2	12.5	3.0	1.7	21.6	6.8
Normal light								
First night								
Start	7.1	4.0	.	.	.	.	.	.
Middle	5.3	5.3	7.0	5.0	4.2	3.3	29.6	16.9
End	19.1	8.7	13.3	9.8	2.6	1.1	23.3	7.8
Second night								
Start	10.9	2.2	.	.	.	.	.	.
Middle	9.8	3.2	4.9	2.9	3.8	2.5	24.6	12.2
End	20.0	6.2	11.0	8.0	2.9	1.0	21.7	7.6

^a Results of the three-way analyses of variance are reported in the text.

Figure 3. Urinary excretion rate ($\text{ng} \cdot \text{min}^{-1}$) of 6-sulphatoxymelatonin during the night shifts — mean values.

adjusted fully to night work but, instead, appeared to have retained a phasing much more appropriate to day work.

Oral temperature

The mean oral temperatures are shown in table 4. A three-way ANOVA indicated that there was a significant fall in oral temperature during night work, but that there were no significant effects of bright

Table 4. Raw and purified data from the oral temperature ($^{\circ}\text{C}$) during the workshifts.^a

	Raw		Purified	
	Mean	SD	Mean	SD
Normal light				
First night				
Start	36.73	0.21	36.56	0.23
Middle	36.50	0.20	36.35	0.25
End	36.50	0.21	36.34	0.23
Second night				
Start	36.51	0.34	36.38	0.31
Middle	36.63	0.22	36.48	0.23
End	36.56	0.33	36.40	0.34
Bright light				
First night				
Start	36.78	0.29	36.64	0.28
Middle	36.65	0.31	36.44	0.24
End	36.55	0.23	36.34	0.26
Second night				
Start	36.66	0.32	36.53	0.32
Middle	36.58	0.21	36.42	0.31
End	36.54	0.30	36.34	0.38

^a Results of the three-way analyses of variance are reported in the text.

light nor significant differences between days. This change in temperature was found with both the raw ($F = 3.661$, $P = 0.041$) and purified ($F = 7.120$, $P = 0.004$) data.

When a two-way ANOVA was performed upon the temperature differences between the start and the

Figure 4. Phase shifts of oral temperature rhythms during the nights with normal and bright light — mean values.

end of the shift, the raw data showed a day effect ($F = 7.281$, $P = 0.019$), the fall being less on the second day. With the purified data there was not only a similar day effect ($F = 7.199$, $P = 0.020$), but also a trend towards a light effect ($F = 3.609$, $P = 0.082$), as the result of higher values at the start of the night shifts.

When the shifts in rhythm were considered (figure 4), there was a tendency for the raw data to be shifted more in the presence of bright light ($F = 1.898$, $P = 0.193$). With the purified data this tendency was also found, and the amount of shift was slightly greater on the second night ($F = 2.633$, $P = 0.131$). However, by far the clearest change was seen with the three-way ANOVA when any effects of purified versus raw data were considered also. In this case the delays with the raw data were significantly ($F = 32.535$, $P < 0.001$) greater.

Sleep

The nurses' sleep patterns were slightly different during the two periods on night duty (as shown in figure 5), although the total amount of sleep was equivalent.

During the shift with bright light the nurses showed a more balanced sleep pattern and a significantly shorter sleep period between the two night shifts (t paired = -2.55 , $P = 0.024$). This behavior was not significantly correlated with any of the subjective feelings of tiredness, fatigue, or sleepiness.

Discussion

The results indicated that there was a small positive effect of bright light upon some mood, psychophysical, and performance variables in our sample of nurses. Thus with bright light they felt less anxious and less wanting in energy, and they performed the SAM test better. These effects were small, however,

Figure 5. Hours of sleep during the night shift periods — mean values.

and did not extend to the other measures of mood, psychophysical variables, or performance. In addition there were no significant changes in the physiological variables, as judged by the phases of hormone rhythms or purified temperature data.

The results suggest that the positive effects of the bright light used in this study cannot be attributed to shifts in the internal clock, although the exact cause remains to be determined. Masking effects upon the temperature data were clear and could have led to misleading inferences being drawn. For this reason, the shifts observed in the phase of the masked, but not purified, temperature data were probably caused by changes in activity.

Other accounts exist which indicate far more pronounced effects than those measured in our study, and also a wider variety of variables, including deep body temperature (20–24). Variations in protocol — particularly in the intensity, duration, and timing of the light exposure — are likely to account for many of the differences. Exposures to light of high intensity and for prolonged periods of time (see, eg, references 21 and 22) were not feasible for our subjects while they were actively involved in intensive care nursing. Indeed, we noted that melatonin secretion was not suppressed appreciably by the bright light used in our study. Even so, other researchers (20, 24) have used light with an intensity similar to ours and observed shifts in several variables, including body temperature. However, these studies were different, both with regard to the duration of light exposure and with regard to the details of timing.

Our light exposure schedule was determined not only by the constraints imposed by the work conditions in intensive care, but also by our objective to remove as many of the negative effects of nightwork as possible without causing a shift in the body clock. We did not wish to adjust the body clock because

the shift system used was a rapidly rotating one and therefore phase adjustment of body rhythms was not required. In other words, light of an intensity and duration sufficient to adjust the body clock (8, 25) might be of value when adjustment to permanent nightwork or to a slow rotation of shifts is involved, but it would be of much less an advantage — and might even prove to be disorienting — in a rapidly rotating shift system.

We suggest that the use of bright light during nightwork needs to be tailored to whether or not adjustment of circadian rhythms is required. For rapidly rotating shift systems, a balance must be struck between using a light exposure protocol that is too weak and produces no effects and one that is too strong and produces large phase shifts.

The present results suggest that the kind of light exposure used in this study might be beneficial in rapidly rotating shift systems. This assumption needs to be confirmed by other field studies, but it is worth stressing that any support measure to increase tolerance to nightwork, as exposure to bright light (26), should be adopted only after the adoption of the best possible shift schedule according to physiological, psychological, and social criteria (27), and not in spite of them.

Finally, our results obviously relate only to the immediate effects of bright light. Whether, and for how long, such positive effects would remain if the use of bright light were to continue is not known. Nor is it known if such short-term advantages would also reduce the long-term negative effects upon health and well-being.

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