

Suppression of sleepiness and melatonin by bright light exposure during breaks in night work

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Accepted in revised form 7 November 2003; received 30 July 2003

SUMMARY Night work is non-optimal for performance and recuperation because of a lack of circadian influence that fully promote a night orientation. Our study assessed, in an industrial setting, the effects of bright light exposure (BL) on sleepiness, sleep and melatonin, during night work and during the following readaptation to day work. In a crossover design, 18 workers at a truck production plant were exposed to either BL (2500 lx) during breaks or normal light during four consecutive weeks. Twenty minute breaks were initiated by 67% of the workers between 03:00 and 04:00 hours. Sleep/wake patterns were assessed through actigraphs and ratings were given in a sleep/wake diary. Saliva melatonin was measured at 2-h intervals before, during and after night shift weeks. A significant interaction demonstrated a reduction of sleepiness in the BL condition particularly on the first two nights at 04:00 and 06:00 hours. Day sleep in the BL condition was significantly lengthened. Bright light administration significantly suppressed melatonin levels during night work and most strongly at 02:00 hours. Daytime melatonin during the readaptation after night work remained unaffected. The present findings demonstrate the feasibility and benefits of photic stimulation in industrial settings to increase adaptation to night work.

KEYWORDS circadian rhythms, shift work, sleep

INTRODUCTION

Night work is associated with disturbed sleep and wakefulness, particularly in relation to the night shift (Åkerstedt *et al.* 2000). The effects are the result of circadian interference with sleep during the daylight hours and circadian suppression of metabolism at night (Jewett *et al.* 1991). In particular, core temperature and/or melatonin secretion seem to be involved in the associated variation of alertness (Åkerstedt *et al.* 1982; Badia *et al.* 1991). Exposure to bright light will suppress melatonin (Lewy *et al.* 1980) and, depending on phase, adjust the circadian system (Czeisler *et al.* 1989). It has therefore been suggested as a countermeasure against night work impairment of sleep and alertness (Czeisler *et al.* 1990). In laboratory-based night shift studies (or simulated night work field studies where participants sleep at home), artificial light exposure has

successfully been introduced to induce phase shifts and to improve sleep, performance and alertness (Czeisler *et al.* 1990; Dawson and Campbell 1991; Eastman 1992; Eastman *et al.* 1995).

Field studies of night work and melatonin rhythms indicate that the degree of phase delay and adjustment to night work is strongly dependent on the dose and on the human response curve to light (Burgess *et al.* 2002; Koller *et al.* 1994). In addition, it has been demonstrated that a delayed circadian phase prior to night work, derived from a diurnal type scale, may promote the degree of circadian adaptation to night work (Dumont *et al.* 2001). Although not given the same attention in research, bright light has also been shown to exert an immediate influence on physiology and alertness (lack of a sharp drop in body temperature and EEG beta activity) that gives further support to the use of bright light in night work (Badia *et al.* 1991).

In most studies the exposure to light has been quite long, which might present a feasibility problem in industrial and health care settings. However, in a rapidly rotating shift system

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containing two consecutive night shifts, nurses obtained a short exposure (Costa *et al.* 1995) to bright light at night (4×20 min, 2350 lx). This resulted in less fatigue during the bright light condition and improved performance on a search and memory test. However, physiological variables (urinary aMT6s and body temperature) were not affected. Another study, using a short (120 min) BL for night workers on an oil platform, concluded that the adaptation to night work was not significantly enhanced by the exposure (Bjorvatn *et al.* 1999). Instead the normal indoor light appeared sufficient for a rapid adaptation as the workers were isolated from the outdoor light. However, readaptation of alertness on free days after 2 weeks on the oil platform was significantly accelerated by use of light boxes in the homes of the shift workers. Another study of night work at NASA in connection with launching a space shuttle, indicated that use of light boxes at home before and after sleep increased subjective sleep quality, subjective performance and well-being (Stewart *et al.* 1995).

The present study tested if a short (20 min) exposure to bright light during regular breaks would improve night shift alertness, suppress melatonin and improve sleep across a series of night shifts, and also whether any effects would be seen on readaptation to day work. The latter has not been investigated before and is of key importance for acceptability in working life.

METHODS

Studied group

The participants worked as operators in a truck production plant in Sweden. They supervised automatic turning-lathes, producing mainly cogwheels for truck engines.

Twenty-four shift workers volunteered (half the total numbers of workers) and gave informed consent, but six workers had to be excluded in the final analysis because of sickness (one worker), change of work (one worker), change of individual work schedule (three workers) and personal reasons (one worker). Thus, 18 workers remained for analysis, of which one was a female.

The group had a mean age of 36.2 ± 3.0 years (ranging from 24 to 56 years). They had been working at the plant for 8.4 ± 1.7 years and had been on shift schedules containing night shifts for 5.4 years. The background questionnaire indicated that day sleep was disturbed, making the group suitable for an intervention program. Seventy-two percent of the workers 'sometimes' felt 'unrefreshed' by sleep after night work while only 33% experienced this in connection to afternoon shifts. The Ethical Committee of the Karolinska Institutet approved the study.

Schedule

The workers worked in a two-shift system including morning and evening shifts but with additional night work during peak periods. Each week consisted of five consecutive work shifts of

the same type (morning, evening or night shift) and free weekends. Starting times were at 24:00, 06:30 and 15:15 hours. Night work periods involved four consecutive weeks. The night shifts had a length of 6.5 h except for the first shift of each week, which started at 21:45 hours (Sunday evening) and lasted for 8.75 h. The workers were permitted two short breaks at night, 12 + 10 min (+ 10 min on Mondays), but work also allowed a worker to leave his workstation for shorter periods. The timing of breaks was not predefined and thus self-chosen.

Protocol

Workers were randomly assigned to two groups in a crossover design. One group obtained BL in the spring and the other group received normal indoor light (NL). A similar treatment was undertaken in the autumn. Each worker participated during both conditions and an equal number of workers were studied at the same time in both conditions. Detailed measurements were carried out during a pretest day before night work, during the first, second and fourth week of night work, and during the readaptation week when workers either worked or had days off. Workers wore actigraphs during each week studied and they filled out a sleep/wake diary for the same period. Two questionnaires were distributed during the study, one initially to obtain background information, and one at the end of the study, including questions on the evaluation and usefulness of light exposure.

Light exposure

One of two similar rooms for breaks was modified for BL. Fluorescent tubes in the ceiling were installed using an up-light armature that gave an indirect white light with a mean luminance level of 350 candela m^{-2} , generated by full-spectrum light tubes with temperatures of 5,000 K (TL-D 90 58W/950, 26 mm $\varnothing \times 1500$ mm; PhilipsTM, Eindhoven, The Netherlands). To increase illuminance an off-white floor was installed and white textiles covered the walls of the room. This generated a mean exposure of 2,500 lx at eye level (with an 80° gaze angle) for a person sitting down. The room had the same lighting level as is used in several Swedish hospitals for treating seasonal affective disorder. Workers were instructed to go to the light room for all breaks during night work. During the NL condition, workers went to the room with normal illumination (300 lx).

Sleep/wake diary

Subjective sleep was reported at awakening using the Karolinska Sleep Diary (Åkerstedt *et al.* 1994). Ratings were made every 2 h on the scales: Karolinska Sleepiness Scale (KSS; (Åkerstedt and Gillberg 1990), a nine-point scale with verbal anchors ranging from 'very alert' (1) to 'very sleepy, fighting sleep, an effort to stay awake' (9). Workers noted in the sleep/wake diary the timing and duration of breaks as well as time spent in daylight (walking, driving, etc.). Those stating that

they had not been outdoors were assigned 0 min of daylight exposure. However, the brightness of outdoor light was not assessed. Workers also reported times when naps were taken. At the end of the day workers judged how many percent of the work period (or alternatively during their free day) that had included tiredness, stress and difficulty concentrating. Also work strain was measured using a five-point scale ranging from 'no strain' (1) to 'extremely strained' (5). Finally, the number of coffee cups consumed during the day was reported.

Activity measures

Twenty-four hour activity was measured using actigraphs (ActiwatchTM, Cambridge Neurotechnology, Cambridge, UK). Movements were sampled every 1/32 s and the peak amplitude of each second was captured. The sum for values of 60 s formed an activity score for each epoch of 1 min. Three sources of data defined the scoring of sleep. First, the workers were asked to push an event marker on the actigraph when initiating sleep (at lights out) and at final awakening after main sleep periods and naps. Secondly, additional help in defining sleep was obtained from the sleep diary where bedtime, sleep latency and time of rising were reported for sleep and napping. Thirdly, the activity scores were used to define the minute of initiating sleep and the minute of final awakening. The predefined sleep period was finally subjected to a sleep analysis (Actiwatch Sleep Analysis, version 1.03) using a medium level of sensitivity. The data included measures of sleep efficiency (ratio of amount of sleep from bedtime to final awakening/total time in bed) and total sleep time.

Salivary melatonin

Samples of saliva for analysis of melatonin were obtained every second hour on a Thursday before night work (at 06:00, 08:00, 10:00, 12:00 and 14:00 hours), Monday and Thursday during the first and fourth week of night work (at 24:00, 02:00, 04:00 and 06:00 hours), and during Monday and Thursday during the week of readaptation to day work. Samples were stored in a deep freezer (-70 °C) until analyzed through a direct radioimmunoassay using an I125- labeled tracer (Stockgrand Ltd, Guildford, UK) using the method of English *et al.* (1993). Non-detectable levels were assigned a level of 2 pg mL⁻¹.

Statistical analysis

All statistics were computed using the program SuperANOVA (version 1.11, © 1991 Abacus Concepts Inc., Cary, NC, USA). The data obtained during night work were submitted to ANOVA for repeated measures, with correction for unequal variances according to Huynh and Feldt (1976). The two-way ANOVA included the factors of condition (BL/NL) and day (15 examined night shifts). A third factor, time of day, was added for variables with several measures during 1 day (for melatonin and KSS). A fourth factor, week (three studied night

work weeks), was added to give a more detailed analysis of KSS ratings. *Post hoc* mean comparisons were carried out with contrasts. Although 18 workers have been included in the study, some missing data cells are present because of the workers having forgotten to enter data in their diaries or forgotten to take saliva samples or because of technical failures in the activity recordings. Therefore, the number of workers varies in the presented data analysis. When mean values are reported the standard error of mean (\pm SE) is also presented.

RESULTS

Light exposure

In both conditions the workers took at least one break at work and the occurrence of two breaks was 30%. The first break in the BL condition had a mean length of 20.0 \pm 0.48 min and the second break lasted for 20.9 \pm 0.78 min. The timing of breaks or their frequency did not significantly differ between conditions.

The timing of breaks within the BL condition is summed in Fig. 1 for data from all 15 studied night shifts. Forty-four percent of all breaks were initiated between 03:00 and 04:00 hours, when 67% of the workers normally took a break. An initial break at midnight was also frequent (12% of all breaks). On the extended Monday night shift (starting at 21:45 hours), the break pattern differed significantly from other nights as 66% of the workers took two breaks and the first midnight break lasted for 32.8 \pm 2.29 min.

Outdoor BL was estimated from reports. The workers spent a mean of 15.0 \pm 1.9 min traveling from work, normally by car. In connection to night shifts, the major exposure times occurred after day sleep in the afternoon. The total daily outdoor light exposure reached 104 \pm 7 min day⁻¹ in the BL condition and 111 \pm 6 min day⁻¹ in the NL condition, the difference being non-significant (see Table 1).

Sleepiness and wake diary

KSS ratings during the night shift week (means of 3 weeks) are plotted in Fig. 2. As some workers showed missing data on

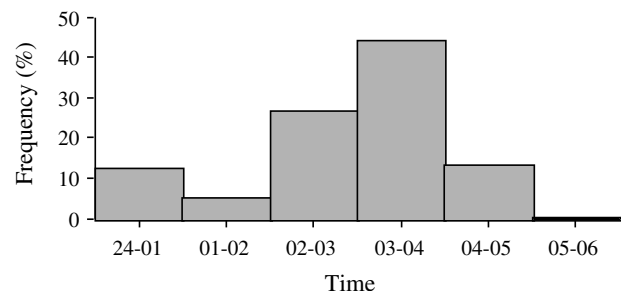


Figure 1. The occurrence of breaks (percent) with bright light exposure within each hour of night work during 15 studied night shifts ($n = 18$).

	<i>n</i>	Condition	Night	Interaction
Tired during work (diary, %)	16	6.41*	NS	NS
Stress during work (diary, %)	16	NS	NS	NS
Different concentrate at work (diary, %)	16	NS	3.24**	NS
Work strain [†] (diary)	16	NS	NS	NS
Light exposure outside work (diary, min)	15	NS	NS	NS
Coffee consumption (diary, cups per day)	15	NS	NS	NS
Bed time (actigraph)	15	NS	NS	NS
Time final awakening (actigraph)	15	NS	1.80*	NS
24 h sleep length (actigraph)	15	6.10*	4.58***	NS
Sleep efficiency (actigraph)	15	NS	NS	NS
Sleep quality index (diary)	17	NS	NS	NS

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

[†]Five-point scale (1 = no strain, 2 = a little strained, 3 = quite strained, 4 = much strained, 5 = extremely strained).

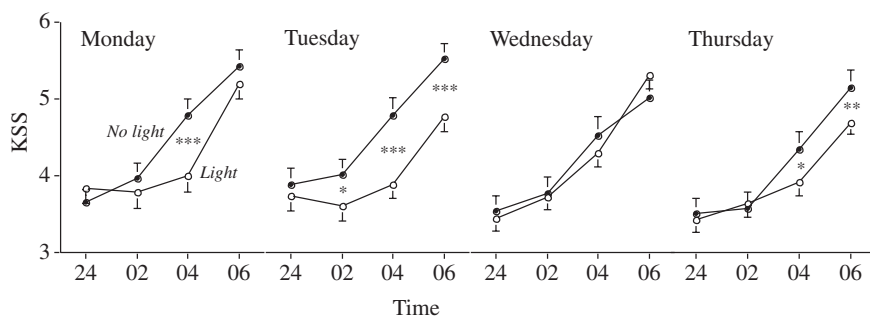


Table 1 *F*-values and level of significance for two-way ANOVAS of sleep and sleepiness using the factors light condition (bright light/NL), night (15 studied night shifts) and interaction of light and night

Figure 2. Mean and standard error of sleepiness levels (KSS – Karolinska Sleepiness Scale) during night work, where open circles represent the bright light condition and filled circles the NL condition. Data that were collapsed for weeks 1, 2 and 4 from Monday to Thursday ($n = 16$). Asterisks indicate the level of significance (* $P < 0.05$, ** $P < 0.01$, *** $P \leq 0.001$) of *post hoc* mean comparisons using contrasts.

Fridays, this day was omitted from the analysis. To reflect the many data points, a four-way ANOVA including the factors of condition, week (3 weeks), night (night 1–4 of each week) and time of day, were used. No main effects were obtained except for time of day showing an increase of sleepiness throughout the night shift ($F = 36.46$; $P = 0.0001$; d.f. = 3/45). A significant interaction was obtained (Fig. 2) for the interaction of condition, night and time ($F = 2.39$; $P = 0.0365$; d.f. = 9/135). Sleepiness was significantly reduced in the BL condition at 02:00 hours on Tuesdays; at 04:00 hours on Mondays, Tuesdays and Thursdays; and at 06:00 hours on Tuesdays and Thursdays as shown by the *post hoc* mean comparisons. The reduction of sleepiness in the BL condition was further emphasized by the significant interaction of condition and time of day ($F = 3.07$; $P = 0.0429$; d.f. = 3/45). The interaction of week and light was insignificant.

Analyses of other daily ratings are reported in Table 1. The item ‘% of time being tired during work’ showed a significant effect of condition, $10.7 \pm 1.1\%$ in the BL condition and $15.9 \pm 1.4\%$ in the NL condition. Other daily ratings of stress, difficulty concentration at work and work strain were unaffected by condition.

Workers were allowed to drink coffee during the experimental period and the consumption pattern of three to four cups per day did not significantly differ between conditions (Table 1). Coffee consumption remained the same also during weekends and in connection to day work.

Sleep in connection with night work

According to actigraph measures workers in the BL condition initiated sleep after night shift, at 07:44 hours \pm 13 min, and in NL at 07:44 hours \pm 12 min. In bright light, the workers awoke at 14:31 hours \pm 8 min and in NL at 14:16 hours \pm 7 min. Bed times and time of final awakenings did not differ with respect to condition (Table 1). A majority of the workers also supplemented day sleep with naps. When calculating the total 24-h sleep length including naps, a significant effect of condition appeared (see Fig. 3 and Table 1) as the BL condition generated an extended mean sleep (6.53 ± 0.10 h) compared with the NL condition. *Post hoc* analysis demonstrated that mean sleep differences were particularly enhanced during the fourth and last experimental week [night 17 ($P = 0.067$), 18 and 20; Fig. 3]. Differences between day sleeps within each week became significant, showing a reduction of sleep during Fridays of about 1.2 h, reaching 5.42 ± 0.13 h. The short sleep on Fridays was caused by earlier rising times of around 45 min and a lack of complementary napping. For the measures of sleep quality, no differences according to condition were observed. Sleep efficiency amounted to $90.4 \pm 0.5\%$ in the BL condition and $89.5 \pm 0.5\%$ in the NL condition. In the sleep diary, the questions of ‘sleep quality’, ‘calm sleep’, ‘ease of falling asleep’ and ‘sleep throughout’ was summed into a sleep quality index (Kecklund and Åkerstedt 1997). Neither single items, nor the

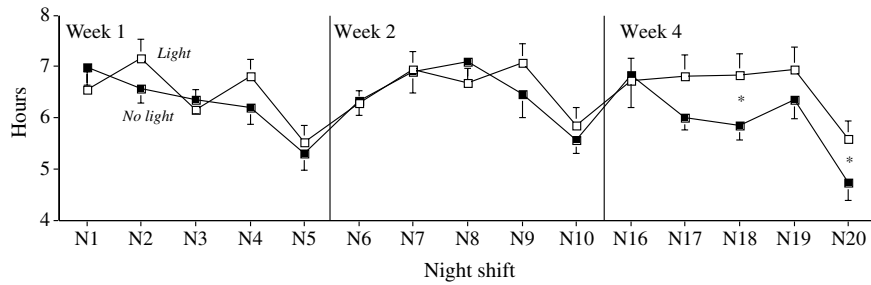


Figure 3. Mean and standard error of 24 h actigraph sleep length in connection with four weeks of night work (measures taken during Monday to Friday of week 1 (N1–N5), week 2 (N6–N10) and week 4 (N16–N20)). Open boxes represent the bright light condition and filled boxes the NL condition ($n = 14$). Asterisks indicate the level of significance ($*P < 0.05$) of *post hoc* mean comparisons using contrasts.

index, were affected by bright light. Sleep was generally rated as being ‘4: fairly good’ in both the BL (4.00 ± 0.04) and NL condition (4.04 ± 0.04).

Sleep after night work

The workers wore actigraphs during three free weekends in connection to night work. Mean bed times on weekends were initiated after midnight and showed a tendency of being later timed (01:34 hours \pm 16 min), in the BL condition than in the NL condition (01:00 hours \pm 13 min; $F = 3.06$; $P = 0.0994$; d.f. = 1/16). Final waking times remained unaffected by BL, however, the difference between days became significant, with a later wake time at 10:13 hours \pm 13 min on Sundays than on Saturdays (09:26 hours \pm 14 min; $F = 6.75$; $P = 0.0194$;

d.f. = 1/16). The mean 24 h sleep length reached 7.2–7.9 h on weekend days and was not affected by BL.

After 4 weeks of night work the workers returned to day work. A few workers took a vacation. An evaluation of bed times is therefore not possible. An ANOVA for a small ($n = 8$) group that worked the postexperimental week under both conditions showed that bright light did not significantly influence total 24-h sleep; in the BL condition workers slept for 7.38 ± 0.21 h and in the NL condition for 6.74 ± 0.17 h of sleep.

Melatonin

Mean levels for concentrations of salivary melatonin are presented in Fig. 4. A three-way ANOVA demonstrated a

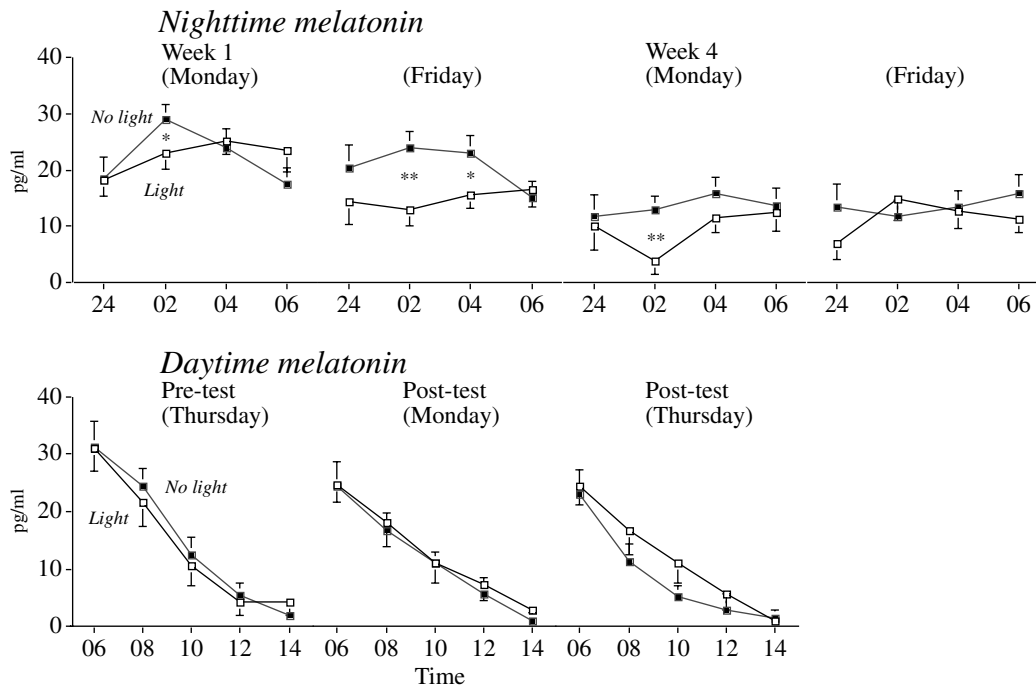


Figure 4. Mean and standard errors of salivary melatonin (pg min^{-1}) during four night shifts during week 1 and week 4 (upper panel) and during daytime (lower panel) on a pretest day (Thursday) and post-night week (Monday and Thursday). Open boxes represent the bright light condition and filled boxes the NL condition ($n = 12$). Asterisks indicate the level of significance ($*P < 0.05$, $**P < 0.01$) of *post hoc* mean comparisons using contrasts.

Table 2. Post experimental evaluations of bright light exposure ($n = 16$)

	Mean \pm SE	P-value*
Alertness	2.53 \pm 0.13	0.0035
Mood	2.69 \pm 0.15	0.0555
Irritation/tired eyes	3.12 \pm 0.16	NS
Well-being at work	3.06 \pm 0.11	NS
Possibility relax after work	2.56 \pm 0.16	0.0140
Difficulty falling asleep	3.00 \pm 0.00	NS
Sleep quality	2.93 \pm 0.18	NS
Global evaluation of light treatment [†]	2.31 \pm 0.15	0.0004

*One-group *t*-test against $m = 3.0$. Evaluation scale 1–5: 1 = much better with bright light, 3 = no change, 5 = much better normal light.

[†]Evaluation scale 1–5: 1 = highly recommendable, 3 = indifferent, 5 = not to be recommended.

significant main effect of condition on the night shift (Fig. 4 upper panel, $F = 6.48$, $P = 0.0233$; d.f. = 1/14) reaching a mean level of 15.02 ± 0.88 pg mL⁻¹ in the BL condition and 18.10 ± 0.87 pg mL⁻¹ in the NL condition. Significant mean comparisons indicated that the bright light appeared to suppress melatonin most strongly at 02:00 hours on most days (except Friday) and at 04:00 hours on the first Friday night. The difference between nights became significant, showing a melatonin decrease in both conditions towards the end of the last measured night ($F = 11.78$; $P = 0.0001$; d.f. = 3/42). The time of day effect and interactions became non-significant.

Saliva samples of melatonin were taken in parallel with sleepiness ratings. A significant positive correlation (Pearson product moment correlation) was found for melatonin and sleepiness (KSS) during the BL condition ($n = 252$, $r = 0.21$, $P = 0.0008$).

For daytime measures on the pretest day and on two post-test days during the readaptation week, the effect of bright light did not reach significance (Fig. 4 lower panel). The effect of time of day was significant with a sharp decrease of melatonin levels from 06:00 to 14:00 hours ($F = 77.90$; $P = 0.0001$; d.f. = 4/44). The difference between days was not significant ($F = 3.03$; $P = 0.0693$; d.f. = 2/22).

Evaluation of bright light exposure

The questionnaire evaluation of the effects of BL is reported in Table 2. A one-group *t*-test ($n = 16$, against mean = 3.0) revealed that perceived alertness, possibility to relax after work, and global satisfaction were significantly and positively affected by the BL, but mood was only mildly affected and no effects on perceived sleep length and sleep quality were observed.

DISCUSSION

The present study showed a clear effect of BL during breaks on nightshift alertness, sleep and melatonin levels.

Wake diary records indicate that breaks never ended later than 04:30 hours. It is therefore reasonable to argue that the exposure was positioned before the zero phase position of the

circadian rhythm of most workers; a set-up that is likely to give a phase delay and promotion of the adaptation to night work (Czeisler *et al.* 1989; Dawson and Campbell 1991). But the bright light treatment also showed significant direct alerting effects during the experiment. It is likely that the NL condition also induced some alertness, as was demonstrated in a laboratory study where typical room lightning of 90–180 lx gave immediate alerting effects during the biological night (Cajochen *et al.* 2000). The significant effects of the present study were obtained with a rather short pulse of bright light of 20 min for the majority of the workers who took only one break (33 min on the first night shift of the week). On the contrary, the illuminance was rather high (350 candela m⁻²). The present study used a comfortable, non-direct light source, without blinding, to minimize avoidance behavior. The results suggest that intermittent bright light combined with normal work light exposure strengthen the photic drive as opposed to continuous normal work light conditions. The strong resetting properties of brief intermittent bright light have also recently been emphasized (Rimmer *et al.* 2000). A lack of physiological effects in earlier work, despite longer exposure times, might be related to the intensity of light reaching the eyes (Costa *et al.* 1995).

An interesting finding is the significant interaction effect of alertness across nights and time of day showing that sleepiness was reduced on the first two nights of each workweek but to a less extent on the two following night shifts. It appeared that some adaptation to night work was observed in both conditions across five night shifts but was counteracted during weekends. The significant correlation between alertness and melatonin levels confirms recently reported laboratory data (Cajochen *et al.* 2000). Given the immediate influence, intermittent bright light treatment at night might increase alertness in both permanent night work and in quickly rotating schedules.

Total sleep time was positively affected by light exposure. However, neither sleep efficiency nor the wake diary gave any indications of an improvement of quality of sleep. In laboratory settings it has been shown that bright light in connection to night work, affects day sleep during the last hours of sleep, showing an increase of sleep efficiency and a decrease of EEG-measured stage 0 (Dawson and Campbell 1991). The insignificant effects in the present experiment could be the result of a lack of a forced bed-rest and fixed bed times.

Night shift melatonin levels significantly decreased across the experiment in both conditions, implying that a general adaptation to night work occurred, however, being rather slow in the NL condition. Despite short exposure times, the direct effects of bright light were evident. But natural dark/light circumstances other than spring and autumn could have given different results, for example, during the Scandinavian winter. Then a complete lack of morning bright light might not counteract night work adaptation, which normally occurs when morning daylight is present (Eastman *et al.* 1994).

The subjects in the present study were aware of the two conditions and thus the study lacked a true placebo condition. It is likely that this could have influenced the results. Before the start of the experiment, the workers were aware that light

treatment could positively affect alertness. But we believe that placebo effects could not solely account for all significant results as ratings of stress, difficulty concentrating and work strain that were given simultaneously with ratings of tiredness remained unaffected by bright light. And it is even more unlikely that the effects on melatonin, that paralleled the subjective ratings, would have been generated by other factors than bright light. In addition, the consistent alerting effect at the beginning of each workweek is difficult to explain merely by placebo. Finally, the significant effects on objective sleep support the significant effect of bright light.

The present study shows positive results of BL during night work on physiology, alertness and sleep and give further support for the use of photic stimulation to increase adaptation to night work. Also, the post-experimental ratings were generally positive and no worker was negative towards the BL. It is likely that an increased duration of BL at work would have strengthened the results. However, several research questions have to be answered before it is possible to optimize BL at the work place. Some of these questions are centered on intensity, spectral quality and timing of exposure (Rimmer *et al.* 2000; Skene 2003). From an economic perspective, it is more cost-effective to install light facilities in specially designated rooms as opposed to the whole workplace. Also the effectiveness and costs of light exposure have to be compared with other known non-photoc synchronizers such as food timing (Krauchi *et al.* 2002), exercise (Horowitz and Tanigawa 2002) and melatonin administration (Skene 2003).

ACKNOWLEDGEMENTS

The authors would like to thank the head of the Volvo Health Care Unit, Jan Settergren MD, for his outstanding support and Anna-Leena Kullingsjö and Else-Marie Bäckström for their excellent help in the data collection.

The Swedish Work Environment Fund and the Volvo Powertrain Cooperation supported the study.

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