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The Effect of Bright Light on Physiological Circadian Rhythms and Subjective Alertness of Shift Work Nurses in Iran

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In this study, the effects of bright light (BL) on the rhythms in body temperature, plasma melatonin, plasma cortisol and subjective alertness, in 34 shift work nurses at a university hospital were assessed. They were exposed to very BL (4500 lx) during 2 breaks (21:15–22:00 and 3:15–4:00) or dim light (300 lx). The subjects were studied under 24 h of realistic conditions during which their plasma cortisol and melatonin were measured at 3-h intervals; their body temperature was also measured during and after night shift work. Subjective alertness was evaluated with the Karolinska sleepiness scale. Administration of BL significantly suppressed night-time melatonin levels. A one-way ANOVA revealed that BL tended to increase cortisol levels and body temperature and significantly improved alertness. These results demonstrate that photic stimulation in a hospital setting can have a powerful influence on the adjustment of the circadian system.

circadian rhythms shift work nurse bright light alertness melatonin cortisol body temperature

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1. INTRODUCTION

Modern society requires that many people reverse their inherent diurnal activity pattern to ensure 24-h availability of services. Currently, the amount of shift work in the developing world is increasing and at least one fourth of the working population in most of those countries are shift workers, the same as in the developed world [1]. There are nearly half a million workers in Iran who regularly work shifts. Many are employed in occupations in which peak functioning is critical (e.g., nurses, and physicians, airline pilots, industrial workers, police, and heavy machinery and commercial drivers) [2]. Shift work that includes night-time work has been reported to decrease alertness, performance, and induce sleep disorders, fatigue and health disturbances [3, 4]. Alterations in the circadian rhythm of some hormonal markers constitute a more useful biological approach in the evaluation of shift work-induced disturbances. The effects are the result of circadian interference with sleep during the daylight hours and circadian suppression of metabolism at night [5]. In particular, core temperature and melatonin secretion seem to be involved in the associated variation of alertness [6]. Cortisol, a reliable indicator of stress, displays pronounced variation across the time-of-day with high levels in the morning and low in the evening [7]. In general, shift work is a stressful condition which interferes with the normal synchronization of body functions [8].

Exposure to specialized bright light (BL) is the only effective means of shifting circadian rhythms back to their normal pattern. One of the most remarkable effects of light with the blue wavelength (460–480 nm) is suppression of night-time melatonin production [9, 10]. BL, in excess of 2500 lx of blue-green light, has been reported to have certain physiological and behavioral effects on humans, e.g., alterations of the melatonin-rhythm generating system [11] and suppression of melatonin secretion [12], and effectively entraining of the internal desynchronizations among circadian rhythms [13, 14]. Desynchronizations, typically observed in patients with seasonal affective disorders [15, 16], jet-lag syndrome [17] and delayed sleep phase insomnia [18], could be adjusted and improved with exposure to BL, leading to the so-called phase-shift hypothesis [15, 19]. Therefore, it is possible that exposure to BL will increase alertness and shift the body clock also by adjusting desynchronizations. Eastman's [20] and Eastmain and Miescke's [21] studies have shown that BL could entrain the circadian body temperature rhythm to a 26-h sleep–wake schedule (a gradual 2-h delayed schedule); they suggested that BL could be used to help shift workers rotate between day and night shifts.

Previous studies used simulated day–night shifts, e.g., several (base-line) days with night-time sleep followed by several night shifts with daytime sleep [22, 23, 24]. In Iran, however, a day–evening–night rapidly rotating shift system, in which the same health care work shift does not last more than 5 or 6 days, is the most common. Although some recent studies have addressed the effects of BL on the psychophysiological and physical activities and sleep patterns of nurses carrying out rapidly rotating shift work [25, 26, 27], as far as we know no researcher has investigated changes both at hormonal levels and body temperature during nurses' shift work in a developing country like Iran. Field studies of shift work and melatonin rhythms indicate that the degree of phase delay and adjustment to night work strongly depend on the dose and on the human response curve to light [28]. Costa, Gaffuri, Ghirlanda, et al. found that exposure to short periods of BL (4×20 min, 2350 lx) on two consecutive night shifts reduced self-reported tiredness and produced an improved sleeping pattern in nurses, as compared with two night shifts with normal lighting [29]. Performance on a cognitive test also improved, although there was no change in physiological correlates of phase shifting (hormonal levels and body temperature). The duration of exposure to BL in constant conditions (a clinical setting) is usually ~2–3 h [30, 31], but such a long exposure is not feasible in the workplace. We, therefore, compared plasma melatonin and cortisol, subjective alertness, and body temperature before and after exposure to BL (2×45 min, 4500 lx) and dim light conditions during regular breaks

during the night shift in a group of shift work nurses at a university hospital.

2. MATERIALS AND METHODS

2.1. Subjects

Thirty-four female nurses from a university hospital in Shiraz province, Iran, entered the study. All subjects were carefully screened to ensure they were healthy and free of medications and drugs, and had no history of psychiatric disorders [2]. Their mean age was 27 years (range: 22–32), and they had been working at the hospital as nurses on shift schedules that included night shifts for 5.5 years (range: 5–10). The subjects gave written informed consent. The Ethical Committee of Tehran University of Medical Sciences approved the study.

2.2. Schedule

The subjects worked in a three-shift system of day (8:00–15:30), evening (15:30–20:00), and night shifts (19:00–8:00). Each week consisted of five consecutive work shifts of the same type. The rotating pattern of shifts was irregular, but a typical shift pattern was three normal days, preceded by one day off, followed by two night and three evening shifts. The night shifts were 11 h long and the nurses were permitted two breaks (21:15–22:00 and 3:15–4:00).

2.3. Protocol

We investigated two series of five consecutive days (day–evening–night–day–evening) with the typical shift pattern described above. During the first series, the subjects were not exposed to BL for 4 weeks, and the illumination in the rooms for resting was ~300 lx (dim light condition) horizontally at eye level. During the second series, they were exposed to BL for the 30 days (BL condition). The mean interval between the last night shift before intervention (without exposure to BL) and the first night shift of the second series (intervention with BL) was 30 days.

The female nurses' workload appeared to be the same in both series of shifts. The illumination level was measured at eye level. The nocturnal melatonin and cortisol levels in plasma, and body temperature were measured at least 24 h before and after intervention. Subjective alertness was also measured twice (before and after intervention) with self-administered rating scales.

2.4. Light Exposure

The rooms for resting were modified for the BL condition. The light was administered from ceiling-mounted fluorescent lamps (with color temperature of 5000 K, 60W/950, 26 × 1500 mm; Osram, Germany) that gave indirect white light. These lamps generated a mean exposure of 4500 lx at eye level for a sitting person. Nurses were instructed to go to those rooms for all breaks during night work. They were exposed to BL mainly during their two breaks during the night shifts (21:15–22:00 and 3:15–4:00). During the dim light condition, the nurses went to the nurse unit room with dim light (300 lx).

2.5. Measurements

2.5.1. Neuroendocrine rhythms

Serial blood sampling for melatonin and cortisol was sampled at 3-h intervals for 24 h through an indwelling cather with a heparine lock placed in the forearm. Blood sampling was performed under 300 and 4500 lx. Immediately after sampling, blood was centrifuged to separate plasma and frozen at –82 °C until assay. Plasma melatonin or N-acetyl-methoxytryptamine concentration was measured with radioimmunoassay. This assay has a sensitivity of 2.5 pg/ml, an interassay coefficient of variation averaged 13.8% for values <10 pg/ml, 8.6% in the range of 10–30 pg/ml, and 5.2% for values >30 mg/ml. Values reported represent the means of two determinations for each sample. Plasma cortisol assays were also made with the radioimmunological method routinely used in laboratories [7].

2.5.2. Body temperature

All subjects were checked over a 24-h period for body temperature. It was continuously measured with a thermometer probe. The results were then computerized.

2.5.3. Subjective alertness

Subjective alertness and sleepiness were evaluated with the Karolinska sleepiness scale (KSS) [31, 32], which was used before and after intervention. This 9-point scale contains verbal anchors ranging from *very alert* to *very sleepy, fighting sleep, an effort to stay awake.*

2.6. Data Analysis

The three physiological variables (body temperature, plasma melatonin and plasma cortisol) and one mood variable (subjective alertness) were derived from fitted curves. The visual analogue scale (VAS) score changes from before and after intervention were used as psychological variables in this study. A one-way analysis of variance (ANOVA) with repeated measures was used to determine the main and interaction effects of BL (on/off), and day (30 examined day shifts) on the physiological variable and the score changes.

3. RESULTS

3.1. Plasma Melatonin

Figure 1 presents mean levels for concentrations of plasma melatonin in two conditions. Three hourly values from 19:00 to 16:00 were plotted for subjects under bright and dim light test conditions. A one-way ANOVA demonstrated a significant main effect of condition on the night shift (Figure 1; $F = 18.25$, $P = .004$) reaching a mean level of 59.75 ± 31.16 pg/ml in the BL condition and 67.04 ± 39.69 pg/ml in the dim light condition. Significant mean comparisons indicated that BL appeared to suppress melatonin most strongly at 2:00 on most days. An even more profound reduction in melatonin was observed during the initial 4-h light exposure period. Exposure to BL from 1:00 to 4:00 suppressed melatonin secretion by more than 70%, compared to the dim light condition over the same period. The data clearly show that exposure to BL also caused a significant delay in the time when melatonin reached peak concentration in the circulation. Mean blood levels of melatonin peaked for shift work nurses (after 30 days of BL exposure) at 1:00 in the dim light condition, a delay of 3 h. In contrast, peak concentrations of melatonin for shift work nurses with night sleep occurred at 4:00 in the dim light exposure condition (Table 1). This result illustrates that the BL condition phase was significantly delayed with respect to the dim light condition. In general, the nocturnal melatonin synthesis was completely suppressed during BL exposure in the subjects but immediately resumed upon return to the dim light condition.

3.2. Plasma Cortisol

Plasma cortisol levels were also measured in the subjects at 3-h intervals for 24 h (19:00–16:00)

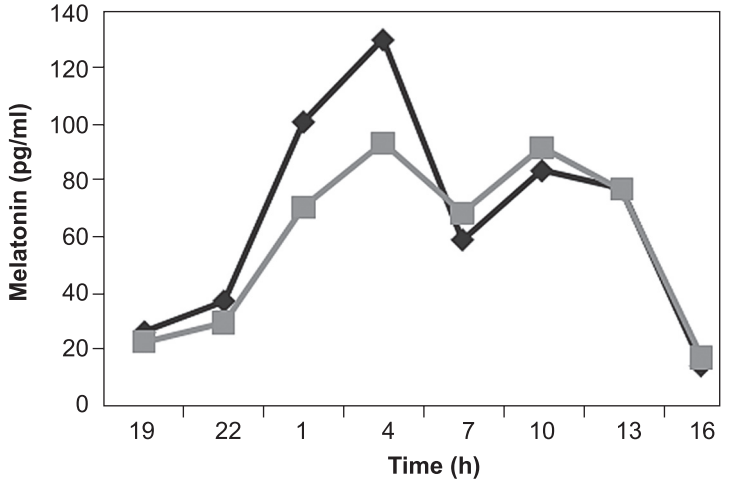

Figure 1. Plasma melatonin profile in shift work nurses under 2 light conditions. *Notes.* ■—bright light, ◆—dim light.

under three conditions (Table 1). Figure 2 also illustrates the averaged plasma cortisol rhythms in the subjects under bright and dim light conditions. The mean level of plasma cortisol in BL and dim light conditions was 37.71 ± 6.33 and 35.96 ± 6.30 μg/dl, respectively. As shown in Figure 2, plasma cortisol was significantly higher during the BL condition than during dim light. The repeated measurement design and the least square differences test revealed significant differences among the times of day (P = .000) and between the two light conditions (P = .000).

3.3. Body Temperature

Figure 3 illustrates the average of 24-h circadian rhythms in body temperature under two light conditions. ANOVA confirmed the significance of the time of day variation (P = .000). There were significant differences between body temperature at 19:00 and 23:00 (P = .025), at 2:00 and 8:00 (P = .000) and at 20:00 and 2:00 (P = .000). Figure 3 shows that the trend of variations in body temperature in the BL condition was similar to the dim light condition. However, we observed significant effects of exposure to BL on the increase in body temperature during 24 h.

3.4. Subjective Alertness

Table 2 presents the mean score change in each KSS scale during night work and intervention

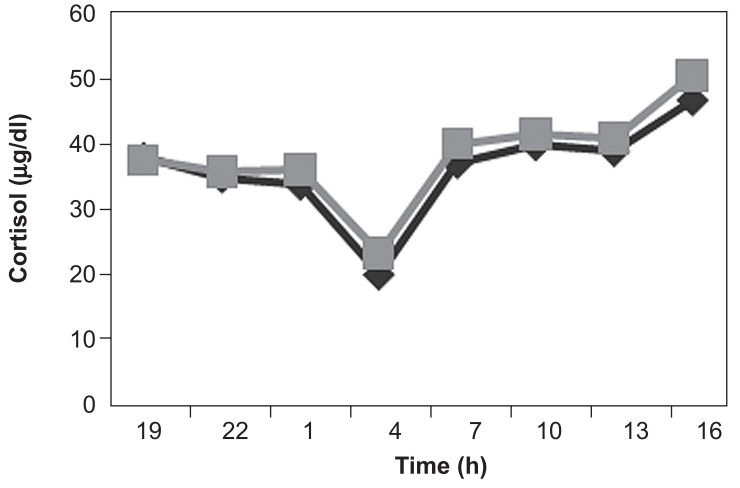

Figure 2. Plasma cortisol profile in shift work nurses under 2 light conditions. *Notes.* ■—bright light, ◆—dim light.

TABLE 1. Mean Plasma Melatonin (pg/ml) and Cortisol (μg/dl) Levels of Shift Work Nurses Under 3 Conditions

	BL		DL		NS	
Time	M	C	M	C	M	C
19:00	23.51	37.16	27.00	37.40	27.00	37.40
22:00	30.45	35.66	38.05	34.93	57.17	15.01
1:00	71.60	36.00	102.12	33.99	132.42	41.91
4:00	94.43	25.30	131.49	22.58	161.49	25.30
7:00	69.39	39.21	59.96	36.75	59.96	59.97
10:00	92.83	40.47	84.67	39.03	24.67	42.88
13:00	78.00	39.97	78.11	38.26	17.53	35.66
16:00	17.77	47.91	14.91	44.73	14.91	23.30
M	59.75	37.71	67.04	35.96	61.89	35.18
SD	31.16	6.33	39.69	6.30	55.68	13.99

Notes. BL—bright light, DL—dim light, NS—night sleep, M—melatonin, C—cortisol.

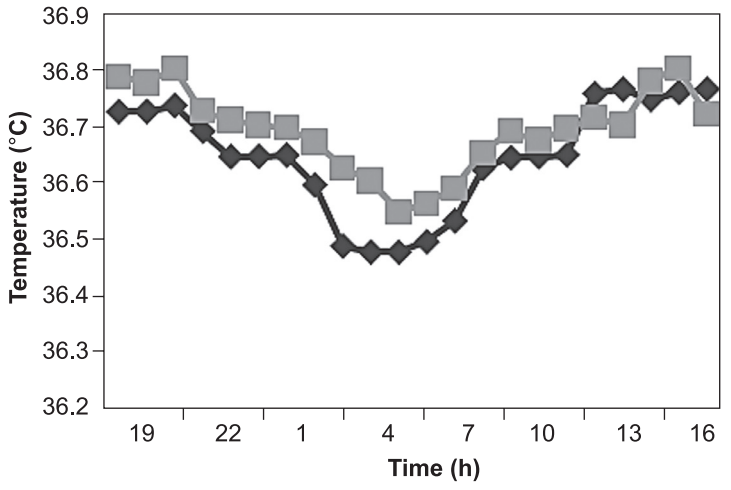

Figure 3. Body temperature profile in shift work nurses under 2 light conditions. *Notes.* ■—bright light, ◆—dim light.

conditions; the 24-h subjective alertness was substantially lower at 3:00, 4:00, and 5:00. The results show that the mean 24-h variation of alertness for BL subjects was higher than for dim light subjects. Thus BL subjects were more alert than dim light ones ($P = .000$).

TABLE 2. Variations of Mean Subjective Alertness of Shift Work Nurses Under 2 Light Conditions

	Subjective Alertness	
Time	BL	DL
19:00	9.95	9.85
20:00	9.93	9.88
21:00	9.88	9.89
22:00	9.81	9.82
23:00	9.64	9.70
24:00	9.41	9.44
1:00	8.93	8.86
4:00	5.12	4.47
5:00	5.38	5.00
6:00	4.94	4.65
7:00	3.32	2.88
8:00	3.12	2.88
9:00	4.21	3.24
10:00	3.82	3.62
11:00	4.88	4.32
12:00	5.44	5.06
13:00	4.06	3.79
14:00	4.38	3.47
15:00	4.68	2.76
16:00	3.32	2.76
M	3.52	3.16
SD	1.45	1.29

Notes. BL—bright light, DL—dim light.

4. DISCUSSION

This experimental study was conducted in a realistic situation at a general hospital in a developing country. A group of female shift work nurses similar in age, working experience, and shift work schedule took part in the study. The ability of BL to induce a powerful influence on the adjustment of the circadian system and to suppress melatonin production in humans under controlled laboratory and realistic conditions is now well known [12, 13, 14]. The realistic situation of shift work schedules demonstrated the potential of applying circadian principles to the problem of night shift work [22, 25, 28]. The present study indicated a clear effect of BL during breaks on nocturnal secretion patterns of melatonin and cortisol, body temperature, and nightshift alertness. It should be noted, however, that this picture was not necessarily consistent for the concentration we studied.

As mentioned earlier, in humans melatonin secretion increases soon after the onset of darkness, peaks in the middle of night (between 2:00 and 4:00), and gradually falls during the second half of the night. Night shift melatonin levels were significantly suppressed across the experiment in both conditions, implying that there was general adaptation to night work; however it was rather slow in the dim light condition (Table 1). Previously, Costa et al. exposed 14 hospital nurses working on a

rapidly rotating shift schedule comprising two consecutive night shifts to BL (2350 lx) for short periods (4 × 20 min), and found neither hormonal excretion nor body temperature changed, although there were some positive effects on psychophysical conditions and performance efficiency [29]. In contrast, our subjects were exposed to BL mainly at around two breaks (21:15–22:00 and 3:15–4:00, 4500 lx) during the night shifts, so the direct effects of BL were evident. Despite short exposure times, the present study provided a phase shift in endogenous melatonin secretion with the first evidence of a delay of 3 h after 30 days of BL exposure at 1:00 in the dim light condition. In contrast, peak concentrations of melatonin for the subjects with night sleep occurred at 4:00 in the dim light exposure condition. Melatonin synthesis was immediately resumed after the return to dim light (Table 1) and the significantly delayed phase indicates a true rebound. This is supported by Barnes, Deacon, Forbes, et al., who determined adaptation of the 6-sulphatoxymelatoni rhythms in shift workers on offshore installation during a 2-week 12-h night shift [33]. Most previous studies showed that the shift work system induced a marked disturbance in the cortisol circadian rhythm for the night shift.

Plasma cortisol shows a marked circadian rhythm with typically lowest secretion during half of night time sleep, an abrupt elevation during the second half of sleep, peak levels shortly after awakening and continuously decreasing levels over the remainder of the day, except for stress-related cortisol surges that superimpose on the normal circadian rhythm [34, 35]. The cortisol secretion profile of the subjects with night sleep (Table 1) is in agreement with previous studies about morning and afternoon levels [36]. In the subjects, the results indicated that the trend of variations of cortisol secretion in the BL condition was nearly similar to the dim light condition. However, there was a difference between the amount of cortisol secreted between 7:00 and 16:00 in the subjects with night sleep and in the subjects who were awake during night work. This study also demonstrated that BL appeared to increases cortisol secretion from 13:00 to 16:00 on most days. In general, exposure to BL induced a consistent change in the cortisol circadian profile with both a displacement of the acrophase and a higher amount of cortisol (39.21–47.91 μg/dl) in the evening. This possibility is supported by the observations that the circadian cycle of body temperature is linked to the 24-h cycle of subjective sleepiness and inversely related to serum melatonin concentrations [37, 38]. The main findings regarding the body temperature data are the following: firstly, during the night shift, the subjects showed a typical body temperature increase after exposure to BL. Secondly, the phase shift in the circadian cycle of body temperature could also be observed during shift work under the BL condition (Figure 3).

In both field and laboratory studies, exposure to BL during the night shift was associated with reduced sleepiness scores and increased body temperature [39, 40, 41]. In the present study, the body temperature at 5:00 was significantly lower under BL conditions than dim light conditions (Figure 3), which appeared to lower the body temperature most strongly at 3:00–4:00. BL is known to decrease subjective sleepiness and increase alertness [41, 42]. A close correlation between body temperature and sleepiness has recently been suggested in humans [39, 41]. The present finding suggests that an increase in subjective alertness in BL conditions is due to phase shift of body temperature during night shift work. Finally, the significant effects on reduction in sleepiness support the significant suppression of melatonin secretions under BL conditions.

5. CONCLUSION

Overall, we have demonstrated that exposure to very BL (4500 lx) during night work can affect positively physiological circadian rhythms and subjective alertness. Clearly, BL exposure during night work changes the phase-shifting effects of melatonin, cortisol and body temperature. The present protocol supports BL exposure to improve circadian adaptation to shift work. However, previous investigations answered questions that it was possible to optimize BL at

the work place. Some of these questions focused on doses of BL, timing of exposure and type of shift work [28, 29, 31, 41]. From a human errors preventive strategy and an economic perspective, it is more effective to install BL facilities in specially designated rooms such as rooms for resting or nurses' rooms as opposed to the whole workplace.

REFERENCES

1. Akersttedt T. Psychological and psychophysiological effects of shift work. Scand J Work Environ Health. 1990;16:67–73.
2. Zamanian Ardakani Z, Kakooei H, Ayattollahi SMT, Choobineh A, Nasle Seraji G. Prevalence of mental disorders among shift work hospital nurses in Shiraz, Iran. Pak J Biol Sci. 2008;11(12):1605–9.
3. Koller M. Health risks related to shift work. Int Arch Occup Environ Health. 1983;53:59–75.
4. Akerstedt T. Sleepiness as a consequence of shift work. Sleep. 1988;11:17–34.
5. Jewett E, Kronauer RE, Czeisler CA. Light-induced suppression of endogenous circadian amplitude in humans. Nature. 1991;350:59–62.
6. Akerestedt T, Gillberg M, Wetterberg L. The circadian covariation of fatigue and urinary melatonin. Biol. Psychiatry. 1982; 17:547–54.
7. Hennig J, Kiefrdore P, Moritz C, Huwe S, Netter P. Changes in cortisol secretion during shiftwork: implications for tolerance to shiftwork? Ergonomics.1998;41: 610–21.
8. Knauth P, Emade E, Rutenfranz J, Kiesswetter E, Smit P. Reentrainment of body temperature in field studies of shift work. Int Arch Occup Environ Health. 1981;49:137–49.
9. Illnerova H, Vanecek J. Response of rat pineal serotonin N-acetyltransferase to one min light pulse at different night times. Brain Res. 1979;167:431–4.
10. Brainard GC, Lewy AJ, Menaker M, Fredrickson R, Miller L, Weleber R, Cassone V, Hudson D. Effect of light wavelength on the suppression of nocturnal plasma melatonin in normal volunteers. Ann NY Acad Sci. 1985;453:376–8.
11. Wetterberg L. Lighting: nonvisual effects. Scand J Work Environ Health. 1990;16:26–8.
12. Lewy AJ, Wehr TA, Newsme DA, Markey SP. Light suppresser melatonin secretion in humans. Science. 1980;210: 1267–9.
13. Czeisler CA, Richardson GS, Zimmerman JC, Moore MC, Weitzman ED. Entrainment of human circadian rhythms by light-dark cycles: a reassessment. Photochem Photobiol. 1981;34:239–47.
14. Wever R, Polasek J, Wildgruber C. Bright light affects human circadian rhythms. Pflugers Arch. 1983;396:85–7.
15. Lewy AJ, Sack RL, Miller LS, Hoban TM. Antidepressant and circadian phase-shifting effects of light. Science. 1987;235:352–4.
16. Blehar MC, Rosenthal NE. Seasonal affective disorders and phototherapy. Arch Gen Psychiatry. 1989;46:469–74.
17. Czeisler CA, Allan JS. Acute circadian phase reversal in man via bright light exposure: application to jet-lag. Sleep Res. 1987;16:605.
18. Rosenthal NE, Joseph-Vanderpool JR, Levendosky AA, Johnston SH, Allen R, Kelly KA, et al. Phase-shifting effects of bright morning light as treatment for delayed sleep phase syndrome. Sleep. 1990;13:354–61.
19. Lewy AJ, Sack RL. Light therapy and psychiatry. Proc Soc Exp Bio Med. 1986; 183:8–11.
20. Eastman CI. Circadian rhythms and bright light: recommendations for shift work. Work Stress. 1990;4:245–60.
21. Eastman CI, Miescke KJ. Entrainment of circadian rhythms with 26-h bright light and sleep–wake schedules. Am J Physil. 1990;259:R1189–97.
22. Gallo LC, Eastman CI. Circadian rhythms during gradually delaying and advancing sleep and light schedule. Physiol Behav. 1993;53:119–26.
23. Eastman CI, Liu L, Fogg LF. Circadian rhythm adaptation to simulated night shift work: effect of nocturnal bright-light duration. Sleep. 1995;18:399–407.

24. Czeisler CA, Johnson MP, Duffy JF, Brown EN, Ronda JM, Kronauer RE. Exposure to bright light and darkness to treat physiologic maladaptation to night work. N Engl J Med. 1990;322:1253–9.
25. Costa G, Ghirlanda G, Minors DS, Waterhouse JM. Effect of bright light on tolerance to night work. Scan J Work Environ Health. 1993;19:414–20.
26. Watanabe M, Akamatsu Y, Furui H, Tomita T, Watanabe T, Kobayashi F. Effects of changing shift scheduales from a full-day to a half-day shift before a night shift on physical activities and sleep patterns of single nurses and married nurses with children. Ind Health. 2004;42:34–40.
27. Kobayashi F, Furui H, Akamatsu Y, Watanabe T, Horibe H. Changes in psychophysiological functions during night shift in nurses. Int Arch Occup Environ Health. 2004;69:83–90.
28. Burgess HJ, Sharkey KM, Eastman CI. Bright light dark and melatonin can promote circadian adaptation in night shift workers. Sleep Med Rev. 2002;6:407–20.
29. Costa G, Gaffuri E, Ghirlanda G, Minors DS, Waterhouse JM. Psycho-physiological conditions and hormonal secreation in nurses on a rapidly rotating shift schedule and exposed to bright light during night work. Work Stress. 1995;9:148–57.
30. Asano Y. Phototherapy and psychiatry. Japanese Journal of Psychiatric Treatment. 1990;5:323–32.
31. Monk TH, Buysse DJ, Reynolds CF 3rd, Berga SL, Jarrett DB, Begley AE, et al. Circadian rhythms in human performance and mood under constant conditions. Sleep Res.1997;6:9–18.
32. Akerstedt T, Hume K, Minors D, Waterhouse J. The subjective meaning of good sleep—an intraindividual approach using the Karolinska sleep diary. Percep Mot Skills. 1994;79:287–96.
33. Barnes RG, Deacon SJ, Forbes MJ, Arendt J. Adaptation of the 6-sulphatoxy-melatonin rhythms in shift workers on offshore installation during a 2-week 12-h night shift. Neurosci Let. 1998;241:9–12.
34. Born J, Hansen K, Marshall L, Mölle M, Fehm HL. Timing the end of nocturnal sleep. Nature. 1999;397:29–30.
35. Kudielka BM, Buchtal J, Uhde A, Wust S. Circadian cortisol profiles and psychological self-reports in shift workers with and without recent change in the shift rotation. Biol Psychol. 2006;74:92–103.
36. Czeisler CA, Kleman EB. Circadian and sleep-dependent regulation of hormone release in humans. Recent prog in hormone research. 1999;54:97–130.
37. Cagnacci A, Elliott JA, Yen SSC. Melatonin: a major regulator of the circadian rhythm of core temperature in humans. J Clin Endocrinol Metab. 1992; 75:447–52.
38. Deacon S, Arendt J. Melatonin-induced temperature suppression and its acute phase-shifting effects correlate in dose-dependent manner in humans. Brain Res. 1995;688:77–85.
39. Krauchi K, Cajochen C, Werth E, Wirz-Justice A. Functional link between distal vasodilation and sleep-onset latency. Am J Physiol Regul Integr Comp Physiol. 2000; 278:741–8.
40. Fort A, Harrison MT, Mills JN. Psycho-metric performance: circadian rhythms and effect of raising body temperature. J Physiol. 1973;231:114–5.
41. Lowden A, Akerstedt T, Wibom R. Suppression of sleepiness and melatonin by bright light exposure during breaks in night work. J Sleep Res. 2004;13:37–43.
42. Cajochen C, Zeitzer JM, Czeisler CA, Dijk DJ. Dose–response relationship for light intensity and ocular and electroencephalographic correlates of human alertness. Behav Brain Res. 2000; 115:75–83.