Light Treatment for Sleep Disorders: Consensus Report.

VI. Shift Work

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Abstract The unhealthy symptoms and many deleterious consequences of shift work can be explained by a mismatch between the work-sleep schedule and the internal circadian rhythms. This mismatch occurs because the 24-h zeitgebers, such as the natural light-dark cycle, keep the circadian rhythms from phase shifting to align with the night-work, day-sleep schedule. This is a review of studies in which the sleep schedule is shifted several hours, as in shift work, and bright light is used to try to phase shift circadian rhythms. Phase shifts can be produced in laboratory studies, when subjects are kept indoors, and faster phase shifting occurs with appropriately timed bright light than with ordinary indoor (dim) light. Bright light field studies, in which subjects live at home, show that the use of artificial nocturnal bright light combined with enforced daytime dark (sleep) periods can phase shift circadian rhythms despite exposure to the conflicting 24-h zeitgebers. So far, the only studies on the use of bright light for real shift workers have been conducted at National Aeronautics and Space Administration (NASA). In general, the bright light studies support the idea that the control of light and dark can be used to overcome many of the problems of shift work. However, despite ongoing practical applications (such as at NASA), much basic research is still needed.

Key words bright light, circadian rhythms, shift work

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INTRODUCTION

About 20% of the workers in industrialized nations are shift workers. The most common complaint of shift workers who work night, rotating, or early morning shifts is of sleep disruption. Other problems include fatigue, gastrointestinal disturbances, impaired performance, and diminished job and public safety (L.C. Johnson et al., 1981; Minors and Waterhouse, 1981; Folkard and Monk, 1985; U.S. Congress Office of Technology Assessment, 1991).

The most serious problems are associated with the night shift, because the circadian rhythms of the workers do not usually phase shift to adjust to the night work and day sleep schedule (see discussion below). Therefore, workers are required to work during the "wrong" phase of their circadian rhythms, when they are the most sleepy, inefficient, and prone to accidents (Åkerstedt, 1988; Mitler et al., 1988; Dijk et al., 1992; M.P. Johnson et al., 1992). Then they try to sleep during the day, again during the "wrong" phase of their circadian rhythms, which results in disrupted and shortened sleep (Czeisler et al., 1980; Åkerstedt and Gillberg, 1981, 1982; Zulley et al., 1981; Tilley et al., 1982; Kogi, 1985). Daytime noises (traffic, children) may compound the problem. Because circadian rhythms do not adjust, many researchers advocate rapidly rotating shift systems that are not intended to shift circadian rhythms (Knauth, 1993). However, circadian adaptation to the night shift would be preferable, especially in situations in which safety is a concern, for example, intensive care units in hospitals and nuclear power plant control rooms. Although the greatest decrements are associated with the night shift, the morning shift can also produce sleep deprivation and its related negative consequences if it starts too early (Folkard and Barton, 1993).

DO THE CIRCADIAN RHYTHMS OF SHIFT WORKERS EVER PHASE SHIFT?

Masking effects can obscure the phase of circadian rhythms. Therefore, we have only included studies here if we judged that their main conclusions were not invalidated by masking. Most studies show that the circadian rhythms of night shift workers do not phase shift, but instead maintain a phase relationship similar to that of their day-shift coworkers or to their own rhythms on the day shift or on days off (van Loon, 1963; Colquhoun et al., 1969; Åkerstedt et al., 1977; Knauth et al., 1981; Weitzman and Kripke, 1981; Folkard, 1989; Åkerstedt, 1990; Minors and Waterhouse, 1993; Roden et al., 1993). However, there have been a few night work studies in which circadian rhythms showed partial to complete phase shifting to align with daytime sleep. This, combined with studies misinterpreted because of masking, has led to some confusion in the literature over whether circadian adaptation to night work is possible.

Our survey suggests that circadian rhythm phase shifting only occurs in special circumstances (for more details, see Eastman, 1994). Although important methodological details about some studies are not known, it appears that outdoor exposure to natural light is one of the most important factors determining whether circadian rhythms will phase shift. Complete, or nearly complete, phase shifting can be achieved if subjects are confined to the laboratory and are thus protected from sunlight (Knauth et al., 1978; Lynch et al., 1978, and see Fig. 15 in Aschoff, 1981). Complete phase shifting has also been recorded in Portland, Oregon (about 46° N), where night shift workers may be exposed to little or no natural light in the winter (Sack et al., 1992, 1994). As would be expected from variations in sunlight exposure, there were individual differences in circadian adaptation, ranging from no appreciable phase shifting through partial to complete phase shifting. Phase shifting can also occur in the Arctic and Antarctic, where there are extreme variations in natural light (Sharp, 1961; Midwinter and Arendt, 1991). In the constant dark of the winter there is no bright light to oppose circadian rhythm phase shifts. In the natural light of the summer, a favorable light-dark (LD) cycle is artificially created by the sleep-wake schedule and man-made adaptations, such as blindfolds.

Other factors that affect whether circadian rhythms adapt to night work are individual differences in underlying circadian rhythm mechanisms. Moog (1987) found that the circadian rhythms of evening types, but not of morning types, could gradually shift to night work. Evening types are people who go to sleep and wake up later and whose circadian rhythms are phase delayed compared to the norm. Another factor that might affect circadian adaptation is individual differences in the strength or rigidity of the underlying oscillators. Yet another factor that affects adaptation is the number of consecutive night shifts. Because night shift workers typically revert to sleeping at night on their days off (Lee, 1992; Sack et al., 1992), and may be exposed to natural light during the day, any partial adaptation of their circadian rhythms may be reversed.

BRIGHT LIGHT LABORATORY STUDIES

The discovery of the importance of the intensity of light for human nocturnal melatonin suppression (Lewy et al., 1980) triggered studies of the phase-shifting effects of artificial high-intensity light. Several studies involved large phase shifts of the sleep-wake schedule and are thus relevant to both shift work and jet travel. However, most of them were performed in temporal isolation units or in laboratories in which subjects were confined to the lab. Therefore, these studies lack the conflicting (shift work) or congruent (jet travel) natural zeitgebers of the real-life situation, such as the natural LD cycle. Although these laboratory studies are invaluable for learning how the human circadian system responds to bright light combined with phase shifts of sleep, they cannot answer the question of how bright light protocols will work in the field. We know that complete circadian adaptation (complete phase shifting) can be produced in laboratory situations when subjects are isolated from the natural LD cycle, even without the use of bright light. However, it is much more difficult to shift circadian rhythms in the field, since it is the "job" of the 24-h zeitgebers to keep circadian rhythms phase locked at their normal positions. Therefore, we will review the laboratory studies briefly, and then concentrate on the field studies.

A few laboratory studies measured circadian phase after high-intensity ("bright") light or low-intensity ("dim") light using large (≥ 6 h) abrupt phase shifts of the sleep-wake schedule, either an advance (Honma et al., 1991) or a delay (Wever, 1985; Dawson and Campbell, 1991; Campbell et al., 1994). It is difficult to compare the results of these studies with precision, because they used different circadian rhythms for phase markers and different methods. However, it appears that circadian rhythms shifted about 1 h/day in the dim light conditions (which might be a free-run), and as much as 2 to 3 h/day in the bright light conditions.

There were also two laboratory studies that compared different timings of bright light after large abrupt phase advances (Samel et al., 1992) or phase delays (Gander and Samel, 1991) of the sleep-wake schedule. The results of these studies are puzzling because circadian rhythms shifted about 2 h/day regardless of the timing of the bright light exposure. There was little difference between the conditions predicted to enhance phase shifting and the conditions predicted to inhibit the phase shift.

Wever (Wever et al., 1983; Wever, 1985, 1989) compared the strength of various zeitgebers in temporal isolation experiments in which the period of the zeitgeber was gradually increased or decreased (fractional desynchronization). A bright-light/dim-light zeitgeber (3000:300 lux) produced a range of entrainment of about ± 4 h. Since there were no acoustic signals (gongs) and no darkness to force the subjects to go to bed, entrainment cannot easily be attributed to social cues or to the imposition of a sleep-wake schedule. This may well have been the first demonstration that bright light alone can be an effective zeitgeber for human circadian rhythms. An "information zeitgeber" (acoustic signals for bed and wake times) in otherwise constant dark or constant light produced a range of entrainment of about ± 2 h. This showed that a sleep-wake schedule alone could be an effective zeitgeber for humans. The largest range of entrainment (about ± 6 h) was obtained with bright-light/dark cycles (3000:0.1 lux) plus acoustic signals (i.e., bright light plus a sleep-wake schedule).

BRIGHT LIGHT FIELD STUDIES

Bright light sleep schedules have been designed for shift workers. One (Eastman, 1987, Fig. 2) is intended for a work schedule common in nursing, an alternation between day and night shifts every 2 weeks, and another (Eastman, 1990, Fig. 3) was planned for a weekly rotation from day to evening to night shifts. In both schedules, the sleep-wake schedule gradually delays by 1 to 3 h per day during some parts of the schedule. Bright light is timed for the hours immediately before sleep (to coincide with the delay portion of the phase response curve [PRC]), and bright light is to be avoided after sleep (in case subjects woke before the end of the advance portion of their PRC). These types of light-sleep schedules would undoubtedly be rejected by most shift workers, because of their complexity and the requirement of adhering to the schedule even on days off. Nevertheless, they offer the advantage of attempting to shift the circadian rhythms of the worker even before the first night shift to produce efficiency on the night shift and good daytime sleep as quickly as possible.

To determine whether such light-sleep schedules could actually phase shift the circadian rhythms of subjects living at home, exposed to the competing 24-h zeitgebers, a field study was conducted (Eastman, 1986; Eastman and Miescke, 1990). Subjects slept at home in bedrooms made dark by covering the windows with black material. They followed a 26-h sleep-wake schedule "around the clock," until they were once again sleeping at their usual time. They used portable light boxes at home either before bed or after waking (2 h of about 2000 or 4000 lux). To attenuate light exposure at other specified times, they stayed indoors, or wore dark welder's goggles when outside in daylight. As predicted, the "evening light" condition (bright light before sleep and avoidance of bright light after waking), was the most likely to produce entrainment of the temperature rhythm to the 26-h schedule, that is, about a 2-h/day phase delay shift of the temperature rhythm. Thus this study showed that a certain schedule of bright light, dim light, and sleep in darkness could phase shift and entrain human circadian rhythms, despite the conflicting 24-h zeitgebers.

In this study the circadian rhythms of a few subjects in the evening light condition did not phase shift, but remained entrained to the 24-h zeitgebers. Another bright light field study with gradually shifting sleep-wake schedules (Gallo and Eastman, 1993) showed that the circadian rhythms of many subjects could not be phase shifted with the technology used. The failures might be attributed to many factors including insufficient artificial bright light exposure (e.g., portable light boxes that were too small and did not sufficiently illuminate the visual field; cf. Dawson and Campbell, 1990) or greater exposure or sensitivity to the 24-h zeitgebers in some individuals.

Other bright light field studies used a large, abrupt shift of the sleep schedule, which is what most shift workers experience when they change from the day or evening shift to the night shift. Rotating shift workers may experience a shift of as much as 12 h in the change from day to night shifts. In one simulated night shift study (Eastman, 1992), the sleep schedule was shifted 12 h and the subjects slept at home in very dark bedrooms (black plastic covered the windows). Subjects wore dark welder's goggles (1% transmission) whenever they went outside during daylight. Subjects were thus exposed to attenuated natural light during the 2-h "travel-home window" between the end of the 8-h simulated night shifts and bed. Nocturnal bright light exposure was produced by an array of light boxes surrounding the subject, positioned to produce about 5000 lux. Various patterns of bright light exposure were tested, but they all occurred around the trough of the temperature cycle, to hit the most sensitive portions of the PRC. There were moving ("nudge") and stationary ("squash") patterns composed of 6 h of bright light on the first 4 nights and 3 h/night thereafter.

Regardless of the pattern of artificial bright light exposure, the circadian rhythm of temperature phase shifted by about 2 h/day in 21 out of 24 subjects. The circadian rhythms of three subjects did not shift. The direction of phase shift (advance or delay) was determined by the timing of the 6-h exposures relative to the baseline phase of the temperature rhythm. When most of the light exposure occurred before the temperature minimum, the circadian rhythms usually delayed; when most of the light exposure occurred after the temperature minimum, the circadian rhythms usually advanced. Thus this study showed that the inflection point for the light PRC is when the middle of the bright light exposure occurs at about the time of the temperature minimum, as shown by others (e.g., Czeisler et al., 1989; Minors et al., 1991). The subjects reported increased fatigue during the first few night shifts and reduced sleep (average of about an hour) during the first few day sleeps. These symptoms decreased as the circadian rhythm of temperature phase shifted to align with the daytime sleep period.

A subsequent study assessed the relative contributions of the bright light and dark goggles to the circadian temperature rhythm phase shifts (Eastman et al., 1994). There was a 2 × 2 design: light (bright, dim) and goggles (present, absent), with a total of 50 subjects. Many elements were the same as in the previous study (Eastman, 1992), a 12-h shift of the sleep-wake schedule, sleep at home in a very dark bedroom, a 2-h travel-home window, and so on. However, bright light exposure only occurred during the first two of the eight simulated night shifts. The light was 6 h in duration, about 5000 lux, and occurred around the temperature minimum. The subjects in the goggles groups wore goggles with 0.35% transmission during the travel-home window. The day sleep period ended after sunset, and thus subjects were not exposed to natural light at any time except during the travel-home window.

The results were that both bright light and goggles were important for producing temperature rhythm phase shifts. The temperature rhythm of the subjects in the dim-light, no-goggles group did not shift, or shifted very little. A few subjects in the bright-light-only and goggles-only groups had substantial phase shifts. But the combination of bright light and goggles was the most effective for circadian rhythm adaptation. Larger temperature rhythm phase shifts were associated with better subjective daytime sleep, less subjective fatigue, and better mood.

When the temperature rhythm phase shifted, the direction of shift depended on the use of goggles. When subjects wore goggles, their circadian rhythms either advanced or delayed after the 12-h shift of the sleep schedule, as in the previous study (Eastman, 1992). However, when they did not have goggles, the circadian rhythms only advanced, they never delayed. Apparently, sunlight during the travel-home window was sufficient to keep the circadian rhythms from delaying. Light at this time is expected to coincide with the advance portion of the PRC. This study showed that goggles are important for producing circadian rhythm adaptation by phase delay.

Another field study (Eastman et al., in press) compared bright light durations of 6, 3, or 0 h during the simulated night shifts, with a total of 46 subjects. The method was similar to the previous study (Eastman et al., 1994) except that dark goggles were not used. To compensate, bright light was used during all eight night shifts. As expected, the 0-h bright light condition (the dim light condition) produced little circadian phase shifting. In contrast, both the 3- and 6-h conditions were very effective in shifting the temperature rhythm to the daytime sleep schedule, and there was no significant difference between 3- and 6-h exposures. Thus extremely long bright light durations may not be necessary to treat real shift workers, making the procedure more convenient and feasible.

Although these subjects did not have special dark goggles, in some cases the temperature rhythm phase delayed to align with daytime sleep. However, many more subjects phase advanced than phase delayed. Thus repeated bright light exposures can produce phase delays despite daylight exposure during the travel-home window.

In another simulated night work study (Czeisler et al., 1990), bright light exposure (7.5 h, 7000 to 12,000 lux) was repeated for four night shifts. The sleep schedule was shifted by about 9 h, and subjects slept at home in specially darkened bedrooms. Circadian rhythms measured on the sixth night shift were completely shifted in all five subjects. In contrast, when the subjects were kept in dim light during the simulated night shifts, and were not required to sleep at a specified time or in the dark, the circadian rhythms did not phase shift. Self-reported daytime sleep in the bright light condition averaged 7.7 h out of the required 8 h of dark, in-bed time. In the dim light condition, when no specific sleep schedule was required, sleep averaged 5.7 h.

In this study, the subjects were not given dark goggles, but it is possible that the large "dose" of light phase delayed the circadian rhythms through the travel-home window. The circadian rhythms of the bright light group either delayed 9.6 h or advanced 14.4 h. With constant routines applied 5 days apart, it is difficult to distinguish between a delay and an advance. However, a phase delay of 9.6 h over 5 days is consistent with the 2-h/day phase shifts in the other bright light studies.

APPLICATIONS AT NASA

All the bright light field studies discussed so far used volunteers, usually students, rather than shift workers working their regular jobs. The National Aeronautics and Space Administration (NASA) was one of the first agencies to implement bright light for phase shifting the circadian rhythms of shift workers. The astronauts of the Space Shuttle mission STS-35 were exposed to bright light at night during the week-long prelaunch quarantine period to phase shift their circadian rhythms prior to night work while on orbit (Czeisler et al., 1991). The sleep schedule was abruptly delayed by about 9 h and the light exposures were for about 9 h, occurring at about the time of the previous sleep periods. The light intensity was about 10,000 lux for the first four nights, and 1500 to 3000 lux for the last two nights. The enthusiasm of these astronauts, as well as melatonin data that supported a phase shift in circadian rhythms, attested to the success of this procedure.

Bright light was then used in 10 subsequent Space Shuttle missions (Stewart and Eastman, 1992; Stewart et al., 1992; for more details see Eastman, 1994). Based on the field study by Eastman (1992), bright light was used primarily before the presumed temperature minimum to induce phase delays and primarily after the presumed temperature minimum to induce phase advances. Schedules were designed based on the assumption that circadian rhythms would shift an average of about 2 h/day. Light exposures varied from 1 to 6 h depending on the schedule and the day of the schedule. Sleep was gradually shifted in some cases and abruptly shifted in others. Astronauts were provided with the same dark goggles used in previous studies (Eastman, 1992; Eastman et al., 1994) to wear if their duties forced them to be outside at times when bright sunlight exposure might interfere with the desired phase shift. The bright light phase-shifting procedure is so successful that it has become a permanent part of the Space Shuttle program.

The astronauts have optimal physical conditions for phase shifting, special living quarters with convenient high-intensity lights, away from their families and noises that might disturb daytime sleep. It is even more of a challenge to phase shift the circadian rhythms of shift workers who must live at home. Two controlled studies were performed using members of the payload support crew who work in control rooms at NASA's Marshall Space Flight Center (Stewart et al., in press). These individuals work shifts during some of the space shuttle missions because they must coordinate operations on the shuttle. Subjects in the experimental groups received bright light exposure at home with portable light boxes placed in reflective work stations producing about 9000 to 10,000 lux. The same welder's goggles used in previous studies (Eastman, 1992; Eastman et al., 1994) were provided for times at which bright light was to be avoided. Bedroom windows were covered with black plastic. Night shift workers who received light treatment fared better than control subjects on virtually all measures, especially self-rated job performance, fatigue, and sleep quality.

CONCLUSION

It is clear that bright light exposure can be used to help shift workers adapt to their unusual work and sleep routines. However, the desired results were not produced in all studies (Moline et al., 1989; Gallo and Eastman, 1993) and puzzling results were obtained in other studies (Cole and Kripke, 1991; Gander and Samel, 1991; Samel et al., 1992). Many basic research questions remain to be answered. For example: What are the optimal and minimal intensities and durations of light exposure necessary to produce a given phase shift? For each desired phase shift and bright light pattern, how important is the avoidance of bright light and the attenuation of sunlight exposure with dark goggles? The technology for producing high-intensity light has grown in recent years, whereas the development of dark goggles has lagged behind. There is an urgent need for very dark goggles that fit snugly over eyeglasses, that quickly change transmittance with ambient light intensity, and that do not block the peripheral vision necessary for driving. Other research questions are: If light treatment is used to shift circadian rhythms for the night shift, then what type of treatment is needed when workers have to change shifts, for example, to the day shift, or on days off? Will the repeated phase shifting of circadian rhythms be a worse health hazard than repeatedly working and sleeping at the "wrong" circadian phase? Finally, most experiments have been performed on young adults. Studies on middle-aged and older subjects are necessary since the response to circadian rhythm phase shifts and to the phase shifting effects of bright light may change with age.

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