The effect of evening light on circadian-related outcomes: A systematic review*

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Summary

Bright light exposure at night can help workers adapt to their shift schedules, but there has been relatively little research on evening light. We conducted a systematic review of studies that manipulated light exposure in the evening (broadly defined as 16:00 to 22:00) before real or simulated night shifts. Across the five eligible studies, evening light produced phase delays in melatonin, body temperature, and sleep propensity; it also improved sleep quality, sleep duration, memory, and work performance. There were mixed effects for mood, no changes in sleepiness, and no negative effects. The confidence in these results ranged from moderate for physiological markers of circadian phase delays to very low for mood. Future studies should compare the relative effectiveness and safety of evening versus night-time light exposure. Overall, the benefits of evening light for shift workers are tentative yet promising.

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Introduction

Around a quarter of employees in North America^{1,2} and Europe³ are shift workers. Although working outside of typical daytime hours is often necessary,⁴ it has been linked to various negative effects. Shift workers often experience *circadian misalignment*, in which physiological rhythms deviate from the demands of the environment.⁵ In the short term, shift work and the resulting misalignment are associated with sleep deprivation, which can increase fatigue and sleepiness, impair cognition, reduce mood, and disturb metabolic function.^{6–10} Working at night additionally increases the risk of accidents at work^{11,12} and while driving.^{13,14} In the longer term, shift work is associated with a higher risk of health conditions, including cardiovascular disease, Type II diabetes, ischemic stroke, and cancer.^{7,15,16}

Light exposure at night

Researchers have attempted to reduce some of these negative effects by targeting circadian disturbances. Bright light exposure at strategic times is one of the most effective ways to shift circadian rhythms and reduce misalignment.^{17,18} Light exposure modulates circadian rhythms through the central pacemaker in the suprachiasmatic nucleus of the hypothalamus.¹⁹ Bright light during the first half of the night followed by light avoidance in the morning can induce phase delays, in which circadian rhythms are shifted later to delay sleep times. Conversely, avoiding light at night followed by bright light exposure in the morning can induce phase advances, which promote earlier awakenings.⁵ The “crossover point” — when light exposure transitions from causing phase delays to phase

advances — usually occurs near the body temperature minimum, around 2 to 3 h before the habitual wake time.²⁰ Light exposure around this time is most effective at shifting circadian rhythms^{5,20,21} and is often used in interventions to reduce circadian misalignment in shift workers.^{22,23}

These light-based interventions typically have two components: bright light exposure and light avoidance. A recent review of laboratory and field studies to promote phase delays in shift workers recommended bright light in the evening and night (18:00 to 04:00) along with light avoidance in the morning (06:00 to 09:00).¹⁷ Field studies combining these components have produced phase delays in body temperature, cortisol, and melatonin; improvements in sleep duration, cognitive performance, alertness, and mood; and reductions in insomnia and fatigue.^{23–26} These effects may be stronger in permanent night shift workers, who receive light exposure over several consecutive nights which leads to greater phase delays.²⁷ For rapidly rotating shift workers, who often alternate between day shifts and night shifts within the same week, partial circadian alignment may be possible and provide short-term benefits.^{25,28} Beyond these circadian effects, bright light exposure can also temporarily improve alertness and mood.^{19,29}

Potential downsides of light exposure at night

Studies looking at phase delays typically use light exposure late at night, near the body temperature minimum.⁵ However, because this exposure period often takes place during the night shift, it may be less feasible at work. Interventions during work hours require institutional buy-in, which is often costly and slow. Some work environments may also be less suited to light exposure at night; in hospitals, for example, providing light exposure to shift workers could impair patients' sleep.³⁰ Determining the optimal timing of light exposure presents additional concerns.³¹ Since the crossover point varies among individuals,³² the effect of the light exposure during the night can be hard to predict. For

example, two workers with respective crossover points at 05:00 and 03:00 who receive light at 04:00 would shift in opposite directions; one would phase delay, becoming more aligned with the night shift schedule, while the other would phase advance, exacerbating circadian misalignment. Without individualised and feasible ways to estimate circadian phase, light exposure during the night shift may thus have unintended consequences.

Night-time light exposure also raises safety concerns. Accumulating evidence shows that receiving light at night may harm physical and psychological health.^{33–35} For example, it is a risk factor for obesity and cancer,^{33–35} with animal studies supporting these findings.³⁴ Rodents show impaired glucose tolerance,^{36,37} increases in tumour growth, and slower responses to breast cancer treatments.^{38,39} Further, people living in areas with more night-time light exposure are more likely to have depressive symptoms and suicidal behaviour.⁴⁰ Given the potential health risks of night-time light exposure, it is important to consider alternative strategies to reduce circadian misalignment in shift workers.

Evening light as an alternative

A more feasible and potentially safer alternative for permanent and rapidly rotating shift workers would be bright light during the evening rather than at night. Evening light exposure is easier to implement because it can take place before the night shift, thereby removing the need for institutional buy-in. Workers could use a portable light box at home or even get sunlight exposure on their way to work. Further, because the evening light occurs well before the crossover point, it is less likely to cause inadvertent phase advances.

However, it is unclear how effectively evening light can shift circadian rhythms. Circadian adaptation studies typically focus on night-time light exposure because it is the most effective at inducing rapid phase delays. If evening light elicits smaller delays, this could mean slower adaptation for permanent night shift workers. In contrast, compared to

light at night, evening light may facilitate the transition back to day-oriented schedules, especially for rapidly rotating shift workers. In any case, current guidelines to reduce circadian misalignment often recommend night-time light exposure while evening light is relatively ignored (with some exceptions¹⁷). To assess the potential impacts of evening light exposure in shift workers, we conducted, to our knowledge, the first systematic review on the topic.

Methods

We searched eight databases relevant to sleep and circadian rhythms: Embase, Web of Science, MEDLINE, Cochrane Library, PsycINFO, ProQuest Central, OSF Preprints, and Europe PMC. Our search included randomised controlled trials⁴¹ that assessed the impact of light exposure on circadian-related outcomes during real or simulated shift work. We additionally searched for studies assessing jet lag, a related form of circadian misalignment. Table 1 shows the specific search terms which we translated for each database. We also searched the relevant keywords in our own citation library. After a preliminary database search to assess feasibility, we registered the review online (<https://osf.io/z5yws>).

We searched the databases on 2 Jun 2021, which returned 2,104 articles. After removing duplicate records by title using the metagear R package,⁴² a total of 1,187 unique articles remained.

Table 1: Search terms for MEDLINE which were adapted for other databases.

#	Search term
1	melatonin*.mp. or Melatonin/
2	REM sleep.mp. or Sleep, REM/
3	Circadian Rhythm/ or Sleep Disorders, Circadian Rhythm/ or circadian*.mp.
4	Jet Lag Syndrome/ or (jetlag* or "jet lag*").mp.
5	Shift Work Schedule/ or shift*.mp.
6	Phototherapy/ or phototherap*.mp.

#	Search term
7	Heliotherapy/ or heliotherap*.mp.
8	light treatment*.mp.
9	light therap*.mp.
10	light intervention*.mp.
11	light expos*.mp.
12	bright light*.mp.
13	sunlight.mp. or Sunlight/
14	artificial light*.mp.
15	day light*.mp.
16	daylight*.mp.
17	evening light*.mp.
18	morning light*.mp.
19	afternoon light*.mp.
20	1 or 2 or 3
21	4 or 5
22	6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19
23	((randomized controlled trial or controlled clinical trial).pt. or randomized.ab. or randomised.ab. or placebo.ab. or drug therapy.fs. or randomly.ab. or trial.ab. or groups.ab.) not (exp animals/ not humans.sh.)
24	(intervention* or experiment* or random*).mp.
25	23 or 24
26	20 and 21 and 22 and 25

First, two raters screened each abstract to ensure it included human participants, used an experimental design, tested a real or simulated shift work paradigm (or travel across time zones), studied a healthy population, and manipulated light exposure. A total of 226 abstracts passed this screening phase.

Next, the two raters read each abstract (or article if necessary) and kept only those with bright light exposure in the evening; at least one biological, psychological, or behavioural outcome relevant to circadian rhythms; and at least one real or simulated night shift (or time zone crossing of at least 8 h). We broadly defined bright light as light exposure above 100 lux to avoid excluding potentially relevant articles with varying definitions of brightness. Due to the variability of light sources available to shift workers, we did not exclude any light sources or types of light. The evening was broadly defined as between 16:00 and 22:00, capturing the earliest and latest sunset times across much of

North America and Europe.^{43,44} This period typically falls within the delay portion of the human phase response curve.⁴⁵ We chose biological, psychological, and behavioural outcomes relevant to circadian rhythms based on previous studies.^{5,21,26,46} Biological measures included physiological indicators of circadian phase, such as melatonin and body temperature. Psychological measures included well-being, mood, fatigue, depression, stress, anxiety, job-related quality of life, and work satisfaction. Behavioural measures included alertness, sleepiness, vigilance, cognition, work performance, absenteeism, and sick days. Finally, we operationalised night shifts as at least one night (minimum 8 h) during which participants remained awake following the light exposure. Forty-five articles met these criteria.

Two raters then verified that none of the studies used light exposure (>100 lux) past midnight in their evening light condition. Studies typically deliver bright light for several hours; with this midnight cut-off, we sought to include as many evening light interventions as possible while ensuring that the light exposure would not extend too far into the night. This cut-off also helped ensure that the bright light would primarily occur before the night shifts, which often begin after 22:00.⁴⁷

The raters extracted the following data from the remaining six articles: country, season, setting, population, sample size, sex, age, light characteristics, study design, experimental conditions, outcome measures, and results. After the data extraction, one otherwise eligible article⁴⁸ was excluded because the comparison group was confounded by additional light exposure. This exclusion represented one of the three deviations from our registered protocol. Finally, we checked the reference lists of the five remaining articles which returned no additional eligible studies. Figure 1 summarises the screening process.

Figure 1: Study screening procedure.

Data analysis

We used a narrative synthesis to summarise the findings; a meta-analysis was not possible due to the variety of interventions and outcomes. We grouped the results into five outcome categories relevant to the circadian rhythm literature or to shift workers: physiological indicators of circadian phase delay, sleep, sleepiness/fatigue, performance, and mood. This allowed us to combine conceptually related outcomes despite the heterogeneity of measures. Finally, as in other reviews,^{49,50} we categorised each finding as either *favourable*, *unfavourable*, or *no impact*. Each result was categorised based on statistical significance (e.g., $p < .05$); when the p value was not reported, we used the authors' interpretation. Favourable meant that the finding was consistent with a phase delay (e.g., a later dim light melatonin onset) or had a positive acute effect (e.g., an increase in positive mood during the exposure). Unfavourable meant that the finding was consistent with a phase advance or had a negative acute effect. A finding was deemed as having no impact if there was no difference from the comparison group. Two raters classified the findings while a third resolved disagreements through discussion. The overall outcome category was deemed as favourable, unfavourable, or having no impact if at least two thirds of the interpretable findings received the same rating; otherwise, the category was rated as mixed.

Quality of evidence

We next assessed the quality of the evidence using the Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) framework.⁵¹ Study findings were grouped by outcome category to determine quality. We assessed risk of bias according to the five recommended categories for randomised controlled trials: randomisation, allocation concealment, blinding, loss to follow-up, and selective outcome reporting. We also assessed the studies for large effects and the presence of a dose-response gradient. Finally, we assessed inconsistency, indirectness, imprecision, and publication

bias. Evaluations were completed by two raters who resolved disagreements through discussion. Consistent with the GRADE framework, we also rated our confidence in the quality of the findings by consensus.

Results

Samples

There were 98 participants across the five studies, 85 of whom took part in our conditions of interest. Many of these participants (39%) were from a single study of nurses working rapidly rotating shifts who had no diagnosed health conditions that could affect fatigue.⁵² The rest of the sample was composed of healthy volunteers who were not shift workers.^{27,53–55} Participants ranged from 19 to 58 y old,^{52,53} with the majority being under 35. Half of the participants (52%) were women, excluding one study ($n = 8$) which did not report sex. See Table 2 for additional study details.

Table 2: Study details. Values show mean $\pm$ SD. BL = bright light; DL = dim light.

Authors	Country	Season	Setting	Population	Sample	Age (y)	Light time	Light source (lux)
Tzischinsky & Lavie, 1997 ⁵⁵	Israel	Summer + winter	Lab + home actigraphy	Healthy volunteers	12 men (11 completed both conditions)	23.5 $\pm$ 2.6	Summer: 20:00 to 22:00 ($n = 4$), winter: 19:00 to 21:00 ($n = 8$)	Bright light fixture; BL = 2500, DL = 200
Foret et al., 1998 ⁵⁴	France	Mar. and Sep.	Lab only	Healthy volunteers	8 men	19 to 23	20:00 to midnight	Ceiling fixture; BL = 700 to 1000, DL = 50
Daurat et al., 2000 ⁵³	France	Oct. to Mar.	Lab only	Young good sleepers	8 (4 per condition)	19 to 25	Experiment B: 20:00 to midnight	Ceiling fixture; BL = 2000, DL < 50
Dumont et al., 2009 ²⁷	Canada	May to Sep.	Home (baseline) + lab (intervention)	Healthy volunteers	38 (Delay group: 7 women, 5 men; Control: 8 women, 5 men; other condition not relevant)	Delay group: 26.7 $\pm$ 4.6; Control: 26.6 $\pm$ 4.2	17:00 to 23:00	Ceiling light; BL = 1800, Moderate = 150 to 300, DL = 20

Authors	Country	Season	Setting	Population	Sample	Age (y)	Light time	Light source (lux)
Olson et al., 2019 ⁵²	Canada	Not reported	Home (real-world)	Rapidly rotating shift nurses	33 (25 women, 8 men)	32.7 ± 8.6 (22 to 58)	50.1 ± 29.1 min, commonly around 17:00 and 18:00 (before 19:30 shifts) or 22:00 (before 23:30 shifts)	Portable light box; BL = 5500

Light exposure

Our intervention of interest included bright light exposure (> 100 lux) at any point between 16:00 and 22:00 (but not beyond midnight) prior to a real or simulated night shift. Each bright light intervention was used either alone^{53–55} or in combination with other phase delaying strategies such as light avoidance or altered sleep times.^{27,52} The timing of the bright light varied from around 17:00 to midnight. One study⁵⁵ adjusted the light exposure timing to the season, and one field study⁵² gave the light exposure before night shifts, which had different starting times. The duration of the light exposure also varied by study; the longest was 4 h from 20:00 to midnight^{53,54} and the shortest was an average of 50 minutes.⁵² The majority of studies used light fixtures with intensities ranging from 150 to 5,500 lux. Most of the interventions took place in a laboratory environment. See Tables 2 and 3 for details.

Table 3: Study results. Values show mean $\pm$ SD. BL = bright light; DL = dim light; REM = rapid eye movement; SAM = Search and Memory test.

Authors	Design	Intervention	Comparison	Outcomes	Results
Tzischinsky & Lavie, 1997 ⁵⁵	2 conditions (BL vs. DL); participants assigned in alternating order	2 h evening BL for 5 d. On 5th day, participants remained awake until 07:00 the following morning. Began 7/13 sleep-wake paradigm for 72 trials (24 h) under DL	Same paradigm, but DL instead of BL	Objective: 1. Sleep propensity (PSG recordings during each 7 min sleep attempt): total amount of sleep (stages 1, 2, 3/4, and REM) per 7 min trial 2. Oral temperature (measured every hour with an ovulation thermometer, after each 7 min sleep attempt) Subjective: 1. Mood (Global Vigor and Affect [GVA]) 2. Fatigue (GVA) 3. Alertness (GVA)	Objective: 1. Phase delay of sleep gate after BL from 23:04 $\pm$ 134 min to 23:54 $\pm$ 100 min. In BL condition, increased morning sleep propensity (no statistics provided). Between 21:00 and 23:00, BL increased total sleep time relative to DL. Between 21:00 and 23:00, BL also increased time spent in stage 2 sleep relative to DL. Interaction between time of day and light conditions for REM sleep (no details provided). No interaction for stage 1 or 3/4 2. Oral temperature acrophase: phase delay from 15:28 $\pm$ 100 min to 16:53 $\pm$ 150 min Subjective: 1. Delay in the acrophase of negative mood in BL condition from 01:20 $\pm$ 02:36 to 03:32 $\pm$ 01:38. No change in positive mood 2. No change in fatigue 3. No change in alertness
Foret et al., 1998 ⁵⁴	Counter-balanced crossover; 2 conditions (BL from 20:00 to midnight vs. 04:00 to 08:00)	Slept a normal night, then awake for 24 h: during the day (08:00 to 20:00) received natural light through a window, during the first night (20:00 to 08:00) remained awake in DL except during the 4 h BL pulse (20:00 to midnight). Slept during the following day and remained awake again in DL from 20:00 to 08:00 (second night)	The DL period of the 04:00 to 08:00 BL group for night 1 only; specifically, from the start of the day (08:00) until 03:59 (i.e., right before the start of the 04:00 to 08:00 BL)	Objective: 1. Rectal temperature (monitored continuously by a portable recorder) 2. Cognitive performance (SAM 1, 3, and 5) Subjective: 1. Alertness (French shortened version of the Activation/Deactivation Adjective Checklist)	Objective: 1. Night 1: 20:00 to midnight BL did not increase temperature in comparison to DL 2. Night 1: No effect of time nor light condition on SAM 1. Performance on SAM 3 improved at 23:30 by the 20:00 to midnight BL. Performance was improved on SAM 5 at 02:30 in the 20:00 to midnight BL condition Subjective: 1. Night 1: No increase in general activation during the 20:00 to midnight BL

Authors	Design	Intervention	Comparison	Outcomes	Results
Daurat et al., 2000 ⁵³	Experiment B: between-participants; 2 conditions (BL from 20:00 to midnight vs. from 04:00 to 08:00)	After one night of lab recording (23:00 to 07:00), participants remained awake under quasi-constant routine during day and following night. BL from 20:00 to midnight or from 04:00 to 08:00. DL at all other times. Participants remained awake for 24 h the following day	The DL period of the 04:00 to 08:00 BL exposure group; specifically, from the start of quasi-constant routine until 03:59 (i.e., right before the start of the 04:00 to 08:00 BL)	Objective: 1. Rectal temperature (continuous recording) 2. Serum melatonin (radioimmunoassay; blood samplings every 2 h from 20:00 to 08:00) 3. Physiological sleepiness (overnight quantified EEG): theta (4–8 Hz) to alpha (8–12 Hz) power density ratio 4. Performance (measured every 3 h overnight): letter cancellation, logical reasoning, SAM 3, and SAM 5 Subjective: 1. Sleepiness (deactivation sleepiness; Thayer’s Adjective Check List) 2. Alertness (general activation; Thayer’s Adjective Check List) 3. Mood (POMS)	Objective: 2. Plasma melatonin lower during 20:00 to midnight BL relative to DL 3. The 20:00 to midnight BL induced no difference in theta band 4. For letter cancellation, SAM 3, and SAM 5, speed was better during BL. Logical reasoning was measured but not reported Subjective: 1. BL did not affect sleepiness 2. The 20:00 to midnight BL showed no increase in general activation 3. Mood not reported

Authors	Design	Intervention	Comparison	Outcomes	Results
Dumont et al., 2009 ²⁷	Between-participants; 3 conditions (delay vs. advance vs. control)	5 d at home, no napping, with fixed 8 h sleep episodes determined by MEQ score: 23:00 to 07:00 (morning types), 01:00 to 09:00 (evening types), or midnight to 08:00 (neither type). Then, one week in lab: original fixed sleep times for the first 2 nights (D2 to D3). DL (under 15 lux) on day 2, 50 lux on day 3, and below 2 lux during sleep. Simulated night work from midnight to 08:00 during the next 4 nights (D4 to D7; 50 lux during the first 3 nights and below 15 lux on the fourth night). Daytime sleep from 09:00 to 17:00. Daytime light profiles the first 3 d of simulated night work (D4 to D6). Participants were allowed 3 h sleep in the middle of D7. DL (<15 lux) on day 2 and during the last 24 h in the lab. Delay group: moderate "outdoor" light (400 lux) from 08:00 to 09:00, sleep from 09:00 to 17:00, moderate indoor light (150 to 300 lux) from 17:00 to 23:00, and dim light (20 lux) from 23:00 to midnight	Stable group: same paradigm but participants received BL (1,800 lux) from 08:00 to 09:00, slept from 09:00 to 17:00, had moderate indoor light (150 lux) from 17:00 to 20:00, and had DL (20 lux) from 20:00 to midnight	Objective: 1. Circadian phase (salivary melatonin measured every 30 min during the 6.5 h preceding bedtime on day 2 and every 30 min during the last 24 h in the lab) 2. Circadian phase (urinary aMT6s excretion measured every 2 h from wake time on day 2 until 22:00 on day 7, except during sleep episodes)	Objective: 1. The delay group showed a phase delay (4.07 h) in dim light melatonin onset relative to baseline by day 7. This delay was 2.37 h larger than in the stable group 2. The delay group showed a phase delay in urinary aMT6s relative to baseline (3.01 h) by days 6 to 7. This delay was 2.21 h larger than in the stable group

Authors	Design	Intervention	Comparison	Outcomes	Results
Olson et al., 2019 ⁵²	Within-participants; 2 conditions (baseline then intervention)	2 to 4 consecutive night shifts (from 19:30 to 07:30 or 23:30 to 07:30) as well as the 1 or 2 d before and after the shifts. Day before first night shift: 1 h delayed bedtime and 40 min of BL before bed. Day of night shifts: slept in, light avoidance (sunglasses) after waking, late nap (if needed), and 40 min of BL before work. After night shifts: light avoidance until sleep and dark sleeping environment. No sunglasses after the final night shift and shortened sleep (to transition back to day shifts)	2 to 4 consecutive night shifts as well as the 1 or 2 d before and after those shifts without any intervention	Subjective: 1. Fatigue (Daily Fatigue Short Form) 2. Sleepiness (Karolinska Sleepiness Scale) 3. Mood (International Positive And Negative Affect Schedule Short Form) 4. Sleep quality (Sleep Quality Scale) 5. Sleep duration (sleep diary) 6. Sleep latency (self-report) 7. Work-related errors and near-errors (self-report)	Subjective: 1. Less fatigue increase during intervention (0.24, 95% CI [-0.62, 1.10]; baseline: 2.20 [1.41, 3.04]) 2. Similar increases in sleepiness in both conditions (intervention: 0.33 [-0.00, 0.65]; baseline: 0.51 [0.14, 0.91]) 3. Smaller reduction in positive mood during intervention (-0.79 [-1.41, -0.18]; baseline: -2.25 [-2.86, -1.58]). No change in negative mood 4. Smaller decrease in sleep quality during intervention (-0.02 [-0.29, 0.29]; baseline: -0.72 [-0.99, -0.46]) 5. Smaller decrease in sleep duration during intervention (-0.85 [-1.61, -0.15] h per 12-h period; baseline: -1.49 [-2.11, -0.79] h) 6. No change in relative sleep latency during intervention (-0.99 [-3.24, 1.23] min; baseline: 0.03 [-3.06, 3.18] min) 7. Fewer work errors or near-errors during intervention (5 errors; baseline: 13)

Comparison group

We aimed to compare the bright light intervention to a condition that would allow us to isolate the effects of evening light alone or in combination with additional phase delaying strategies. Thus, our comparison of interest involved a condition in which participants were not exposed to any bright light in the evening (between 16:00 and 22:00). We made two exceptions to this criterion, which were the final two deviations from the registered protocol. One study used a dim light control condition with an intensity of 200 lux in the evening,⁵⁵ which would have matched our broad definition of bright light (> 100 lux). However, since their bright light condition was more intense (2,500 lux), we accepted the 200 lux as a valid comparison group. Another comparison group²⁷ received light

exposure (150 lux) from 17:00 to 20:00, which was meant to replicate typical daylight patterns and thus mimic a baseline condition. Again, because the intervention group received brighter light (300 lux), we accepted this baseline condition as a comparison group.

Three of the five studies used within-participant comparisons^{52,54,55} with washout periods ranging from one to approximately three weeks. The comparison groups included a baseline phase,⁵² a dim light condition,⁵⁵ a combination of a baseline phase with a condition simulating typical light exposure patterns,²⁷ and bright light given at a different time.^{53,54} For these last two studies, we only included data up until the start of the light exposure in the comparison group. Both comparison groups received light exposure from 04:00 to 08:00; excluding the data after 04:00 allowed us to isolate the effects of evening light.

Outcomes

See Table 3 for details regarding the outcome measures and results.

Physiological indicators of circadian phase delays Four of the five studies assessed phase delays using either body temperature,^{54,55} melatonin,²⁷ or both.⁵³ This was the only outcome category that included strictly objective measures and effect sizes for each outcome. Tzischinsky and Lavie⁵⁵ found a phase delay in oral temperature, while Foret and colleagues⁵⁴ found no change in rectal temperature. Daurat and colleagues⁵³ found a reduction in plasma melatonin during the evening light exposure. Finally, relative to the baseline and control group, Dumont and colleagues²⁷ reported a delay in the salivary dim light melatonin onset and in a urinary melatonin metabolite (aMT6s). Overall, we categorised the effects of evening light as favourable: 86% of the interpretable results showed a phase delay or a positive acute effect.

Sleep Two of the studies assessed different aspects of sleep^{52,55} using self-report measures and physiological (EEG) assessments. Tzischinsky and Lavie⁵⁵ found a phase delay of the sleep gate (i.e., the steepest increase in sleep propensity), increased morning sleep propensity, and increases in both stage 2 sleep and total sleep time between 21:00 and 23:00. However, they did not find differences in stage 1 nor stage 3/4 sleep. Olson and colleagues⁵² found improvements in sleep quality and duration but no change in sleep latency. Overall, the effects of evening light on sleep were rated as favourable: 67% of the effects were beneficial while the rest had no impact.

Sleepiness/fatigue Four of the five studies measured sleepiness, alertness, or fatigue. Two studies assessed sleepiness using self-report⁵² or EEG,⁵³ three studies measured alertness (two of which used the same questionnaire),^{53–55} and two studies measured self-reported fatigue.^{52,55} Tzischinsky and Lavie⁵⁵ found no change in alertness nor fatigue. Similarly, Daurat and colleagues⁵³ reported no change in alertness during the light exposure and no impact on physiological or self-reported sleepiness. Foret and colleagues⁵⁴ likewise found no acute effect of evening light on alertness. Finally, although Olson and colleagues⁵² reported reductions in fatigue, they did not find a change in sleepiness. We thus concluded that evening light had no impact on this category: 88% of the outcomes showed no effect.

Performance Three studies assessed performance using laboratory or real-world measures. During evening light exposure, Daurat and colleagues⁵³ found improvements in three memory and attention tasks (3-letter Search and Memory [SAM] task, 5-letter SAM task, and letter cancellation). Foret and colleagues⁵⁴ also found improvements on the 3- and 5-letter SAM tasks, but no difference on the 1-letter version. Further, Olson and colleagues⁵² reported reductions in work-related errors. Overall, we concluded that evening light had a favourable impact on performance: 85% of the reported outcomes showed positive effects.

Mood Two studies reported results for mood, which was measured using different questionnaires.^{52,55} This was the only category that included only subjective measures. Tzischinsky and Lavie⁵⁵ found a phase delay in negative mood but no change in positive mood. In contrast, Olson and colleagues⁵² found an increase in positive mood but no change in negative mood. We therefore concluded that the effects on mood were mixed.

Quality of evidence The risk of bias was rated as very serious for all five outcomes. Inconsistency was low for all outcomes except mood, which was rated as high. No outcomes were downgraded for indirectness, whereas all outcomes were downgraded by one or two points for imprecision and publication bias. Our overall confidence in the results was moderate for physiological indicators of phase delay; low for sleep, sleepiness/fatigue, and performance; and very low for mood. See Tables S1 and S2 for more detail.

Discussion

Many shift workers experience circadian misalignment which can impact health and work performance. Bright light exposure at night can reduce this misalignment, though it is limited by feasibility and safety concerns. We investigated evening light as a potential alternative and conducted, to our knowledge, the first systematic review on the topic. Across five studies, we saw favourable outcomes for circadian phase delays, sleep, and performance. There were mixed effects for mood, no changes in sleepiness, and no negative effects. Overall, the benefits of evening light are tentative yet promising.

Physiological indicators Evening light produced phase delays as indicated by both melatonin and body temperature. These delays are consistent with experimental data of phase response curves. Light exposure can have a delaying effect starting around 3 h before the dim light melatonin onset,⁵⁶ which normally occurs between 19:30 and 22:00.⁵⁷

Given that the 3 h preceding this onset often occur in the evening, we would expect the light times included in our review to cause phase delays. This evidence also aligns with studies showing that light avoidance in the evening can reduce phase delays.⁵⁸ Our confidence in this category of results was medium, making it the most robust in the review.

Sleep Evening light also had a favourable impact on sleep duration and quality. Other intervention studies using timed light exposure at night similarly found increases in sleep duration.^{22,59,60} The increase in subjective sleep quality is in line with studies showing objective increases in sleep efficiency from timed light exposure in shift workers.⁶⁰ One study in our review also found a phase delay in sleep propensity,⁵⁵ consistent with the delays seen in other physiological indicators. However, the variety of sleep-related outcomes across the two relevant studies prevented us from drawing any general conclusions and our confidence remained low.

Sleepiness/fatigue We saw no effect on physiological or subjective sleepiness, while one study found a positive effect on fatigue. Light exposure at night has been shown to have positive effects in some studies^{61,62} but not in others.⁶³ A Cochrane review found mixed and inconclusive results regarding the effects of night-time light on sleepiness and fatigue during the light exposure or the next day.⁶⁴ It is therefore unclear which conditions are needed for the light exposure to be beneficial. For example, people may not be sufficiently sleepy in the evening to experience the immediate alerting effects of light exposure.⁵³ Given the heterogeneity of the measures and the overall quality of the evidence, our confidence in these results was low.

Performance Evening light improved performance on both laboratory and real-world outcomes. This finding is consistent with other studies showing that bright light exposure during night shifts can improve performance on various laboratory tasks,^{65–67} although

some negative effects such as increased motor errors have also been reported.⁶⁸ Overall, our confidence in these results was also low.

Mood Research has shown that both positive and negative affect follow a circadian rhythm.⁶⁹ Since disruptions to either circadian rhythms or sleep can impair mood,^{10,70} improving these factors could theoretically be beneficial;^{10,70} however, the two studies in our review showed inconsistent results. Similarly mixed results have been found in studies of night-time light exposure.^{26,65,71,72} Due to the inconsistent findings and low quality of the evidence, our confidence in these results was very low.

Implications and limitations

Studies have shown that night-time light exposure followed by light avoidance in the morning can promote adaptation to night shifts.^{5,17} Perhaps the largest benefit of evening light over night-time light exposure is its feasibility for shift workers. Receiving light at night would require institutional buy-in and light equipment at work, timing the light may require phase estimation of co-workers to prevent inadvertent phase advances, and the light equipment may need a separate area to avoid disturbing others. If evening light can promote phase delays to improve circadian alignment, receiving light exposure before a night shift (and avoiding light the next morning) could be a feasible and effective intervention for shift workers.⁵² Our review suggests that evening light may have at least some of the benefits of night-time light exposure.

Still, our results must be interpreted with caution. We had five eligible studies, only three of which directly studied circadian adaptation in the context of shift work.^{27,52} The studies were difficult to compare given that they varied in their outcomes, control groups, light duration, and light intensity. In addition, the light intensity was provided in lux measured at the source rather than in melanopic lux;⁷³ this newer measure better predicts circadian effects by quantifying how light is received on the retina.⁷⁴

Further, we had a broad definition of evening light, ranging from 16:00 to 22:00 (provided that the light ended before midnight). Although the majority of the light exposure took place in the evening, the timing ranged from 17:00 to midnight, which made it difficult to isolate the impact of the evening light. In addition, all of the studies examined the effects of light exposure for under one week: two studied the same night as the light exposure, one had five days of evening light (along with morning light which may have counteracted some of the effects), and two studies looked at four consecutive night shifts. Longer periods of light exposure may have produced larger improvements, since light over several days can have additive effects.²⁷ Finally, the studies were published over a span of two decades and therefore varied in their statistical practices and reporting. Few of the studies reported standardised effect sizes and confidence intervals, which made it difficult to compare the magnitude of the effects within our review or to other studies of night-time light exposure.

More broadly, consistent with the conclusions of the Working Time Society,¹⁷ it remains difficult to make general recommendations about light exposure to promote circadian adaptation in shift workers. Intentionally shifting circadian rhythms to and from night shifts may have unknown long-term health effects. For example, promoting circadian alignment through light exposure may have positive acute effects while potentially increasing circadian dysregulation over time.

Future research

Future studies should examine the safety of bright light in the evening versus at night. Night-time light exposure can lead to headaches, eye strain, and irritable mood; animal studies have also suggested that it can increase chronic disease.⁷⁵ It is currently unknown whether evening light has similar drawbacks. Studies should also examine shift workers with sleep disorders, which we excluded because we were interested in the general

effectiveness of evening light. Other studies have shown benefits in clinical populations; one study found that a combination of evening light and morning light avoidance improved sleep in nurses with clinical levels of insomnia.²⁶ Similarly, studies should look at more demographically diverse populations given individual differences in sensitivity to evening light.⁷⁶ Most of the participants in this review were under 35; one study had participants aged between 23 and 56 but the large majority were in their 20s and 30s.⁵² Because there is conflicting evidence about how circadian adaptation changes across the lifespan,^{77,78} it remains unclear which age groups could most benefit from evening light.

Conclusion

Given the broad consequences of shift work, it is important to find safe and feasible strategies to improve sleep and health. Evening bright light exposure appears to improve both objective and subjective outcomes that are relevant for shift workers, such as circadian adaptation, sleep, and performance. Evening light is thus a potentially promising solution that warrants further investigation.

Practice points

Evening bright light exposure may:

1. delay circadian rhythms to promote adaptation to night shifts,
2. improve sleep as well as performance on laboratory and real-world tasks, and
3. serve as a more feasible alternative to night-time light exposure.

Research agenda

Future research should:

1. isolate the effects of evening light from night-time light exposure,

2. quantify the long-term benefits of evening light for shift workers,
3. assess any short- or long-term adverse effects, and
4. study demographically diverse healthy and clinical populations.

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Supplementary tables

Table S1: GRADE assessment. We interpreted the results based on the direction of the effects rather than the magnitude since effect sizes were rarely reported.

Outcomes	Initial quality	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Large effect	Dose-response	Total	Confidence
Physiological phase delay	High	-2	0	0	-1	-1	0	0	-4	Moderate
Sleep	High	-2	0	0	-2	-1	0	0	-5	Low
Sleepiness/fatigue	High	-2	0	0	-2	-1	0	0	-5	Low
Performance	High	-2	0	0	-2	-1	0	0	-5	Low
Mood	High	-2	-2	0	-1	-1	0	0	-6	Very low

Table S2: GRADE risk of bias assessment.

Authors	Randomisation	Allocation concealment	Blinding	Loss to follow-up	Selective outcome reporting	Other	Limitations
Tzischinsky & Lavie, 1997	Unclear	Unclear	No	8.3%	Missing category search task	No	Very serious
Foret et al., 1998	Yes	Unclear	No	None	Missing EEG and blood sample results	No	Very serious
Daurat et al., 2000	Unclear	Unclear	No	None	Missing mood and logical reasoning	No	Very serious
Dumont et al., 2009	No	No	Unclear	5.3%	Missing compliance with sleep profiles	No	Very serious
Olson et al., 2019	No	No	No	5.7%	Missing step count (measure was faulty)	Unvalidate outcome measure	Very serious