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

Mariève Cyr[†] Despina Z. Artenie[‡] Alain Al Bikaii[§]
David Borsook[¶] Jay A. Olson[||]

Summary

Bright light exposure at night can help shift workers adapt to their 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; increased sleep quality and duration; and improved 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 promising though tentative.

*Preprint (2022-01-30). Corresponding author: J. A. Olson (jay.olson@mail.mcgill.ca).
[†]Faculty of Medicine and Health Sciences, McGill University, Montréal, QC, Canada
[‡]Department of Psychology, Université du Québec à Montréal, QC, Canada
[§]McGill University Health Centre, Montréal, QC, Canada
[¶]Departments of Psychiatry and Radiology, Massachusetts General Hospital, Boston, MA, USA
[||]Department of Psychology, Harvard University, Cambridge, MA, USA

Keywords

circadian rhythms, shift work, circadian misalignment, evening light, light exposure, light therapy

Introduction

Around a quarter of employees in North America[1,2] and Europe[3] are shift workers. Although working outside of typical daytime hours is often necessary,[4] it has been linked with 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 hours 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 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] Beyond these circadian effects, bright light exposure can also temporarily improve alertness and mood.[19,27]

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, light exposure for the shift workers could impair the sleep of patients who already report sleeping poorly.[28] Determining the optimal timing of light exposure presents additional concerns, because the crossover point varies across individuals.[29] 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 psychological and physical health;[30–32] it is a risk factor for obesity and cancer,[30–32] with animal studies supporting these findings.[31] Rodents show impaired glucose tolerance,[33,34] increases in tumour growth, and slower responses to breast cancer treatments.[35,36] Further, people living in areas with more night-time light exposure are more likely to have depressive symptoms and suicidal behaviour.[37] 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 would be bright light in 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 unlikely to cause accidental 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 phase delays. Similarly, guidelines to reduce circadian misalignment often recommend night-time light exposure while evening light is relatively ignored (with some exceptions[17]). To assess the potential benefits of evening light exposure for 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 trials[38] 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 across 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,[39] 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.
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.

#	Search term
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 hours). 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.[40,41] This period typically falls within the delay portion of the human phase response curve.[42] We chose biological, psychological, and behavioural outcomes relevant to circadian rhythms based on previous studies.[5,21,26,43] 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 fit these criteria.

Two raters then ensured that none of the studies used light exposure (>100 lux) past midnight in their evening light condition. 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 article[44] 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.

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,[45,46] 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 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

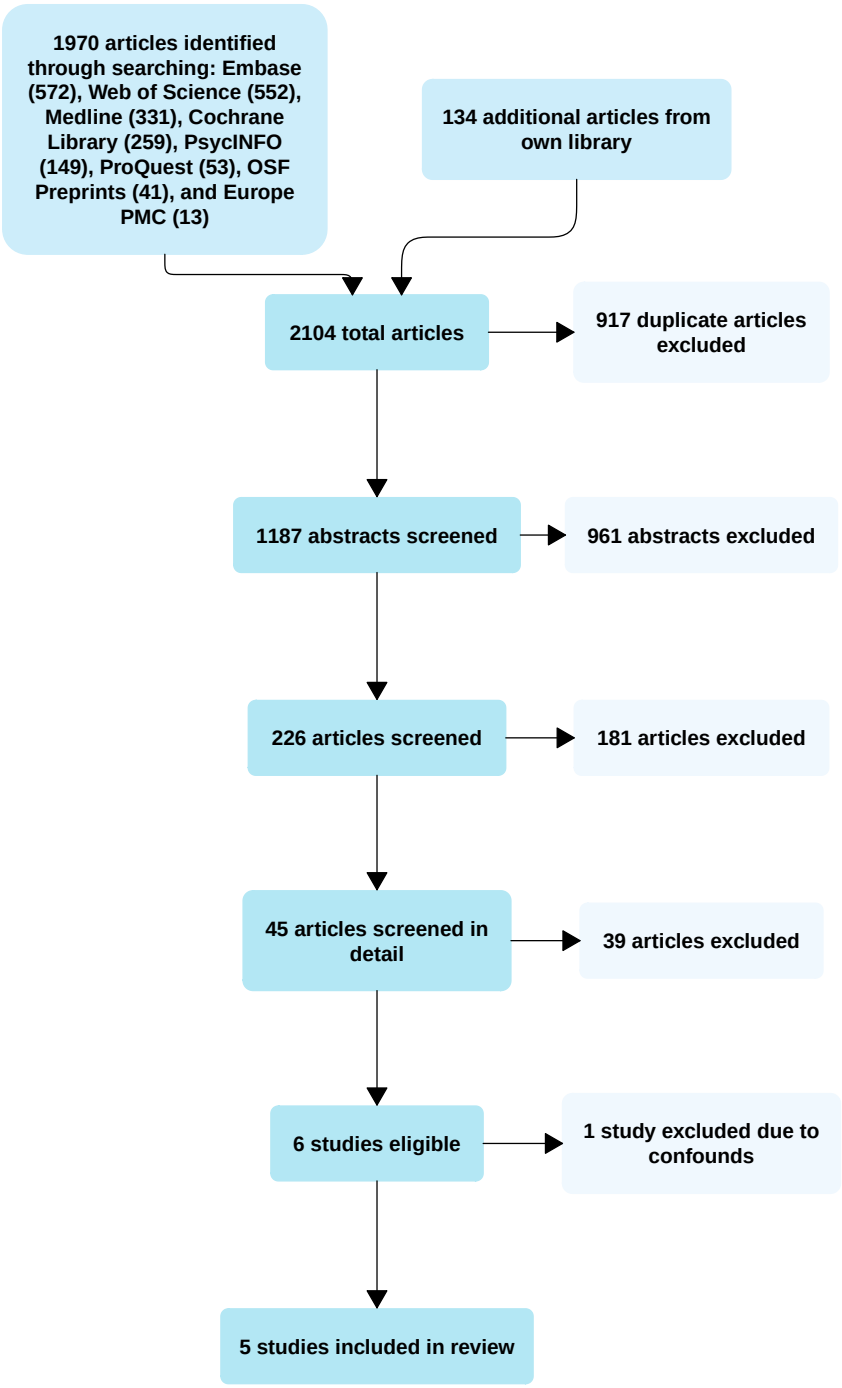

Figure 1: Study screening procedure.

no difference from the comparison group. Categorisations were classified by two raters 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.[47] 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.[48] The rest of the sample was composed of healthy volunteers who were not shift workers.[49–52] Participants ranged from 19 to 58 y old,[48,49] with the majority being under 35. Half of the participants (52%) were women, excluding one study (n = 8) that did not

report sex. See Table 2 for additional study details.

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

Authors	Country	Season	Setting	Population	Sample	Age (y)	Light time	Light source (lux)
Tzischinsky & Lavie, 1997[52]	Israel	Summer + winter	Lab + home actigraphy	Healthy volunteers	12 men (11 completed both conditions)	23.5 ± 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[50]	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[49]	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[51]	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 ± 4.6; Control: 26.6 ± 4.2	17:00 to 23:00	Ceiling light; BL = 1800, Moderate = 150 to 300, DL = 20
Olson et al., 2019[48]	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 (range: 30 to 235), 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[49,50,52] or in combination with other phase delaying strategies such as light avoidance or altered sleep times.[48,51] The timing of the bright light varied from around 17:00 to midnight. One study[52] adjusted the light exposure timing to the season, and one field study[48] 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 hours from 20:00 to midnight[49,50] and the shortest was an average of 50 minutes.[48] The majority of studies used light fixtures, but their intensity ranged 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 ± 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[52]	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[53] **2.** Fatigue[53] **3.** Alertness[53]	**Objective:** **1.** Phase delay of sleep gate after BL from 23:04 ± 134 min to 23:54 ± 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 ± 100 min to 16:53 ± 150 min **Subjective:** **1.** Delay in the acrophase of negative mood in BL condition from 01:20 ± 02:36 to 03:32 ± 01:38. No change in positive mood **2.** No change in fatigue **3.** No change in alertness

Authors	Design	Intervention	Comparison	Outcomes	Results
Foret et al., 1998[50]	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
Daurat et al., 2000[49]	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[51]	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 days 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 (salivatory 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[48]	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 days 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 days 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 [-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,[52] 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 group[51] 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[48,50,52] with washout periods ranging from one to approximately three weeks. The comparison groups included a baseline phase,[48] a dim light condition,[52] a combination of a baseline phase with a condition simulating typical light exposure patterns,[51] and bright light given at a different time.[49,50] 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 about the outcome measures and results.

Physiological indicators of circadian phase delays Four of the five studies assessed phase delays using either body temperature,[50,52] melatonin,[51] or both.[49] This was the only outcome category that included strictly objective measures and effect sizes for each outcome. Tzischinsky and Lavie[52] found a phase delay in oral temperature, while Foret and colleagues[50] found no change in rectal temperature. Daurat and colleagues[49] found a reduction in plasma melatonin during the evening light exposure. Finally, relative to the baseline and control group, Dumont and colleagues[51] 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[48,52] using self-report measures and physiological (EEG) assessments. Tzischinsky and Lavie[52] found a phase delay of the sleep gate (i.e., the steepest increase in sleep propensity), increased morning sleep propensity, and changes 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 colleagues[48] 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-report[48] or EEG,[49] three studies measured alertness (two of which used the same questionnaire),[49,50,52] and two studies measured self-reported fatigue.[48,52] Tzischinsky and Lavie[52] found no change in alertness nor fatigue. Similarly, Daurat and colleagues[49] reported no change in alertness during the light exposure and no impact on physiological or self-reported sleepiness. Foret and colleagues[50] likewise found no acute effect of evening light on alertness. Finally, although Olson and colleagues[48] 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 colleagues[49] found improvements in three memory and attention tasks (3-letter Search and Memory [SAM], 5-letter SAM, and letter cancellation). Foret and colleagues[50] also found improvements on the 3- and 5-letter SAM tasks, but no difference on the 1-letter version. Further, Olson and colleagues[48] 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.[48,52] This was the only category that included only subjective measures. Tzischinsky and Lavie[52] found a phase delay in negative mood but no change in positive mood. In contrast, Olson and colleagues[48] 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,[54] which normally occurs between 19:30 and 22:00.[55]

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.[56] 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.[22,57,58] The increase in subjective sleep quality is in line with studies showing objective increases in sleep efficiency from timed light exposure in shift workers.[58] One study in our review also found a phase delay in sleep propensity,[52] 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[59,60] but not in others.[61] 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.[62] 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.[49] 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,[63–65] although

some negative effects such as increased motor errors have also been reported.[66] Overall, our confidence in these results was also low.

Mood Research has shown that both positive and negative affect follow circadian rhythms.[67] Since disruptions to either circadian rhythms or sleep can impair mood,[10,68] improving these factors could theoretically be beneficial;[10,68] however, the two studies in our review showed inconsistent results. Similarly mixed results have been found in studies of night-time light exposure.[26,63,69,70] 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.[48] 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.[48,51] The studies varied their duration and intensity of light exposure as well as their subsequent light avoidance; they also differed in the types of control groups and outcomes measured. 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. 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.[51] 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 it can increase chronic disease.[71] 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. 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.[48] Because there is conflicting evidence about how circadian adaptation changes across the lifespan,[72,73] 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. cause circadian phase delays 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.

References

1. Centers for Disease Control and Prevention. Work organization characteristics (NHIS-OHS) charts. NIOSH Worker Health Charts [Internet]. 2015; Available from: https://wwwn.cdc.gov/NIOSH-WHC/chart/ohs-workorg/WORK?OU=WORKSCHD_RCD&T=I&V=R2

2. Williams C. Work-life balance of shift workers. Statistics Canada: Perspectives on Labour and Income. 2008;9(8):5–16.

3. Parent-Thirion A, Biletta I, Cabrita J, Llave OV, Vermeylen G, Wilczynska A, et al. 6th European working conditions survey: 2017 update. Publications Office of the European Union; 2017.

4. Oexman RD, Knotts TL, Koch J. Working while the world sleeps: A consideration of sleep and shift work design. Employee Responsibilities and Rights Journal [Internet]. 2002;14(4):145–57. Available from: https://doi.org/10.1023%2Fa%3A1021189305076

*5. Smith MR, Eastman CI. Shift work: Health, performance and safety problems, traditional countermeasures, and innovative management strategies to reduce circadian misalignment. Nature and Science of Sleep [Internet]. 2012 Sep;111. Available from: https://doi.org/10.2147%2Fnss.s10372

6. Härmä M, Karhula K, Puttonen S, Ropponen A, Koskinen A, Ojajärvi A, et al. Shift work with and without night work as a risk factor for fatigue and changes in sleep length: A cohort study with linkage to records on daily working hours. Journal of Sleep Research [Internet]. 2018 Jan;28(3):e12658. Available from: https://doi.org/10.1111%2Fjsr.12658

*7. James SM, Honn KA, Gaddameedhi S, Dongen HPAV. Shift work: Disrupted circadian

rhythms and sleep — implications for health and well-being. Current Sleep Medicine Reports [Internet]. 2017 Apr;3(2):104–12. Available from: https://doi.org/10.1007%2Fs40675-017-0071-6

8. Kazemi R, Haidarimoghadam R, Motamedzadeh M, Golmohamadi R, Soltanian A, Zoghipaydar MR. Effects of shift work on cognitive performance, sleep quality, and sleepiness among petrochemical control room operators. Journal of Circadian Rhythms [Internet]. 2016 Feb;14(1). Available from: https://doi.org/10.5334%2Fjcr.134

9. Killgore WDS. Effects of sleep deprivation on cognition. In: Progress in brain research [Internet]. Elsevier; 2010. pp. 105–29. Available from: https://doi.org/10.1016%2Fb978-0-444-53702-7.00007-5

10. Watling J, Pawlik B, Scott K, Booth S, Short MA. Sleep loss and affective functioning: More than just mood. Behavioral Sleep Medicine [Internet]. 2016 May;15(5):394–409. Available from: https://doi.org/10.1080%2F15402002.2016.1141770

11. Åkerstedt T, Wright KP. Sleep loss and fatigue in shift work and shift work disorder. Sleep Medicine Clinics [Internet]. 2009 Jun;4(2):257–71. Available from: https://doi.org/10.1016%2Fj.jsmc.2009.03.001

12. Wagstaff AS, Lie J-AS. Shift and night work and long working hours — a systematic review of safety implications. Scandinavian Journal of Work, Environment & Health [Internet]. 2011 Feb;37(3):173–85. Available from: https://doi.org/10.5271%2Fsjweh.3146

13. Lee ML, Howard ME, Horrey WJ, Liang Y, Anderson C, Shreeve MS, et al. High risk of near-crash driving events following night-shift work. Proceedings of the National Academy of Sciences [Internet]. 2015 Dec;113(1):176–81. Available from: https://doi.org/10.1073%2Fpnas.1510383112

14. Stutts JC, Wilkins JW, Osberg JS, Vaughn BV. Driver risk factors for sleep-related

crashes. Accident Analysis & Prevention [Internet]. 2003 May;35(3):321–31. Available from: https://doi.org/10.1016%2Fs0001-4575%2802%2900007-6

15. Brown DL, Feskanich D, Sanchez BN, Rexrode KM, Schernhammer ES, Lisabeth LD. Rotating night shift work and the risk of ischemic stroke. American Journal of Epidemiology [Internet]. 2009 Apr;169(11):1370–7. Available from: https://doi.org/10.1093%2Faje%2Fkwp056

16. Cordina-Duverger E, Menegaux F, Popa A, Rabstein S, Harth V, Pesch B, et al. Night shift work and breast cancer: A pooled analysis of population-based casecontrol studies with complete work history. European Journal of Epidemiology [Internet]. 2018 Feb;33(4):369–79. Available from: https://doi.org/10.1007%2Fs10654-018-0368-x

*17. Lowden A, Öztürk G, Reynolds A, Bjorvatn B. Working time society consensus statements: Evidence based interventions using light to improve circadian adaptation to working hours. Industrial Health [Internet]. 2019;57(2):213–27. Available from: https://doi.org/10.2486%2Findhealth.sw-9

18. Bhadra U, Thakkar N, Das P, Bhadra MP. Evolution of circadian rhythms: From bacteria to human. Sleep Medicine [Internet]. 2017 Jul;35:49–61. Available from: https://doi.org/10.1016%2Fj.sleep.2017.04.008

19. Blume C, Garbazza C, Spitschan M. Effects of light on human circadian rhythms, sleep and mood. Somnologie [Internet]. 2019 Aug;23(3):147–56. Available from: https://doi.org/10.1007%2Fs11818-019-00215-x

20. Gooley JJ. Light resetting and entrainment of human circadian rhythms. In: Biological timekeeping: Clocks, rhythms and behaviour [Internet]. Springer India; 2017. pp. 297–313. Available from: https://doi.org/10.1007%2F978-81-322-3688-7_14

21. Boivin DB, Boudreau P. Impacts of shift work on sleep and circadian rhythms. Pathologie Biologie [Internet]. 2014 Oct;62(5):292–301. Available from: https://doi.or

g/10.1016%2Fj.patbio.2014.08.001

22. Boivin DB, Boudreau P, James FO, Kin NMKNY. Photic resetting in night-shift work: Impact on nurses' sleep. Chronobiology international. 2012 Jun;29(5):619–28.

23. Suzuki K, Ohida T, Kaneita Y, Yokoyama E, Miyake T, Harano S, et al. Mental health status, shift work, and occupational accidents among hospital nurses in japan. Journal of Occupational Health [Internet]. 2004 Nov;46(6):448–54. Available from: https://doi.org/10.1539%2Fjoh.46.448

24. Boivin DB, James FO. Circadian adaptation to night-shift work by judicious light and darkness exposure. Journal of Biological Rhythms. 2002;17(6):556–67.

25. Crowley SJ, Lee C, Tseng CY, Fogg LF, Eastman CI. Complete or partial circadian re-entrainment improves performance, alertness, and mood during night-shift work. Sleep [Internet]. 2004 Sep;27(6):1077–87. Available from: https://doi.org/10.1093%2Fsleep%2F27.6.1077

*26. Huang L-B, Tsai M-C, Chen C-Y, Hsu S-C. The effectiveness of light/dark exposure to treat insomnia in female nurses undertaking shift work during the evening/night shift. Journal of Clinical Sleep Medicine. 2013;9(07):641–6.

27. Souman JL, Tinga AM, Pas SF te, Ee R van, Vlaskamp BNS. Acute alerting effects of light: A systematic literature review. Behavioural Brain Research [Internet]. 2018 Jan;337:228–39. Available from: https://doi.org/10.1016%2Fj.bbr.2017.09.016

28. Elliott R, McKinley S, Cistulli P, Fien M. Characterisation of sleep in intensive care using 24-hour polysomnography: An observational study. Critical Care [Internet]. 2013;17(2):R46. Available from: https://doi.org/10.1186%2Fcc12565

29. Lack. Chronotype differences in circadian rhythms of temperature, melatonin, and sleepiness as measured in a modified constant routine protocol. Nature and Science of Sleep [Internet]. 2009 Nov;1. Available from: https://doi.org/10.2147%2Fnss.s6234

30. Hansen J, Stevens RG. Case-control study of shift-work and breast cancer risk in danish nurses: Impact of shift systems. European Journal of Cancer [Internet]. 2012 Jul;48(11):1722–9. Available from: https://doi.org/10.1016%2Fj.ejca.2011.07.005

31. Russart KLG, Nelson RJ. Light at night as an environmental endocrine disruptor. Physiology & Behavior [Internet]. 2018 Jun;190:82–9. Available from: https://doi.org/10.1016%2Fj.physbeh.2017.08.029

32. Rybnikova NA, Haim A, Portnov BA. Does artificial light-at-night exposure contribute to the worldwide obesity pandemic? International Journal of Obesity [Internet]. 2016 Jan;40(5):815–23. Available from: https://doi.org/10.1038%2Fijo.2015.255

33. Figueiro MG, Radetsky L, Plitnick B, Rea MS. Glucose tolerance in mice exposed to lightdark stimulus patterns mirroring dayshift and rotating shift schedules. Scientific Reports [Internet]. 2017 Jan;7(1). Available from: https://doi.org/10.1038%2Fsrep40661

34. Opperhuizen A-L, Stenvers DJ, Jansen RD, Foppen E, Fliers E, Kalsbeek A. Light at night acutely impairs glucose tolerance in a time-, intensity- and wavelength-dependent manner in rats. Diabetologia [Internet]. 2017 Apr;60(7):1333–43. Available from: https://doi.org/10.1007%2Fs00125-017-4262-y

35. Blask DE, Brainard GC, Dauchy RT, Hanifin JP, Davidson LK, Krause JA, et al. Melatonin-depleted blood from premenopausal women exposed to light at night stimulates growth of human breast cancer xenografts in nude rats. Cancer Research [Internet]. 2005 Dec;65(23):11174–84. Available from: https://doi.org/10.1158%2F0008-5472.can-05-1945

36. Dauchy RT, Xiang S, Mao L, Brimer S, Wren MA, Yuan L, et al. Circadian and melatonin disruption by exposure to light at night drives intrinsic resistance to tamoxifen therapy in breast cancer. Cancer Research [Internet]. 2014 Jul;74(15):4099–

110. Available from: https://doi.org/10.1158%2F0008-5472.can-13-3156

37. Min J-y, Min K-b. Outdoor light at night and the prevalence of depressive symptoms and suicidal behaviors: A cross-sectional study in a nationally representative sample of korean adults. Journal of Affective Disorders [Internet]. 2018 Feb;227:199–205. Available from: https://doi.org/10.1016%2Fj.jad.2017.10.039

38. Glanville J, Kotas E, Featherstone R, Dooley G. Which are the most sensitive search filters to identify randomized controlled trials in MEDLINE? Journal of the Medical Library Association [Internet]. 2020 Oct;108(4). Available from: https://doi.org/10.5195%2Fjmla.2020.912

39. Lajeunesse MJ. Facilitating systematic reviews, data extraction and meta-analysis with the metagear package for R. Fitzjohn R, editor. Methods in Ecology and Evolution [Internet]. 2015 Oct;7(3):323–30. Available from: https://doi.org/10.1111%2F2041-210x.12472

40. National Oceanic & Atmospheric Administration. Sunset table for 2022 [Internet]. Global Monitoring Laboratory. 2022. Available from: https://gml.noaa.gov/grad/solcalc/table.php?lat=53.533/&lon=-113.494/&year=2022

41. Mira-Pérez J. The last sunset on mainland europe. Cartography and Geographic Information Science [Internet]. 2016 Nov;45(1):56–61. Available from: https://doi.org/10.1080%2F15230406.2016.1249409

42. Khalsa SBS, Jewett ME, Cajochen C, Czeisler CA. A phase response curve to single bright light pulses in human subjects. The Journal of Physiology [Internet]. 2003 Jun;549(3):945–52. Available from: https://doi.org/10.1113%2Fjphysiol.2003.040477

43. Richter K, Acker J, Adam S, Niklewski G. Prevention of fatigue and insomnia in shift workers—a review of non-pharmacological measures. EPMA Journal [Internet]. 2016 Aug;7(1). Available from: https://doi.org/10.1186%2Fs13167-016-0064-4

44. Gil-Lozano M, Hunter PM, Behan L-A, Gladanac B, Casper RF, Brubaker PL. Short-term sleep deprivation with nocturnal light exposure alters time-dependent glucagon-like peptide-1 and insulin secretion in male volunteers. American Journal of Physiology-Endocrinology and Metabolism [Internet]. 2016 Jan;310(1):E41–50. Available from: https://doi.org/10.1152%2Fajpendo.00298.2015

45. Bolster L, Rourke L. The effect of restricting residents' duty hours on patient safety, resident well-being, and resident education: An updated systematic review. Journal of Graduate Medical Education [Internet]. 2015 Sep;7(3):349–63. Available from: https://doi.org/10.4300%2Fjgme-d-14-00612.1

46. Patterson PD, Liszka MK, Mcilvaine QS, Nong L, Weaver MD, Turner RL, et al. Does the evidence support brief (<30-mins), moderate (31–60-mins), or long duration naps (61+ mins) on the night shift? A systematic review. Sleep Medicine Reviews [Internet]. 2021 Oct;59:101509. Available from: https://doi.org/10.1016%2Fj.smrv.2021.101509

47. Guyatt G, Oxman AD, Akl EA, Kunz R, Vist G, Brozek J, et al. GRADE guidelines: 1. Introduction—GRADE evidence profiles and summary of findings tables. Journal of Clinical Epidemiology [Internet]. 2011 Apr;64(4):383–94. Available from: https://doi.org/10.1016%2Fj.jclinepi.2010.04.026

48. Olson JA, Artenie DZ, Cyr M, Raz A, Lee V. Developing a light-based intervention to reduce fatigue and improve sleep in rapidly rotating shift workers. Chronobiology International [Internet]. 2019 Dec;37(4):573–91. Available from: https://doi.org/10.1080%2F07420528.2019.1698591

49. Daurat A, Foret J, Benoit O, Mauco G. Bright light during nighttime: Effects on the circadian regulation of alertness and performance. Neurosignals [Internet]. 2000;9(6):309–18. Available from: https://doi.org/10.1159%2F000014654

50. Foret J, Daurat A, Tirilly G. Effect of bright light at night on core temperature,

subjective alertness and performance as a function of exposure time. Scandinavian Journal of Work, Environment & Health. 1998;115–20.

51. Dumont M, Blais H, Roy J, Paquet J. Controlled patterns of daytime light exposure improve circadian adjustment in simulated night work. Journal of Biological Rhythms [Internet]. 2009 Sep;24(5):427–37. Available from: https://doi.org/10.1177%2F0748730409343795

52. Tzischinsky O, Lavie P. The effects of evening bright light on next-day sleep propensity. Journal of Biological Rhythms [Internet]. 1997 Jun;12(3):259–65. Available from: https://doi.org/10.1177%2F074873049701200307

53. Monk TH. A visual analogue scale technique to measure global vigor and affect. Psychiatry Research [Internet]. 1989 Jan;27(1):89–99. Available from: https://doi.org/10.1016%2F0165-1781%2889%2990013-9

*54. Hilaire MAS, Gooley JJ, Khalsa SBS, Kronauer RE, Czeisler CA, Lockley SW. Human phase response curve to a 1 h pulse of bright white light. The Journal of Physiology [Internet]. 2012 Jun;590(13):3035–45. Available from: https://doi.org/10.1113%2Fjphysiol.2012.227892

55. Pandi-Perumal SR, Smits M, Spence W, Srinivasan V, Cardinali DP, Lowe AD, et al. Dim light melatonin onset (DLMO): A tool for the analysis of circadian phase in human sleep and chronobiological disorders. Progress in Neuro-Psychopharmacology and Biological Psychiatry [Internet]. 2007 Jan;31(1):1–11. Available from: https://doi.org/10.1016%2Fj.pnpbp.2006.06.020

56. Hester L, Dang D, Barker CJ, Heath M, Mesiya S, Tienabeso T, et al. Evening wear of blue-blocking glasses for sleep and mood disorders: A systematic review. Chronobiology International [Internet]. 2021 May;38(10):1375–83. Available from: https://doi.org/10.1080%2F07420528.2021.1930029

57. Sasseville A, Hébert M. Using blue-green light at night and blue-blockers during the day to improves adaptation to night work: A pilot study. Progress in Neuro-Psychopharmacology and Biological Psychiatry [Internet]. 2010 Oct;34(7):1236–42. Available from: https://doi.org/10.1016%2Fj.pnpbp.2010.06.027

58. Yoon I-Y, Jeong D-U, Kwon K-B, Kang S-B, Song B-G. Bright light exposure at night and light attenuation in the morning improve adaptation of night shift workers. Sleep [Internet]. 2002;25(3):351–6. Available from: https://doi.org/10.1093%2Fsleep%2F25.3.351

59. Karchani M, Kakooei H, Yazdi Z, Zare M. Do bright-light shock exposures during breaks reduce subjective sleepiness in night workers? Sleep and Biological Rhythms [Internet]. 2011 Apr;9(2):95–102. Available from: https://doi.org/10.1111%2Fj.1479-8425.2011.00490.x

60. Dawson D, Campbell SS. Timed exposure to bright light improves sleep and alertness during simulated night shifts. Sleep [Internet]. 1991 Nov;14(6):511–6. Available from: https://doi.org/10.1093%2Fsleep%2F14.6.511

61. Bjorvatn B, Pallesen S, Waage S, Thun E, Blytt KM. The effects of bright light treatment on subjective and objective sleepiness during three consecutive night shifts among hospital nurses a counter-balanced placebo-controlled crossover study. Scandinavian Journal of Work, Environment & Health [Internet]. 2020 Oct;47(2):145–53. Available from: https://doi.org/10.5271%2Fsjweh.3930

*62. Slanger TE, Gross JV, Pinger A, Morfeld P, Bellinger M, Duhme A-L, et al. Person-directed, non-pharmacological interventions for sleepiness at work and sleep disturbances caused by shift work. Cochrane Database of Systematic Reviews [Internet]. 2016 Aug;2016(8). Available from: https://doi.org/10.1002%2F14651858.cd010641.pub2

63. Smith MR, Fogg LF, Eastman CI. Practical interventions to promote circadian adaptation to permanent night shift work: Study 4. Journal of Biological Rhythms [Internet]. 2009 Apr;24(2):161–72. Available from: https://doi.org/10.1177%2F0748730409332068

64. Motamedzadeh M, Golmohammadi R, Kazemi R, Heidarimoghadam R. The effect of blue-enriched white light on cognitive performances and sleepiness of night-shift workers: A field study. Physiology & Behavior [Internet]. 2017 Aug;177:208–14. Available from: https://doi.org/10.1016%2Fj.physbeh.2017.05.008

65. Kretschmer V, Schmidt K-H, Griefahn B. Bright light effects on working memory, sustained attention and concentration of elderly night shift workers. Lighting Research & Technology [Internet]. 2011 Sep;44(3):316–33. Available from: https://doi.org/10.1177%2F1477153511418769

66. Griepentrog JE, Labiner HE, Gunn SR, Rosengart MR. Bright environmental light improves the sleepiness of nightshift ICU nurses. Critical Care [Internet]. 2018 Nov;22(1). Available from: https://doi.org/10.1186%2Fs13054-018-2233-4

67. Emens JS, Berman AM, Thosar SS, Butler MP, Roberts SA, Clemons NA, et al. Circadian rhythm in negative affect: Implications for mood disorders. Psychiatry Research [Internet]. 2020 Nov;293:113337. Available from: https://doi.org/10.1016%2Fj.psychres.2020.113337

68. Walker WH, Walton JC, DeVries AC, Nelson RJ. Circadian rhythm disruption and mental health. Translational Psychiatry [Internet]. 2020 Jan;10(1). Available from: https://doi.org/10.1038%2Fs41398-020-0694-0

69. Sletten TL, Raman B, Magee M, Ferguson SA, Kennaway DJ, Grunstein RR, et al. A blue-enriched, increased intensity light intervention to improve alertness and performance in rotating night shift workers in an operational setting. Nature and Science of Sleep [Internet]. 2021 May;Volume 13:647–57. Available from: https:

//doi.org/10.2147%2Fnss.s287097

70. Boyce PR, Beckstead JW, Eklund NH, Strobel RW, Rea MS. Lighting the graveyard shift: The influence of a daylight-simulating skylight on the task performance and mood of night-shift workerst. Lighting Research and Technology [Internet]. 1997 Sep;29(3):105–34. Available from: https://doi.org/10.1177%2F14771535970290030501

*71. Navara KJ, Nelson RJ. The dark side of light at night: Physiological, epidemiological, and ecological consequences. Journal of Pineal Research [Internet]. 2007 Oct;43(3):215–24. Available from: https://doi.org/10.1111%2Fj.1600-079x.2007.00473.x

*72. Saksvik IB, Bjorvatn B, Hetland H, Sandal GM, Pallesen S. Individual differences in tolerance to shift work — a systematic review. Sleep Medicine Reviews [Internet]. 2011 Aug;15(4):221–35. Available from: https://doi.org/10.1016%2Fj.smrv.2010.07.002

*73. Burch JB, Tom J, Zhai Y, Criswell L, Leo E, Ogoussan K. Shiftwork impacts and adaptation among health care workers. Occupational Medicine [Internet]. 2009 Mar;59(3):159–66. Available from: https://doi.org/10.1093%2Foccmed%2Fkqp015

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	Indirect-ness	Impreci-sion	Publication bias	Large effect	Dose–response	Total	Confidence
Physiologica 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	Randomisatio	Allocation concealmer	Blinding	Loss to follow-up	Selective outcome reporting	Other	Limitations
Tzischinsky & Lavie, 1997[52]	Unclear	Unclear	No	8.3%	Missing category search task	No	Very serious
Foret et al., 1998[50]	Yes	Unclear	No	None	Missing EEG and blood sample results	No	Very serious
Daurat et al., 2000[49]	Unclear	Unclear	No	None	Missing mood and logical reasoning	No	Very serious
Dumont et al., 2009[51]	No	No	Unclear	5.3%	Missing compliance with sleep profiles	No	Very serious
Olson et al., 2019[48]	No	No	No	5.7%	Missing step count (measure was faulty)	Unvalidate outcome measure	Very serious