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Developing a light-based intervention to reduce fatigue and improve sleep in rapidly rotating shift workers

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ABSTRACT

Over a quarter of employees in North America and a fifth of those in the European Union do shift work. Working these schedules increases fatigue, sleepiness, and errors at work. In the long term, it may also increase the risk of cardiovascular disease, gastrointestinal problems, and cancer. Some of these consequences may be partly due to circadian misalignment, in which sleep and activity patterns no longer align with one's circadian rhythms. Previous research has found that controlling light exposure can improve circadian alignment in individuals who work permanent night shifts. However, light-based interventions are rarely tested with rapidly rotating shift schedules, which include more than one type of shift within the same week (e.g., day shifts followed by night shifts). Further, many of the available interventions are seldom used in the workplace and may be less feasible in healthcare environments. In hospitals, the health and safety of both workers and patients can be compromised by increases in fatigue. We thus developed a practical intervention based on circadian and sleep hygiene principles to reduce some of the negative consequences associated with shift work. We then tested this intervention in a feasibility study of 33 nurses working rapidly rotating shifts. The study took place over two separate periods: the control (observation) period and the intervention period. Each period included two to four consecutive night shifts as well as the two days before and after those shifts. Nurses completed daily self-report questionnaires during both periods. During the intervention period, the nurses additionally followed a fatigue reduction plan. The plan involved 40 min of bright light exposure from a portable light box before night shifts, light avoidance using sunglasses after those shifts, and suggestions regarding the ideal times to sleep and nap. Results showed that nurses complied with the large majority of these recommendations. During the intervention period, nurses reported less fatigue, fewer work errors, better and longer sleep, and a more positive mood. Moreover, nurses with a preference for evenings (i.e., later chronotypes) reported the strongest benefits. Though more controlled studies are needed to assess causal mechanisms and long-term effectiveness, these promising results suggest that light-based interventions are feasible and may be effective at reducing fatigue in rapidly rotating shift workers.

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Introduction

Context

More than a quarter of employees in North America (27–28%) and a fifth of those in the European Union (21%) do shift work (Centers for Disease Control and Prevention 2015; Parent-Thirion et al. 2017; Williams 2008). Work outside of daytime hours is common in professions requiring 24-hour services, such as healthcare or law enforcement (Oexman et al. 2002). Although necessary, these work schedules are associated with various negative health and safety consequences. In the short term, shift work disrupts sleep quality and can result in up to 4 hours of sleep debt per day (Åkerstedt 1998, 2003; Åkerstedt and Wright 2009). Over time, these disturbances can increase fatigue and sleepiness, impair cognition, and affect mood (Åkerstedt 1998; Dawson and Reid 1997; Harrington 2001; James et al. 2017). In the long term, shift work has been linked to more serious consequences, including an increased risk of cardiovascular disease, gastrointestinal tract dysfunction, Type II diabetes, and cancer (Harrington 2001; James et al. 2017; Straif et al. 2007). Shift work

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can also compromise the safety of workers and the public. Indeed, shift workers such as nurses and police officers make more errors and suffer more injuries during night shifts than day shifts (De Cordova et al. 2016; Rogers et al. 2004a; Vila et al. 2002; Wagstaff and Lie 2011; Wong et al. 2010).

Many of these consequences may be partly due to *circadian misalignment*, in which sleeping and activity patterns (e.g., work schedules) no longer align with one's circadian rhythms. For example, circadian-related increases in melatonin result in high sleep propensity and efficiency at night; however, night shift workers must stay awake during this time (Boivin and Boudreau 2014; Lavie 1997; Zisapel 2007). Conversely, the associated decline in melatonin makes sleeping more difficult after a night shift (Dijk et al. 1997). As a result, night shift workers report more sleep disturbances than day workers (Drake et al. 2004). Improving circadian alignment may thus help reduce some of these negative consequences.

The most effective known method to shift circadian rhythms is timed bright light exposure, either from sunlight or a light box (Boivin and Boudreau 2014). In general, light in the morning causes circadian rhythms to advance (e.g., to promote earlier waking), while light at night causes delays (Pittendrigh 1981). In natural environments, bright light typically shifts circadian rhythms by 1 to 2 hours per day (Eastman 1990; Smith and Eastman 2012). In addition, laboratory and field studies have demonstrated that timed bright light exposure, often in combination with sleep hygiene recommendations, can have beneficial effects. Specifically, light exposure during night shifts, light avoidance after the shifts, dark sleeping environments, and sleeping in on days off have been shown to delay circadian rhythms and improve alignment (Boivin and James 2002; Eastman et al. 1995; Martin and Eastman 1998; Smith and Eastman 2012), reduce fatigue (Eastman et al. 1995), as well as increase sleep quality and performance at work (Smith et al. 2009). Such interventions are also effective for slowly rotating shift workers (Boivin et al. 2012), those who work the same type of shift for at least one week (e.g., a week of night shifts, followed by a week off, and then a week of day shifts). Other interventions that focus on improving sleep hygiene and counter-acting fatigue, such as napping before night shifts and drinking coffee to maintain alertness, have shown similar benefits (Bonnet and Arand 1994; Ker et al. 2010; Schweitzer et al. 2006; Scott et al. 2010; Walsh et al. 1990).

Problem

In contrast, less is known about improving circadian alignment for *rapidly rotating shift schedules*, in which shift types vary within a single week (e.g., two day shifts followed by two night shifts). Working such schedules has been associated with greater fatigue, reduced work performance, and poorer sleep relative to working permanent night shifts (Dall'Ora et al. 2016; Pilcher et al. 2000; Sallinen and Kecklund 2010). In a recent review of light-based interventions for shift workers, only 3 out of the 12 studies tested rapidly rotating schedules (Neil-Sztramko et al. 2014). Some experts in the field suggest that there is "no way to reduce circadian misalignment for a rapid rotation that includes both night shifts and day shifts" and that such schedules should be "abolished" (Smith and Eastman 2012, 125). We agree that complete alignment is unlikely and that institutional changes are required; however, because many people continue to work these shift schedules, it is important to test the effectiveness of partial solutions.

One limitation of several previous interventions is their low feasibility. Current fatigue reduction recommendations — such as modifying schedules, getting bright light exposure at night, or allowing workers to nap — all require institutional change, which is often slower and more expensive (Mistlberger 2004). There is thus a need for feasible and effective interventions that target rapidly rotating shift workers.

Present study

Given these concerns, we developed a light-based intervention for rapidly rotating shift workers. We aimed to balance feasibility and effectiveness by focusing on strategies that do not require institutional buy-in nor any changes during work hours. To test this intervention, we focused on nurses because they commonly work rotating shift schedules yet receive little training to reduce the associated negative effects. In Canada alone, the site of our research, there are approximately 270,000 registered nurses and nearly half of them in hospital settings (48%) work a combination of day, evening, or night shifts (Shields and Wilkins 2006). A survey of 6,000 Canadian nurses showed that under 10% reported having procedures to address fatigue in their organizations (Canadian Nurses Association 2010). In addition, nurse fatigue may impact public safety: shift work is associated with increased work-related errors, falls, and injuries, as well as irregular monitoring of patients (Canadian Nurses Association, 2010; Kalisch and Xie 2014; Kenyon et al. 2007; Mayo and Duncan 2004; Smith-Miller et al. 2014). In one study, for example, nurses ranked "being tired or exhausted" as the third most frequent cause of medication errors (Leape 1995). Fatigued nurses are also less likely to notice and intercept others' mistakes (Dorrian et al. 2006), often leading to further preventable adverse medical events and errors (Landrigan et al. 2004). Thus, providing nurses with strategies to mitigate the effects of shift work may improve the health and safety of both nurses and their patients.

In the present feasibility study, we tested an intervention based on circadian and sleep hygiene principles in nurses working rapidly rotating shifts. We collected initial evidence of its effectiveness in reducing some of the short-term consequences associated with shift work. In particular, we hypothesized that our intervention would reduce fatigue, sleepiness, and errors at work, as well as improve sleep and mood.

Methods

Recruitment and shift schedules

We recruited 65 nurses using posters and presentations for a study on fatigue reduction. Two large teaching hospitals participated, both affiliated with the McGill University Health Center in Montreal, Canada. We targeted three units at each hospital chosen for their high proportion of nurses working rapidly rotating shifts: Intensive Care, Emergency, and Internal Medicine.

Nurses on these units typically follow the *little week/big week* schedule ("petite semaine/grande semaine"), a rapid rotation that alternates between day and night shifts. A common schedule includes: 2 day shifts, 2 days off, 3 night shifts, 2 days off, 2 day shifts, and then 3 days off. The pattern then repeats with the day and night shift sequences reversed. Shifts are usually 12 hours long, with day shifts starting at 07:30 and night shifts at 19:30. Some nurses also work 8-hour night shifts that begin at 23:30.

Screening

Nurses underwent a phone screening to determine their eligibility. We included nurses who:

- worked at least 60% of a full-time workload,
- worked rotating schedules that included 2 to 4 consecutive night shifts,
- worked directly with patients,
- had worked at the hospital for at least 6 months,
- owned a smartphone,
- and were between 18 and 65 years old.

To minimize unintended outcomes from the light exposure (e.g., increases in fatigue), we excluded the highest risk nurses from the study. We thus excluded participants who:

- did not meet our inclusion criteria ($n = 6$);
- had been diagnosed with medical or psychological conditions (or who took medication) that could affect fatigue ($n = 10$);
- were diagnosed with a sleep disorder ($n = 5$);
- had been involved in a fatigue-related car accident or near-accident ($n = 3$);
- were pregnant or breastfeeding, or intended to get pregnant within the duration of the study ($n = 3$, because fatigue during pregnancy predicts cesarean deliveries and is associated with higher prematurity rates and anxiety levels; Mamelle et al. 1984; Chien and Ko 2004; Hall et al. 2009);
- had a sun allergy ($n = 1$), glaucoma ($n = 1$), retinopathy, or cataracts (to reduce the

possibility of negative consequences associated with light exposure);

- had experienced an acute stressor in the past year (e.g., a divorce or the death of a loved one) or who anticipated one in the near future ($n = 1$, because this may increase fatigue; Pawlikowska et al. 1994);
- had traveled across multiple time zones in the past month (to minimize other sources of circadian disruptions; Waterhouse et al. 2007);
- or had donated blood within the previous week (since this may also influence fatigue; Sojka and Sojka 2003).

Participants

Our sample included 35 nurses, but 2 of them dropped out after the phone screening for personal reasons prior to the beginning of data collection. The final sample thus included 33 nurses. Participants were evenly distributed across both hospitals ($n = 17$, $n = 16$) and worked in Intensive Care ($n = 20$), Emergency ($n = 9$), or Internal Medicine ($n = 4$). The majority were women (76%) in their 20s and 30s ($M = 32.7$, SD 8.6, range: 22 to 58). After providing consent, nurses completed paper-and-pencil questionnaires assessing individual differences (see below). See Table 1 for participant demographics and details.

We chose our sample size in advance; we had funding to run up to 35 participants, so we continued to recruit and screen them until we attained this number. Data analysis occurred only after collecting the full sample.

Procedure

Participants completed a control (observation) period followed by an intervention period. Both periods lasted approximately one week; they each included 2 to 4 consecutive night shifts as well as the 1 or 2 days before and after those shifts, depending on individual schedules. There was an average gap of 24.9 days (SD 23) between the control and intervention periods. The timing of these periods was determined in collaboration with participants to ensure that their work schedule was the same during both periods (sometimes with small deviations due to unplanned schedule changes). We did not randomize the order of the periods to avoid carry-over effects; for example, if nurses had completed the intervention period first, they may have continued to follow parts of the intervention during the subsequent control period.

During each period, participants completed daily questionnaires on their smartphones to assess fatigue, sleepiness, sleep, mood, and caffeine and alcohol consumption. Participants received a link to the questionnaires by text message and e-mail every morning (07:30) and evening (18:30); we chose these times because they occurred outside of their work hours. On work days, nurses additionally reported work-related errors, near-errors, and overtime. On days off, participants were instructed to complete the morning questionnaires whenever they woke up.

After the control period, nurses were compensated \$60 for completing the first half of the study. They then received the materials necessary to complete the intervention: a fatigue reduction plan tailored to their work schedule, a portable light box, and a sleep mask. Nurses reported their compliance with each component of the intervention in their daily questionnaires throughout the intervention period. Upon completion, we interviewed the nurses about their experience. Finally, they received an additional \$80 in compensation for their participation in the second period.

The study was approved by the Research Ethics Board of the McGill University Health Center (#2018-2858).

Materials

Fatigue reduction plan

Based on a literature review of field and laboratory studies, we compiled a list of guidelines intending to reduce circadian misalignment and improve

Table 1. Participant details ($N = 33$).

Questionnaire	Measure	*M* (*SD*) or %
Demographics	Age	32.73 (8.59)
	Sex (female)	76%
	Years nursing	7.67 (7.30)
	Job satisfaction (1 to 7)	5.73 (0.45)
	Drive to work	58%
	Exercise per week	2.73 (1.91)
Chronotype (rMEQ)	Chronotype (4 [evening] to 25 [morning])	14.48 (3.50)
Fatigue (MFI)	General (4 to 20)	13.09 (2.90)
	Physical (4 to 20)	16.06 (2.76)
	Motivation (4 to 20)	16.67 (2.16)
	Activity (4 to 20)	16.36 (2.43)
	Mental (4 to 20)	14.61 (3.90)
Stress (PSS)	Stress (0 to 40)	13.73 (5.41)
Workload (NASA-TLX)	Mental (5 to 100)	78.33 (20.72)
	Physical (5 to 100)	63.26 (24.13)
	Temporal (5 to 100)	71.14 (19.52)
	Performance (5 to 100)	36.67 (24.23)
	Effort (5 to 100)	65.61 (19.72)
	Frustration (5 to 100)	48.48 (23.86)
Menstruation	Regular	71%
	Cycle length (days)	31.18 (15.83)
	Days since last menstrual onset (control)	17.05 (14.07)
	Days since last menstrual onset (intervention)	23.50 (20.14)
Drinks on work days	Coffee (control)	0.53 (0.68)
	Coffee (intervention)	0.45 (0.68)
	Tea (control)	0.05 (0.28)
	Tea (intervention)	0.05 (0.24)
	Cola (control)	0.16 (0.42)
	Cola (intervention)	0.09 (0.37)
	Energy (control)	0.04 (0.21)
	Energy (intervention)	0.03 (0.19)
	Alcohol (control)	0.07 (0.40)
	Alcohol (intervention)	0.06 (0.40)
Overtime	Worked (control)	10%
	Worked (intervention)	9%
	Minutes (control)	35.20 (80.87)
	Minutes (intervention)	36.28 (83.98)

sleep hygiene. Most of the guidelines aimed to promote circadian phase delays by seeking light at night and avoiding light the next morning. In particular, the plan suggested to:

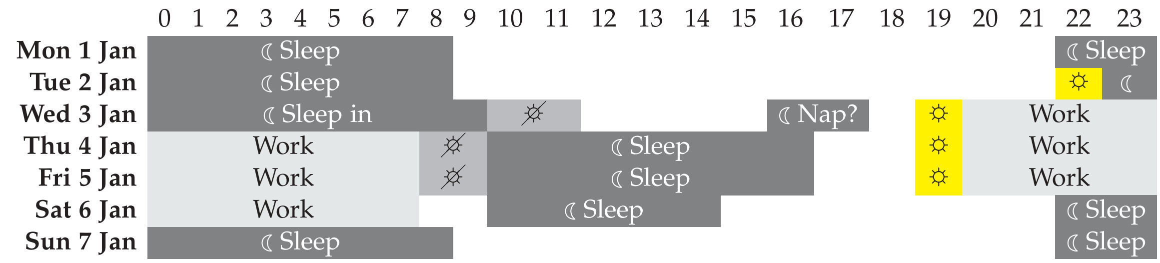
(1) Stay up at least one hour later on the day before the first night shift and receive 40 min of bright light exposure from a portable light box before bed. This ensured a minimum of 30 min of bright light, which has been shown to improve sleep and mood in nurses who do shift work (Huang et al. 2013).
(2) Sleep in as late as possible the following day (i.e., the morning of the first night shift).
(3) Avoid bright light in the morning after waking by wearing sunglasses or staying in a dark environment.
(4) Nap as late as possible before the first night shift (if needed).
(5) Receive 40 min of bright light exposure as late as possible before each night shift (which either started at 19:30 or 23:30).
(6) Wear sunglasses to avoid bright light as soon as possible after the night shift (which typically ended at 07:30), until going to bed.
(7) Sleep as soon as possible after returning home.
(8) Sleep in a dark room and/or wear a sleep mask.
(9) Avoid wearing sunglasses in the morning after the final night shift and shorten the following sleep episode to ease the transition back to a day-oriented schedule.

See Figure 1 for a sample plan. To improve feasibility, all of the suggestions took place outside of work hours. We instructed nurses to follow the plan as closely as possible while making accommodations for their lifestyle.

Light box

Participants were given a portable light box (34 × 20 × 6 cm; TRAVelite Desk Lamp, Northern Lights Technologies, Inc., Montreal, QC) and instructed to place it one arm's length away from their face (approximately 60 cm) without looking directly at it. The light box nominally emits 10,000 lux; following these instructions resulted in a light intensity of approximately 5,500 lux, as measured by a light meter (Universal Photometer, Optikon Corp. Ltd., ON, Canada). This is similar to intensities used in previous interventions (Bjorvatn et al. 2007; Boivin et al. 2012; Kakooei et al. 2010). In order to improve compliance (Orr and King 2015), two hours before their shift, nurses received a text message reminder to use the light box.

Fatigue Reduction Plan



Legend

☼ Use the light box for **40 minutes**. Try to get the light as late as possible before leaving for work. The light box should be in front of you within arm's reach, without looking directly at it. On your way to work, get as much light as possible (e.g., do not wear sunglasses).

Wear sunglasses as soon as you finish work until you go to bed. Close curtains and blinds at home and wear your **sleep mask** when sleeping and napping. Avoid light as much as possible.

☾ **Sleep** Sleep as soon as you feel tired for as long as you can.

☾ **Nap?** Nap if needed, ideally late in the day.

Summary

- Before your night shift, get bright light.
- After your night shift, avoid light.
- Before the set of shifts, sleep in, avoid light in the morning, and nap late.

Figure 1. Sample fatigue reduction plan for a nurse working three 12-hour night shifts starting at 19:30.

Sunglasses

We instructed participants to wear their darkest pair of sunglasses after each night shift. This strategy has been shown to promote circadian phase delays (Smith and Eastman 2012) and improve sleep (Sasseville et al. 2009). We told nurses not to wear their sunglasses while driving, if tired, to minimize safety risks (Weisgerber et al. 2017). Although blue-blocking sunglasses are commonly used in other light intervention studies (e.g., Lee et al. 2006), we did not use these in order to increase feasibility and compliance. We subsequently asked a subset of our participants about their willingness to wear these blue-blocking glasses outside of a study context; 70% of them said they would not.

Sleep mask

Participants also received a sleep mask (Ultralight Comfortable 3D Contoured Eye Blindfold, JJ Autumn, USA) and were instructed to wear it whenever they slept, unless it interfered with their sleep.

Measures

To assess individual differences prior to the beginning of the control period, participants completed paper-and-pencil questionnaires measuring demographics, work characteristics, chronotype, fatigue, stress, and workload.

Individual differences

Demographic and work characteristics. Nurses completed a questionnaire asking about basic demographics (e.g., age and sex), job satisfaction, work experience, commute time, and lifestyle, all of which can affect tolerance to shift work (e.g., der Holst et al. 2016; Ritonja et al. 2019). Job satisfaction was assessed using a single-item measure ranging from 1 ("Extremely dissatisfied") to 7 ("Extremely satisfied"); this item was derived from the Job Satisfaction Scale (Warr et al. 1979) which has been shown to be a valid and reliable measure of overall job satisfaction (Dolbier et al. 2005).

We also included three questions from the Indices of Estrogen Exposure questionnaire (Lord et al. 2009) that assess the regularity of menstrual cycle, cycle length, and the onset of the last menstruation. Menstrual cycle phase has been shown to influence sleep quality and fatigue (Baker and Lee 2018).

Chronotype. *Chronotype* refers to the preference for mornings versus evenings — "morning birds" versus "night owls". We assessed chronotype with the 5-item Reduced Morningness-Eveningness Questionnaire (rMEQ; Adan & Almirall, 1991). An example item is: "Approximately what time would you get up if you were entirely free to plan your day?". Total scores are classified along a morningness dimension, ranging from "definitely evening type" (4) to "definitely morning type" (25). The internal consistency is moderate (Cronbach's $\alpha = .70$; Chelminski et al. 2000), but was lower in our sample (.52), likely because the scale does not account for shift work (Juda et al. 2013). The external validity of this measure is generally good (Natale et al. 2006).

Fatigue. The Multidimensional Fatigue Inventory (MFI; Smets et al. 1995) is a 20-item questionnaire that measures five dimensions of fatigue: general fatigue, physical fatigue, reduced motivation, reduced activity, and mental fatigue. Participants rate how much each statement applies to them on a 5-point Likert scale ranging from 1 ("No, that is not true") to 5 ("Yes, that is true"). Example items for the respective dimensions include: "I feel tired", "Physically, I feel only able to do a little", "I dread having to do things", "I get little done", and "It takes a lot of effort to concentrate on things". Scores on each of these dimensions range from 4 to 20; higher scores indicate greater fatigue. This measure usually has good internal consistency (average $\alpha = .84$; Smets et al. 1995), similar to four of the five dimensions in our sample (αs from .63 to .90). The motivation dimension, however, had unacceptably low internal consistency ($\alpha = .17$). We therefore excluded this dimension from our analyses.

Stress. The Perceived Stress Scale (PSS-10; Cohen and Williamson 1988) measures how stressful participants found life events in the past month. Participants rate each of the 10 items on a 5-point Likert scale ranging from 0 ("Never") to 4 ("Very often"). An example item is: "How often have you found that you could not cope with all the things that you had to do?". The scale ranges from 0 to 40; higher scores indicate more stress. This measure has acceptable to good internal consistency (α values ranging from .74 to .91; Lee 2012), which was similar in our sample (.81).

Workload. The NASA Task Load Index (NASA-TLX; Hart and Staveland 1988) measures six dimensions of perceived workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. Participants rate their experience of a task (in this case, nursing in general) using a 20-point scale ranging from 5 ("Very low") to 100 ("Very high"). The total scores range from 30 to 600; higher scores indicate a greater perceived workload. This measure is recommended for use in nurse populations (Hoonakker et al. 2011; Young et al. 2008). The overall internal consistency is moderate ($\alpha = .72$) and was higher in our sample (.81). Its test–retest reliability is good ($r = .77$; Hoonakker et al. 2011).

Daily measures

Fatigue. The Daily Fatigue Short Form (DFSF; Christodoulou et al. 2013) measures daily fatigue — a feeling of strain or exhaustion (Piper et al. 1989). In this 7-item questionnaire, participants rate each item on a 5-point Likert scale ranging from 1 ("Never") to 5 ("Always"). An example item is: "In the day, how often did you feel tired?". We modified the items to say "In the last 12 hours" rather than the original "In the last day", because nurses completed the questionnaire twice each day. The scale ranges from 7 to 35; higher scores indicate greater fatigue. The scale has been validated in healthy and clinical populations and has high reliability

($\alpha > .90$; Christodoulou et al. 2013), which was similar in our sample (.92).

Sleepiness. The Karolinska Sleepiness Scale (KSS; Åkerstedt and Gillberg 1990) measures state sleepiness: an increased propensity to fall asleep (Curcio et al. 2001). In this single-item questionnaire, participants select the statement on a 9-point scale that best describes their sleepiness in the past five minutes; the scale ranges from 1 ("Extremely alert") to 9 ("Very sleepy, great effort to keep awake, fighting sleep"). It is one of the most widely used measures of subjective state sleepiness, including in shift work studies, and it has been shown to correlate with physiological and behavioral measures (Åkerstedt et al. 2014). In addition to the morning and evening questionnaires, participants were asked to complete this measure once at any point during each night shift. However, we excluded the sleepiness measure collected during the night shift because there was too much variability in the timing of the questionnaire completion (between midnight and 07:00).

Mood. The International Positive And Negative Affect Schedule Short Form (I-PANAS-SF; Thompson 2007) is a 10-item questionnaire assessing affect on two independent dimensions: positive and negative. Participants rate the extent to which they have experienced specific affective states (e.g., "Determined" or "Hostile") in the past day. Items are rated on a 5-point Likert scale ranging from 1 ("Very slightly or not at all") to 5 ("Extremely"). Total scores for each dimension range from 5 to 25. This questionnaire has been shown to have adequate internal consistency and reliability ($\alpha = .75$ for positive affect and .76 for negative affect; Thompson 2007). In our sample, internal consistency was higher for positive affect (.91) and lower for negative affect (.65).

Sleep quality. The Sleep Quality Scale (SQS; Cappelleri et al. 2009) is a single-item scale used to assess sleep quality. For each sleep episode, participants were asked to report the quality of their sleep using a 7-point Likert scale ranging from 0 ("Worst possible sleep") to 6 ("Best possible sleep"). This measure has been shown to have high test–retest reliability ($r = .90$) and to correlate with more extensive sleep questionnaires (Cappelleri et al. 2009).

Sleep duration. Participants reported the times at which they fell asleep and woke up over the past 12 hours, for up to 3 sleep episodes. These sleep reports have been shown to reasonably match objective sleep recordings (Thurman et al. 2018) and have been used in previous nurse studies (Dorrian et al. 2006).

Sleep onset latency. For each sleep episode, participants answered the question: "How long did it take you to fall asleep (in minutes)?". This single question assessing sleep latency has been previously validated and used in daily logbooks (King 1997; Rogers et al. 2004b). We only looked at sleep latency during the main (i.e., longest) sleep episode of the day to avoid having the measure confounded by the recommendation to take more naps during the intervention period.

Work-related errors. The post-shift questionnaire asked about errors and near-errors made during the shift, such as when giving medication or following procedures. We defined work-related errors as "any perceived variation from current standards of practice" (Scott et al. 2006). For example, an error would be mislabeling blood work before sending it to the laboratory; a near-error would be starting to mislabel it then correcting the error before it had any consequences. We grouped errors and near-errors together. As in a previous study (Dorrian et al. 2006), nurses were asked to describe the error and indicate its approximate time, severity (minor, moderate, or serious), and category (medication, transcription, charting, procedural, slip/fall, or other). Such error reports have been shown to yield similar levels of reporting as typical incident reports (O'Neil 1993). Further, we could not use incident reports because the hospital sites do not measure errors at the individual level, but only at the unit level.

Overtime. After each night shift, nurses reported how much overtime (paid or unpaid) they worked. Participants selected an answer among 15-minute intervals ranging from "none" to "more than 4 hours".

Beverages. To track caffeine and alcohol consumption, participants reported the number of cups or drinks of coffee, tea, cola drinks, energy drinks, and alcoholic drinks consumed in the past 12 hours. These questions were selected from a previously validated logbook (Dorrian et al. 2006).

Physical activity. To estimate physical activity during the shift, we provided nurses with a pedometer. However, the pedometer was frequently dropped or reset; only one participant provided complete data. We thus excluded this measure.

Post-intervention questionnaire

Following the intervention period, participants completed a questionnaire that assessed the feasibility and ease of use of each component of the intervention (e.g., the light box) and their willingness to use it in the long term. They also rated the overall perceived effectiveness of the intervention. Each item was rated on a 7-point Likert scale ranging from 1 ("Not at all") to 7 ("Very"). This questionnaire also served as the basis for a semi-structured interview with each participant, during which we discussed potential challenges, impacts on their work and personal lives, suggested improvements, and any adverse effects of the intervention.

Hypotheses

We expected that our intervention would reduce fatigue, sleepiness, errors at work, and sleep latency, as well as improve mood, sleep quality and sleep duration.

Analyses

Data integrity and cleaning

Overall, 3.01% of the daily questionnaires were not filled out at all, split evenly between the control and intervention periods. We excluded state measures (i.e., fatigue, sleepiness, sleep quality, and mood) reported over 6 hours after the questionnaire link was sent. This gave nurses time to complete the questionnaire after their shift (when working overtime), while minimizing recall bias if they completed it too late. In total, this excluded 6.19% of the questionnaires in the control period and 6.34% in the intervention period. We also excluded any other measures completed 24 hours late, which excluded an additional 0.82% in the control period and 0.21% in the intervention period. The online questionnaire system gave warnings when items were skipped, so there was no additional missing data. We then manually removed impossible values from the data, usually caused by input errors mixing 12- and 24-hour times. We also removed the sleep latency measure from two participants with extreme values (2 and 3 hours, with respective z scores of 7.7 and 16.0).

Next, we normalized the data to control for any differences before the work shifts began. To do so, for each period, we subtracted the average morning and evening scores during the two days before the night shifts began (the *baseline*) from the corresponding values on the rest of the days. This resulted in a set of normalized values for each participant, period (control or intervention), day (in each set of shifts), and time (morning or evening). For example, to normalize fatigue scores during the intervention, we subtracted the average fatigue scores on the first two days (i.e., days off) of the intervention phase from the fatigue scores on the remaining work days. Since we were interested in improving outcomes at work, we analyzed only the work days, which we defined as including the measures taken the evening before the first night shift until the morning after the last night shift. We report all measures collected.

Confirmatory and exploratory analyses

We used mixed-effects linear regression to predict each standardized outcome variable (e.g., fatigue), given the day (reference level: first day of shift), time (reference: morning), and presence of the intervention (reference: control), with the participant as a random factor. We only tested period as a predictor in each model; its slope can be interpreted as analogous to a standardized mean difference when controlling for the other predictors.

This analysis method gave high statistical power because we could use data from multiple time points for each participant. We used a Type I error rate of .05 without family-wise error correction. All regressions were forced-entry and assumptions were reasonable. For errors, we used a Wilcoxon–Mann–Whitney test comparing errors between periods when stratified by participant. This non-parametric test is similar to a paired-samples *t* test but does not require the assumption of normality, which was violated. All tests were confirmatory and directional (see *Hypotheses*) unless explicitly labeled as exploratory.

Our exploratory analyses focused on predicting intervention effectiveness based on individual difference measures (e.g., demographics, chronotype). For these analyses, we plotted the data and computed correlations.

To complete the analyses, we used R 3.6.1 (R Core Team 2019), with packages lme4 1.1–21 for mixed-effects linear regression, Hmisc 4.3–0 for bootstrapped confidence intervals, and ggplot2 3.2.1 (Wickham 2009) for graphs. Square brackets throughout denote bootstrapped 95% confidence intervals.

Results

Consistent with our hypotheses, nurses showed less fatigue, made fewer errors at work, slept better and longer, and reported being in a more positive mood during the intervention (Figure 2). However, we did not see improvements in sleepiness, sleep latency, or negative mood. See Table 2 for descriptive statistics and Table 3 for statistical tests.

Fatigue

Relative to the control period, nurses reported being less fatigued during the intervention period. During the control period, nurses generally became more fatigued throughout their night shifts by $2.20\,[1.41, 3.04]$ units and reverted to their initial fatigue levels during their days off (Figure 3). During the intervention period, however, nurses showed relatively little increases in fatigue $(0.24\,[-0.62, 1.10]$ units) throughout their night shifts; their fatigue resembled their baseline levels. As one participant claimed, "After I used the light, I would arrive at work feeling like it was my first night [in the set of shifts]".

Errors

Nurses reported fewer work errors or near-errors during the intervention period. During the control period, they reported a total of 13 errors whereas they reported 5 during the intervention period (Wilcoxon–Mann–Whitney $z = 1.80$, $p = .036$). The majority of the errors were rated as minor in severity (83%); the rest were moderate. Overall, nurses primarily reported charting and transcription errors, but others included giving medication late, mislabeling blood work, ordering the wrong

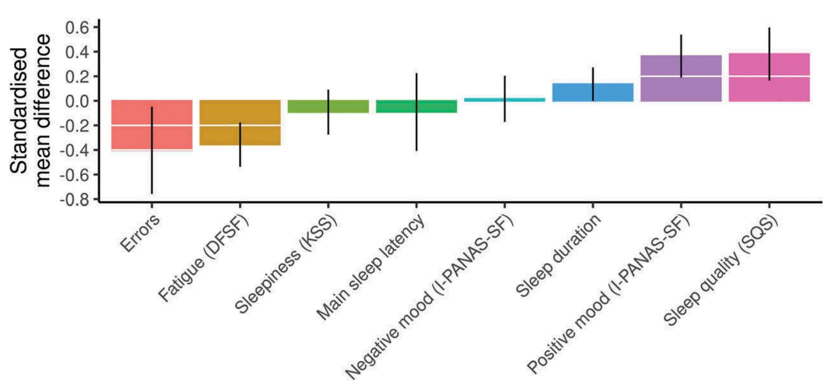


Figure 2. Differences during the intervention period, controlling for day of shift and time. Error bars show 95% confidence intervals. See Table 3 for full regression results. To compute a standardized mean difference for the error measure, we used a paired-samples *t* test.

Table 2. Descriptive statistics for each period. Values show means (and standard deviations).

Measure	Period	Baseline	During shifts	Normalized
Fatigue (DFSF; 7 to 35)	Control	13.85 (4.42)	16.04 (5.35)	2.20 (5.71)
	Intervention	13.59 (4.84)	13.83 (4.60)	0.24 (5.90)
Errors	Control		$N = 13$	
	Intervention		$N = 5$	
Sleepiness (KSS; 1 to 9)	Control	3.78 (1.92)	4.29 (2.29)	0.51 (2.66)
	Intervention	3.57 (1.69)	3.90 (2.20)	0.33 (2.19)
Positive mood (I-PANAS-SF; 5 to 25)	Control	16.06 (4.40)	13.81 (4.72)	−2.25 (4.25)
	Intervention	15.88 (4.47)	15.09 (4.23)	−0.79 (4.11)
Negative mood (I-PANAS-SF; 5 to 25)	Control	5.83 (1.41)	6.20 (1.83)	0.37 (1.94)
	Intervention	5.61 (0.83)	6.05 (1.76)	0.43 (1.63)
Sleep quality (SQS; 0 to 6)	Control	4.23 (1.01)	3.51 (1.45)	−0.72 (1.41)
	Intervention	3.95 (1.42)	3.92 (1.37)	−0.02 (1.55)
Sleep duration (h per 12 h)	Control	5.16 (3.60)	3.67 (2.98)	−1.49 (4.77)
	Intervention	4.77 (3.58)	3.92 (3.19)	−0.85 (5.16)
Main sleep latency (min)	Control	12.69 (10.52)	12.72 (12.64)	0.03 (12.78)
	Intervention	11.74 (10.03)	10.75 (9.75)	−0.99 (9.86)

Table 3. Results of regression models predicting standardized measures given the day, time, and presence of the intervention. b shows the standardized slope, which is analogous to the standardized mean difference between the periods when controlling for the other predictors. p values are based on directional hypotheses.

Measure	Predictor	b	95% CI	SE	df	t	p
Fatigue (DFSF)	Day of work	0.11	[0.01, 0.21]	0.05	331.44	2.18	
	Time	0.05	[−0.14, 0.24]	0.10	320.72	0.50	
	Intervention	−0.36	[−0.54, −0.18]	0.09	318.34	−3.89	<.001
Sleepiness (KSS)	Day of work	0.11	[0.01, 0.21]	0.05	334.16	2.12	
	Time	−0.32	[−0.52, −0.13]	0.10	322.35	−3.28	
	Intervention	−0.09	[−0.27, 0.09]	0.09	319.52	−0.99	.161
Positive mood (I-PANAS-SF)	Day of work	−0.13	[−0.22, −0.03]	0.05	331.40	−2.57	
	Time	0.18	[−0.00, 0.37]	0.09	321.77	1.94	
	Intervention	0.36	[0.19, 0.54]	0.09	319.51	4.11	<.001
Negative mood (I-PANAS-SF)	Day of work	0.04	[−0.06, 0.15]	0.05	335.66	0.81	
	Time	−0.09	[−0.28, 0.11]	0.10	323.94	−0.85	
	Intervention	0.02	[−0.17, 0.20]	0.10	321.10	0.17	.568
Sleep quality (SQS)	Day of work	−0.03	[−0.15, 0.08]	0.06	207.89	−0.58	
	Time	0.10	[−0.17, 0.38]	0.14	215.25	0.75	
	Intervention	0.38	[0.16, 0.60]	0.11	198.71	3.48	<.001
Sleep duration	Day of work	−0.21	[−0.29, −0.14]	0.04	370.70	−5.69	
	Time	1.31	[1.17, 1.46]	0.07	350.86	17.95	
	Intervention	0.14	[−0.00, 0.27]	0.07	346.27	1.96	.026
Main sleep latency	Day of work	0.01	[−0.20, 0.22]	0.10	135.50	0.11	
	Intervention	−0.09	[−0.41, 0.23]	0.16	116.98	−0.57	.715

blood test, and poking oneself with a needle. Table 4 lists all of the errors and near-errors.

Sleepiness

Contrary to our hypotheses, nurses reported no improvement in sleepiness during the intervention period. During the control period, sleepiness increased by $0.51\,[0.14, 0.91]$ units throughout the shifts; during the intervention, it increased by $0.33\,[\text{-}0.00, 0.65]$. Nurses generally reported values equivalent to being "rather alert" on the scale.

Mood

Nurses reported more positive affect during the intervention period. During the control period, nurses reported a decrease in positive affect of $\text{-}2.25\,[\text{-}2.86, \text{-}1.58]$ units throughout their shifts; during the intervention, this change was $\text{-}0.79\,[\text{-}1.41, \text{-}0.18]$. One participant stated, "I felt a lot more enjoyable to work with. I felt

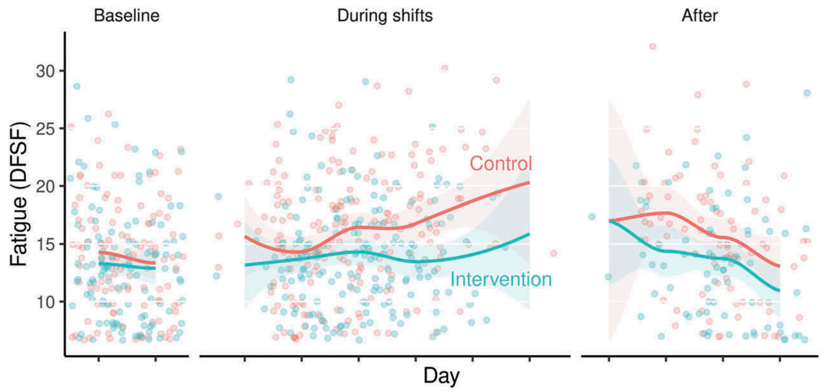


Figure 3. Fatigue by day (before, during, and after the set of night shifts). Fatigue was lower during the intervention. Lines show smoothed averages with shading to indicate the 95% confidence band. Dots represent individual measurements and are jittered to reduce overplotting. Note that participants worked different numbers of night shifts.

like a better colleague and nurse". We did not see a change between the periods in negative mood; it increased by 0.37 [0.10, 0.65] units during the control period and 0.43 [0.20, 0.66] during the intervention period.

Sleep

Quality

Nurses reported better sleep quality during the intervention period. During the control period, sleep quality decreased throughout the shifts (-0.72 [-0.99, -0.46] units), whereas there was little change in the intervention period (-0.02 [-0.29, 0.29]).

Duration

Nurses also reported sleeping longer during the intervention period. During the control period, nurses slept less throughout the days of the shifts (-1.49 [-2.11, -0.79] h per 12-h period); this decrease was smaller during the intervention (-0.85 [-1.61, -0.15] h).

Latency

We expected that participants would fall asleep faster during the intervention period, since their sleep episode may be closer to their biological night, which facilitates sleep onset (Boivin and Boudreau 2014). Contrary to our hypothesis, we saw no change in sleep latency during the main sleep episode. Compared to the baseline days before the shifts, nurses took slightly more time to fall asleep during the control period (by 0.03 [-3.06, 3.18] min) and slightly less during the intervention (by -0.99 [-3.24, 1.23] min).

Table 4. Errors and near-errors reported by period.

Period	#	Description
Control ($n = 13$)	3	Charted on wrong patient
	3	Mislabeled bloodwork
	2	Ordered wrong blood test
	1	Lost track of dialysis additives
	1	Gave medication late
	1	Procedural error
	1	Error when giving report to nurse
	1	Wrote down wrong information
Intervention ($n = 5$)	1	Poked self with needle
	1	Procedural error
	1	Mislabeled bloodwork
	1	Called wrong patient
	1	Wrote down wrong information

Individual differences

Exploratory analyses revealed that chronotype predicted improvements in many of the outcome measures. Participants with evening preferences (i.e., "night owls") seemed to benefit the most from the intervention (Figure 4). They showed, for example, the largest reductions in fatigue ($r = 0.43$ [0.05, 0.70]) and sleepiness ($r = 0.37$ [0.11, 0.60]) as well as the largest improvements in positive mood ($r = -0.49$ [-0.66, -0.25]). We did not see strong correlations with the other individual difference measures (i.e., fatigue, stress, or workload).

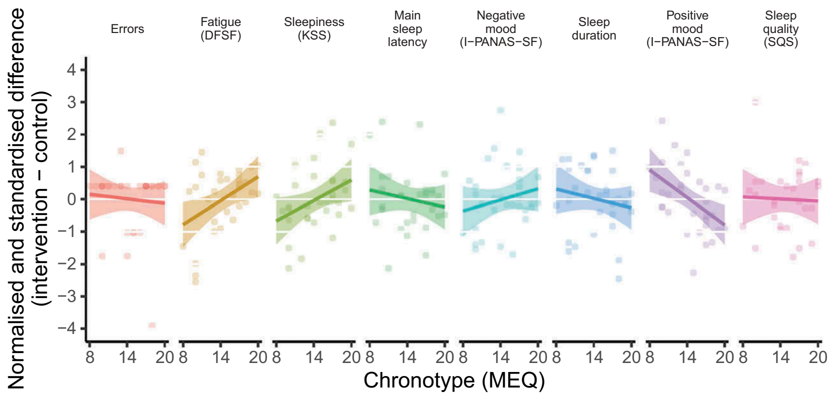


Figure 4. Changes in outcome variables given chronotype. Participants with more of an evening preference (i.e., lower chronotype scores) reported the greatest improvements in fatigue, sleepiness, and positive mood. Colored lines show the linear predictions with shading to indicate the 95% confidence band. Dots represent individual participants.

Compliance

Compliance with the intervention was high. Participants reported sleeping with the sleep mask during 73% of their sleep episodes and wearing their sunglasses after 89% of their shifts. They used the light box before 98% of their shifts, usually for 50.1 min (*SD* 29.1, range: 30 to 235). The light box was most commonly placed between 30 to 60 cm (66% of cases) or else under 30 cm (19% of cases) away from participants' faces. The light was commonly used around 17:00 and 18:00 (before 19:30 shifts) or 22:00 (before 23:30 shifts).

Feasibility and subjective effectiveness

Overall, nurses considered each component of the intervention easy to follow and feasible. They also reported that they would be likely to follow the components of the intervention in the long term (Table 5). In addition, nurses found the intervention generally effective at producing the expected effects (Table 6).

Adverse effects

We saw little evidence of adverse effects, including on the days off after the night shifts of the intervention period (e.g., Figure 3). One participant reported eye strain during the light exposure and another reported a momentary headache.

Discussion

Many rotating shift workers experience health and performance decrements due in part to circadian misalignment. In the healthcare sector, these decrements can have important safety implications for both workers and their patients. Although circadian-based interventions have been shown to improve circadian alignment and its associated effects, few have been tested with rapidly rotating shift workers or are feasible in hospital settings. We thus aimed to develop and test a feasible intervention to reduce fatigue, sleepiness, and work-related errors as well as improve sleep and mood in rapidly rotating nurses.

As predicted, during the intervention period, nurses reported reduced fatigue, fewer work-related errors, improvements in sleep quality, longer sleep durations, and a more positive mood relative to the control period. These findings are consistent with the current literature.

Table 5. Means (and standard deviations) of how feasible and easy nurses found the components of the intervention, as well as how likely they would be to follow the components in the long term. The scales ranged from 1 ("Not at all") to 7 ("Very").

Component	Feasibility	Ease of use	Long-term
Sunglasses	6.61 (0.83)	6.52 (1.06)	6.42 (1.03)
Sleep mask	6.00 (1.85)	5.97 (1.85)	5.61 (2.21)
Light box	5.55 (1.09)	5.21 (1.76)	5.24 (1.62)
Sleep/nap times	5.36 (1.75)	5.56 (1.50)	5.36 (1.65)

Table 6. Ratings of subjective effectiveness of the intervention. Scales ranged from 1 ("Not at all effective") to 7 ("Very effective").

Effect	*M* (*SD*)
Improving alertness	5.03 (1.05)
Reducing fatigue	4.70 (1.29)
Improving sleep quality	4.64 (1.34)
Improving mood	4.45 (1.56)
Reducing errors	3.70 (1.57)

Previous studies conducted with other types of shift workers have reported similar improvements in fatigue (Smith and Eastman 2012; Smith et al. 2009), errors (Babkoff et al. 2002; Campbell and Dawson 1990; Czeisler et al. 1990; Daurat et al. 2000; Gillberg et al. 1996; Härmä et al. 1989; Kretschmer et al. 2011; Wright Jr. et al., 1997), mood (Boudreau et al. 2013; Smith et al. 2009), and sleep (Boivin et al. 2012) as a result of circadian and sleep hygiene interventions.

Contrary to our expectations, participants reported no changes in sleepiness levels, negative mood, or sleep latency. These findings are inconsistent with results of previous interventions (Babkoff et al. 2002; Chapdelaine et al. 2012; Crowley et al. 2004; Daurat et al. 2000; Rogers et al. 1989; Schweitzer et al. 1992; Wright Jr. et al., 1997). The lack of change in sleepiness may have been due to the intervention only helping a subset of the sample: namely, those with more of an evening preference (Figure 4). When interviewed, however, nurses reported that the intervention was most effective at reducing their sleepiness. This discrepancy may have arisen from the limited time frame captured by the questionnaire (i.e., before and after the night shift). It is possible that participants (especially those with earlier chronotypes) experienced improvements in alertness earlier in their shifts, which we could not measure.

Similarly, although the intervention increased positive mood, it did not reduce negative mood, contrary to previous studies (Eastman et al. 1995; Huang et al. 2013; Smith et al. 2009). Nurses generally reported low levels of negative mood throughout our study, with the majority of them (61%) giving the minimum value on the scale. This floor effect left little room for improvement.

There was also no change in sleep latency between the periods. Although commonly used, self-report measures of sleep latency may not be a valid indicator of how long it takes to fall asleep. The use of logbooks to measure sleep parameters has been validated in field studies (Dorrian et al. 2006), but researchers have found low concordance rates between self-reported sleep latency and estimates derived from actigraphy ($r = .10$; Thurman et al. 2018). The lack of change observed in this measure is thus difficult to interpret.

Unexpectedly, exploratory analyses suggested that nurses with more of an evening preference experienced the largest improvements in fatigue, sleepiness, and mood. Since morning type individuals typically have more difficulty adjusting to night shifts (Gamble et al. 2011), one might expect that they would experience larger benefits from the intervention. Yet, our results suggest the opposite. Evening types generally have an easier time adjusting to night shifts due to their naturally delayed circadian phase (Gamble et al. 2011; Ritonja et al. 2019; Saksvik et al. 2011); perhaps they may only require a small additional phase delay in order to experience the benefits associated with partial circadian alignment. Our intervention may thus have elicited sufficient circadian phase delays to benefit evening types, but not morning types. These results suggest the possibility that controlled light exposure interventions could be personalized based on individual characteristics such as chronotype. Still, the internal consistency of our chronotype measure was low, so future studies should verify these results using a measure that is better suited for shift workers (e.g., Juda et al. 2013).

If some of these improvements represent causal effects of the intervention, there are at least three mechanisms of action: circadian rhythms, sleep hygiene, or light therapy. First, the light exposure suggestions were designed to phase delay circadian rhythms to promote adaptation to night work. Light avoidance in the morning before sleep may have additionally promoted this adaptation by reducing circadian phase advances. In our study, partial circadian realignment may be responsible for some of the observed improvements. Second, some of our suggestions were well-validated sleep hygiene recommendations shown to improve sleep (Atlantis et al. 2006; Kecklund and Axelsson

2016) and may have helped independent of circadian alignment. Third, light exposure has been shown to improve mood and temporarily improve alertness (Souman et al. 2018; Stephenson et al. 2012). A combination of these three mechanisms — as well as expectations or demand characteristics, which we could not control for in our present study — could be responsible for our positive results.

Given that we developed the intervention with feasibility in mind, most nurses followed the intervention as instructed, and they generally reported that the intervention was feasible and easy to implement. Our participants particularly liked wearing the sunglasses after their night shifts, likely because this was the easiest component to follow. Although they rated the light box as the least feasible component, they reported that they would likely implement the full intervention in the long term if they had access to the necessary materials. This is especially important given that long-term implementation is the end goal and would be necessary to potentially reduce some of the long-term side effects of circadian misalignment.

Limitations

Despite these promising findings, our study has several limitations. The most important limitation is the lack of a separate control group, which prevents us from making causal claims or assessing which components of the intervention are most effective. Further, given that this is a feasibility study, we only used self-reported measures. To minimize biases, we tried to select measures that had been validated against objective ones, but future studies would ideally include objective measures of sleep and activity (e.g., actigraphy), compliance (e.g., light sensors), sleepiness (e.g., psychomotor vigilance tasks), and circadian phase (e.g., melatonin). In addition, our study was relatively short — approximately one week for the control period and one week for the intervention — meaning that we could not assess the long-term impact of our intervention.

Another limitation involves our exclusion criteria, which likely prevented the most fatigued nurses from participating. We excluded nurses with fatigue-related medical conditions and those who had been involved in fatigue-related driving accidents in order to minimize potential adverse effects of our intervention. For example, if the light exposure happened to cause some nurses to phase advance rather than delay, the intervention could have increased their fatigue at work. Excluding fatigued nurses likely limited the strength of the observed effects, since the nurses most likely to benefit from our intervention could not participate. This also prevents us from generalizing the effects of the intervention to shift workers suffering from sleep disorders. Given that we saw no major adverse effects of the intervention, future studies could use more lenient exclusion criteria.

Finally, future studies should also assess whether our intervention places nurses at a higher risk of road accidents due to possible increases in fatigue when returning home from work. The goal of many circadian alignment strategies is to delay the daily peak in drowsiness during the night shift into the daytime sleep episode (Smith and Eastman 2012). This involves peak drowsiness levels inevitably occurring during the commute home on some days. Future research should compare these risks against the benefits of fatigue reduction during night shifts, especially in professions that require driving. In any case, we saw no evidence that the intervention increased fatigue in our sample, even after the night shifts or during days off.

Conclusion

Overall, our results demonstrate the feasibility and potential effectiveness of light-based interventions for rapidly rotating shift workers. In addition to its feasibility, a major benefit of this intervention is its low cost: beyond the light box, the intervention uses inexpensive materials that many shift workers already own. Although we agree with other researchers urging institutions to use shift schedules that minimize fatigue (e.g., Smith and Eastman 2012), employees working these rotating schedules nonetheless require practical counter-measures. This intervention offers a potential solution that focuses on workers and requires no administrative buy-in. Overall, our results support the potential of circadian-based interventions to minimize the health and safety impacts associated with working rapidly rotating shifts.

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Declaration of interest

The authors report no conflicts of interest.

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Data availability statement

The Research Ethics Board did not permit data sharing, since some of the data are sensitive (e.g., errors made at work or alcohol consumption) and may be identifiable given the small sample size. Researchers can contact us to run any additional analyses.

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