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WEARING BLUE-BLOCKERS IN THE MORNING COULD IMPROVE SLEEP OF WORKERS ON A PERMANENT NIGHT SCHEDULE: A PILOT STUDY

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Night shiftworkers often complain of disturbed sleep during the day. This could be partly caused by morning sunlight exposure during the commute home, which tends to maintain the circadian clock on a daytime rhythm. The circadian clock is most sensitive to the blue portion of the visible spectrum, so our aim was to determine if blocking short wavelengths of light below 540 nm could improve daytime sleep quality and nighttime vigilance of night shiftworkers. Eight permanent night shiftworkers (32–56 yrs of age) of Quebec City's Canada Post distribution center were evaluated during summertime, and twenty others (24–55 yrs of age) during fall and winter. Timing, efficacy, and fragmentation of daytime sleep were analyzed over four weeks by a wrist activity monitor, and subjective vigilance was additionally assessed at the end of the night shift in the fall–winter group. The first two weeks served as baseline and the remaining two as experimental weeks when workers had to wear blue-blockers glasses, either just before leaving the workplace at the end of their shift (summer group) or 2 h before the end of the night shift (fall–winter group). They all had to wear the glasses when outside during the day until 16:00 h. When wearing the glasses, workers slept, on average \pm SD, 32 ± 29 and 34 ± 60 more min/day, increased their sleep efficacy by $1.95 \pm 2.17\%$ and $4.56 \pm 6.1\%$, and lowered their sleep fragmentation by $1.74 \pm 1.36\%$ and $4.22 \pm 9.16\%$ in the summer and fall–winter group, respectively. Subjective vigilance also generally improved on Fridays in the fall–winter group. Blue-blockers seem to improve daytime sleep of permanent night-shift workers. (Author correspondence: marc.hebert@crulrg.ulaval.ca)

Keywords Light wavelength, Blue-blockers, Shiftwork, Sleep, Vigilance

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INTRODUCTION

In our modern society, working at night has become unavoidable in many fields. Night work is not only associated with acute (Giebel et al., 2008) and chronic health problems (Haus & Smolensky, 2006), but also with social impairment (Wirtz et al., 2008), lower performance (Rosa et al., 1990), increased risk of error (Gold et al., 1992), and industrial (Frank, 2000; Ong et al., 1987; Smith et al., 1994) and road accidents (Akerstedt et al., 2005; Folkard et al., 2005; Ingre et al., 2006; Novak & Auvil-Novak, 1996). Essentially, the most frequent complaints among shiftworkers are the lack of proper sleep during the day and lower vigilance while working at night (Akerstedt et al., 2008; Shield, 2002). Humans being are diurnal mammals; thus, a night-shift schedule induces misalignment between the rest-activity cycle and circadian clock, causing increasing sleepiness while working at night (Czeisler et al., 1990) and difficulty in maintaining sleep during the daytime (Akerstedt, 1995). In fact, when night workers try to sleep during the day, although sleep deprived, they have to struggle against the increasing circadian alertness signal, which results in more awakenings during a much shorter daytime sleep (Akerstedt, 1995; Akerstedt & Gillberg, 1981; Akerstedt et al., 1991; Dijk & Czeisler, 1994, 1995; Tilley et al., 1982). Moreover, it has been demonstrated that even on a permanent night shift, the circadian clock does not undergo sufficient adjustment to be beneficial for health and safety (Folkard, 2008).

It is possible to induce a phase delay in the circadian clock to improve the adaptation to a night schedule by exposing workers to bright light before the temperature minimum (T-min), generally occurring around 05:00 h, followed by a strict 8 h period of darkness enforced by wearing very dark glasses outdoors during the daytime (Burgess et al., 2002; Eastman & Martin, 1999). More interestingly, it was demonstrated that each part of this strategy (bright light and 8 h darkness period) could independently account for 50% of the resulting phase shift of the circadian clock (Boivin & James, 2002; Horowitz et al., 2001). Unfortunately, staying in the dark for eight consecutive hours during the day is hardly realistic for night workers, who are scarcely sleeping 4 to 5 h, whereas the use of very dark glasses can be hazardous while driving (Eastman & Martin, 1999).

It is now well established that the circadian clock is most sensitive to the blue portion of the visual spectrum, with a peak sensitivity between 446 and 483 nm (Brainard et al., 2001; Thapan et al., 2001). In addition, our team has recently shown that blocking all wavelengths <540 nm with blue-blocker glasses could prevent the capacity of a 4000 lux white light to suppress melatonin production, therefore suggesting these glasses have the potential to render “blind” the circadian clock

(Sasseville et al., 2006). Based on those findings, blue-blockers could become a simple means to help provide an 8 h period of circadian darkness during the day, while workers are outside, without compromising vision. In this pilot study, we assessed the effectiveness of blue-blocker glasses to improve daytime sleep and, consequently, subjective vigilance at work of actual permanent night shiftworkers exposed to a relatively bright environment. The study was undertaken in two consecutive phases. First, a group was evaluated during the summer season and wore glasses only when outdoors. Second, another group was assessed through the fall and winter and wore the glasses indoors during the last 2 h of the night shift as well as outdoors. In the latter group, modifications in the intervention were implemented, as we expected the light environment to be much darker during the commute home due to the late sunrises during the daylight saving time change period through fall and winter in Canada. Consequently, because we wanted the blue-blockers to be worn during the most significant light exposure period, the two last hours of the shifts, supposedly after the T-min, were included in the circadian darkness period.

METHODS

Study Participants

Permanent night workers from the Canada Post's distribution center of Quebec City (Quebec, Canada) were recruited on a voluntary basis. The study conformed with international ethical standards (Portaluppi et al., 2008) and was approved by the institutional ethics committee. Written informed consent was obtained prior to participation. All participants reported being in good health, not having journeyed through more than one time zone the month preceding the study, and being between 25 and 55 yrs old. Based on the Horne-Östberg Morningness-Eveningness Scale (Horne & Östberg, 1976), participants who revealed extreme chronotypes (<30 or >70) were to be excluded, but we did not encounter such a case. The chronotype scores of the workers ranged between 48 and 64 with a mean value of 55. In the facility, all workers were exposed to relatively bright fluorescent lights (F34CW/SS/ECO/CVP, Sylvania, Mississauga, Ontario, Canada), set up 1 m from each other on the ceiling, that resulted in 500 lux of white-light exposure measured horizontally at eye level (IL 1700 radiometer, International Light, Peabody, Massachusetts, USA). This specific light intensity, although unusually high, was fixed by Canada Post's management as a proper standard to read addresses on envelopes and packages.

Two groups, the summer and fall–winter ones, completed the study. The summer group (July to August 2004) was composed of eight

(6 females, 2 males) workers; their mean age (\pm SD) was 42.2 (\pm 7.1) yrs. The fall–winter group (September 2005 to February 2006) included 20 different (9 females, 11 males) workers; their mean age (\pm SD) was 37.2 (\pm 9.8) yrs. Participants from the summer group always worked an 8 h night shift (00:00 to 08:00 h) Monday to Friday and were off weekends. The fall–winter group followed the same weekly schedule, except for 9 workers who worked from 23:00 to 07:00 h (see Table 1). Both groups were evaluated over four consecutive weeks, during which the first two served as baseline (week 1 and 2) and the remaining two weeks as experimental (week 3 and 4).

Study Protocol

Throughout the study, participants were asked to wear an activity/light monitor, the Actiwatch-L (Mini Mitter Co., Inc., Bend, Oregon, USA), on the non-dominant wrist for actigraphy measurements. Data were logged at a 30 sec epoch, and the Actiware-sleep 3.4 software (Mini Mitter Co., Inc.) was used on the activity output to obtain the time before bedtime (TBB = time between the end of the shift and bedtime), time in bed (TIB = time between bedtime and wake time), total sleep time (TST = time between the first and the last 10 min period in which no more than one epoch is scored as mobile), sleep efficiency (SE = total sleep time divided by the time spent in bed, multiplied by 100), and movement and fragmentation index (MFI = summation of the percentage of minutes spent moving during sleep with reference to the percentage of 1 min immobility phases). Activity recordings were inspected for evidence the monitor was worn throughout the study; suspicious periods without movement were excluded from analyses. The light-exposure data were used to determine the amount of time spent outside after the end of the shift, which is hypothesized to represent the commute home time. Actigraphy data from one participant in the fall–winter group were excluded due to device failure.

TABLE 1 Sunrise time in Quebec City (46° 48' N – 71° 75' O) for the winter–fall group

Group	Month	N	Time of sunrise	Time of shift
Summer (2004)	July	4	04:46 to 05:19 h (DST)	00:00 to 08:00 h
	August	4	05:21 to 06:03 h (DST)	00:00 to 08:00 h
Fall–winter (2005–2006)	September	6	06:04 to 06:41 h (DST)	00:00 to 08:00 h
	October	5	06:43 to 07:22 h (DST)	00:00 to 08:00 h
	October	6	06:26 to 07:07 h (EST)	23:00 to 07:00 h
	February	3	07:09 to 06:27 h (EST)	23:00 to 07:00 h

Abbreviations: DST = Daylight Saving Time, EST = Eastern Standard Time.

In addition, for the fall–winter group, subjective vigilance of the workers was evaluated with visual analogue scales (VAS) derived from a French translation of the Stanford Sleepiness Scale (Hoddes et al., 1973) to investigate the impact of wearing blue-blockers while working. The test is composed of five items to assess vigilance and mood: alertness, energy level, happiness, anxiety, and overall state. In the first four items, status was self-rated with a mark on a 100 mm line, with opposing conditions on each side (e.g., not alert vs. very alert). The measured distance from the left edge to the participant's mark represented the score (range from 0 to 100), where higher score meant better status. For the fifth item, the overall state, participants had to indicate one of seven options corresponding to their state:

1. feeling active and vital, alert, wide awake;
2. functioning at a high level, but not at peak, able to concentrate;
3. relaxed, awake, not at full alertness, responsive;
4. a little foggy, not at peak, let down;
5. fogginess, beginning to lose interest in remaining awake, slowed down;
6. sleepiness, prefer to be lying down, fighting sleep, woozy; or
7. almost in reverie, sleep onset soon, lost struggle to remain awake.

Participants who ended their shift at 08:00 h performed the VAS in a quiet isolated room at 05:30, 06:30, and 07:30 h of each work day (Monday to Friday), while those who ended their shift at 07:00 h performed the VAS at 04:30, 05:30, and 06:30 h. For analysis purposes, tests were grouped in VAS done 150, 90, and 30 min before the end of the night shift.

Experimental Conditions

All participants were instructed to wear blue-blocker glasses before going outside the facility, at the end of their shift, until returning home, as well as whenever they went outside before 16:00 h from Monday to Thursday of each experimental week. Wearing the glasses on Friday was not necessary, as those workers typically revert to a diurnal schedule on days off, and, therefore, postpone their sleep to Friday night. In addition, the subjects of the fall–winter group had to wear their glasses the last 2 h of their shift. This modification was justified by the fact that sunrise occurs around 07:00 h during the Canadian winter (see Table 1), and under those conditions workers were not expected to receive much light in the morning (usually <400 lux) during their commute home compared to summertime (4,000 to 10,000 lux). Moreover, as those workers were exposed to a relatively high intensity of light during the night (500 lux), we were hoping the subjects of the fall–winter group could benefit from being shielded from the blue light present in the fluorescent lamps (see

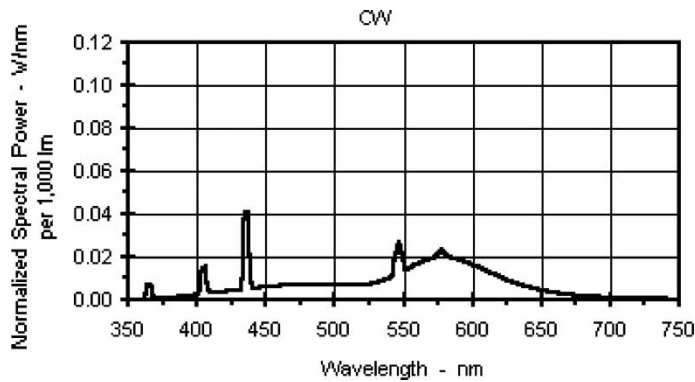


FIGURE 1 Spectral power distribution curve supplied by the fabricant for the F34CW/SS/ECO/CVP white fluorescent lamps in the work place. They were composed of T12 bulb of 34W with a color temperature of 4100 K.

Figure 1) during the expected phase-advancing portion of the circadian clock's phase-response curve (PRC), generally occurring after the core body temperature minimum (T-min), sometime around 05:00–06:00 h (Czeisler et al., 1989), which would tend to resynchronize their circadian clock's rhythm to a diurnal schedule. Because workers from the winter group were to wear blue-blockers at work, we wanted to observe the impact of cutting short wavelength from 500 lux of white light on subjective alertness during the last 2 h of the night shift, when workers were expected to be at their lowest vigilance.

The summer group used blue-blocking security glasses (Uvex, Fuerth, Germany), and the winter group used custom-made blue-blockers (Telemedoptique, Quebec City, Canada). Both glasses block short wavelengths, but the custom-made blue-blockers allowed passage of a small portion of 540 nm ($\leq 25\%$) light to the eyes (see Figure 2), making them less likely to interfere with color vision while working. Also, when the glasses were handed out at the beginning of the experimental condition, all participants were instructed to stop their use if, at any moment, they felt sleepier than usual, especially when driving. However, none of the 28 participants reported a need for such.

Data Analysis

In both groups, age-dependent changes were assessed with the Spearman correlation test. Then, actigraphy parameters (TBB, TIB, TST, SE, and MFI) of the daily average from baseline weeks were compared with equivalent data of the experimental weeks. Pooling corresponding data from each day of the two weeks was seen as more representative of the overall condition of our workers, mostly because TIB can fluctuate

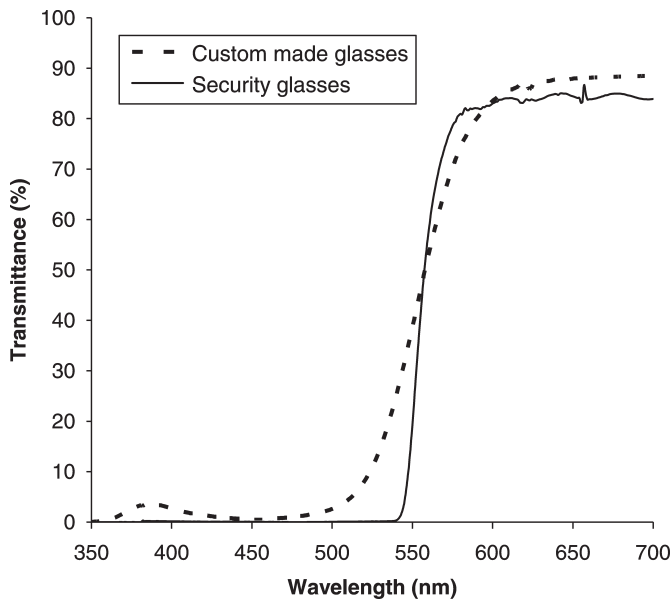


FIGURE 2 Transmittance level of the two optical filters used. The blue-blocking security glasses (—) allow passage of 0.1% of light of wavelengths <540 nm, 40% at 555 nm, and 82% >600 nm. The custom-made, blue-blockers (- - -) allow 3.5% of the 387 nm light to pass through, then allow passage of 0.5% of the light at 450 nm, 25% at 540 nm, 45% at 555 nm, and 83% >600 nm.

highly between workers due to individual and/or external circumstances. Differences were evaluated using a 2 (conditions) \times 4 (Monday, Tuesday, Wednesday, and Thursday) analysis of variance (ANOVA) for repeated measures. When no interactions were found, all days of the week were averaged together in order to measure the overall condition effect using Student's t-test. The same analyses were performed on MFI derived from the first 2 h after bedtime to clarify the effect of short wavelengths of light exposure before going to sleep. For the subjective vigilance measurement from the fall-winter group, a 2 (conditions) \times 3 (time before the end of the night shift: 150, 90, and 30 min) ANOVA for repeated measures was performed on the data of each night after calculating the mean VAS value from the two-week daily average for the baseline as well as experimental conditions.

RESULTS

No age-dependent variations were found with the Spearman correlation test. Actigraphy data showed night workers from this facility had a mean (\pm SD) commute home time of 19.6 (\pm 5.6) min. The TBB for the summer group was 79 (\pm 49) and 70 (\pm 34) min for the baseline and experimental condition, respectively, but neither the ANOVA

TABLE 2 Sleep actigraphy parameters among shiftworkers from the summer group

Study condition	Time in bed hours (\pm SD)	Sleep time hours (\pm SD)	Sleep efficiency % (\pm SD)	Movement and fragmentation index % (\pm SD)
Baseline	6:58 (\pm 0:56)	6:12 (\pm 1:34)	84.8 (\pm 4.0)	19.0 (\pm 2.6)
Experimental	7:15 (\pm 1:09)	6:44 (\pm 1:40)	86.8 (\pm 4.4)	17.3 (\pm 1.7)
Difference	0:17 (\pm 0:12)	0:32 (\pm 0:29) ($p = 0.02$)	2.0 (\pm 2.2) ($p = 0.04$)	-1.7 (\pm 1.4) ($p = 0.01$)

SD = standard deviation, N = 8.

[$F(1,4) = 0.98$, $p > 0.05$] nor the Student's t-test on pooled days of the weeks showed significant differences between conditions. Also, the ANOVA for TIB [$F(3,18) = 4.63$, $p > 0.05$], TST [$F(3,18) = 0.88$, $p > 0.05$], SE [$F(3,18) = 0.59$, $p > 0.05$], and MFI [$F(3,18) = 2.27$, $p > 0.05$] showed no day-of-week effect. As shown in Table 2, after averaging all days of the week, the Student's t-test revealed, under the experimental condition, that workers had a longer mean TST of 32 min without augmentation of TIB. We also noted an improved SE by 1.95% along with a lower MFI by 1.74%. Moreover, Student's t-test of the data of the first 2 h in bed did not reveal any difference in the MFI between conditions ($p > 0.05$), suggesting the improvement in sleep was not the result of better sleep quality at the beginning of the sleep period resulting from shielding the worker from the possible stimulatory effect of blue light.

Similar to the summer group, the TBB for the fall-winter group was 107 (\pm 61) and 100 (\pm 60) min for the baseline and the experimental condition, respectively. Again, the ANOVA [$F(1,10) = 0.15$, $p > 0.05$] and Student's t-test on pooled days of the weeks showed no significant difference between conditions. The ANOVA on TIB [$F(3,14) = 2.62$, $p > 0.05$], TST [$F(3,14) = 5.46$, $p > 0.05$], SE [$F(3,14) = 1.73$, $p > 0.05$], and MFI [$F(3,9) = 4.08$, $p > 0.05$] revealed no day-of-week effect and, as reported in Table 3, Student's t-test on the combined data showed workers had a significantly longer TST of 34 min for the same TIB, improved sleep efficiency by 4.56%, plus a lower MFI by 4.22%. Once

Table 3 Sleep actigraphy parameters among shiftworkers from the fall-winter group

Condition	Time in bed hours (\pm SD)	Sleep time hours (\pm SD)	Sleep efficiency % (\pm SD)	Movement and fragmentation index % (\pm SD)
Baseline	7:23 (\pm 1:11)	6:16 (\pm 1:12)	78.1 (\pm 5.9)	30.2 (\pm 18.3)
Experimental	7:19 (\pm 1:24)	6:50 (\pm 1:09)	82.6 (\pm 5.8)	26.0 (\pm 16.3)
Difference	0:04 (\pm 0:56)	0:34 (\pm 1:00) ($p = 0.02$)	4.5 (\pm 6.1) ($p = 0.004$)	-4.2 (\pm 9.2) ($p = 0.053$)

SD = standard deviation, N = 18.

more, the first 2 h in bed did not differ between conditions on the MFI ($p > 0.05$; Student's *t*-test).

In addition, for this group, the ANOVA revealed no significant time effect in VAS scores over the last 150 min of any night shift, with the exception of the overall state on Tuesday [$F(2,36) = 11.58, p = 0.001$]. Apart from the energy level, the experimental condition significantly improved the overall state on Tuesday [$F(1,18) = 5.43, p = 0.03$] and reduced anxiety on Wednesday [$F(1,18) = 5.94, p = 0.03$]. However, a better consensus was observed on Friday, when alertness [$F(1,15) = 8.60, p = 0.01$], happiness [$F(1,15) = 7.67, p = 0.01$], and overall state [$F(1,15) = 6.95, p = 0.02$] were all significantly improved.

DISCUSSION

Keeping in mind that this was an effectiveness more than an efficacy trial (Nathan et al., 2000), the goal of this pilot study was to induce a circadian darkness period of about 8 h during the day to improve adaptation to night work in an uncommonly high light intensity indoor environment. Because participants generally stayed awake >1 h after the end of the night shift and remained in bed for an average of 7 h, obstructing short wavelengths (blue) of light in the morning, especially from the sun, was considered the main target for circadian darkness enforcement in our study. In that sense, because the fall–winter group was evaluated in a different lighting environment (less morning sunlight expected in winter time), participants were additionally instructed to wear the glasses inside the facility at a potentially strong “daytime resynchronizing” period (Lack & Wright, 2007). Considering those modifications, similar improvements of sleep duration and quality in both groups suggest that adjusting the strategy was adequate in different lighting situations, and using a different filter, allowing minimal short-wavelengths transmittance, did not negatively impact the results. Indeed, for both groups, more sleep was obtained within the same time in bed, suggesting fewer awakenings and, therefore, better sleep efficacy. This was also reported in another field study with shiftworking nurses (Yoon et al., 2002), where sleep quantity and quality were improved after four days of being exposed to bright light at night and wearing dark glasses in the morning. It may be argued that an average improvement in sleep of 30 min/day is not meaningful. However, this represents an additional 2 h of sleep/week, which in the long-term might be significant, knowing the implications of chronic sleep deficit on alertness when working at night (Akerstedt, 2003). Also, given that more effects could have been expected in the summer due to the presence of brighter morning light, slightly better results for the winter group could indicate that, even if the real impact of such differences is hard to judge (Bjorvatn et al., 2007), blocking blue wavelengths for the

greater amount of time between the T-min and bedtime could increase the possibility of obtaining beneficial effects on daytime sleep.

Although circadian phase assessment was not performed in our study, we believe ambient exposure (500 lux of white light) at night could have been sufficient to lead to a circadian phase delay (Boivin et al., 1996; Zeitzer et al., 2000), given that the workers' eyes were shielded from the blue wavelength at an appropriate time in the morning in order to interfere with morning light resynchronization (Sasseville et al., 2006). Causing a partial circadian clock adjustment could have been the reason why the workers experienced better sleep as observed in other studies (Czeisler et al., 1990; Dawson et al., 1995; Eastman et al., 1994). Behavioral changes in our participants could also have influenced the results, and these should be controlled in a subsequent crossover design study that includes circadian assessment. On the other hand, sleep improvements during the day could have been induced by preventing the alerting effect of blue light in the morning. These effects, however, have only been demonstrated in the evening or early night (Cajochen et al., 2005; Campbell, 2006; Lockley et al., 2006; Revell et al., 2006). In fact, the alerting effect of blue light implies that it could counter-balance the influence of sleep deprivation after a night shift. We do not believe this is the case, as a more profound decrease of vigilance would have been expected in the fall-winter group while wearing the blue-blocker during the last 2 h of the night shift. In fact, our findings for subjective vigilance are similar to another study that concluded that wearing blue-blockers did not alter normal subjective and objective vigilance during simulated night shiftwork (Kayumov et al., 2005). Thus, as suggested by others, it might be relevant to refine the work done on the vigilance-enhancing effect of short wavelengths by trying to replicate it at different clock times, such as after a night shift, to quantify its relative magnitude (Campbell, 2006). In our study, the amount of blue light present in the light source that provided the 500 lux exposure might have not been great enough to counteract the effect of sleep deprivation in night workers at the end of the night shift.

The vigilance of the winter group generally tended to improve on the last day (Friday) of the experimental night-working weeks. This was also reported in another study on shiftworking nurses (Yoon et al., 2002). In the later study, when compared to room light, better subjective vigilance was obtained after four daily exposures to a 4 h episode of bright light at night combined with wearing very dark glasses in the morning. Because subjective alertness shows a circadian rhythm that can reliably be measured in an actual work conditions (Cariou et al., 2008), improvement occurring at the end of the week might reflect a gradual adaptation of the circadian clock (Eastman & Martin, 1999). Unfortunately, this expected gradual improvement was not observed in the sleep parameters over the course of the experimental weekdays. This is probably due to the

high variability in sleep episodes among participants and even from day to day in the same individual. Due to our small sample size, it is also possible that the analytical power was not strong enough to detect a difference.

A limitation of this pilot study was the smaller number of participants in the summer group compared with the winter group. As we needed workers to be available for consecutive weeks, only a few of them were available in July and August to participate in our study because of summer vacation. An additional limitation was that workers who volunteered in this study displayed very good sleep profiles for night shiftworkers, as the TST and SE were higher than what is usually reported in the literature (Akerstedt, 1995). Moreover, none of our workers were selected if presenting an extreme chronotype. We can assume the participants were coping fairly well with night work, as they did not report health problems related to the inversion of the sleep/wake cycle. Nevertheless, even considering their better sleep status, which may be partly due to the relatively bright working environment, it is surprising that we were able to further improve their condition by using blue-blockers at an appropriate time. This implies improving light exposure at night plus wearing blue-blockers in the morning could represent a simple and elegant means to improve the daytime sleep of many permanent night workers. Blue-blockers are also known to improve contrast sensitivity, visual acuity, and reduce glare along with chromatic aberration (de Fez et al., 2002; Leat et al., 1990; Rosenblum et al., 2000). This could help improve compliance by moderating the adverse effects, mainly photophobia and eye discomfort, of bright light in the morning. Further research with more complete assessment is needed in different work environments and with different work schedules to examine if the implementation of such strategy could be valuable to night work, in general.

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DECLARATION OF INTEREST

The authors D. Benhaberou-Brun, C. Fontaine, and M.-C. Charon report no conflict of interest. M. Hébert and A. Sasseville may have future financial interest in the commercialization of custom-made blue

blockers similar to those presented in this paper. The authors alone are responsible for the content and writing of the paper.

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