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Using blue-green light at night and blue-blockers during the day to improves adaptation to night work: A pilot study

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ABSTRACT

Background: Bright light at night paired with darkness during the day seem to facilitate adaptation to night work. Considering the biological clock sensitive to short wavelengths, we investigated the possibility of adaptation in shift workers exposed to blue-green light at night, combined with using blue-blockers during the day.

Methods: Four sawmill shift workers were evaluated during two weeks of night shifts (control and experimental) and one week of day shifts. Throughout the experimental week, ambient light (≈130 lx) was supplemented with blue-green light (200 lx) from 00:00 h to: 05:00 h on Monday and Tuesday, 06:00 h on Wednesday and 07:00 h on Thursday. Blue-blockers had to be worn outside from the end of the night shift until 16:00 h. For circadian assessment, salivary melatonin profiles were obtained between 00:00 h and 08:00 h, before and after 4 experimental night shifts. Sleep was continuously monitored with actigraphy and subjective vigilance was measured at the beginning, the middle and the end of each night and day shifts. The error percentage in wood board classification was used as an index of performance.

Results: Through experimental week, melatonin profiles of 3 participants have shifted by at least 2 hours. Improvements were observed in sleep parameters and subjective vigilance from the third night (Wednesday) as performance increased on the fourth night (Thursday) from 5.14% to 1.36% of errors ($p = 0.04$).

Conclusions: Strategic exposure to short wavelengths at night, and/or daytime use of blue-blocker glasses, seemed to improve sleep, vigilance and performance.

1. Background

In our modern society, night working has become unavoidable in many fields of activities. Accordingly, an increasing number of workers suffer from the harmful consequences of working night shifts on their health (Boivin et al., 2007, Haus and Smolensky, 2006) and social life (Berger and Hobbs, 2006). Night shifts generate a misalignment between the biological clock and the sleep/wake cycle, which leads to increased sleepiness and reduced performance at night when the body is set to be asleep, and diurnal sleep problems, when the body is set to be awake (Akerstedt, 1990; Eastman et al., 1995). Since the environmental light and dark cycle (L/D) is the main synchronizer of the circadian clock, relatively low light exposure at night, followed by sunlight exposure in the morning tend to maintain shift workers diurnally aligned (Akerstedt, 1995; Benhaberou-Brun et al., 1999; Dumont et al., 2001). This situation put workers at risk of developing what is now clinically recognized as shift work disorder (AASM, 2005). Modification of the L/D cycle with artificial light at night and a fixed period in a dark bedroom combined with the use of dark glasses when outdoor, have been shown to facilitate adaptation to night shifts in real work settings (Bjorvatn et al., 2007; Boivin and James, 2002; Lowden et al., 2004; Stewart et al., 1995; Yoon et al., 2002). Unfortunately, bright white light exposure at night can cause transient eye discomfort and headaches (Bjorvatn and Pallesen, 2008) which may yield to squinting and avoidance behaviour, therefore hindering efficiency and compliance. Besides, enforcing an 8-hour darkness period during the day is unlikely to be implemented by night shift workers whom diurnal sleep can be as short as 4 hours (Akerstedt, 2007), whereas wearing dark glasses during the morning commute home can be considered hazardous (Lockley, 2007).

It was shown, however, that the short wavelengths (blue range) of the visual spectrum, were more effective at phase shifting melatonin secretion, (Lockley et al., 2003; Revell et al., 2005; Warman et al., 2003; Wright and Lack, 2001; Wright et al., 2004) a reliable marker of the circadian clock synchronization. As well, cutting out short

Abbreviations: L/D, light and dark cycle; MEQ, morningness–eveningness questionnaire; BT, bed time; TIB, time in bed; TST, total slept time; SE, sleep efficiency; SL, sleep latency; VAS, visual analogue scale.

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wavelengths, that is light below 540 nm, seem to impede the capacity of bright light to suppress melatonin secretion (Sasseville et al., 2006). Consequently, controlling short wavelengths as part of a L/D cycle management strategy could reduce the need for using very bright light at night combined with a strict 8-hour dark bedroom regiment and/or wearing dark glasses, in order to re-aligned circadian rhythms. In the present pilot study, we introduced the use of auxiliary blue-green light at night combined with wearing blue-blocking glasses during the day in a real work place. Our aim was to evaluate, in rotating workers, the impact of a circadian-aimed short wavelengths controlled strategy on both the performance at work and circadian clock adaptation to the night shift.

2. Methods

2.1. Study participants

This study conformed to international ethical standards and was approved by the CHUQ ethics committee in Québec City before written informed consent was obtained. Four male workers (46, 45, 31 and 57 years old) were recruited from the Abitibi-Bowater sawmill of *La Doré*, Qc, Canada. Participants reported to be in good health and non-smoker. No drug or medication consumption that could affect sleep, vigilance and/or the circadian clock was allowed. Exclusion criteria consisted of having journeyed through more than two time zones one month prior to the study. Furthermore, based on a French version of the Morningness–Eveningness Questionnaire (MEQ) (Horne and Ostberg, 1976; Taillard et al., 2004), volunteer could not classify as extreme morning (MEQ score >70) or extreme evening (MEQ score <30) chronotypes.

2.2. Workplace setting

All participants worked according to a three-week rotation system (day shifts — 08:00 h to 16:00 h; night shifts — 00:00 h to 08:00 h; evening shifts — 16:00 h to 00:00 h), where each week included five shifts (Monday to Friday), followed by two days off (Saturday and Sunday). Their task was to inspect wood boards on a conveyor belt in order to adjust the computerized classification when required. Workers who volunteered for this study were part of the same team of four "classifiers", where three of them were continuously supervising quality while the forth was performing secondary tasks (i.e. maintenance and performance measurements on machinery). One after another, they were assigned to these secondary tasks for 30 minutes once every two hours throughout the night. In addition, a 30 minute meal break was scheduled at 04:00 h for all workers. Inside the facility, normal light exposure was around 130 lx ($\approx$56 μW/cm^2), as measured horizontally at eye level (IL-1700 radiometer, International Light, Peabody, MA, US) and coming from high-pressure mercury lamps on the ceiling. These illuminating systems produce a polychromatic white-appearing light, with specific wavelength peaks at: 254 nm, 365 nm, 405 nm, 436 nm, 546 nm and 577 nm.

2.3. Study design

Participants were evaluated during one week of 5 consecutive day shifts and two weeks of 5 consecutive night shifts. No intervention was planned on the first night shifts series of the control week during which, workers were instructed to maintain their usual routine. The experimental intervention was introduced on the following night shifts series (three weeks later). The day shift week assessment was set between the control and the experimental weeks. During the experimental week, participants' light environment was supplemented with 200 lx (66 μW/cm^2) of narrowband blue-green light (500 ± 10 nm). The lighting device were composed of two phosphor filled neon-type lamps equipped with green filters (Twin Tower Lo-LIGHT, Sunnex biotechnologies, Winnipeg, MB, Canada) that were placed roughly at 1 foot on the left and right side of the head (aligned with the eyes), using a custom-made support (Fig. 1A). These supports allowed proper side exposure of both eyes of each participant on classification duty. Because of the rotation among the 4 workers on duty between classification and secondary tasks, pulses of no more than 90 minutes of blue-green light were separated by 30 min of ambient light exposure. Lamps were set to be automatically turned-on from 00:00 h to 05:00 h on Monday and Tuesday, from 00:00 h to 06:00 h on Wednesday and from 00:00 h to 07:00 h on Thursday. This progressive exposure pattern was selected to increase the likely hood of inducing a circadian phase delay without having to know the exact circadian phase of each participant (Eastman and Martin, 1999). Finally, after each experimental nights, participants were instructed to wear blue-blocking glasses (Chron-Optic orange lens glasses, Télémedoptique, Quebec City, Qc, Canada) during the commute home as well as whenever outside between wake time and 16:00 h (Fig. 1B). The purpose of the glasses was to create a period of "circadian darkness" as opposed to "visual darkness". The spectral characteristics of the lamp and the glasses are presented in Fig. 1C whereas the protocol is illustrated in Fig. 2.

2.4. Materials

Melatonin assessment was performed on the night before, as well as on the fifth night of the experimental night week. For that second assessment, participants were relieved from their working duty. For both melatonin assessment nights, an hourly saliva sample was collected from 00:00 h to 08:00 h in a dim illuminated (<5 lx) isolated room. Melatonin concentration was subsequently extracted from samples as previously described (Sasseville et al., 2006).

For sleep evaluation, the Actiwatch-L (Mini-Mitter, Bend, OR, USA) was worn continuously during the three weeks of this study as previously described (Sasseville et al., 2009). Sleep characteristics derived from the actigraphy data were: bed time (BT), time in bed (TIB = time between bedtime and get up time), total slept time (TST = through TIB, the time between the first and the last 10-minute period during which no more than one epoch is scored as mobile), sleep efficiency (SE = TIB divided by the time within TST that is scored as sleep according to the Actiware-Sleep algorithm) and sleep latency (SL = time between BT and the onset of TST). Recorded data were matched with sleep log to confirm bedtime. Actigraphy data from the day week of participant 1 were excluded due to device failure.

Participants' subjective vigilance was rated using a visual analogue scale (VAS) appraising the level of alertness (Monk et al., 1989). In this test, status is self-rated with a mark on a 100 mm line with opposing conditions on each side (not alert Vs. very alert). The distance of the participant's mark from the left edge represented the score (range from 0 to 100) with higher scores meaning higher alertness. Measurements (night shift/day shift) were performed at the beginning (00:00 h/08:00 h), before the meal break (03:30 h/11:30 h) and at the end (07:00 h/15:00 h) of each shift.

Finally as an index of performance, a randomly selected sample from each participant's classification task was reclassified manually on the following day by a non-participating worker, to obtain a precise individual percentage of error ratio for each participant and each night shift. Unfortunately, no data from the Tuesday shift of the experimental week were retrieved due to mechanical problems at the facility which halted normal course of work. This

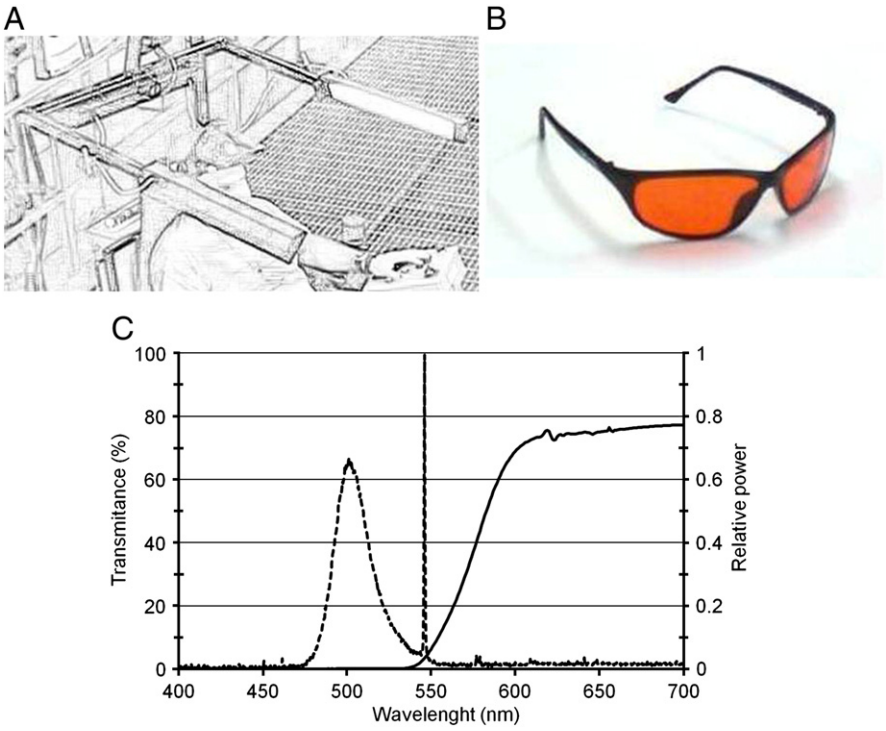

Fig. 1. Details of the material used for short wavelengths management. (A) Representation showings the position of the light source on each side of the worker's head and their orientation toward the worker's face. (B) Picture of the blue-blockers glasses used for this study. (C) Combined graph of the light source and the glasses spectral characteristics. The blue-blockers transmittance spectrum (solid line) is plotted on the left axis in percentage of transmittance. The relative power spectrum of the lighting device (dotted line) is plotted on the right axis in relative power.

assessment was, however, of great interest as it represented an objective evaluation of the real performance using the worker's main task, which is rarely possible in research studies.

2.5. Data analysis

To determine the melatonin secretion phase shift, the first salivary melatonin concentration obtained at 00:00 h before experimental night week was used as a reference. This point was interpolated on the melatonin concentration profile obtained on the fifth night of the experimental week using a non-linear regression curve fit to identify the time when the reference point was reached. The time between these two points was used to assess the extent of the circadian clock phase shift. To compare actigraphy data obtained through the experimental, control and day weeks, a one-way analysis of variance (ANOVA) for repeated measures was used for each sleep parameters on the polled data of all work days of a given week included in this study. A post-hoc Tukey test was used to explore simple effects. Since subjective vigilance did not fluctuate across the day shift, VAS values obtained during the corresponding control and experimental nights were normalized relative to the respective daytime test (beginning, middle and end of shift). A $2\times4\times3$ ANOVA for repeated measures was performed on the mean VAS score to assess the effect for the following factors: condition (control and experimental), days (Monday, Tuesday, Wednesday and Thursday) and time of tests (00:00 h, 03:15 h and 06:30 h). Bonferroni pairwise comparison was then used to explore significant effects. For performance measurement, the effect of condition was assessed using a one-tailed (reduction expected) Wilcoxon matched-pairs signed rank test comparing each day of the control week with the corresponding day of the experimental week.

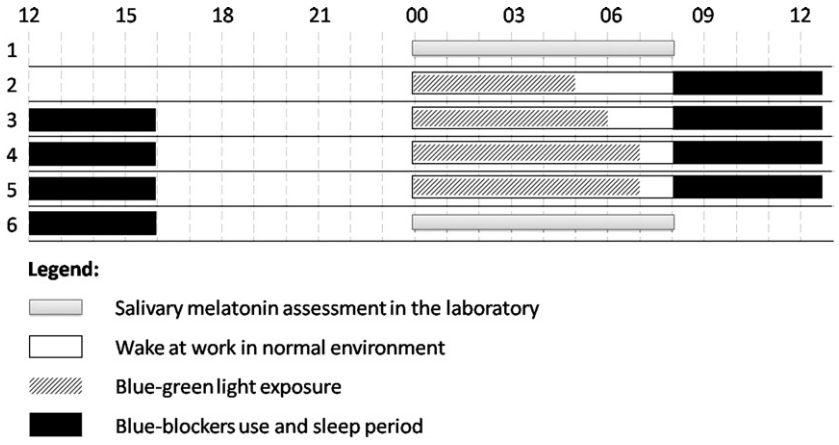

Fig. 2. Schematic representation of the study protocol in the experimental night. Clock time (hours) is represented on the horizontal axis. While under dim light in the laboratory before and after the experimental week (light gray), saliva sample were obtained every hour. During the four night shifts, light exposure intervention was from midnight to 05:00 h on Monday, to 06:00 h on Tuesday and to 07:00 h on Wednesday and Thursday. Blue-blockers had to be worn from the end of the shift to 16:00 h when outside.

3. Results

MEQ scores of participant 1, 2, 3 and 4 were 65, 58, 64 and 64 respectively. Melatonin profiles are presented in Fig. 3. After four days of experimental conditions, participant 1 showed no melatonin secretion phase shift (Fig. 3A), whereas participants 2, 3 and 4 presented a phase delay of 4:16 (Fig. 3B), 1:57 (Fig. 3C) and 1:56 (Fig. 3D) hours respectively. Individual sleep results with mean value, derived from actigraphy analysis, are presented in Table 1. A main effect was found for TST ($p=0.007$) and SL ($p=0.049$). Those data suggest that participants had fewer difficulties to initiate and maintain sleep over a similar sleep period. Post-hoc Tukey test (Table 1) confirmed that TST was significantly shorter by $2:00\pm1:10$ ($\pm$SD) in the control weeks when compared to the day week ($p=0.006$) which represent a substantial sleep loss. Moreover, without increasing the TIB, the mean TST improved by $0:40\pm0:55$ in the experimental week when compared to the control week ($p=0.045$) and was no longer different from the day week ($p=0.306$). SE tended to improve during the experimental week but the difference did not reach significance. SL significantly improved by $0:18\pm0:17$ ($p=0.041$) in the experimental condition when compared to control and was also not different from the day week ($p=0.363$). For a better understanding of the sleep results, differences between control and experimental weeks for SE and SL of each participant are presented in Table 2, along with the corresponding phase shift in melatonin secretion on the experimental week. It can be seen that apparent phase shifts in melatonin secretion (participant 2, 3 and 4) seem to be associated with greater improvement in SE, which represent the proportion of time slept throughout TIB, as well as a decreased time to initiate sleep (faster SL). Accordingly, when no phases shift in melatonin secretion was observed (participant 1), SE showed less improvement and there was virtually no change in SL. Analysis of the VAS data revealed no day effect ($F(3,9)=3.16$, $p=0.078$), but a condition ($F(1,3)=33.72$, $p=0.010$) and a time of tests effect ($F(2,6)=8.61$, $p=0.017$), demonstrating that although subjective vigilance behaved differently between conditions, it was always decreasing throughout the night shift. There was also an interaction between conditions and time of tests ($F(2,6)=44.67$, $p=0.001$) suggesting that subjective vigilance

Table 1
Individual sleep characteristics on the day shift week, as well as the control and the experimental night shift weeks. Mean values are presented at the bottom with standard deviation (SD) and significant differences are the result of the ANOVA analysis. (BT = Bed time, TIB = Time in bed, TST = Total sleep time, SE = Sleep efficiency percentage, SL = Sleep latency).

	Day shift				
	Baseline night shift				
	Experimental night shift				
	BT (h)	TIB (h)	TST (h)	SE (%)	SL (h)
1	N/A	N/A	N/A	N/A	N/A
	09:11	5:52	4:57	78.4	0:22
	09:21	6:29	5:50	80.7	0:18
2	23:27	7:33	6:47	79.0	0:20
	08:49	7:52	5:30	66.5	0:44
	08:58	7:20	5:53	71.2	0:06
3	22:19	8:06	7:43	82.2	0:17
	09:00	6:48	6:04	79.5	0:15
	09:18	7:11	7:00	83.7	0:03
4	21:18	9:10	7:32	75.0	0:17
	08:43	7:21	5:38	58.0	0:24
	09:02	8:30	7:17	63.1	0:06
Mean	22:21 (0:45)	8:17 (0:36)	7:32 (0:32)	75.1 (8.0)	0:18 (0:07)
	08:56 (0:10)	6:58 (0:59)	5:32 (0:36)[a]	70.6 (9.1)	0:26 (0:11)
	09:10 (0:10)	7:03 (0:48)	6:12 (0:50)[b]	74.3 (7.1)	0:08 (0:06)[b]

[a] Significant difference between the control and the day shift week ($p<0.05$).
[b] Significant difference between the experimental and the control week ($p<0.05$).

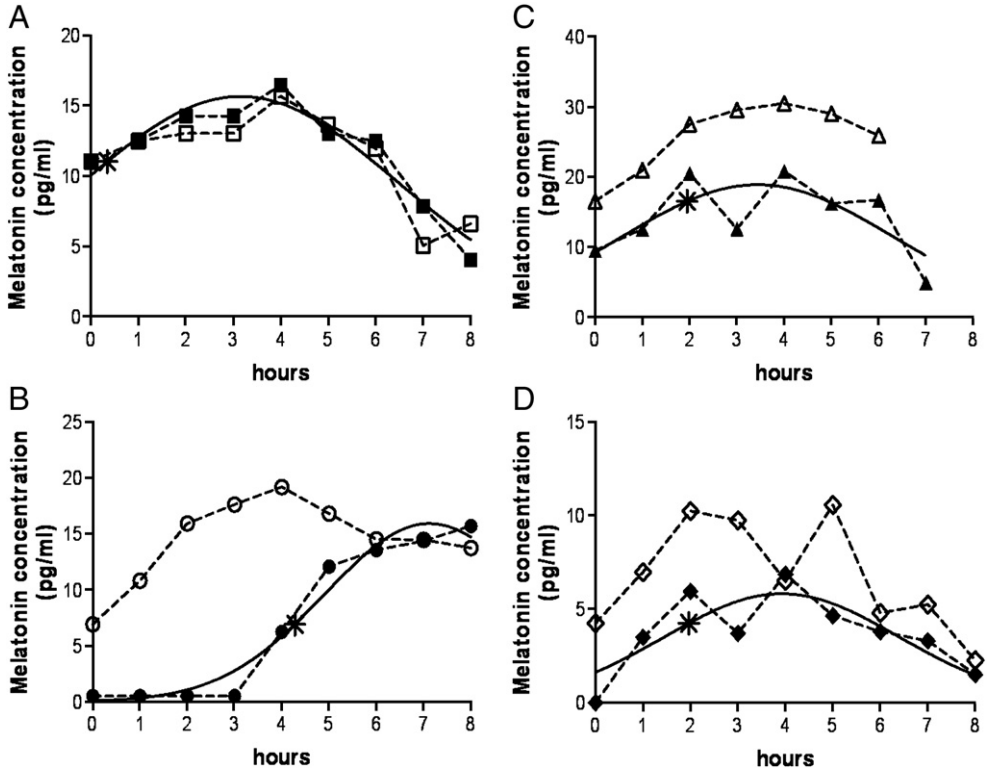

Fig. 3. Melatonin secretion profiles of participants 1 (A), 2 (B), 3 (C) and 4 (D). For participants 1 (square), 2 (circle), 3 (triangle) and 4 (diamond), open symbols represents assessment performed 24 hours before the beginning of the experimental week and filled symbols represents assessment performed during what would have been the fifth shift (Friday) on the experimental week. The asterisk represents the first known melatonin concentration from the baseline week interpolated on a non-linear regression curve fit of the experimental week.

Table 2
Differences in sleep parameters, presented with the corresponding phase shift in melatonin secretion during the experimental week. A greater sleep efficiency and faster sleep onset seem to be linked associated with large phase delays in melatonin. (Δ SE = difference in sleep efficiency between control and experimental week, Δ SL = difference in sleep latency between control and experimental week, Δ Mel = time of the phase shift in melatonin production between assessment before and after the fourth day of the experimental week).

	Δ SE (%)	Δ SL (h)	Δ Mel (h)
1	2.3	0:04	0:05
2	4.7	0:38	4:16
3	4.2	0:12	1:57
4	5.1	0:18	1:56

progressed in a different manner between conditions. Bonferroni pairwise comparison showed that subjective vigilance in the middle and the end of the third night as well as the fourth night of the experimental week significantly improved by 39.5% ($p=0.009$), 34.8% ($p=0.008$), 25.9% ($p=0.001$) and 31.5% ($p=0.039$) respectively when compared to the control week (Fig. 4).

For the percentage of error ratio, the samples included 882, 1425, 898 and 958 boards on Monday, Tuesday, Wednesday and Thursday of the control week and 583, 863 and 1154 boards on Monday, Wednesday and Thursday of the experimental week. No difference was found between conditions on the first ($4.04\pm1.70\%$ Vs. $8.70\pm2.62\%$) and the third shift ($4.17\pm1.24\%$ Vs. $2.44\pm0.99\%$). Data obtained on the fourth shift revealed a trend toward significance in terms of percentage of error reduction between the control and the experimental weeks ($5.14\pm1.63\%$ Vs. $1.36\pm0.90\%$; $p=0.06$) (see Fig. 5). Of note, the higher value observed on the first shift of the experimental week was caused by one of the participant who generated an unusually high percentage of errors (13.94%). Also, the assessment of percentage of error in classification on that shift may have been less representative due to a smaller sampling (583 board ≈ 145 wood board/participant).

4. Discussion

Even with a sample of 4 workers, we were able to observe consistent improvement in terms of vigilance, performance and sleep, along with a melatonin rhythm phase shift. These observations are likely to be associated with the strategic use of adequately timed blue-green light exposure at night combined with blue-blockers during the

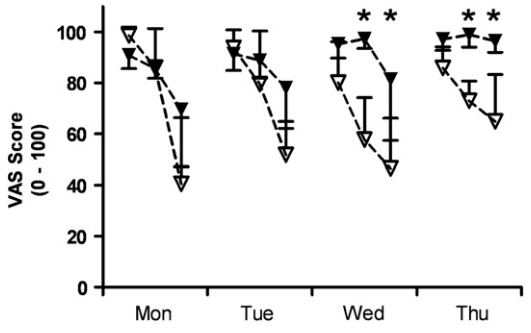

Fig. 4. Mean VAS scores (SEM) of participants. Tested at the beginning, the middle and the end of the Monday (Mon), Tuesday (Tue), Wednesday (Wed) and Thursday (Thu) shifts. Higher scores indicate higher level of vigilance. The inverted triangle, when open, represents assessment performed during the control week and the filled symbol represents assessment performed during the experimental week. Measurements from both the control and experimental weeks are normalized relative to the respective data obtained during the day shift. *Significant difference between the experimental and baseline weeks. ($p<0.05$).

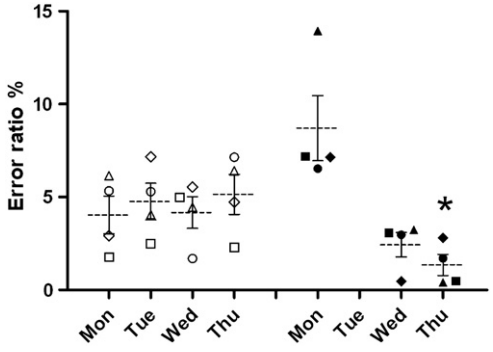

Fig. 5. Mean error ratio of participants. Error percentage recorded for participants 1 (square), 2 (circle), 3 (triangle) and 4 (diamond) on the Monday (Mon), Tuesday (Tue), Wednesday (Wed) and Thursday (Thu) night shifts during control (open symbols) and experimental (filled symbols) weeks. *Significant difference between the baseline and experimental weeks. ($p<0.05$).

day. In fact, melatonin secretion among three of the four participants phase shifted by at least two hours, a degree of phase shift which is not usually reported to occur in night workers exposed to an atypical L/D cycle (Eastman et al., 1995). The circadian rhythm of those three participants can be considered as partially re-entrained, given that a 2-hour phase shift in melatonin secretion should be associated with a corresponding delay of the T-min (Shanahan and Czeisler, 1991). As for the 4-hours phase shifts observed in participant 2, it was closer to the targeted phase shift representing a compromised position which should yield to improvement in mood, fatigue and performance (Smith et al., 2009a,b). This greater phase shift could partly be due to the participant's chronotype. In fact, Crowley et al. (2003) reported that when the T-min occurs later than 07:00 h, as for evening oriented chronotypes (Baehr et al., 2000) like participants 2 (lower MEQ score), circadian phase delay is easier to achieve. The absence of phase shift in participant 1, along with the fact that participants 3 and 4 only reached minimal criteria to be considered partially re-entrained, indicates that some improvements on the intervention might be needed to suit a majority of shift workers with various chronotypes.

After analysis of sleep results, participants expectedly spent 79 less minutes in bed and lost 115 minutes of diurnal sleep daily during the control night week when compared to the day week. Subsequently, during the experimental week, participants slept for an additional 60 minutes without spending more time in bed while keeping similar bed times. Moreover, is seems that about one third (18 minutes) of this improvement could be attributed to a faster sleep onset (improvement in SL). One intriguing finding was that on an individual basis, partial phase shift led to shorter SL along with a seemingly better sleep quality, which is the ratio of actual sleep over the time spent in bed. Considering that the worker who did not showed change in SL was also the one who showed no phase shift, it suggests that phase shifting can lead to day time SL shortening. This observation may be due to the fact that the sleepiest part of the circadian rhythm, namely the T-min, has drifted into the beginning of the day sleep period. This situation would result in a better alignment between the biological clock and the sleep/wake cycle. This would be in agreement with a study in night working nurses, who showed that better sleep was associated with a melatonin secretion that is extended during the diurnal sleep period, suggesting a better suited circadian phase for sleep during the day (Benhaberou-Brun et al., 1999). Furthermore, better sleep, linked or not to circadian adjustment, may have contributed to subjective vigilance improvement observed towards the end of the experimental night week, when values became very close to the supposedly optimal day shift observations. Considering that on the third shift (Wednesday) and more convincingly on the fourth shift (Thursday), participants seemed to fell almost as vigilant as in the day, we may conclude that our strategy could be very

effective to bring night time vigilance similar to daytime work after more than 2 to 3 consecutive nights. This observation is also in line with a delay of the sleepiest part of the circadian rhythm hypothesis, which might lower the pressure to sleep while working at night. Of note, a certain degree of coping with night shifts may contribute to vigilance improvement as seen at the end of the control week, but our study suggests that our strategic controlled of short wavelength exposure considerably accelerate this process. Taken together, sleep and subjective vigilance results are consistent with observations from another pilot study performed by our group (Sasseville et al., 2009) where permanent night shift workers exposed to a relatively bright environment (500 lx) were asked to wear blue-blocking glasses in the morning on their way home. In the latter study, the time spent asleep improved by an average of about 30 min per day, compared to 40 min in the present study. There was also a subjective vigilance improvement at the end of the week on the 5th night, compared to improvement on the 3rd shift in the present study. This discrepancy between the two studies, in terms of improved sleep, could be due to the addition of blue-green light exposure at night in the present study, which may have been more a effective strategy to achieve circadian clock phase shifting. Results of the present study are also similar to those observed on shift workers exposed to 4000–6000 lx of white light at night, from 01:00 h to 05:00 h, combined with the use of dark goggles in the morning (Yoon et al., 2002). In the latter study, Yoon et al. compared their intervention with normal room light environment using actigraphy data. Their intervention caused a significantly lengthening of TST by about 100 minutes, which was accompanied by a longer TTB of 97 minutes. Only a trend was found in the diminution of SL. They also found improvement in subjective alertness using the VAS scale on the pooled value of the second and third nights and again in the forth night shift. Considering that there was no light intervention during the fourth night, the phase shift may have not been as great as the one observed in the present study yielding to a different sleep efficacy result.

Focusing on short wavelengths to control the L/D cycle of real shift workers could therefore improve daytime sleep and vigilance at night, at least in the same way that bright white light does, but with the used of dimmer light at night and glasses that do not negatively impact vision. This strategy might consequently represent a more efficient means of intervention for night shift workers if demonstrated in a larger population of workers.

Regarding performance, classification error values ranging from 4% to 5% are commonly observed among night shift workers by supervisors of the Abitibi-Bowater *La Doré* sawmill (personal communications). The error ratio was used in the present study due to the practical nature of the test and the independence of the measurement. The trend toward a significant reduction of errors observed on the fourth shift of the experimental week represented a meaningful indicator of performance which is not often possible to obtain in research studies. On an occupational health and safety point of view, the higher level of vigilance that was needed to reduce the number of error might also prevent work-related accidents (Santhi et al., 2007).

Overall, these preliminary results suggest that a better performance in night shift workers is probably linked to the improved sleep and subjective vigilance, as well as partial circadian clock adjustment. As already mentioned, there are limitations to this pilot study. Besides the fact that we cannot rule out a placebo effect, particularly with subjective measures, the small sample also limits the power of our observations. Consequently, this pilot study must only be seen as an encouraging proof-of-concept. Moreover, although improvements were mainly observed at the end of the experimental week, which advocate for a gradual adaptation of the circadian clock, we cannot ruled out a direct alerting effect of short wavelengths (Cajochen, 2007). In fact, the participant who did not present a phase shift still contributed to the observed improvement in subjective vigilance, which may well point towards a direct alerting effect of light. As for the biological clock assessment, due to the workers schedule, we selected the first available point of the melatonin profile before the intervention as a time marker, a method which has not been validated yet. Collecting saliva at an earlier clock time to assess the DLMO (dim light melatonin onset — a validated marker of the circadian clock) should then be performed in future studies (Pandi-Perumal et al., 2007). Moreover, in the present study we cannot conclude that the phase shift in melatonin production was solely explained by the light intervention since no assessments were made before and after the control week. It is important to note that the individually adjusted light exposure device which was tuned ON and OFF automatically as well as the nature of the task which forced the participant to maintain gaze, ensured a good compliance in terms of light exposure. Therefore, compliance could have played an important role in the positive outcome of this study. Close follow-up during implantation might then be a key to a successful integration of the short wavelengths control strategies in a real work place. To further improve compliance, it might also be important to assess side effects and concerns from the short wavelengths exposure along with the use of blue-blockers. Even though no problem was reported in the current study, they may arise in a larger population.

5. Conclusions

When planning modifications of the L/D cycle to facilitate adaptation to night work, focusing on the control of short wavelengths could be useful since blue-green light does not need to be as bright as white light to induce partial circadian rhythm adjustment. Moreover, blue-blockers could be worn all day, to provide “circadian darkness” and prevent acute and circadian adverse effects of bright sunlight when outside, without incapacitating drivers' vision. Even though this combined strategies appears applicable, in a real work setting, further strategies appears applicable in a real work setting, further evaluation will have to be performed on a greater number of workers and in different work settings before being recommended for a more extensive use.

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Competing interests: The authors may have future financial interest for the commercialization of blue-blockers similar to those presented in the paper.

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