BLUE LIGHT A SA COUNTERMEASURE TO PREVENT SLEEP-RELATED CRASHES

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SCIENTIFIC BACKGROUND

Numerous studies suggest that shift workers are at significantly higher risk of workplace accidents and injuries than workers with regular daytime schedules (Wong, 2019). Improving nighttime alertness is therefore a concern for any industry that employs workers around the clock. The negative effects of night work are due to the misalignment of the circadian clock with the reversed schedule (Burgess, 2002). Yet, light is the most powerful synchronizer (Cajochen, 2010) and the biological clock has been shown to be more sensitive to blue light (Brainard, 2001; Thapan, 2001). This non-visual effect is known to be mediated by specific blue light sensitive cells in the retina that contain melanopsin with a sensitivity peak at 480 nm (Hattar, 2002; van Bommel, 2006). In addition to its effects on the biological clock, blue-enriched light also affects other non-visual functions. Indeed, compared to green and red light, blue light has been shown to increase heart rate, body temperature and alertness while inducing greater melatonin suppression (Cajochen, 2005). Furthermore, the effects of blue light on subjective and objective alertness have also been confirmed in studies conducted in the evening (Chellappa, 2011) and at night (Lockley, 2006).

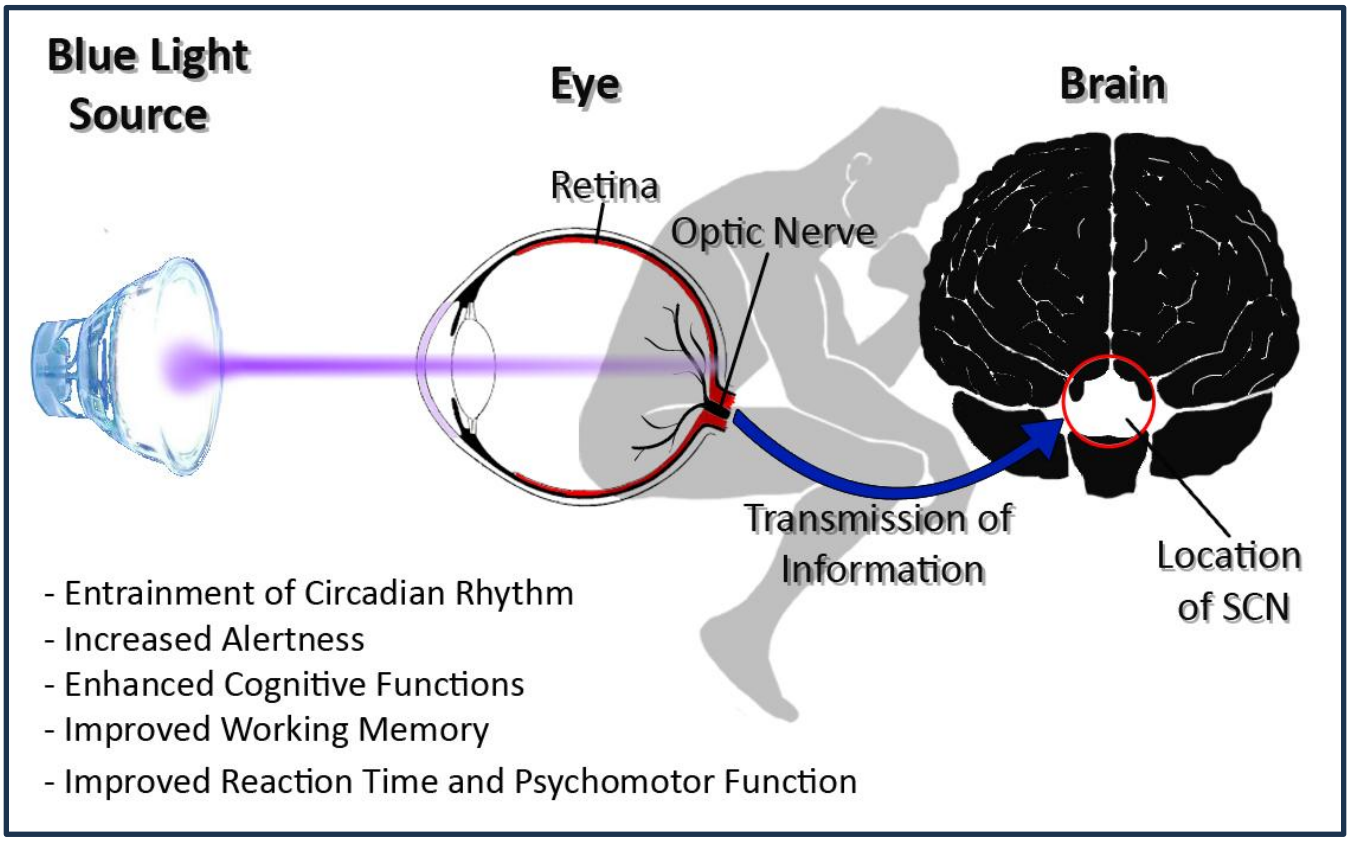


Figure 1 shows the various impact of blue light as it is transmitted from the eye to the brain central circadian clock.

Regions that are targeted by blue light

Locus Coeruleus (LC)

- **Function**: The LC is a major source of norepinephrine in the brain, involved in arousal, attention, and vigilance **(**Berridge & Waterhouse, 2003). Exposure to blue light has been shown to modulate LC activity via melanopsin-containing ipRGCs, enhancing alertness and arousal **(**Vandewalle et al. 2009).

Thalamus

Function: Acts as a sensory relay and supports cortical arousal through connections with the ascending arousal system (Saper et al. 2010).

Anterior Cingulate Cortex (ACC) and Prefrontal Cortex (PFC)

Function: Both regions are well established in their roles for sustained attention, executive functions, and decision-making **(**Bush et al. 2000).

NIGHT DRIVERS RISK OF CRASHES

Because our biological clock makes us drowsy at night, nighttime drivers may be particularly at risk for accidents. For the record, the United States is one of the busiest countries in terms of road traffic, with nearly 284 million vehicles on the road in the third quarter of 2021. This level of traffic is one of the reasons leading to an increase in traffic crashes: In 2019, some 12.15 million vehicles were involved in crashes in the U.S., with about half of that volume consisting of commercial vehicles. A study by the AAA Traffic Safety Foundation estimated that 328,000 drowsy driving accidents occur each year. The same study found that 109,000 of these drowsy driving crashes resulted in injury, and 6,400 of those were fatal. Researchers suggest that the prevalence of fatal crashes related to drowsy driving is more than 350% higher than reported. Driver fatigue ("falling asleep at the wheel") is a major cause of traffic accidents, accounting for up to 30% of serious highway crashes. Several independent studies confirm that a much higher proportion of crashes (4X) occur between 4 pm and 6 am.

RISK MITIGATION BASED ON BLUE LIGHT SCIENCE

The development of an in-vehicle countermeasure is a challenge to prevent drowsiness-related crashes. An initial study was conducted in 2012 to determine whether continuous exposure to a blue light lamp, placed on the dashboard, improves nighttime driving performance. In this study, 48 participants drove 400 km (250 miles) on a highway at night while exposed to 20 lux of monochromatic blue light (468 nm ±8nm). Compared to a placebo (two cups of decaffeinated coffee), the use of blue light produced the same results as two cups of coffee containing 200 mg of caffeine, namely a reduction in line crossings and lateral deviations (Taillard, 2012). Interestingly, **the treatments did not alter the quality, quantity, or timing of the next three nighttime sleep episodes.** A drawback of this study was that eight participants (17%) complained of glare during blue light exposure.

CAFFEINE VERSUS BLUE LIGHT

A study did compare the effects of blue light (~40 lux, 1 hour) and caffeine (240 mg) on cognitive function and alertness. Twenty-one healthy participants completed psychomotor vigilance tasks under four conditions: white light/placebo, white light/caffeine, blue light/placebo, and blue light/caffeine. Both blue light and caffeine alone improved accuracy in a visual reaction task requiring a decision, with additive effects on the fastest reaction times. However, caffeine impaired accuracy in an executive function task with distractions, while blue light consistently outperformed caffeine in such conditions. Blue light also improved simple visual reaction times, especially in blue-eyed participants. It can be concluded from this study that blue light outperformed caffeine, when executive function is involved in the presence of distractions (Beaven and Ekström et al. 2013).

PATENTED BLUE LIGHT TECHNOLOGY

Whereas exposure to blue light while driving may be beneficial, the fact that 17% of people may be dazzled by 20 lux is of concern. In 2007, we (Hébert and Lafleur) proposed a new way to influence the brain with blue light using half the intensity. The patent entitled: APPARATUS AND METHOD FOR INFLUENCING A CONDITION IN A SUBJECT was issued by the United States Patent Office on August 13, 2019 (number: 10,376,710).

This patent demonstrates that when blue light is pulsed at 60 Hz, i.e., turned on and off 60 times per second (50% duty cycle), the light produces twice the melatonin suppression of continuous light of the same intensity. Knowing that the suppression of melatonin by light is related to the magnitude of the biological clock response this means that the biological clock responds twice as much to pulsed light as to continuous light. It was also found that 100 Hz pulsed light resulted in the same suppression of melatonin as continuous light, suggesting that a particular pulse is required. Therefore, by using 60 Hz blue pulsed light, it becomes possible to reduce the light intensity by 50% and thus avoid any glare consequences. So instead of 20 lux of light, only 10 lux is sufficient, which represent the equivalent of 10 candles at 1 meter.

FIELD STUDY WITHG BLUE LIGHT

NASA /HARVARD

A recent study by a group from Harvard (Barger, 2021) conducted in NASA flight controllers working night shifts, demonstrated that the addition of a blue-enriched white, fluorescent light resulted in improved alertness and reaction time which could not be ascribed to differences in sleep, since there was no change in sleep duration between the control and experimental groups. Yet, one could postulate that the use of blue-enriched light at night improves sleep quality. In fact, a study that compared light exposure and sleep using polysomnography proposed that the timing and intensity of light exposure modulates not only aspects of sleep determined by the circadian clock but also by homeostatic pressure, that is, the pressure to sleep that builds up with time awake (Wams, 2017). Although it needs to be proven by further research, the presence of blue light would be important not only for alertness, but also for the quality of our sleep.

BLUEWAKE

Bluewake (4th generation) based on Hebert and Lafleur's patent was introduced commercially in 2020 by Bluewake Technologies after $4M of research and development and the 2nd and 3rd generations were field tested with night shift workers. The Canadian open pit mine Malartic was the first to introduce Bluewake in 37 Caterpillar 793F 250-ton trucks. After two years of use, they conducted a survey of operators, with 85% reporting they were satisfied with the use of Bluewake and 94% reporting better sleep.

Other research (with the 3rd generation of Bluewake) was conducted at a mining company in northern Canada with workers who are required to monitor various indicators on computer screens during 12-hour shifts, on a 2-week rotation. By measuring reaction time, at the beginning and end of each shift (see Appendix 1, Study A for details), it was observed that their speed to react was maintained throughout the rotation when using blue light, whereas there was a daily increase in reaction time when not using blue light. Therefore, the normal increase in reaction time due to cumulated fatigue, was significantly slowed down, or even canceled out in the blue light condition. In yet another study (Appendix 1, Study B), blue enriched white light pods were attached to the helmets of workers in a sawmill. When workers were exposed to the blue enriched white light, their performance was significantly increased compared to that of teammates working at the same time but without the addition of blue enriched white light. Overall, these studies indicate that the addition of blue light reduces night shift fatigue and improves performance.

Currently, we are the only ones using blue light to influence alertness and sleep quality to minimize the risk of drowsiness in the workplace. Naturally, blue light has been known for its important role in the synchronizing the biological clock that controls a myriad of circadian cycles but also for its direct biological impact on suppressing melatonin production while increasing body temperature, heat rate and alertness therefore improving cognitive level. Through our research and development, we have introduced innovative solutions that mimics the natural impact of blue light on individual and provided workers with effective tools to fights fatigue and drowsiness by giving them control on their rest time and alertness.

Of interest, the Center for work and fatigue research which is part of the NIOSH concluded in a systematic review that ‘there is substantial evidence for the use of bright-light treatment to improve night shiftworker alertness’. They allow mention that it seems that ‘short exposition of even 20 min is sufficient’ which appears right based on operators experience with the bluewake.

Appendix 1

STUDY A

Thirteen male individuals (mean (±S.D.) = 48.5 (±7.7) years) working at a mine in the Far North (61°69'N) of the province of Quebec (Canada) participated in the data collection. All participants worked 12-hour night shifts on either a 3:2:2:3 fly-in:fly-out rotational shift schedule (e.g., 3 weeks ON, 2 weeks OFF, 2 weeks ON, 3 weeks OFF), performing essentially computer work and screen monitoring in the mine's mineral concentrator facility which was divided in three sectors (crusher, filtration, flotation). All workers did a rotation with and a rotation without the addition of blue light (counterbalanced design).

Figure 1



Figure 2

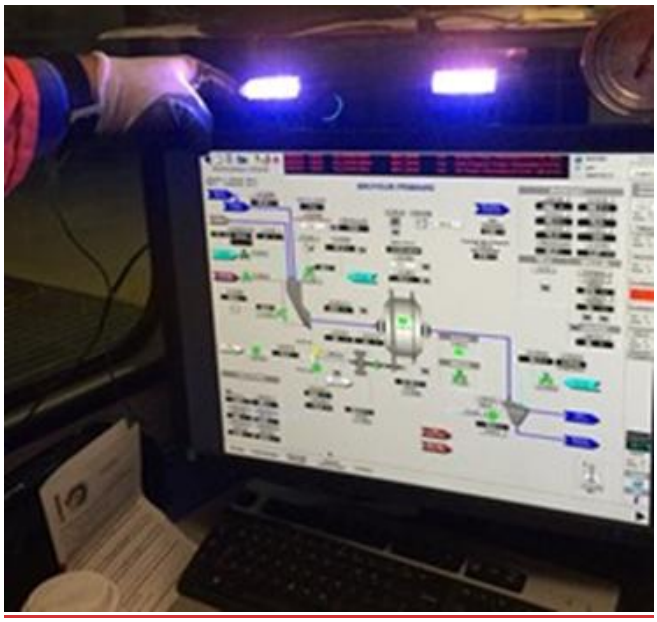
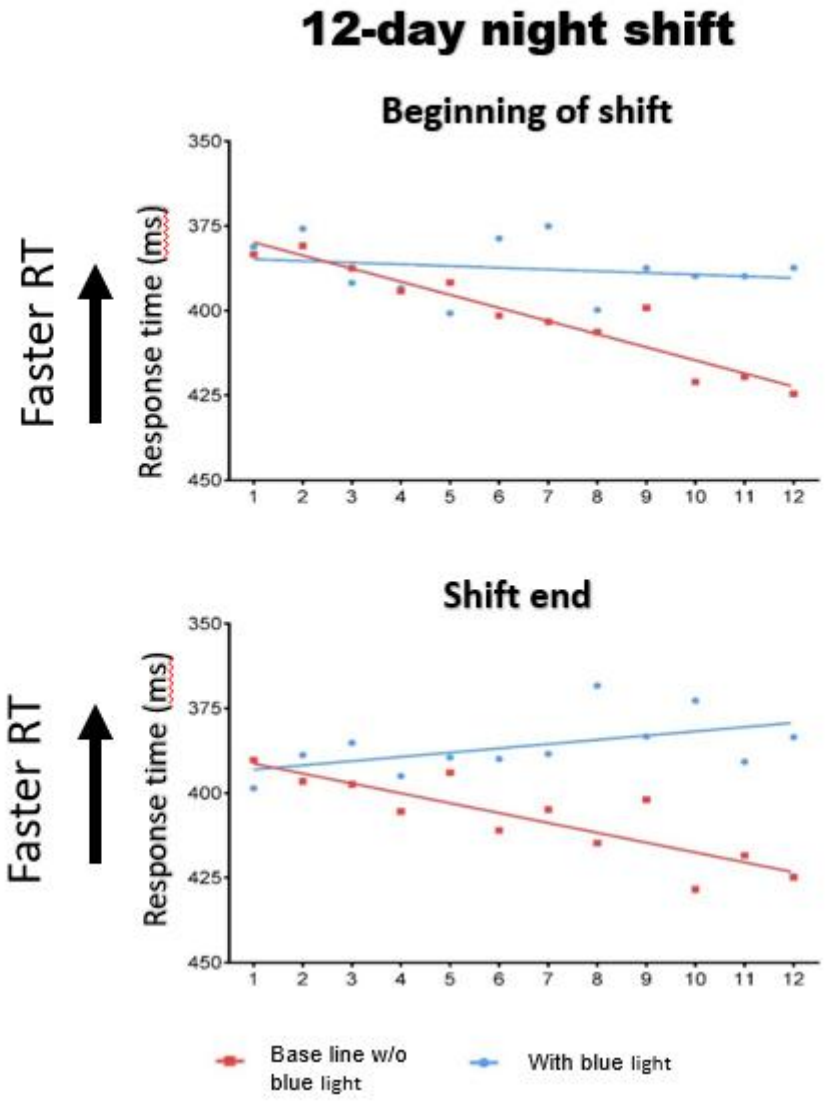


Figure 1. This is a 5-min reaction time test in which subjects are required to touch the device screen when they see a visual stimulus (random inter-stimulus interval between 2 and 10 s). This test is a validated objective measure of decline in attention, alertness, and performance, because

it is sensitive to fatigue and sleepiness in conditions such as shift work (Dinges 1985). Testing took place in an isolated room to avoid distraction during testing.

Results: With the addition of blue light (Figure 2), reaction time is maintained constant for the 12 days at the beginning of shift while improving daily at the end of the night (blue lines). In contrast, while not using blue light (red lines) a daily increase in reaction time is observed over 12 days, both at the beginning and end of shift (see Figure 3). Better reaction time is associated with less fatigue and better performance. This study suggests that the daily performance decrement due to fatigue is stop with the use of blue light.

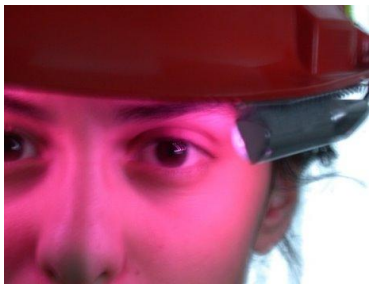
Figure 3



STUDY B

Blue enriched white light was attached to the worker's helmet (Figure 4). The nightshift duration was 8 hours for 5 consecutive nights. One team received the helmet with the attached light device and one team (working at the same time) were only exposed to the standard ambient lighting. The task of the workers was to rate the quality of each plank that was passing in front of them on a conveyor. Performance in terms of rating assessment was done by the company for each worker and translated into dollars per thousand board-feet (TBF). The higher the TBF, the better the performance.

Figure 4.



Results: First (see Table 1), an average performance was calculated over a year using the company data. The experimental group was producing 281,6$ TBF and control group 281.4$ TBF, a difference of only 20 cents TBF. This means that the two teams were very similar in terms of yearly performance. During the trial, the experimental team produced 283.8$ TBF which is 2.2$ more than their annual average. Meanwhile, the control team did worse, that is -2.2$ TBF below their annual average. Overall, the difference on the trial week was 4.6$ TBF in favor of the experimental team, representing over a year an additional profit of 800,000$ TBF if all 12 workers were to use blue enriched white light.

Table 1

	TRIAL WEEK	ANNUAL	DIFFERENCE
Experimental Team	283,8$	281,6$	2,2$
Control Team	279,2$	281,4$	-2,2$
Difference	4,6$	0,20$	

Appendix 2

Dr. Marc Hébert, PhD



Dr. Hébert has been Professor of Ophthalmology at Laval University in Québec city (CAN) since 2001. After his bachelor's degree in psychology at the University of Ottawa (CAN), he did his doctorate in Neurological Sciences at the University of Montreal (CAN) before pursuing a first two-year post-doctorate at Rush University Medical Center and the Illinois Eye and Ear Infirmary (Chicago, USA) and a second two-year post-doctorate at the University of Alberta (CAN). He is currently Deputy Director of CERVO Brain Research Centre.

Dr. Hébert's research is diversified but all have light and the retina of the eye as their primary focus. In fact, in the various research studies conducted on night work or seasonal depression, Dr. Hébert uses and studies the effect of light on both the retina and the brain. In other situations, his laboratory studies the reactions of the retina as a diagnostic tool in various ocular and even psychiatric diseases. He was President of the Society for Light Treatment and Biological Rhythms from 2010-2012 and Editor-in-Chief of the Journal of Chronophysiology and Therapy until 2017. In addition, he was promoted to Honorary Lieutenant Colonel for the 5th Field Ambulance in ValCartier (CAN) from 2013-2016. Since 2018, he has served as President of the Eye Disease Foundation. He is the founder of Chronophotonix (2007) (renamed Bluewake in 2020) and co-founder of diaMentis (2015), which holds exclusive licenses from Laval University for patented discoveries of which Dr. Hébert is the co-inventor. Due to his reputation, he is often asked by the media to speak about the judicious use of light for both night workers and people suffering from seasonal depression or used as a consultant or expert in court in topics related to night work risks.

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