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The effect of blue-enriched white light on cognitive performances and sleepiness of night-shift workers: A field study☆

Majid Motamedzadeh[a], Rostam Golmohammadi[b], Reza Kazemi[c,*], Rashid Heidarimoghadam[d]

[a] Department of Ergonomics, School of Health, Hamedan University of Medical Sciences, Hamadan, Iran
[b] Department of Occupational Hygiene, School of Health, Hamedan University of Medical Sciences, Hamadan, Iran
[c] Department of Ergonomics, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran
[d] Department of Ergonomics, School of Health, Hamedan University of Medical Sciences, Iran

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ABSTRACT

Introduction: Night-shift works are basically accompanied by reduced cognitive performance, sleepiness, and higher possibility for human error and related incidents. It is therefore crucial to improve individuals' performance and alertness in sensitive places like industries' control room with the ultimate goal of increasing efficiency and reducing the number of possible incidents. Previous research has indicated that blue light is a critical cue for entraining circadian rhythm. As a result, the present study was an attempt to investigate whether blue-enriched white light illumination was a practical strategy to decrease sleepiness and improve cognitive performance during night shifts.
Martial and methods: The study, which adopted a before-after interventional design, was conducted among 30 control room staff members of petrochemical industry. After baseline assessments under existing lighting conditions, every participant was exposed to two new lighting conditions (namely, 17,000 K and 6500 K blue-enriched white light), each lasting for a week. Assessments were conducted again at the end of these treatments. In order to measure the subjective sleepiness, Karolinska Sleepiness Scale (KSS) was utilized. Subjects also performed the Conners' Continuous Performance Test II (CPT-II) and 1-back test in order to gauge their cognitive performance, and melatonin assessment was carried out using salivary and Eliza technique. The data was analyzed using two-way repeated measure ANOVA.
Results: The results indicated that, compared to normal lighting conditions, participants' sleepiness and melatonin rhythm significantly declined when they were exposed to blue-enriched white light. Furthermore, the experimental condition had a significant effect on the reduction of working memory errors. It also decreased omission errors and the reaction time during the sustained attention task.
Conclusions: Thus, using blue-enriched white light may be a proper ergonomic strategy for improving performance and alertness, especially during night, in sensitive environments like control rooms.

1. Introduction

Night-shift work is generally associated with reduced performance and efficiency, which may decline production rate and increase the risk of errors and incidents in industries. These performance decrements primarily stem from the conflict between night work schedules and circadian rhythms [1–3]. The results of laboratory and field studies strongly support the idea that changes in humans' circadian rhythm have short-term effects on various aspects of cognitive performance including attention process, working memory, and executive functions [2–4].

Previous research shows that exposure to light not only improves eyesight, but also has numerous non-visual effects such as melatonin suppression, circadian phase shifting, mood, and the increase of body temperature and heart rate [5,6]. Furthermore, recent studies based on imaging techniques such as functional magnetic resonance imaging (FMRI) and photon emission tomography have indicated that, as a result of exposure to polychromatic white light, brain's response to cognitive tasks leads to neural behavioral responses such as alertness and performance improvement [5,7,8].

Prior studies indicate that at least a part of non-visual effects of light is mediated by a recently-discovered melanopsin-dependent photoreceptive system [9,10]. Melanopsin is a photopigment found in intrinsically photosensitive retinal ganglion cells of the eye and is mainly

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* Corresponding author at: PO Box 71645-111, Shiraz, Iran.
E-mail addresses: motamedzade@yahoo.com (M. Motamedzadeh), rezakazemi2007@gmail.com (R. Kazemi), Dr_haidari@yahoo.com (R. Heidarimoghadam).

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sensitive to wavelengths of about 480 nm [11,12]. In two other studies, Lockley et al. (2006) and Cajochen et al. (2005) have illustrated that exposure to blue light at night is more influential (than exposure to yellow or green light) in suppressing melatonin and changing circadian phase. It also regulates body temperature, alertness, and electroencephalographic dynamics in entraining circadian rhythm [13,14]. However, the use of monochromatic blue light is not applicable in real world settings [15].

Lamps and light-producing devices which emit relatively more short-wavelength energy (known as blue-enriched white light) are now commercially available [16]; nevertheless, few studies have concentrated on the non-visual effects (e.g. circadian rhythm, sleepiness, and performance) of blue-enriched white light. Phipps-Nelson and Redman (2003) and Viola et al. (2008) demonstrated that blue-enriched white light illumination during daytime improves subjective alertness and performance, and decreases evening fatigue [17,18]. In an experimental study, Chellappa et al. (2012) suggested that exposure to light at 6500 K was more effective than exposure to 2500 and 3000 K in terms of inducing greater melatonin suppression and enhancing subjective alertness, well-being, and visual comfort [19]. In another experimental study, Baek and Min (2015) showed that exposure to blue-enriched light after having lunch lowers alpha-band activity and improves sustained attention [15].

The above-mentioned studies investigated the impact of blue-enriched white light as a novel light source under laboratory and controlled conditions or during daytime [20]. They also concentrated on non-shift workers who enjoyed natural circadian rhythm. However, the extant literature has failed to find out whether these light sources could be utilized in consecutive night workers, to alleviate shift work symptoms, and to improve alertness and cognitive performance at the real workplace.

As a result, the current study was a field-based attempt which aimed at comparing non-visual effects (including melatonin, cognitive performance, and sleepiness) of two blue-enriched white light sources (6500 K and 17,000 K) and conventional white light among control room operators of a petrochemical industry at night work. Of special interest to the researchers were working memory and sustained attention, which play a determining role in control room operators' proper duty fulfillment [17]. The results of this study can be used to design ergonomics guides for control rooms and improve individuals' adjustment to night-shift work.

2. Material and methods

2.1. Participants

Participants included 30 night-shift workers of the control rooms of one of Iran's petrochemical complexes. They were all males, with a mean age of 30.2 (4.1) years and a mean night-shift work experience of 4.5 (1.8) years. All participants were nonsmokers, and were instructed to refrain from consuming caffeine or alcohol during the 12-h period preceding the experiments. All the participants met the following criteria: (1) none of them used hypnotic drugs; (2) no one suffered from any psychological/main systematic illness or sleep disorder; and (3) none of the participants was “extreme late” (MEQ score $>$ 70) or “extreme early” (MEQ score $<$ 30) type, according to their responses on the Munich Chronotype Questionnaire [21]. This study was conducted in accordance with the ethical guidelines established by Hamadan University of Medical Sciences. In order to observe ethical issues, informed consent was obtained from all the participants prior to the experiment.

2.2. Study design and procedure

The study had a field trial interventional and within-subjects design with three light treatments (baseline, 6500 K, 17,000 K) and was conducted in three stages from 21 January through 20 March 2015. All the studied rooms were almost similar in terms of the intensity of available light and staff's responsibilities. Individuals' shift-work schedule consisted of a 21-day cycle including 7 night shifts, 7 day shifts, and 7 days off, with each shift lasting for 12 h. Since the study aimed at investigating the influence of light during night shift, all the assessments were performed only during night shifts. In addition, in order to eliminate the intervening effect of adaptation to doing several night shifts in a row, in all the three stages, assessments were carried out during the seventh consecutive night shift. In other words, in each stage of assessment, participants had already been exposed to the target type of light for six consecutive nights. In total, the study was conducted in three cycles, encompassing 9 weeks in a row.

Additionally, in order to control the influence of circadian stimuli, the participants were advised not to drink caffeinated drinks from 4 h prior to starting their shift work until the end of the shift. Furthermore, care was taken to exclude alcoholic staff members from the study. The participating workers were also requested to avoid taking naps before and during the study and to have regular sleep schedules during off days. It should be noted that, since staff members were living in camps constructed by the company far from their family, they all followed a relatively similar sleep-wake schedule from 8 a.m. to 3 p.m.

In order to investigate non-visual effects of blue-enriched white light, two different fluorescent light sources (17,000 K and 6500 K) were used. Before the beginning of each work cycle, light sources were changed. Participants' baseline assessments were carried out under the existing lighting conditions (2500–3000 K) in the seventh night shift. Then, at the beginning of the second work cycle, available light sources were replaced by 6500 K ones, with the second round of assessments being conducted at the seventh night shift. Finally, at the beginning of the third cycle, 17,000 K light sources were installed, followed by the third round of assessments at the seventh night of the cycle (Fig. 1).

2.3. Lighting settings

The intervention light sources involved fluorescent tubes with high color temperature (17,000 K, CIE: X = 0.26 Y = 0.26, Philips, ActiViva Active, TLD 36 W), known as cold light, and medium color temperature (6500 K, CIE: X = 0.31 Y = 0.32, Philips, 36 W), called day light. In order to have similar conditions to the existing light sources, 36 W intervention light sources were selected. As indicated in Fig. 2, both types of intervention (17,000 K and 6500 K) and baseline (normal light source of the room, 4000 K, CIE: X = 0.38 Y = 0.37, 36 W) light sources had an approximately similar spectral power distribution in the medium and long wavelength ranges, but it was different among them for wavelengths of 420 to 480 nm. Attempts were made to keep the mean horizontal and vertical luminance stable (compared to the baseline) after replacing light sources (Table 1). The horizontal luminance was measured at the working plane (desk surface), and the vertical luminance was measured at the eye position, when sitting behind the desk (Table 1).

2.4. Working memory

Despite its limited capacity in human beings' memory system, working memory plays a significant role in doing complicated activities including reasoning, comprehension, and learning [1]. In the current study, n-back test (which is a popular test for evaluating memory performance) was utilized to assess participants' working memory [22]. This test has seldom been used in real world settings to measure shift workers' memory functioning; however, it has been frequently utilized in laboratory contexts to evaluate the impact of sleep deprivation on working memory [23,24]. N-back test aims at gauging the capability to process, select, and save information in a short time. In the present study, the computer type and $n = 1$ was used since it has been demonstrated that 1-back test is more sensitive for individuals who

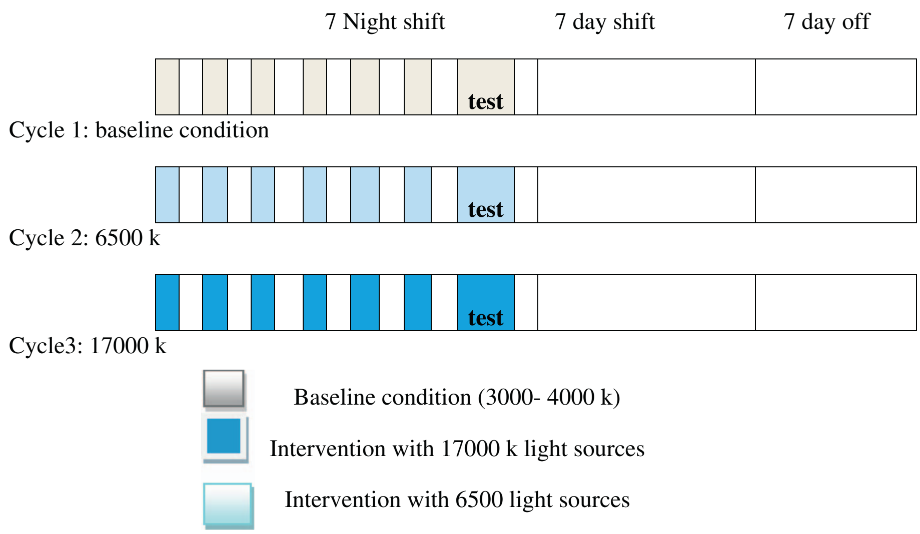

Fig. 1. Schematic representation of study protocol. Three different illumination conditions during the night shift. This schematic represents the last night shift that the measurement had occurred. Clock time (h) is represented on the horizontal axis. The light exposure intervention was from 19:00 to 7:00 h for 7 consecutive night shift and during the last night shift (seventh night shift) measurements had occurred.

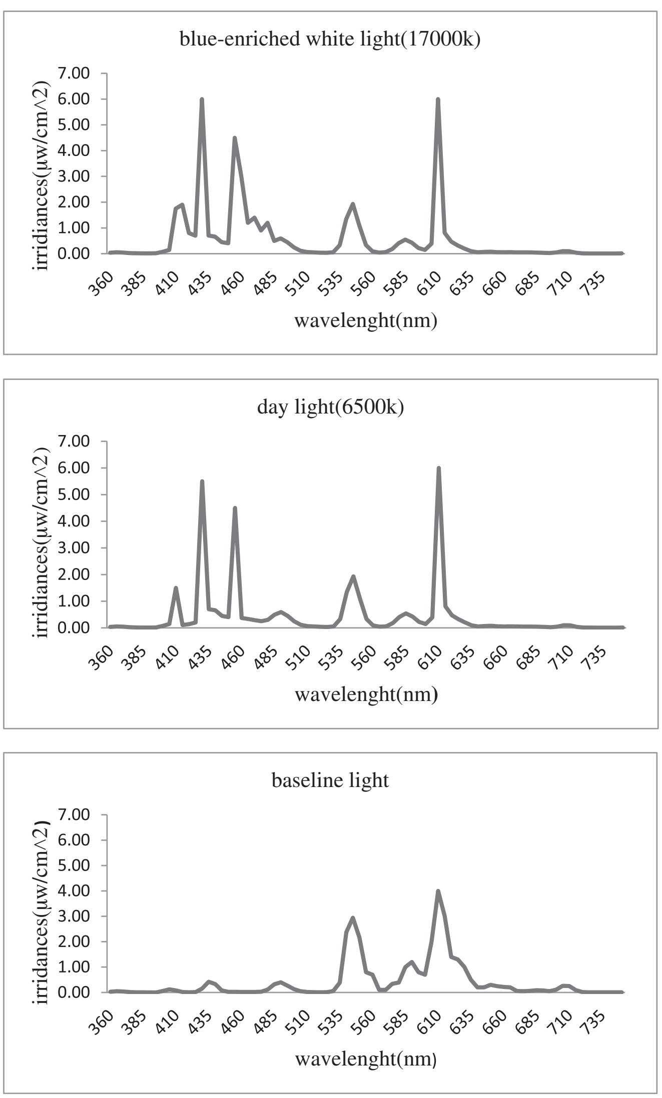

Fig. 2. Spectral composition of the experimental blue-enriched white light (17,000 K, top panel and 6500 K, middle panel) and the baseline (bottom panel) light condition.

Table 1
Horizontal and vertical desk illuminance values on the baseline and intervention condition.

Light condition	Horizontal luminance (lux)	Vertical luminance (with a distance of 50 cm from the Monitor)-lux
Baseline	510	352
6500 K	501	354
17,000 K	506	350

have to deal with sleep deprivation [23]. The test includes playing 120 numbers (one at a time) in the center of the computer screen for 5 min, with 1500 millisecond intervals. Participants are invited to make a comparison between the last number which appears on the screen and the one displayed before that. If the two consecutive numbers are the same, participants should immediately press the answer button on the keyboard. In this test, the dependent variables involve the number of correct answers (i.e. scores) and reaction time (as measured in milliseconds). Previous research has demonstrated the acceptable reliability of this test for assessing working memory [25]. In the current study, participants' working memory was assessed three times during the shift (at the beginning, in the middle, and at the end).

2.5. Continuous performance test

As a standardized computer test with an adequate reliability index, continuous performance test is used for quantitative assessment of sustained attention in the course of time [26]. Sustained attention is the ability to concentrate on an issue over time [27]. In the present study, the test involved displaying 150 visual stimuli (shape and number) on the computer screen, with 20% of them constituting the target stimuli. Participants were requested to press the space bar as soon as a target stimulus was shown. Every visual stimulus was presented for 150 ms, with 500 ms time interval between consecutive stimuli. In this test, the dependent variables were commission error, omission error, and reaction time (ms). Participants' sustained attention was assessed three times during the shift (at the beginning, in the middle, and at the end).

2.6. Karolinska sleepiness scale (KSS)

KSS is a self-declaration method for measuring sleepiness. It consists of a Likert type scale ranging from 1 to 9, with anchors at 1 = very alert, 3 = alert, 5 = neither alert nor sleepy, 7 = sleepy, and 9 = very sleepy and trying to stay awake. Prior research has indicated that the test enjoys a fairly good level of reliability and validity [28]. In all the three stages of the research (before and after the intervention), participants' sleepiness was assessed seven times (in 2 hour intervals) during the shift.

2.7. Melatonin

Melatonin has repeatedly been used as a very reliable indicator for circadian rhythm. In this study, salivary melatonin (which contains approximately 30% of plasma melatonin) was used to determine the level of melatonin. Because of its non-invasive nature, nowadays a larger number of researchers are using this method for measuring melatonin [29]. The samples were collected at four times during the night shift (7 pm, 11 pm, 3 am, and 7 am) via a saliva sample collector (Sartsert, Germany). With the aim of minimizing the intervening effect of food consumption on the melatonin level, participants were asked not to eat anything for at least 1 h before collecting samples. The collected samples were immediately centrifuged, frozen, and stored at − 20 °C and were subsequently transferred to the laboratory. ELIS kit (manufactured by Biotech Company in China) was used to measure melatonin levels. The sensitivity of the tests was 1.6 ± 1.3 pg/ml. Intra-assay coefficient of variation was 8.1% at 1.8 pg/ml and 5.5% at 25 pg/ml. In all the three stages of the research (before and after the intervention), participants' salivary melatonin was assessed four times (in 4 hour intervals) during the shift.

2.8. Statistical analysis

IBM SPSS Statistics 23 (2014) was used to perform the statistical analyses. The data was analyzed using two-way repeated measures ANOVA, with special focus on the influence of the two independent variables (i.e. light and time) and their interaction effect. Furthermore, for 'light condition' levels, pairwise comparisons using the Bonferroni correction were carried out.

3. Results

3.1. Working memory

As illustrated in Table 2 and Fig. 3(a), correct responses to the working memory task was under the significant impact of exposure to different lighting conditions ($F(2.1, 20) = 5.1$, $p = 0.01$). Table 1 also demonstrates that time had a significant effect on the number of correct answers ($F(3, 21.5) = 6.2$, $p = 0.009$). However, illumination × time interaction did not have any considerable influence on the number of correct responses ($F(1.7, 30) = 1.7$, $p = 0.18$). The results of Bonferroni correct factor revealed a significant difference between the means of correct responses in 17,000 K blue-enriched white light condition and the baseline condition ($p = 0.05$) in favor of the former. Moreover, there was a significant difference between the mean score of correct responses of 17,000 K and 6500 K lighting conditions ($p = 0.01$) Additionally, the mean number of correct responses did not differ significantly between 6500 K light and baseline light condition ($p = 1$).

According to Table 2, the reaction time in the working memory task was not affected by lighting condition and time. In other words, there was no significant difference between the reaction time of various lighting conditions ($F(1, 23) = 2$, $p = 0.9$), or time periods ($F(1, 21) = 1.6$, $p = 0.2$).

Table 2
Results from an analysis of ANOVA for repeated measure.

Variables		Light		Time		Light × Time	
		F	p	F	p	F	p
Working memory	Correct responses	5.1	0.01	6.2	0.009	1.7	0.18
	Responses time (ms)	2	0.9	1.6	0.2	0.06	0.94
Sustained attention	Omission error	5.5	0.02	4.5	0.03	1.8	0.2
	Commission error	0.8	0.5	1.7	0.2	0.3	0.6
	Responses time (ms)	9.6	0.001	9.1	0.001	1.2	0.3
Salivary melatonin		13.7	0.001	61.5	0.001	2.6	0.05
Sleepiness		72	0.001	248	0.001	2.3	0. 2

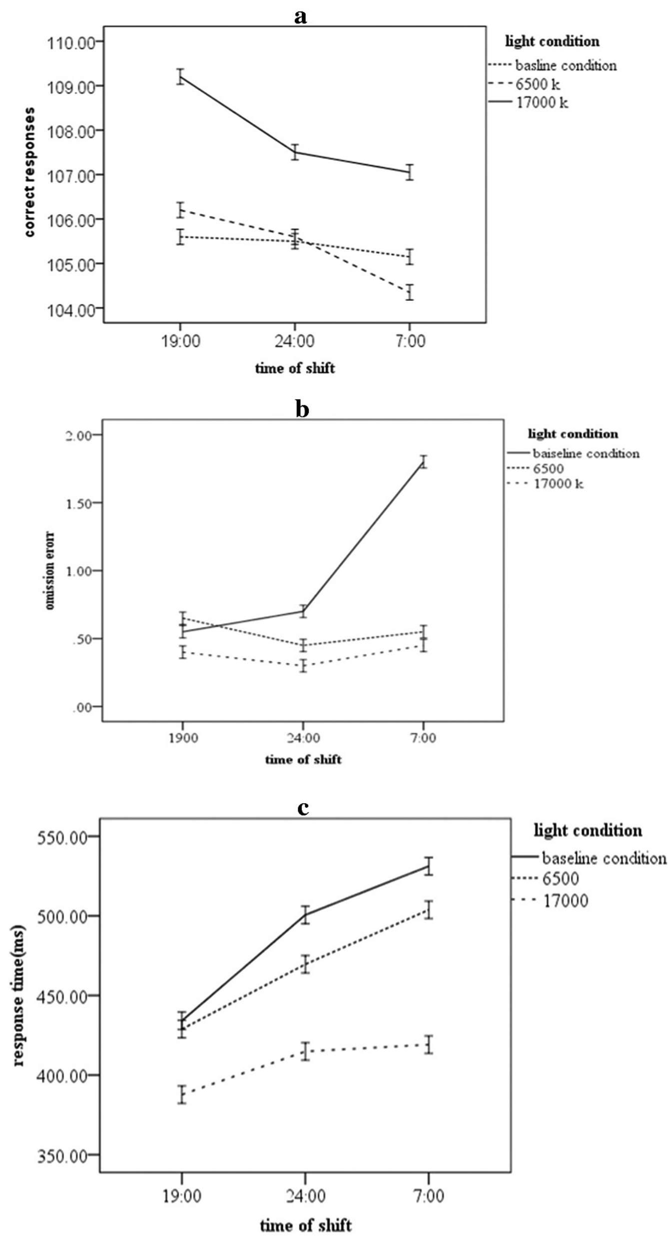

Fig. 3. Effect of light on cognitive performance: a) Mean number (SE) of correct responses for the working memory task, b) Mean number (SE) of omission error for the sustain attention task, c) Mean number (SE) of responses time for the sustain attention task.

3.2. Sustained attention

The results of participants' performance on the sustained attention task (Table 2) showed that exposure to blue-enriched white light did not affect commission error ($F(0.8, 1.8) = 0.8$, $p = 0.5$). With respect

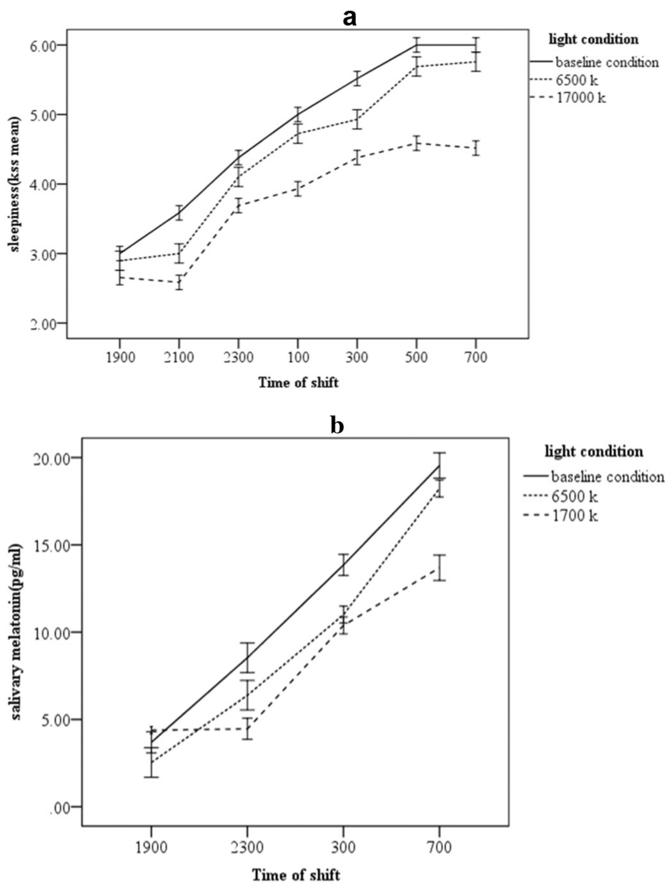

Fig. 4. Effects of light on subjective sleepiness (SE) and a) Salivary melatonin (SE) during night shift b).

to the other two variables (Fig. 3 and Table 2), however, in comparison with the baseline condition, exposure to blue-enriched white light significantly reduced the number of omission errors ($F(2.5, 12) = 5.5$, $p = 0.02$) and the reaction time ($F(0.6, 20) = 9.6$, $p = 0.001$). Additionally, time had a significant effect on reaction time ($F(1, 25) = 9.1$, $p = 0.001$), whereas the interaction effect of light and time period on omission errors and reaction time was not statistically measurable.

The results of Bonferroni correct factor revealed a significant difference between the means of omission error in 17,000 K blue-enriched white light condition and the baseline condition ($p = 0.02$). There was also a measurable difference between the omission error under 17,000 K condition and that of the 6500 K ($p = 0.01$). Additionally, the mean number of omission error did not differ significantly between 6500 K light and baseline light conditions ($p = 0.4$).

3.3. Salivary melatonin

Fig. 4 and Table 2 demonstrate changes in salivary melatonin during the night shift under different lighting conditions. The results of data analysis showed that lighting conditions have a significant effect on the rhythm of salivary melatonin ($F(3.7, 14) = 13.7$, $p < 0.001$). Furthermore, the effect of time period ($F(2, 67.5) = 61.5$, $p < 0.001$) and the interaction effect of light × time period ($F(2.5, 5) = 2.5$, $p < 0.05$) were statistically significant. On the other hand, the results of post hoc analysis using Bonferroni correction factor revealed that there was a significant difference between 17,000 K and 6500 K lighting conditions in terms of the mean level of salivary melatonin ($p = 0.04$). There was also a measurable difference between the level of salivary melatonin under 17,000 K condition and that of the baseline ($p = 0.004$). Similarly, the means of melatonin level of 6500 K and baseline were statistically different ($p = 0.01$). Therefore, 17,000 K blue-enriched white light is more influential in suppressing melatonin than 6500 K light, which is, in turn, more effective than baseline light condition.

3.4. Sleepiness

As shown in Table 2 and Fig. 4, sleepiness scale was significantly influenced by exposure to light. The results of statistical analysis revealed a significant difference in the mean sleepiness indices at various lighting conditions ($F(1.8, 75) = 72$, $p < 0.001$). In addition, time had a linear, increasing, significant effect on sleepiness ($F(2, 288) = 248$, $p < 0.001$). The interaction effect of illumination and time on sleepiness, however, was not significant ($F(2.3, 3) = 2.3$, $p < 0.2$). Bonferroni post hoc analyses indicated a significant decline in sleepiness under the three different lighting conditions. More specifically, there was a significant difference between the two blue-enriched white lighting conditions (17,000 K and 6500 K) ($p < 0.001$) and between 17,000 K blue-enriched white light condition and the baseline ($p < 0.001$). The sleepiness mean under 6500 K light condition was significantly higher than that of the baseline ($p < 0.001$). Therefore, the highest index of participants' sleepiness was registered for the baseline condition, while the lowest one was recorded for the 17,000 K blue-enriched white light condition.

4. Discussion

4.1. Cognitive performance

Most of the prior studies have subjectively assessed cognitive performance and alertness in exposure to blue light among participants on non-shift works or simulated shift works. They have demonstrated the positive effect of blue light on performance and alertness [5,17]. In the current study, n-back and continuous performance tests were used to investigate the effect of light on cognitive performance (including sustained attention and working memory). These tests are undoubtedly more reliable than former subjective methods. The results showed that, compared to baseline light and 6500 K, blue-enriched white lighting (17,000 K) is more influential in improving control room workers' working memory and sustained attention.

Light improves cognitive performance through visual and circadian systems. Kretschmer et al.'s (2012) study demonstrated that bright light stimulates the sympathetic nervous system via the visual system and, by so doing, improves working memory and attention. Based on Jahnemann's model, they explained that brightness stimulates the eye's sympathetic nervous systems and, consequently, increases the information processing capacity. Thus, cognitive performance improves as a result of increasing light intensity [1]. On the other hand, melatonin suppression and alertness rising (which take place due to the high sensitivity of circadian rhythm to blue light) can play a role in improving cognitive performance. In an interventional study, Baek et al. (2015) pointed out that blue light reduces brain's alpha-band activity, hence increasing people's cognitive performance after having lunch, as measured by a sustained attention task [15]. These findings are in line with the ones obtained in the present study. Klimesch (1999) believes that the decline of alpha and theta brain wave activities improves working memory and attention [30,32]. Research has also shown that blue light significantly increases brain activity in a number of higher order cortical areas, which are all known to be involved in working memory and executive control [31]. Vandewalle et al. (2006) have claimed that blue light facilitates restoration of diminished attentional resources, leading to the improvement of cognitive performance [8].

Neurobiological evidence also supports observations. Compared to classical image-forming photoreceptors (i.e. rods and cones), intrinsically photosensitive retinal ganglion cells are more sensitive to short wavelength light (480 nm) and are extensively connected to various brain areas. These cells, which express melanopsin, mediate non-visual effects of light on humans. As a result, light (especially blue light) entrains circadian rhythm as well as neurobiological and endocrine functions, which are known as non-visual effects.

Post hoc comparisons of this study showed that, compared to 6500 K and baseline light sources, 17,000 K blue-enriched white light source had a significantly stronger effect on studied parameters, namely melatonin, sleepiness, and cognitive performance. Also, the effect of 6500 K light source was significantly stronger than that of the baseline light source on sleepiness and melatonin. In fact, more blue-enriched light sources cause more melatonin suppression which, in turn, decreases sleepiness and enhances cognitive performance. These results are consistent with the findings of previous studies [19]. Baek et al. (2015) showed that 66% blue-enriched light is more influential than 33% blue-enriched light and white polychromatic light in enhancing brain's alpha wave activity and attention [15]. In addition, Viola et al. (2008) concluded that, compared to 4000 K and white light sources, 17,000 K light has a stronger effect on performance, mood, alertness, and sleep quality [17].

In our study, time had a significant effect on cognitive performance, meaning that cognitive performance declined in the course of time. This result can be attributed to the fact that during night, the level of melatonin and the degree of sleepiness increase (as shown in this study). Thus, alertness and, consequently, performance go down [32]. The interaction effect of illumination and time was not significant, indicating that light has a similar effect on cognitive performance over the time.

4.2. Melatonin rhythm

The findings of the current study showed that, compared to white light, blue-enriched white lighting is more effective in suppressing melatonin. A large number of studies have investigated the influence of bright light on melatonin suppression among shift workers and concluded that increasing light intensity leads to more melatonin suppression [33]. However, few studies (especially field studies) have concentrated on the impact of blue-enriched white lighting on melatonin pattern among night-shift workers. The results of the present study are in line with those obtained in Chellappa et al.'s (2011) research, which indicated that exposure to 6500 K light is more influential than exposure to 3000 K and 2500 K lights in terms of suppressing evening melatonin among non-shift workers [34] Moreover, the findings in the current study showed that 17,000 K lighting sources are more effective than 6500 K lighting sources in attenuating melatonin.

These results can be attributed to the high sensitivity of circadian rhythm to short wavelength lights. Previous studies have shown that short wavelength lights exercise their effect on the circadian system through retinal ganglion cells [33,35]. In this regard, blue light is a critical cue in entraining biological rhythms [15]. In comparison with common light sources, blue-enriched white lighting has a higher level of radiation in short wavelengths; therefore, it is more effective than white light in suppressing melatonin [17].

On the other hand, based on the findings, time had a significant effect on the level of salivary melatonin in all the three stages (before and after intervention). More precisely, the melatonin level increased in the course of time. This finding is consistent with previous studies which have registered the maximum and minimum level of melatonin in blood circulation over an entire day among non-shift workers at 4 a.m. and 4 p.m., respectively. Furthermore, it has been reported that there is a positive correlation between salivary and blood circulation melatonin [36]. In addition, the significant interaction effect of light × time can be related to the strong power of 17,000 K light in suppressing melatonin spatially at the beginning of the shift. As indicated in the figure, in the primary hours of the shift, light (rather than time) is the only factor causing melatonin suppression.

4.3. Sleepiness

In the present study, like melatonin rhythm, subjective sleepiness was influenced by the type of light sources. That is, exposure to blue-enriched white lighting significantly reduced sleepiness (compared to white light). The same findings have been echoes in previous field studies on the effect of light intensity on sleepiness [35,37,38]. Badia et al. (1991) were among the first group of researchers who showed that light exposure affects humans' alertness [39]. Lowden et al. (2004) also demonstrated that bright light intervention during shift workers' break time significantly reduces sleepiness [40]. In another laboratory study, after each 4 h, participants were exposed to 470 nm light (blue light) for 50 min, with the entire experiment lasting for 72 h. The results showed that blue light decreases sleepiness and enhances alertness [5].

The results of the current study revealed that changes in alertness depend on color temperature of the light source; that is, increasing color temperature would enhance the level of blue-enriched light which, in turn, declines individuals' sleepiness and raises their alertness. Through conducting a laboratory study, Phipps-Nelson (2009) concluded that blue light increases delta and theta brain wave activities, hence raising people's alertness [5]. On the other hand, as observed in the present research, increasing the color temperature of the light source will enhance the amount of blue-enriched light. This will in turn suppress melatonin (the hormone of darkness) and, consequently, decrease the level of sleepiness.

The results also indicated that time had a significant effect on sleepiness, in that, participants' felt more sleepy in the course of time. This result may have to do with the circadian rhythm of sleepiness-alertness. According to previous studies, sleepiness-alertness circadian rhythm is in line with melatonin rhythm and core body temperature, experiencing changes as a result of shifts in lighting conditions. During the night, melatonin increase results in a stronger feeling of sleepiness, while during the day, the decline of melatonin increases the level of alertness [35]. In this regard, the results of the current study are consistent with those of Viola et al. (2008) who exposed non-shift administrative workers to blue-enriched light (17,000 K) for 4 weeks and concluded that, compared to non-blue-enriched light condition, people's alertness and sleep quality increased [17].

5. Conclusion

The results of this study showed that improving lighting by blue-enriched white light sources adjusted circadian rhythm to night-shift work, reduced sleepiness, and enhanced cognitive performance among night-shift workers of control room. The aforementioned effects are magnified as stronger blue-enriched light sources are used. Thus, as an ergonomic solution, such light sources can be used in sensitive areas, like control rooms, which require maximum alertness and performance during night.

6. Limitations of the study

It is admitted that, like any other research project, the present study suffers from some limitations, which should be taken into account while interpreting the findings. First, 1-back test was used in the current study to assess participants' working memory. We acknowledge that using 3-back test for the same purpose was more advisable; however, participants did not have a positive attitude toward it since it is a difficult test. On the other hand, the field-based nature of the study made it difficult to conduct the 3-back test.

Another limitation of the study is that self-reported perceptions in alertness were utilized, which might be biased in terms of the reliability of measurements. Besides, like other experimental designs investigating the effect of lighting, it is almost impossible to implement a double-blinded design. Therefore, it is unavoidable for the results to be at risk of influence of Hawthorne effect, where respondents might perform outstandingly well (sometimes bad), as they know that they are being observed and cared.

The results of this study display the positive influence of blue-enriched light on night shift workers' performance and alertness. However, previous research has demonstrated that using blue light may cause retina damage and oxidative stress [41–43]. As a result, care must be taken in implementing blue light in workplaces [15]. In order to reduce the negative effect of blue-enriched light, it is recommended that workers avoid being directly exposed to this type of light. On the other hand, all the studies that have demonstrated the negative influence of blue light have been conducted under laboratory settings [41–43]. It is therefore suggested that future studies try to investigate the influence of this type of light on people's health under field conditions.

Disclosure statement

The authors declare that they have no competing interest.

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