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Cognitive task performance in simulated night shifts: impact of optical filtering on 450–500-nm wavelength light under bright lighting conditions

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Objectives: Circadian rhythms, which are crucial for regulating sleep-wake cycles, are particularly sensitive to light exposure, influencing alertness and performance during night shifts. Notably, blue light has gained attention for its potential impact, prompting this study under bright lighting conditions using goggles with targeted wavelength filtering.
Methods: This study employed a randomized double-blind crossover design. Participants engaged in simulated night shift experiments using goggles that either filtered 450–500-nm wavelength light or placebo goggles. Outcomes included the psychomotor vigilance task (PVT), digit symbol substitution test (DSST), and heart rate variability.
Results: No significant differences were observed in PVT, DSST, or heart rate variability while using the goggles.
Conclusion: Filtering 450–500-nm wavelength light did not affect performance. These findings suggest the need for a comprehensive approach to maintain and improve performance during night shifts. Such an approach should consider light and other factors, including napping, nutrition, and various environmental influences.

Keywords: night shift work, blue light exposure, cognitive task performance, wavelength-specific filtering, simulated night shift

Introduction

Night shift work is a crucial job role that supports the demands of a modern 24-hour society. Approximately 20% of workers in Japan engage in night shift work, and this percentage is increasing annually.[1] However, night shift work requires employees to work and rest against the rhythm of the circadian clock, making maintaining performance levels on par with daytime work difficult. This can lead to reduced task performance and increased accidents.[2–4] In addition, sleep after completing night shifts is frequently insufficient, contributing to further performance deterioration, subsequent health issues, and mental disorders.[5–9] In contemporary society, addressing performance enhancement during essential night shift work is critical.

Light including sunlight is an essential synchronizing factor for the human circadian clock, which regulates the circadian rhythm to align with the external environment and daily life patterns. Light in the 450–500-nm wavelength range, commonly known as "blue light," is notable in that it is involved in synchronizing the circadian clock and promoting wakefulness.[10,11] The advancement of modern lighting and information communication technologies has resulted in increased exposure to blue light regardless of the time of day.

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Studies such as that of Ouyang et al.[12] primarily emphasized the side effects and "harm" due to excessive blue light exposure, demonstrating its association with retinal damage and eye conditions, such as glaucoma. Mainster et al.[13] and Ouyang et al.[12] proposed that daily blue light exposure from lighting and electronic devices poses minimal harm, except for specific high-energy light-related occupations such as welding and dentistry. This indicates a need for more careful consideration of the perceived dangers of blue light compared with the previously overstated concerns.

Several studies have explored research using light in the 450–500-nm wavelength range. For instance, investigations into cognitive tasks conducted in environments where blue light was added to white light reported significantly higher performance in cognitive tasks, including sustained attention and arousal under enhanced white light compared with those under regular white light.[14,15] Moreover, studies manipulating the background color of monitors used for cognitive task stimuli, either in blue or orange light, noted no overall performance differences. However, when the background color was blue, certain tasks were performed better.[16] A systematic review by Silvani et al.[17] on cognitive task studies concluded that in 4 of 7 studies, blue light exposure significantly influenced cognitive performance, emphasizing the need for further research to draw definitive conclusions. Research results to date lack consistency, with several studies focusing on exposure to enhanced or monochromatic blue light. Therefore, the present study aimed to investigate the impact of 450–500-nm wavelength light under bright lighting conditions during simulated night shifts using goggles with wavelength-specific filtering.

Materials and Methods

Participants

Participants in this study were healthy adults aged 20–40 years. The following were the exclusion criteria: (1) individuals with medical conditions that could affect their cognitive function or sleep; (2) individuals with physical or psychological symptoms that make complying with the study protocol difficult; (3) individuals taking prescription medications, supplements, or substances known to impact cognitive function or sleep; (4) individuals engaged in regular night shift work or late night activities; and (5) individuals unable to wear goggles for any reason. This study was conducted with the approval of the Ethics Committee of the School of Medical Sciences, Kitasato University (Approval No. 2014-002). Informed consent was obtained from all participants through verbal and written communication prior to participation in the study.

Methods

A randomized double-blinded crossover design was used in this study. Participants were randomly assigned to the 450–500-nm wavelength-filtering goggle group (intervention group) and the placebo goggle group (control group). Cognitive tasks were performed over 2 nights with more than a 5-day interval. The order of the intervention and control groups was switched between the first and second experiments. The goggles used were designed by the Tokai Optical Corporation, with one set filtering 95% or more of the 450–500-nm wavelength light and the placebo goggles filtering 95% or more of the 650–700-nm wavelength light. Both goggles transmitted more than 95% of the light in other wavelength ranges. Moreover, to accommodate light from the lateral direction, lenses were embedded on the sides of the goggles.

Participants maintained their usual weekday patterns, refraining from activities such as overnight work, staying up late, or excessive alcohol consumption for at least 5 days before each cognitive task. They recorded a daily sleep diary at home. From the morning of the experiment until the end of the day, they were prohibited from consuming caffeine, ethanol, or other stimulants that could affect cognitive performance or sleep. For female participants, to minimize the potential influence of nighttime insomnia or daytime sleepiness on the results, experiments were conducted during the follicular phase.

Participants arrived at the laboratory at 18:00 hours on each experiment day, wore their assigned goggles, and completed a total of 5 cognitive tasks at 21:00, 23:00, 01:00, 03:00, and 05:00 hours. The study ended at 08:00 hours the following morning.

Inside the laboratory, 4 bright light devices (Bright Light ME; Solartone, Inc., Tokyo, Japan) with spectral characteristics equivalent to sunlight were installed, maintaining an illumination of 1000–2000 lux and a temperature of 22°C–25°C. Beverages and meals provided on each experiment day at 19:00, 00:00, and 06:00 hours excluded caffeine, ethanol, or other stimulants. The beverage and food intake volumes were left up to the participants' discretion.

Measures

All subsequent measurements were performed after obtaining the participants' consent to participate in the study. A questionnaire regarding age, gender, medical conditions under treatment, and use of medications, habits, over-the-counter drugs, and supplements was administered to obtain demographic data.

The Pittsburgh Sleep Quality Index (PSQI) is a scale that assesses general sleep quality and sleep disturbances, with a score of 6 or higher indicating the presence of some form of sleep disorder.[18] The Morningness–Eveningness Questionnaire (MEQ) measures sleep-wake rhythm and time-of-day preferences, with higher scores indicating a tendency toward morningness.[19,20] The MEQ is closely related to circadian rhythm.[21]

The Epworth Sleepiness Scale (ESS) measures daytime sleepiness, with higher scores indicating greater sleepiness and 11 or more points indicating excessive sleepiness.[22]

To assess sleep-wake rhythms for the 5 days before each experiment, a sleep diary was requested to be completed. Bedtime, wake time, and naps were the outcomes of the diary.

Cognitive tasks

The cognitive tasks were conducted in both nighttime experiments at the following times: 21:00, 23:00, 01:00, 03:00, and 05:00 hours. The Psychomotor Vigilance Task (PVT) is a 20-minute assessment that assesses the impact of sleepiness on cognitive performance.[23] Participants responded by clicking a computer key only when a predefined target stimulus, represented by 3 different shapes, randomly appeared. The number of lapses and reaction times were calculated.

The Digit Symbol Substitution Test (DSST) is used to assess attention, information processing, and motor speed.[24] This task comprises 9 predetermined symbols that are individually matched with the numbers 1–9. Participants were tasked to replace these numbers with their corresponding symbols on a sheet provided as quickly as possible and within 90 seconds. The total number of correctly drawn symbols was recorded. The DSST presented 4 different versions randomly assigned in a sequential order for each of the 5 trials to minimize the learning effect.

Autonomic nervous system activity

The heart rate variability recording device (HRS-08WE [Heart Rate Scanner; Hirose Electric Global, Kanagawa]) is used for measuring autonomic nervous system responses. By recording the variability in the heart rate, it is possible to analyze the activity of the autonomic nervous system that influences heart pulsations.

Low-frequency/high-frequency (LF/HF) ratios are used as indicators of cardiac parasympathetic and sympathetic nervous activity. Measurements were taken during the PVTs.

Table 1. Participants' characteristics (N = 20)

Variables	Mean ± SD
Age	22.30 ± 1.26
Gender	13 M, 7 F
ESS	8.00 ± 2.85
MEQ	48.5 ± 6.61
Definitely morning type	0%
Moderately morning type	5%
Neither type	85%
Definitely evening type	10%
Moderately evening type	0%
PSQI	5.45 ± 2.56

SD, standard deviation; M, male; F, female; ESS, Epworth Sleepiness Scale; MEQ, Morningness-Eveningness Questionnaire; PSQI, Pittsburgh Sleep Quality Index

Statistical analysis

The indices between each condition were analyzed using repeated measures analysis of variance. In the presence of significant effects or interactions, Student's *t*-tests were used. A significance level of $P = 0.05$ was set for all statistical tests. All analyses were performed using JMP 17 software (SAS Institute, Cary, NC, USA).

Results

Participants' characteristics

The participants' characteristics and self-reported questionnaire responses are shown in Table 1. The participants in this study were 20 healthy adults (22.30 ± 1.26 years old; 13 men, 7 women). Of the 23 participants who registered for the study, 3 withdrew, and the 20 individuals who completed the experiments were included in the analysis. As a group average, the cutoff values for both ESS and PSQI were not exceeded.

Comparison of the goggle parameters and gender

PVT

No significant differences were observed in lapses and mean reaction time for PVT due to the goggles (Table 2). However, the placebo goggles tended to result in more lapses at 05:00 hours than did the intervention goggles. In addition, no significant gender differences in PVT performance were observed.

DSST

No significant differences in the number of correct responses in the DSST were observed between the goggles (Table 2). However, a significant gender difference was

Table 2. Comparison between goggle parameters and gender

Variable	Goggles (mean ± SD)			Gender (mean ± SD)		
	Intervention	Control	P value	Male	Female	P value
PVT lapses all (h)	0.31 ± 0.43	0.40 ± 0.43	0.50	0.42 ± 1.13	0.23 ± 0.46	0.17
21:00	0.25 ± 0.72	0.35 ± 0.75	0.73	0.35 ± 0.74	0.21 ± 0.51	0.68
23:00	0.25 ± 0.91	0.25 ± 0.72	0.99	0.31 ± 0.85	0.14 ± 0.43	0.60
01:00	0.25 ± 0.44	0.30 ± 0.47	0.86	0.23 ± 0.38	0.36 ± 0.59	0.69
03:00	0.40 ± 1.35	0.15 ± 0.37	0.42	0.38 ± 1.05	0.07 ± 0.32	0.33
05:00	0.40 ± 0.88	0.95 ± 1.88	0.07	0.85 ± 1.54	0.36 ± 0.76	0.13
PVT mean RT all (h)	374.85 ± 20.00	375.82 ± 20.00	0.62	373.06 ± 49.34	379.56 ± 36.58	0.34
21:00	379.70 ± 48.83	379.20 ± 36.38	0.90	379.54 ± 43.10	379.29 ± 33.28	0.99
23:00	365.05 ± 37.71	364.70 ± 38.15	0.89	361.54 ± 34.98	371.07 ± 39.34	0.52
01:00	360.20 ± 41.86	366.55 ± 44.38	0.54	361.04 ± 41.38	367.71 ± 40.68	0.66
03:00	375.65 ± 43.67	370.80 ± 40.72	0.86	372.42 ± 42.52	374.71 ± 31.72	0.88
05:00	393.65 ± 46.38	397.85 ± 63.00	0.65	390.77 ± 50.55	405.00 ± 58.91	0.34
DSST all (h)	69.88 ± 6.06	71.03 ± 6.06	0.46	68.22 ± 5.07	74.61 ± 6.91	0.00
21:00	70.25 ± 12.54	75.55 ± 17.51	0.18	69.81 ± 15.76	78.64 ± 12.92	0.04
23:00	73.30 ± 11.23	68.90 ± 11.45	0.32	68.88 ± 12.01	75.21 ± 9.23	0.14
01:00	66.90 ± 8.36	66.90 ± 9.73	0.95	65.50 ± 9.49	69.50 ± 7.49	0.35
03:00	66.15 ± 11.32	68.05 ± 12.53	0.60	64.69 ± 12.60	71.57 ± 8.99	0.11
05:00	72.80 ± 14.78	75.75 ± 18.36	0.44	72.19 ± 17.76	78.14 ± 13.67	0.17
LF/HF all (h)	2.73 ± 1.27	2.51 ± 1.23	0.86	3.15 ± 1.03	1.59 ± 1.44	0.00
21:00	2.18 ± 1.56	1.58 ± 0.89	0.55	2.13 ± 1.44	1.42 ± 0.79	0.38
23:00	3.56 ± 4.30	2.03 ± 1.95	0.11	3.36 ± 3.94	1.59 ± 0.93	0.04
01:00	2.70 ± 2.61	2.82 ± 2.76	0.76	3.46 ± 2.87	1.15 ± 0.77	0.01
03:00	2.65 ± 2.26	3.17 ± 2.76	0.43	3.38 ± 2.39	2.11 ± 2.65	0.14
05:00	2.55 ± 2.35	3.02 ± 3.38	0.51	3.38 ± 3.37	1.63 ± 0.97	0.05

SD, standard deviation; PVT, Psychomotor Vigilance Test; RT, reaction time; DSST, Digit Symbol Substitution Test; LF/HF, low frequency/high frequency

noted, with the men performing better than the women in the DSST. A gender difference was also evident at 21:00 hours when the women had more correct responses than did the men.

LF/HF

No significant differences were observed in LF/HF due to the goggles (Table 2). Conversely, a significant gender difference was observed, with men having significantly higher sympathetic nervous system activity at 23:00 and 01:00 hours overall.

Discussion

This study investigated the effects of 450–500-nm wavelength light filtration on cognitive performance during simulated night shifts. The results revealed no significant differences in cognitive performance and variability in heart rate due to the 450–500-nm wavelength light filtration. These findings correspond to the results of previous studies.[16,17]

Participants' characteristics

The participants were healthy adults with no signs of sleep disorders or regular sleep insufficiency. Although PVT lapses were slightly lower, other parameters such as the PVT and DSST showed values typical for their age group.[14,25–27] Regarding LF/HF, a bias toward sympathetic nervous system dominance was noted, possibly influenced by the unique nighttime research setting at the university.

Cognitive tasks and heart rate variability

No significant differences were observed when filtering 450–500-nm wavelength light. Lee et al.[16] suggested that the impact of 450–500-nm wavelength light on arousal is not potent enough to affect behavior, particularly in cognitive tasks. This study employed bright light, and the awakening effects of such light, encompassing wavelengths beyond 450–500 nm, may have influenced the outcomes.[28,29] Moreover, under high-intensity light conditions, participants may be influenced by 450–500-nm wavelength light, even with 95% light filtering. Previous studies have mainly focused on enhancing or irradiating monochromatic blue light.[14–16] Their effects may differ from those in our study, which specifically filtered certain wavelength lights.

Other studies have explored factors other than light for maintaining arousal and cognitive function during night shifts, such as the appropriate timing and duration of naps and meals. A review and meta-analysis by Dutheil et al.[30] suggested that napping during the early hours of the night positively impacted cognitive function. A common recommendation is limiting meal intake; however, studies during night shift simulations have suggested that snacking, rather than fasting, improves cognitive function.[31] In the present study, participants were free to select the amount of food and beverages they consumed. Nighttime cognitive function depends on factors beyond light, and no differences were noted with 450–500-nm wavelength light alone. A comprehensive approach that considers the light environment, napping, meals, and workplace conditions is crucial to optimize performance during night shifts.

Furthermore, the present study revealed significant gender differences. Although few gender differences were observed in the DSST, women scored significantly higher. Torquati et al.[32] reported a higher risk of mental health issues, especially depression, in women working night shifts. Furthermore, Fasanya and Pope-Ford[33] noted gender differences in the impact of night shift work on workers' well-being. In their study, men reported higher levels of sadness and anxiety, whereas women reported more sleep difficulties. Stimuli, environmental factors, gender differences, and biological elements must be considered in future research when assessing nighttime cognitive function and suitability for night shifts.

Limitations

This study had some limitations. First, the study participants were students, notably distinct from individuals typically involved in the night shift work. Second, the study was conducted in a controlled laboratory environment, which may have affected participant alertness. Therefore, future studies should further account for and explore those factors.

Conclusion

The filtering of 450–500-nm wavelength light did not affect cognitive task performance during simulated night shifts under bright lighting conditions. To effectively address the maintenance of cognitive function and alertness during night shifts, future research is warranted to comprehensively investigate combined factors, including light exposure, dietary considerations, and napping strategies.

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Conflicts of Interest

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