International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

PO133

AN EXPERIMENTAL STUDY OF THE LIGHTING FOR NONE NATURAL LIGHT OFFICE SPACE BASED ON NON-VISUAL BIOLOGICAL EFFECTS

Yi Lin et al.

DOI 10.25039/x46.2019.PO133

from

CIE x046:2019

Proceedings
of the
29th CIE SESSION
Washington D.C., USA, June 14 – 22, 2019

(DOI 10.25039/x46.2019)

The paper has been presented at the 29th CIE Session, Washington D.C., USA, June 14-22, 2019. It has not been peer-reviewed by CIE.

CIE Central Bureau
Babenbergerstrasse 9
A-1010 Vienna
Austria
Tel.: +43 1 714 3187
e-mail: ciecb@cie.co.at
www.cie.co.at

AN EXPERIMENTAL STUDY OF THE LIGHTING FOR NONE NATURAL LIGHT OFFICE SPACE BASED ON NON-VISUAL BIOLOGICAL EFFECTS

Lin, Y.[1,2], Liu, C.[3], Lu, W.H.[1,2], Zeng, X.X.[1,2]
[1] College of Architecture and Urban Planning, Tongji University, Shanghai, CHINA
[2] Key Laboratory of Ecology and Energy-saving Study of Dense Habitat (Tongji University), Ministry of Education, Shanghai, CHINA
[3] Tongji Architectural Design (Group) Co., Ltd.

linyi_tjcaup@tongji.edu.cn

DOI 10.25039/x46.2019.PO133

Abstract

Lighting environment of office space is not only related to the visual effects for office workers, but also has influence on sleep, mood, and alertness and then has an important effect on physical and mental health of the staff through the non-visual forming system. Two lighting modes in a simulate office space without daylight were used to quantified high-intensity blue-enriched-white light's effects on human melatonin, cognitive ability, brain Electricity, alertness and other physiological factors. The results show that a significant difference exits in the melatonin content of saliva under basic lighting mode (300lx illuminance of the horizontal working plane and 4000K) and circadian lighting mode (eye illumination 1000 lx, 12000K). However, melatonin secretion is not sufficiently suppressed by the artificial circadian lighting stimulate from 9:00am to 11:00am. Significant differences could not be found in both visual performance and cognitive performance. The circadian lighting causes a certain degree of glare and results visual fatigue increasing.

Keywords: Circadian Rhythm, Melatonin, Cognition, Office lighting

1 Introduction

Light directly affects the body's internal timing system to regulate the circadian rhythm system, which in turn has an important impact on health. Since the human' main biological clock has a cycle of just over 24 hours (Mooreede, B. M. C. et al., 1982), in order to keep pace with the solar time outside, light-dark stimulation on the retina is needed to reset the SCN's timing system. However, if the cycle of light-dark stimulation is too long, too short or non-cyclical, or lack of light-dark stimulation, SCN may lose the timing control of human circadian rhythm, resulting in the disruption of circadian rhythm and many health problems (Rea, M. S.et al., 2008). As urban people spend more and more time indoor, they have stronger demands for healthy lighting environment, and their requirements for light environment quality are gradually extending from visual health to meeting psychological and physiological health needs. Especially for office workers who spend a lot of time indoors in the daytime, the influence of the light level they can get in the office space on their rhythm health turns out to be more critical.

In 2010, HUBALEK et al. used a head-mounted measuring device to track the light income in the eyes of 23 office workers for a week. The results showed that the light income in the eyes during the day had a significant effect on the sleep quality at night (Hubalek, S.et al., 2010).Mohamed Boubekri et al. compared the sleep quality of the two groups of office workers with and without windows in the workplace by monitoring the behaviours and activities of office workers during sleep and wakefulness with wrist motion meter, and found that the sleep quality, work performance and vitality of office workers who can receive sunlight are higher than those who can't get sunlight (Boubekri, M.et al., 2014). Aries et al. recorded the daily light income and sleep quality of 42 office workers in 10 office buildings, and concluded that there was a significant relationship between the illuminance at eyes and sleep quality (Aries, M. B. C., 2005). Figueiro and Rea tracked 11 office workers in winter and summer, and the results showed that since office workers received significantly more sunlight in summer than in winter, their sleep time and sleep quality in summer were significantly higher than those in winter (Figueiro, M. G., & Rea, M. S., 2016). The field experiments from Artonen and Lönnqvist J. (2000) during the

winter in Finland showed that office workers' vitality increased significantly after 4 weeks of high intensity illumination (2500lx at eye level) (Partonen, T., & Lönnqvist, J., 2000).
With the wide use of computers, office visual objects have changed from paper to self-luminous display. Visual objects can be seen without external lighting, so indoor artificial lighting has been ignored. In the previous field survey of 20 office sites in Shanghai, we found that a large number of existing office buildings have low-level illumination (Lin, Y. et al., 2016). 30% of average illuminance (natural and artificial light) in the office spaces' working surface is less than 300lx, only 35% is more than 500lx. The average vertical illumination of all office work position in office space is less than 1000lx, only 4 office work position are more than 500 lx. The on-site questionnaire survey conducted at the same time showed that the sleep quality of the workers was significantly related to the distance from work position to window. At the same time, the field test results also showed that the near-window workers could obtain higher intensity natural light. A large number of office workers far away from window were difficult to get enough light illumination, which caused their rhythmic health damaged. Therefore, in order to meet the needs of office workers' circadian light stimulation during daytime, this study attempted to use artificial light in the morning working hours to give the rhythm stimulation of blue-rich white light to the participants, assuming it will help inhibit melatonin secretion, improve alertness and be conducive to cognitive levels and sleep quality.

2 Experiment design

2.1 Experiment scheme

In this experiment, a simulated office experiment space was set up to observe and record the influence of artificial lighting on melatonin secretion, alertness, emotion and cognitive ability of subjects under simulated working conditions. A comparative study was conducted to explore the effects of different lighting conditions (basic lighting mode and circadian lighting mode). The participants came to the laboratory for two experiments at a fixed time in each morning on separate days and experienced one lighting condition for one experiment. Participants were randomly assigned to the order of experimental conditions. There was no daylight contribution in the room during this experiment.

2.2 Participants

Ten postgraduates were recruited to participate in the experiment, including 4 males and 6 females. The subjects aged between 24 and 31. Participants self-reported they were non-smokers with good health, and their characteristics meet the following requirements: they had normal or corrected to normal vision and didn't have obstacles in distinguishing colours or diseases that affect their light sensitivity or similar medications; Participants didn't consume caffeine and alcohol the day before or after the experiment; There was no significant sleep problems found after the questionnaire of The Pittsburgh Sleep Quality Index (PSQI) was filled out.

2.3 The design of experimental scene

This experiment was based on the previous investigation of office spaces (Figueiro, M. G., & Rea, M. S., 2016) and the results of the field experiment (Partonen, T., & Lönnqvist, J., 2000) of the subject. A laboratory of Wenyuan Building in Tongji University was selected as the experimental room, the dimension of which is 4.0m by 2.2m. There is no window, no natural light, but artificial lighting in the room. The temperature in the room remained the same (25□) during the experiment. The ceiling was suspended white plasterboard with a reflectance of 0.7, and the height of the ceiling was 3.8m above floor level. The walls were painted flat white with a reflectance of 0.7; the floor throughout the room was carpeted, the carpeted was dark grey in colour, with a reflectance of 0.3.

The experiment room was lit by two sets of luminaire systems. One consisted of a regular array of Three 40W Osram LED TOUCH PANEL lights in the suspended ceiling, with a correlated colour temperature (CCT) of 4000K, providing general lighting. These panel lights were controlled by stepless dimming knob switch. The other was a customized white wooden frame on the working plane closed to the wall with Three 18W, T5, Philips MASTER TL5 fluorescent lamps of a CCT of 17,000K mounted inside, providing indirect illuminance for rhythmic stimulation. The off-white work table was placed against the wall with a black chair.

Two illumination scenes were set in this study. The scene A (basic lighting mode） was designed to meet the minimum requirements for office lighting as set out in the Chinese national standard "Architectural Lighting Design Standards" (GB50034-2013), the maintained illuminance on work surface which was 0.75m above floor level shall not fall below 300 lx. the illuminance was measured and the mean illuminance of the desktop was 339.3lx. The CCT is 4000K CCT, based on the previous measured data of typical office space lighting in Shanghai. The Scene B (circadian lighting mode) design is according to the previous related researches of photobiological effects, which suggest that eye illuminance of at least 1000 lx could activate the circadian effect. In the experiment the illuminance at the participant's eyes was 1185 lx, and the CCT was 12000K. The completion of the lighting scene construction was given in Figure 1. The corresponding measured lighting data were given in Table 1.

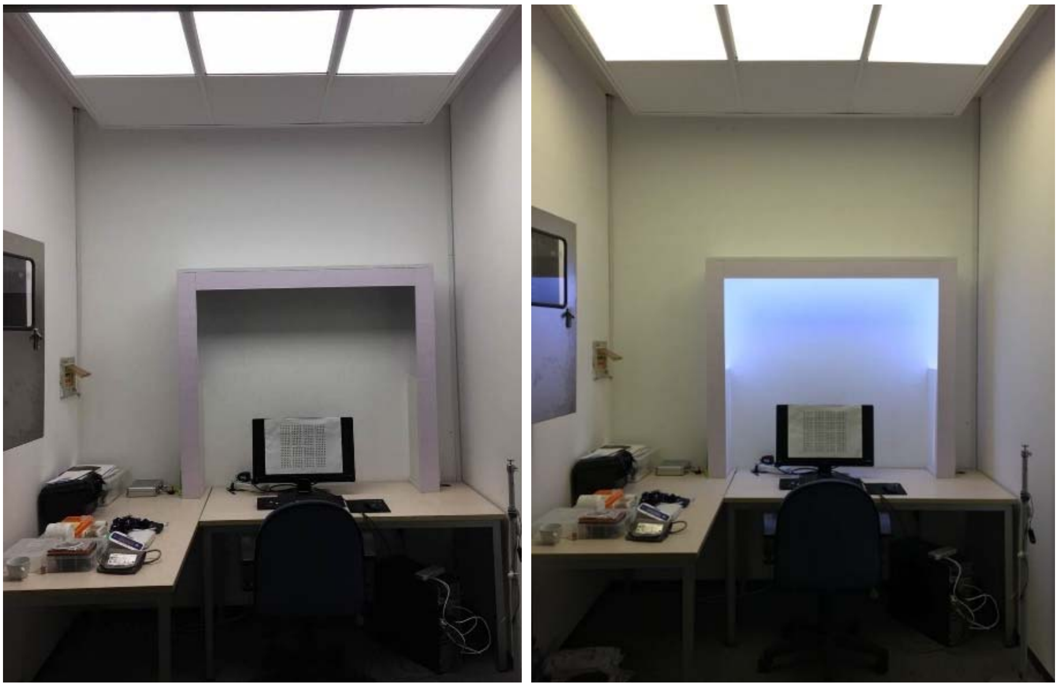


Figure 1 – lighting environment A (left), lighting environment B (right)

Figure 2 – Luminance analysis of subjects' main visual range in Scene A (Source: Self-painting)

Figure 3 – Luminance analysis of subjects' main visual range in Scene B (Source: Self-painting)

Table 1 – The parameters of two lighting environment

Scene	the maintained illuminance on work surface (lx)	the illuminance at eyes (lx)	CCT (K)	Mean luminance (cd/m2)
A	339.3	133.1	3796	40.58
B	1338	1185	11750	151.1

Figure 4 – Measured absolute spectral curve of subjects' eyes in scene A

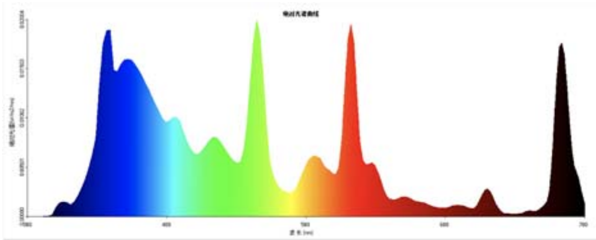


Figure 5 – Measured absolute spectral curve of subjects' eyes in scene B

2.4 Experimental process

The participants came to the laboratory one day before the experiment. After being introduced to the experimental procedure and precautions, they voluntarily signed the informed consent form. They were given the UP3 sleep monitoring bracelets, and downloaded the UP software in the mobile phone to ensure the sleep bracelet connected well with the mobile phone. The bracelets recorded the sleep conditions on the night of the day before the test, the day of the experiment and the day after the experiment, and the participants would fill the electronic questionnaire of the sleep log in the morning after the sleep was recorded.

Each participant completed the experimental process of two illumination scenes in no particular order, with at least one day interval between the two experiments.

The experiment was carried out at 9:00 to 11:00 in the morning, and the light environment remained unchanged during the experiment. The experiment process was given below.

- 1 The preparation phase began after the participants arrived in the laboratory. Saliva was sampled, and then the participants correctly worn EEG electrode cap to ensure it worked well. According to the waveforms collected by the blinking and closing eyes in the sitting state. The participants were adjusted to their comfortable sitting posture and experiment began.
- 2 The participants were adjusted to a comfortable sitting position, relaxed and resting on the chair to feel the overall light environment. After the waveform was stable, the participants were allowed to collect the EEG for three minutes. Then, the participants kept their eyes closed and three minutes of EEG was collected. Throughout the process, the participants were required to strictly fix the body and minimize the frequency of blinking.
- 3 After the EEG acquisition, the participants assessed their alertness through the Karolinska Drowsiness Scale (KSS).
- 4 Then, the first round of behavioural testing is performed through the Stroop paradigm and the GO/NOGO paradigm.
- 5 There were 5-10 minutes for rest before the second EEG was collected.
- 6 After the completion of the visual effect of landau ring identification test, record the number of identification and identification time.

- 7 The second round of behavioural testing was performed through the Stroop paradigm and the GO/NOGO paradigm.
- 8 The third time to record EEG, measure heart rate and blood pressure.
- 9 The saliva was sampled at last with the experiment ended.

2.5 Data collection

In this experiment, the amount of melatonin in the spontaneously secreted saliva was used as an indication for the circadian rhythm of the human body. Before and after the end of the experiment, the spontaneously secreted saliva was collected by 5 ml medical plastic test tubes and then immediately frozen and stored. After the experiment, the professional detection company analysed the amount of melatonin.

The differences in power density of the subjects' brainwave activity in different frequency bands were collected by the Neuracle neusen.w32 wireless EEG device. The electrode position distribution of the EEG cap in this experiment was determined by the 10-20 system developed by the international computer graphics society in 1958.After the cap was worn according to the electrode impedance feedback system, whether the cap was worn correctly was judged by testing the subjects' signature EEG signals of eye closing, blinking and eye movement in left and right. If the relevant waveforms can be detected, the EEG cap is considered to have been worn correctly.

The sleep quality will be monitored by Jawbone UP3, a sleep monitoring device, and data will be downloaded through the APP. A sleep log is also required. The heart rate and blood pressure data were collected by Omron portable sphygmomanometer. Subjective evaluation questionnaire was used to evaluate the alertness and emotion of the subjects during the experiment. The questionnaire included the Karolinska Sleepiness Scale (KSS) and mood scale of Pleasure- Arousal- Dominance (PAD). The subjects' cognitive level was monitored by the usual Stroop paradigm and GO/NOGO paradigm. Data such as response time of each stimulus and accuracy were saved by E-prime software, then extracted and analysed by MATLAB2016.

3 Experimental results

3.1 Melatonin

Melatonin in saliva was detected by the technique of avidin biotin complex ELISA (ABC-ELISA). The samples collected by the experiment were all tested with parallel test holes. The average value of the parallel tests was taken as experimental analysis data, as given in Figure 2. In scene A, before the start of the experiment, the melatonin levels in the saliva of all the participants were in the range of 10-20pg/ml. After the experiment, the melatonin levels in the saliva of the participants showed different degrees of growth, and the melatonin levels in the saliva of six participants increased over two times than the initial level. In scene B, before and after the experiment, the melatonin levels in the saliva of the participants either increased or decreased, while the variation range was small.

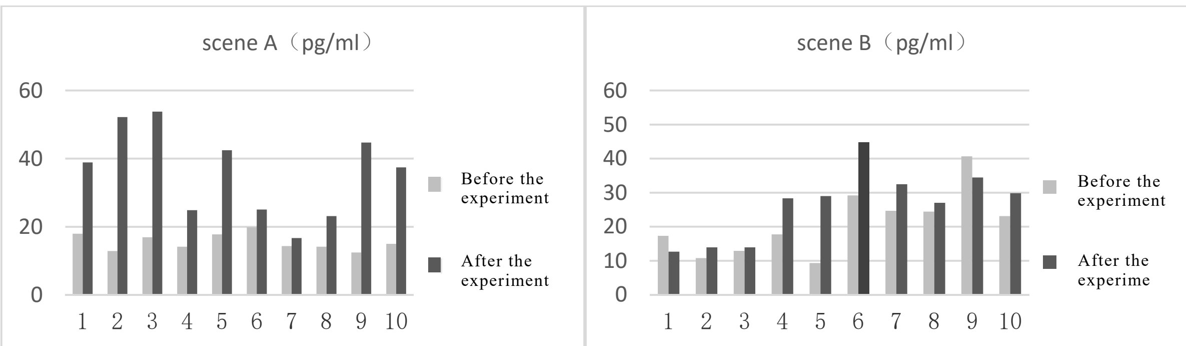


Figure 6 – Comparison of melatonin in saliva before and after the two lighting environment

3.2 Alertness

There was no significant difference in the values of alertness in the A and B scenes (p=0.722>0.1). The average values of the alertness in the two scenes were relatively close, and the value of the B scene was slightly higher than the A scene's, but the alertness values in the two scenes were all below 0 (neither alert nor sleepy). In general, artificial light illumination scenes without natural light were not conducive to the alertness of office workers.

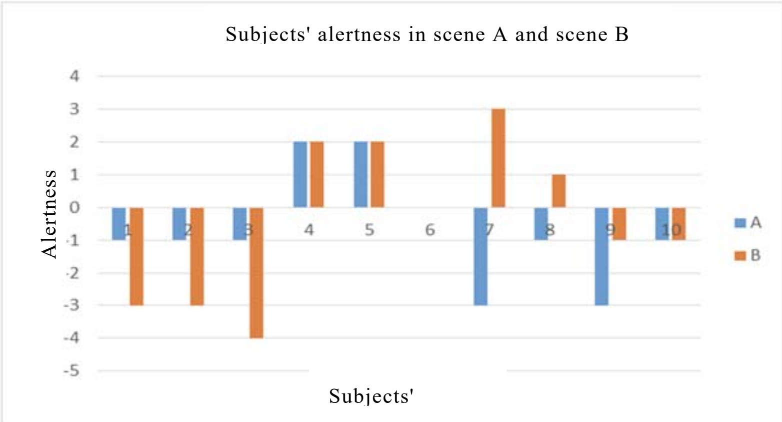


Figure 7 – Subjects' alertness in scene A and scene B

3.3 Visual performance

Landau Ring Recognition Test was used to evaluate the visual performance in this experiment. During the test, reaction time and accuracy were taken as statistical indexes of paired-samples t test. The statistical results are shown in Table 2 and Table 3.

Table 2 – Paired sample T test of reaction time for visual performance in Scene A and Scene B

statistics of paired sample	mean(unit:s)	N	standard deviation				
A	173.5556	9	42.24367				
B	181.0000	9	67.71447				
verification of paired samples	mean	standard deviation	95% confidence interval		T	df	significance test of Two-tailed
			lower limit	upper limit			
A-B	-7.4444	15.5716	-43.352	28.4637	-0.478	8	0.645

Table 3 – Paired sample T test of accuracy rate for visual performance in Scene A and Scene B

statistics of paired sample	mean(unit:s)	N	standard deviation				
A	0.9805	10	0.02110				
B	0.9748	10	0.02800				
verification of paired samples	mean	standard deviation	95% confidence interval		T	df	significance test of Two-tailed
			lower limit	upper limit			
A-B	0.00565	0.02713	-0.0137	0.02506	0.659	9	0.527

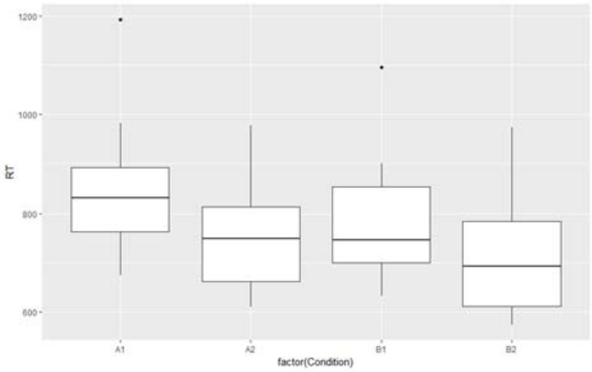
3.4 Behaviouristics

The Behavioural test was divided into GO/NOGO paradigm and Stroop paradigm for analysis. The collected data of reaction time and accuracy were analysed by R programming language.

A total of four tests were conducted for the same participants in the GO/NOGO paradigm, including two tests in scene A and two tests in scene B. In the data analysis, the before-and-after comparison of scene A, the before-and-after comparison of scene B, the first mutual comparison of scene A and B and the second mutual comparison of scene A and B are statistically analysed. The comparative analysis method adopted the paired sample t test.

The results showed that the reaction time of most participants in the second test (A2) in scene A was shorter than that in the first test (A1). Paired sample t test was performed on the mean of the two reaction times of each participant, and the results showed that the reaction time of A2 was significantly less than that of A1 ($p=0.035<0.05$). In scene B, there was no significant change trend in the two reaction durations, and there was no significant difference in paired-samples t test. There was no significant difference in the accuracy of the two GO/NOGO tests before and after scene A and B. It can be seen from the comparison of the average accuracy rate that the accuracy rate of scene A is basically unchanged, while that of scene B is significantly reduced in the second test.

A total of four Stroop paradigm tests were performed on the same participant, twice in scene A and twice in scene B. The "consistent" situation of the same text and colour was compared with the "inconsistent" situation of different text and colour. The results show that the mean reaction time of the second test is shorter than that of the first test in both scene A and scene B. The comparison between scene A and B showed that the mean value of the two reaction times of scene B under the condition of "inconsistency" was significantly shorter than that of scene A, while the mean value of the first reaction times of scene B under the condition of "consistency" was also significantly shorter than that of scene A, and the second difference is not significant. The accuracy of the four tests did not show a significant difference.



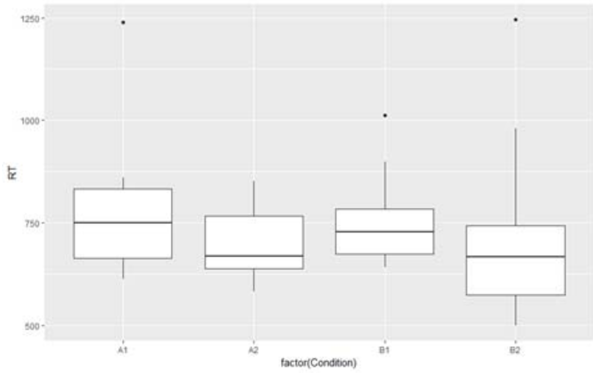


Figure 8 – RT statistical analysis of the "inconsistent" situation of the Stroop paradigm

Figure 9 – RT statistical analysis of the "consistency" Stroop paradigm

3.5 EEG

The EEG data recorded in this experiment was resting-state EEG, which was recorded for 3 minutes respectively when eyes were open and eyes were closed. A total of 3 times were recorded in each scene. From the analysis of the whole electrode average of the participants in the open-eye state and the closed-eye state, the whole process of the three-time measurement of the two-light scene was close in the power density of α、β、θ and δ wave bands, and no significant difference trend was observed. In scene B, Fz electrode data related to the forebrain part showed that in the open-eye state, the power density of θ band decreased as the time of illumination increased. In the closed state, the power density of α, β, and θ were increased compared with that in the state of no light stimulation. Significant differences were observed in the EEG signals collected by Cz and Pz electrodes with and without light stimulation.

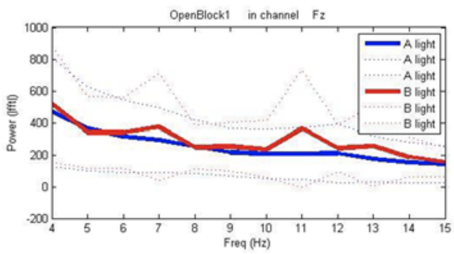
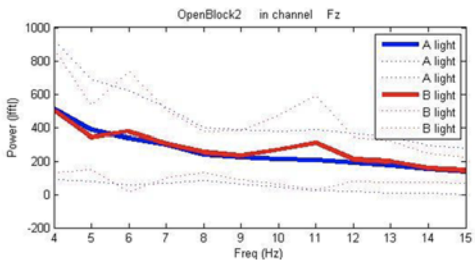


Fig 10 – First resting-state EEG frequency domain analysis in the open-eye state



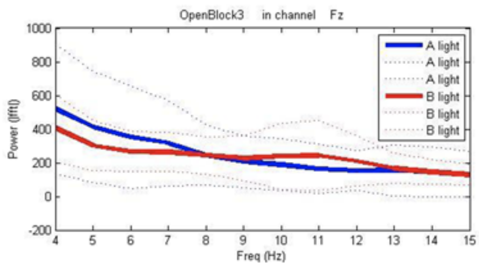


Figure 11 – Second resting-state EEG frequency domain analysis in the open-eye state

Figure 12 – Third resting-state EEG frequency analysis in the open-eye state

4 Discussion

Melatonin secretion is an iconic physiological index of human rhythm. The results of this experiment showed that in scene A, the MLT secretion of the 10 participants exhibited a significant upward trend from 9:00 to 11:00. This result is contrary to the typical rhythm trend of MLT secretion. Scene A (4000K, 300 lx vs.) meets the existing national standard illumination level requirements and ensures the visual demand. However, the results of melatonin test showed that the artificial lighting level was far from enough to stimulate the rhythm of human beings. If office workers are in such low-light-level space for a long time during the day, especially in the morning, melatonin cannot be fully inhibited during the day, which will also affect the secretion of melatonin at night. In the long term, this will lead to the disorder of melatonin secretion and directly affect the rhythmic health.

After the paired sample t-test analysis of the Melatonin content difference before and after the experiment in scene A and scene B, the results showed that the difference of melatonin content in human body before and after the experiment in two lighting scenes presented a significant change trend ($p=0.031<0.05$). This indicates that the rhythm stimulation of 1000lx, 17000K blue-rich white light added in scene B played a certain role in the secretion of melatonin. However, although the increase in melatonin was inhibited, the secretion of melatonin in 8 participants showed an upward trend. This may indicate that the rhythm stimulation used in the experiment has not fully acted on the rhythm system.

In addition, many previous studies showed that the participants' awakening degree is significantly increased under the irradiation of blue-rich white light. However, the alertness in this experimental questionnaire was not significantly correlated with the reported results in scene A and B. This may be because the rhythm stimulation of blue-rich white light in scene B failed to inhibit the secretion of melatonin of the participants, leading to no significant difference. However, the detection of resting-state EEG showed that the forebrain region affected by the light stimulation was corresponding to the Fz electrode, and the power density of the θ wave gradually decreased with the extension of the illumination time in the open-eye state of the scene B. It is generally believed that the appearance of θ wave indicates the cerebral cortex is in a state of inhibition, and this wave occurs when an adult is sleepy. Therefore, the results indicate that the rhythm illumination stimulation of blue-rich white light has a certain effect on inhibiting brain drowsiness. But it may require more targeted experimental research about why the subjective feelings of the participants did not reflect the differences.

Table 4 – The t-test of melatonin in saliva before and after the two lighting environment

statistics of paired sample	mean(unit:s)	N	standard deviation				
A	20.3617	10	13.22385				
B	5.6292	10	8.22020				
verification of paired samples	mean	standard deviation	95% confidence interval		T	df	significance P test of Two-tailed
			lower limit	upper limit			
A-B	14.73250	18.25291	1.67515	27.78985	2.552	9	0.031

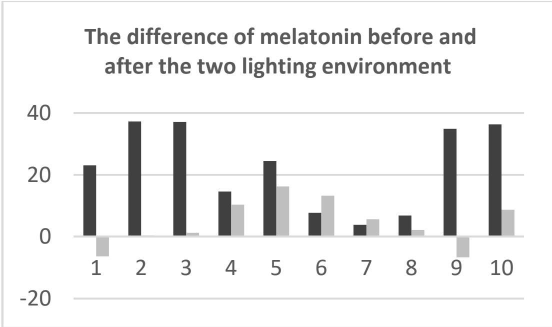


Figure 13 – The difference of melatonin before and after the two lighting environment

In terms of visual performance and cognitive behaviour, scene A and scene B in this experiment do not fully conform to the results of the hypothesis, which is through rhythmic stimulation to improve alertness and excitement, promote visual performance and enhance cognitive efficacy. The results showed no significant difference in reaction time and accuracy. In the comparison of the mean values of the identification time, the reaction time under scene B is slightly higher, while the visual recognition accuracy rate is slightly lower. Considering the evaluation results of satisfaction and subjective feelings about light environment in the participants' questionnaires, the overall satisfaction of scene B is lower than that of scene A, while the dazzling evaluation is higher. In scene B, the background brightness of the participants' work is too high due to the stimulation of high illumination rhythmic illumination, which has a certain negative impact on visual recognition, increases visual fatigue, and leads to a decrease in efficacy. In cognitive behavioural tests, both GO/NOGO and Stroop paradigm failed to show significant differences on accuracy in the effects of light stimulation on scene A and scene B. In terms of reaction time, due to the practice effect, the second test of GO/NOGO in scene A is significantly shorter than the first test and shows a significant correlation. However, in the scene B, there is no shortening trend and the average of the reaction time is relatively long. But in the Stroop paradigm test, the average response time before and after in the scene B is shorter than that in the scene A. Compared with GO/NOGO, Stroop paradigm is more difficult to be recognized, so rhythmic illumination stimulation may have a more significant promoting effect on the task with higher cognitive requirements. But due to the limited number of participants in this study and the limited types of cognitive paradigm, this conclusion still needs to be explored by follow-up targeted studies. Visual and cognitive tests show that visual comfort has a significant effect on office workers' human factor efficacy, and visual effect may have a greater effect on the office workers' visual performance than circadian effect in a short time. Uncomfortable-visual lighting environment also has a significant negative impact on the office workers' cognitive behaviour. Therefore, in the future studies on healthy office lighting, how to use artificial lighting to achieve high-intensity rhythmic lighting in the daily work space while ensuring visual comfort and reducing visual fatigue will be the research focus and difficulty in the application level.

5 Conclusion

Office workers spend a lot of time in the office space during the day, so indoor illumination level plays an important role in the rhythm of health. Artificial light can also be used as a source of rhythmic stimulation. In this study, participants were given circadian stimulation by high-intensity of blue-rich white light (1000 lx at eye level, mixed colour temperature about 12000K) in daily working space and working condition, and the hypothesis is circadian lighting would inhibit melatonin and improve their alertness and cognitive ability. However, the experiment showed that photobiology effect of the artificial circadian lighting is limited in the spaces without natural light, and high intensity illumination for a long time will aggravate human visual fatigue to some extent, which has certain adverse effect on visual performance. Therefore, after sufficient theoretical research has been carried out, how to apply the results in office lighting design and provides full circadian light stimulate while ensuring visual performance and comfort should be explored in the future.

References

Aries, M. B. C. 2005. Human lighting demands: Healthy lighting in an office environment.

Boubekri, M., Cheung, I. N., Reid, K. J., Wang, C. H., & Zee, P. C. 2014. Impact of windows and daylight exposure on overall health and sleep quality of office workers: a case-control pilot study. *Journal of clinical sleep medicine*, *10*(06), 603-611.

Figueiro, M. G., & Rea, M. S. 2016. Office lighting and personal light exposures in two seasons: Impact on sleep and mood. *Lighting Research & Technology*, *48*(3), 352-364.

Hubalek, S., Brink, M., & Schierz, C. 2010. Office workers' daily exposure to light and its influence on sleep quality and mood. *Lighting research & technology*, *42*(1), 33-50.

Lin, Y., Liu, C., Fu, M.Q., Dong, Y.J.. 2016. Sleep Quality, Arousal and the Distance to Window in Offices — A Field Survey Study of Office Lighting in The High-Density Urban Areas. *China Illuminating Engineering Journal*, (2016. 05), 32-37.

Mooreede, B. M. C., Sulzman, F. M., & Fuller, C. A. 1982. The clocks that time us: physiology of the circadian timing system. *Quarterly Review of Biology, 44*(2), 33-33. 2

Partonen, T., & Lönnqvist, J. 2000. Bright light improves vitality and alleviates distress in healthy people. *Journal of Affective disorders*, *57*(1-3), 55-61.

Rea, M. S., Bierman, A., Figueiro, M. G., & Bullough, J. D.. 2008. A new approach to understanding the impact of circadian disruption on human health. *Journal of Circadian Rhythms*.