An Experimental Study on Evaluating Glare in Blue Light Exposure

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Abstract. It is known that blue light exposure to the eyes improves our arousal level. It is expected that exposure of office workers to blue light can maintain their concentration on their intellectual work and it may improve efficiency of their work. When blue light is exposed enough to improve arousal, however, it may cause feeling of dazzling and disturb their concentration on the contrary. In this study, therefore, an experiment was conducted to reveal the condition where they don't feel dazzling and their concentration is not disturbed, when changing the luminance and luminous area of blue light source. The participants performed cognitive tasks where blue light source was placed on their desks under one of four blue light conditions. As the result, it was found that the reasons why participants felt dazzling are asymmetrical intense light exposure and large luminous area.

Keywords: Blue light · Intellectual concentration · Melanopsin cells · Glare

1 Introduction

In recent years, they made efforts to improve intellectual productivity by improving the office environment. Many research studies on how to improve intellectual productivity in office work have been found [1][2]. For example, the studies focusing on the relationship between office room light and intellectual productivity have been made to propose lighting environments aiming at improving intellectual productivity [3]. On the other hand, some studies have revealed that blue light exposure improves human arousal [4]. The authors, therefore, have assumed that improvement of arousal by blue light exposure leads to an improvement of arousal and intellectual concentration, and an experiment was conducted to evaluate the intellectual concentration improvement effect by blue light exposure [5]. However, when exposing the blue light enough to improve arousal, the feeling of dazzling by the strong blue light sometimes disturb intellectual concentration. In order to reduce the glare and maintain the arousal enhancement effect by blue light exposure at the same time, it may be effective to increase the light emitting area and decrease the luminance in order to keep the total amount of blue light. In this study, therefore, an experiment was conducted to find the conditions that

don't make them feel dazzling and disturb intellectual work with changing the luminance and the light emission area of blue light without changing the total amount of blue light to be exposed.

2 Proposal of Blue Light Exposure to Improve Intellectual Concentration

2.1 Principle of intellectual concentration improvement by blue light exposure

It had been supposed that there were two types of photoreceptors in the human retina which were rod cells and pyramidal cells. In recent years photoreceptors called melanopsin cells have been discovered as the third photoreceptor [6]. The spectral sensitivity of the melanopsin cells is shown in Fig. 1. As shown in Fig. 1, they have spectral sensitivity peaks around the wavelength of 480 nm, that is, near the blue light wavelength. Therefore, melanopsin cells are thought to have a strong response to stimulation of blue light.

In addition, it has been proved that stimulated melanopsin cells improve human arousal [4]. The results of the study suggest that when blue light is projected on the retina, the melanopsin cells are stimulated and arousal is improved. Taking into consideration that arousal is a state in which the brain actively works, it is expected to improve concentration of intellectual work when the arousal is improved. Based on the above, the authors have assumed that exposure to blue light improves arousal, and intellectual concentration is improved as a result.

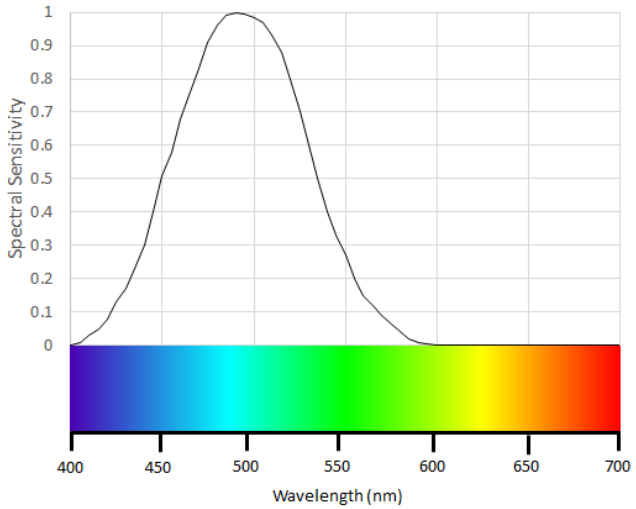

Fig. 1. Spectral Sensitivity of Melanopsin Cells and Wavelength of Color.

2.2 Design of blue light source

A blue light source was designed which dimensions are a width of 95 mm, a height of 200 mm, and a depth of 100 mm for easy installation for practical desk work. The shape of light emitting surface was a rectangle with a length of 145 mm and a width of 80 mm. Regarding the intensity of blue light, based on the spectral sensitivity of the melanopsin cell shown in Fig. 1, the intensity of the blue LED was determined so as to be equivalent to the stimulus that they receive as the same amount for white light with illuminance 3000 lx and color temperature 5000 K. According to Weber-Fechner's law, human being perceives an external stimulus with a sensory quantity proportional to the logarithm of the intensity of the stimulus. Therefore, by setting the light conditions that increase the luminance exponentially, it is considered that the difference in brightness perceived under each light condition is constant. Base on the above consideration, the luminance of the blue light was designed so that the output can be changed in four stages of 100%, 50%, 25%, and 12.5% with the luminance of the standard output. As the light conditions, 1 unit luminance 100% output, 2 units luminance 50% output, 4 units luminance 25% output and 8 units luminance 12.5% output were set in order to

keep total amount of blue light exposure. In the light condition of 1 unit luminance 100% output, the light source was placed diagonally on the left of users as shown in Fig. 2(a). Under other light conditions, they were placed symmetrically on the left and right front of users as shown in Fig. 2 (b)(c)(d).

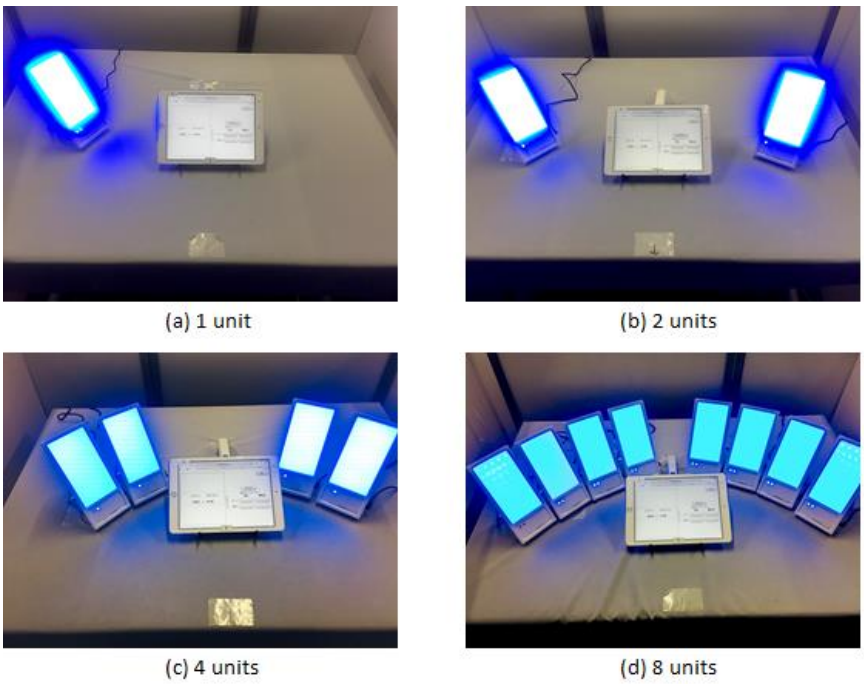

Fig. 2. Placement of blue light sources under each condition.

3 Glare Evaluation Experiment

3.1 Purpose and outline of experiment

The purpose of this experiment is to investigate which blue light condition does not cause feeling of dazzling or disturb intellectual concentration. The experiment was conducted in the environmental control laboratory in Kyoto University from November 22nd to 26th in 2018. As the experimental conditions, the four light conditions as shown in Fig. 2 were set and each participant performed a cognitive task called 'comparison task' under the light conditions in random order. At the end of the task under each condition, a glare questionnaire was conducted to subjectively evaluate the glare, and another questionnaire was conducted to subjectively evaluate their fatigue, arousal and concentration. At the end of the experiment, a final questionnaire was conducted to investigate which light condition was distractive while doing tasks and which light conditions was not acceptable for work.

3.2 Methods

As an intellectual task to measure the subjective evaluation of glare, a comparison task which requires language processing ability and numerical processing ability often employed in actual office work was assigned to the participants. The screen of the task is shown in Fig. 3. The comparison task is a cognitive task that simultaneously compares the meaning categories of the two words and compares two numbers displayed on iPad. In the word comparison, two words belonging to one of the four categories of (i)place name, (ii)artifact, (iii)animal and (iv)plant are displayed, and they have to judge whether those words belong to the same category or not. On the other hand, in numeric comparison, two of four-digit numbers are displayed with an inequality sign and they have to judge whether the inequality is correct or not. When they tap the button corresponding to the combination of these two comparison answers, the next question is displayed. The participants were asked to solve it one after another until the task time was over.

The environmental conditions of the experimental room are shown in Table 1. The temperature and humidity were kept constant by using air conditioning equipment and 4 circulators. The ventilation was also controlled in order to keep the carbon dioxide concentration under 1200 ppm.

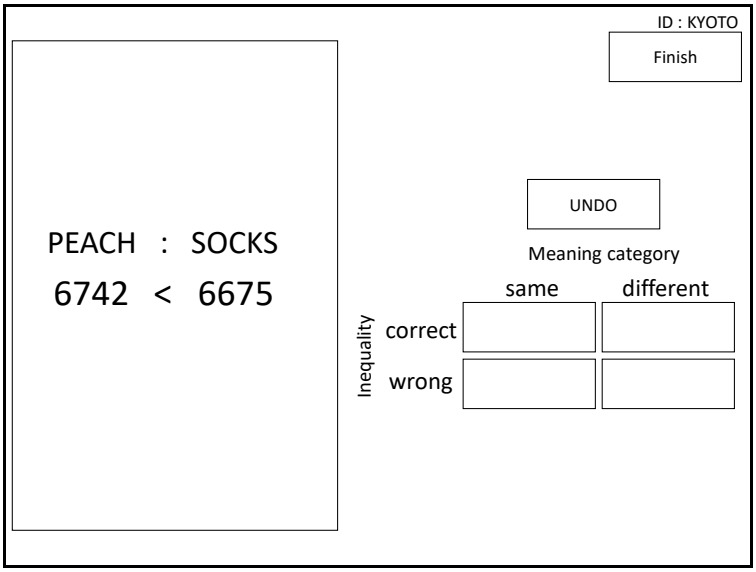

Fig. 3. Screen of Comparison Task.

Table 1. Environmental Conditions of Experimental Room

Environmental factor	Value
Temperature	23.5±0.5℃
Humidity	35±5%
CO_2 concentration	Under 1200ppm
Desk surface illuminance	650±50lx

The experiment schedule is shown in Fig. 4. 5-minute practice SET was prepared for the participants to become accustomed to the comparison task. While practicing it they experienced all the blue light conditions in the order from low luminance to high luminance for about 1 minute each. At the end of each task SET, they answered the regular questionnaire and the glare questionnaire. After completing all the task SETs, they experienced all the light conditions again and answered the final questionnaire. Since there were four types of blue light conditions, the order of the blue light conditions in each SET was exchanged depending on the participants in order to take the counterbalance of the order effect of the conditions.

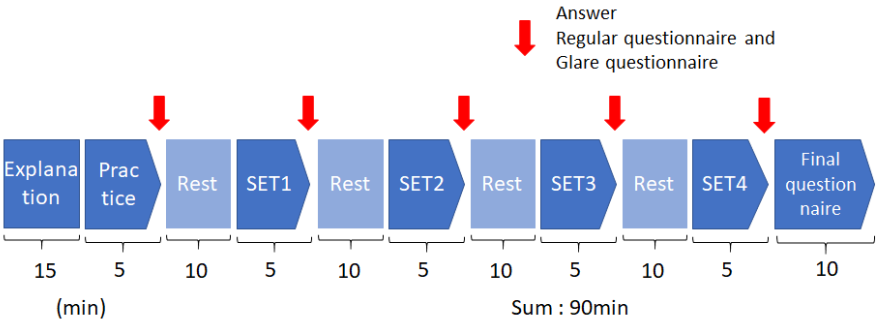

Fig. 4. Schedule of Experiment.

As an evaluation index, subjective dazzling was measured using the glare questionnaire. Subjective fatigue, subjective arousal, degree of concentration were also measured using the regular questionnaire to check whether there was any physical influence under each light condition. The glare questionnaire asked subjective dazzling of each blue light condition with 9 grades referring to BGI (British Daylight Glare Index). The grades were "1: Imperceptive, 3: Perceptible but not unacceptable, 5: Unacceptable but not uncomfortable, 7: Uncomfortable but not intolerable, 9: Intolerable". The regular questionnaire asked subjective fatigue, refreshment of brain and concentration with a numerical value from 0 to 100 after each task SET.

At the end of the experiment, they experienced all the blue light conditions again and then answered the final questionnaire. It asked them which light conditions were distractive while doing the task and were not acceptable with free description of their reasons.

The participants were 25 university students of Kyoto University. They are healthy males of the ages from 19 to 26, with normal eye sight.

3.3 Results

Fig. 5 shows the results the average answers of the glare questionnaire depending on the task SETs and the blue light conditions. Regarding to the task SETs, the subjective dazzling of the task SET 1 was the most, while it was reduced from SET 1 to SET 3. In the last SET, it increased again. Regarding the blue light conditions, on the other hand, the feeling of dazzling under the condition of 1 unit luminance 100% output was the most, while the least was that under the condition of 2 units luminance 50% output. Those under other two conditions of 4 units luminance 25% output and 8 units luminance 12.5% output were almost the same.

Regarding the regular questionnaire, no significant difference was found in all the items between the task SETs and the blue light conditions

Table 2. shows the answers of the final questionnaire and the summary of the reasons for the response. Regarding "Which light conditions are distractive while doing the task", the number of participants who selected the light condition of 1 unit luminance 100% output was the most, and as the number of units increased, the number of answers decrease. According to the free descriptions following this question, there were many opinions that they felt dazzling under the light condition of 1 unit luminance 100%

output because intense light was exposed asymmetrically only from their left side. As for "Which light conditions are unacceptable for work," the answer of the light condition with 1 unit luminance 100% output was the most, and the light condition with 8 luminance 12.5% output was the second . As for the reason why the light condition of 1 unit luminance 100% output is intolerable, many opinions were obtained as the same as the above. On the other hand, the reason why the light condition of 8 units luminance 12.5% output was not acceptable neither was mainly because the light emitting area was large and it made them feel dazzling. The number of participants who answered the light condition of 2 units luminance 50% output was intolerable was the least among all the light conditions.

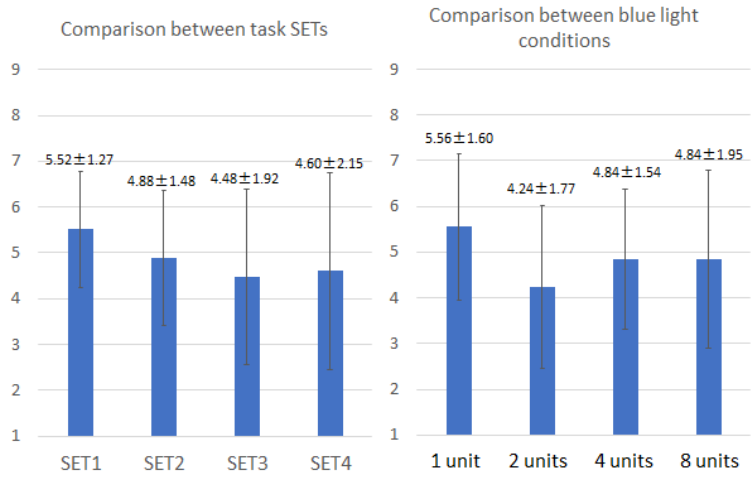

Fig. 5. Result of Glare Questionnaire.

Table 2. Answer of Final Questionnaire

Distractive				Intolerable				The summary of description answer
1	2	4	8	1	2	4	8	←the number of units
	✓	✓	✓			✓	✓	2, 4 and 8 units conditions are bright with a lot of light
✓	✓			✓				Light in 1 or 2 units conditions are strong and the light condition of 8 units is bright with lots of light
✓								All light conditions acceptable but 1 unit is uncomfortable
✓								All light conditions acceptable but 1 unit is uncomfortable
		✓				✓		Light in 4 units condition is strong
✓	✓				✓			1 unit condition is dazzle because strong light comes from only one side
								All the light conditions acceptable
✓				✓				1 unit condition is distractive because light comes from only one side
✓			✓	✓			✓	The amount of light in 8 units condition is too much and 1 unit condition is strongly bright with only one point of sight
	✓				✓			1 unit condition has an intense light, and 8 units are uncomfortable because the light emitting area is large.
✓			✓	✓				1 unit condition has light from one side, 8 units condition has large emission area, so both are uncomfortable
✓	✓			✓				1 unit condition has light from one side and the balance is bad
✓	✓			✓				1 unit condition has light from one side, and 8 units have large light emitting area, so both are uncomfortable
	✓	✓	✓			✓	✓	I cannot concentrate because they are hit by light from both sides in 2, 4 and 8 units conditions
✓				✓		✓		1 unit condition has intense light from one side, so it is uncomfortable
✓				✓		✓	✓	1 unit condition has light from one side, and 4 and 8 units have large light emitting area, so they are uncomfortable
		✓	✓			✓	✓	4 and 8 units conditions are dazzled and distractive
✓	✓							1 and 2 units conditions are distractive because they have locally blue light
		✓	✓				✓	I feel that 8 units condition is bad for the eyes, I don't want to work for a long time
✓		✓	✓	✓			✓	1 unit condition is intolerable because it has light from one side
	✓			✓				1 unit condition has is the most dazzling
✓	✓				✓			1 and 2 units conditions have intense light, so they are distractive
✓		✓						1 and 4 units conditions are more dazzling than others
✓		✓	✓	✓			✓	I'm not usually exposed to blue light, so it is uncomfortable
✓								1 unit condition is distractive because light is coming from one side
17	10	8	8	11	3	6	8	←the number of answers

3.4 Discussions

Regarding the glare questionnaire, the answer of SET 1 obtained the most between the task SETs The participants experienced the blue light exposure only for the last 5 minutes of the practice SET, and it was supposed that they were not yet accustomed to the blue light and they felt excessively dazzling in SET 1. In comparison between the blue light conditions, a large difference was found between the light condition of 1 unit luminance 100% output and that of 2 units luminance 50% output.

Regarding the regular questionnaire, no significant difference was found in the influence on fatigue, refreshment of brain and concentration between the blue light conditions.

Regarding the final questionnaire, there were the most participants who answered that 1 unit luminance 100% output was intolerable and the least who answered that 2 units luminance 50% output. This result was consistent with the result of the glare questionnaire. The reasons why they answered "It is distractive while doing tasks" or "It is not acceptable for work" under the light condition of 1 unit luminance 100% output are that the blue light was exposed asymmetrically from only their left side and it was intense. In addition, regarding the light condition of 8 units luminance 12.5% output, many opinions were found that large light emitting area was uncomfortable.

Based on the above results of the glare questionnaire and the final questionnaire, in order not to disturb the intellectual work in the blue light exposure with keeping the effect of arousal enhancement, it is necessary to symmetrically irradiate blue light of low luminance from both sides of the field of view and to reduce the light emitting area. If the luminance or the light emission area is reduced to suppress the glare, the effect of arousal enhancement by the blue light exposure may be diminished. In order to realize a blue light exposure environment for intellectual concentration improvement, therefore, it is necessary to balance the luminance and light emission area to an appropriate value within a range obtaining the effect of arousal enhancement without causing dazzling.

4 Conclusion

In this study, the authors conducted an experiment to measure the subjective evaluation of glare to find what kind of blue light condition did not cause feeling of dazzling and disturb intellectual work. As the result, three factors of luminance, light emitting area, and asymmetric irradiation of light were found as the factors that caused feeling of dazzling. In other words, they feel dazzling when the luminance was high, the emission area was large, or when the light emitted asymmetrically. Therefore, it is supposed that the blue light exposure that does not disturb the intellectual work and improve arousal is that the luminance is low to some extent, the emission area is small, and the light is exposed symmetrically. In the future, with reference to this experimental result, it is necessary to conduct another experiment to confirm that an appropriate blue light exposure can improve intellectual concentration with the effect of arousal enhancement.

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