Effect of Blue Light–Reducing Eye Glasses on Critical Flicker Frequency

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Purpose: This study aims to evaluate the effect of blocking short-wavelength light on critical flicker frequency (CFF).

Design: This is a prospective clinical study.

Methods: Thirty-three participants (17 men and 16 women; age range, 28–39 years) were divided into 3 groups. Each group wore 1 of 3 types of lenses while performing an intensive computer task for 2 hours. To evaluate the effect of blocking short-wavelength light before and after the task, we measured the CFF and evaluated subjective questionnaires. We used the analysis of variance test to examine whether the type of lenses tested affected any of the visual fatigue-related parameters.

Results: The type of lens worn significantly affected the CFF; however, answers to the subjective questionnaires did not differ significantly between the groups. Two of the 13 question items showed a statistical difference between lens transparency and increase in the CFF (lens 3 > lens 2 > lens 1).

Conclusions: The higher the blocking effect of the lens, the lower the reduction in the CFF, suggesting that blocking short-wavelength light can reduce eye fatigue.

Key Words: eye fatigue, blue light, VDT, CVS, critical flicker frequency

In association with advances in computer technology, human reliance on computers to execute work-related tasks has increased immensely.1 In the past, these tasks were performed via a man-machine interface using traditional hardware equipment such as meters, dials, and monochrome televisions. However, since computers have replaced the man-machine interface, the scope of these work-related tasks and the time taken to perform them has changed, and newer-generation monitors are being employed for mainstream use. Notably, the use of computers at work has been found to contribute to occupational stress.2 As one would expect, visual and musculoskeletal disorders are highly prevalent in visual display terminal (VDT) users.3–5

Computer vision syndrome (CVS) refers to a complex of eye and vision conditions related to the use of computers. Computer vision syndrome is characterized by visual symptoms caused by exposure to VDTs or their environment. Most studies indicate that visual symptoms occur in 50% to 90% of VDT users. One study conducted by the National Institute of Occupational Safety and Health showed that 22% of VDT users have musculoskeletal disorders. Vision problems are currently pervasive among computer workers and are the primary source of worker discomfort and decreased work performance.6

Currently, a majority of computer screens are liquid crystal displays (LCDs). Liquid crystal displays emit more blue light than the previous-generation cathode ray tubes. In addition, we are surrounded by more fluorescent light and light-emitting diodes than before. These lighting instruments also emit more short-wavelength light than the incandescent lamps used previously.

Compared with green light of the same intensity, blue light has been shown to have a greater effect on various physiological factors such as melatonin suppression, alertness, thermoregulation, heart rate, cognitive performance, and electroencephalographic dynamics.7,8 Blue light is considered to be 1 of the causes of eye strain.9

Retinal rod and cone photoreceptors transmit conscious visual information through retinal ganglion cells and lateral geniculate nuclei to the visual cortex. For more than 100 years, those who used these lights have often found that their sense of brightness does not match the values measured by light meters. Areas lit by lighting that has a bluish tint appear brighter than the same areas lit by lighting with a more orange or reddish tint, even though a light meter may indicate the opposite. The 6 to 7 million cones that mediate the eye’s color sensitivity can be divided into red cones (64%), green cones (32%), and blue cones (2%), based on the measured response curves. However, the blue sensitivity of our final visual perception is at least comparable (and may be even better) to the red and green sensitivities, suggesting the presence of a somewhat selective “blue amplifier” in the visual processing system of the brain.

Furthermore, the light response of the rods peaks sharply in blue light; they respond poorly to red light. Rod sensitivity is shifted toward shorter wavelengths (507 nm) as compared with cone sensitivity.10

In 2002, a subset of retinal ganglion cells (<1% in humans) was found to function as photoreceptors.11 These photosensitive retinal ganglion cells (pRGCs), which express the blue light–sensitive photopigment melanopsin, transmit information via the retinal hypothalamic tract. The cells synapse directly on neurons in the suprachiasmatic nuclei and other nonvisual brain centers.12 Approximately 3000 pRGCs make up a light-sensitive network that spans the retina. Peak absorption by isolated pRGCs and melanopsin is noted at 480 nm.11 Therefore, the nonvisual effects produced through exposure to light are greater when the wavelengths are shorter than when the light is geared toward daytime vision.13 The nonvisual effects associated with pRGCs include physiological responses such as the suppression of melatonin,14 circadian phase shifting,15 the elevation of core body temperature,16 and an increase in heart rate.17 Furthermore, exposure to polychromatic white light elicits behavioral responses including enhanced alertness and performance18–20 and improved brain responses to cognitive tasks, as detected by photon emission tomography21 and..
functional magnetic resonance imaging. These findings show that the visual and nonvisual effects of short-wavelength light may affect eye fatigue.

The flicker fusion threshold is lower for a fatigued observer. Decrease in the critical fusion frequency (CFF) has often been used as an index of central fatigue. The ability to perceive flicker depends strongly on the light intensity and the wavelength of the stimulating light.

In response to this research, several types of computer glasses have been designed to block short-wavelength light, relax ocular muscles, decrease eye strain, enhance contrast, reduce glare, and increase visual endurance and productivity. In this study, we investigated the effect of computer glasses on CFF, as an index of eye fatigue, after brief computer tasks.

MATERIALS AND METHODS

This study included 33 subjects (17 men and 16 women) aged 28 to 39 years. The demographics of the study participants are summarized in Table 1. Each had a corrected visual acuity of 0.7 or better and normal color vision. The study population was divided into 3 groups depending on the type of glasses worn during the study; these are as follows: blue light filtering lenses (lens 1, high blocking rate), blue light filtering lenses (lens 2, low blocking rate), or transparent lenses (lens 3, control). The blue light filtering lenses were cut to filter light with a wavelength of 380 to 500 nm. The lenses were evaluated based on the British Standard Specification for sun glare eye protectors for general use (BS 2724: 1987). The associated data are shown in Table 2 and Figure 1. The protocol for this experimental study was approved by the institutional review board.

The participants worked on the computer for 2 hours, performing tasks that required constant attention, using ChipClick at Minamiaoyama Eye Clinic. Before and after the experimental tasks were conducted, the participants had normal vision and did not wear glasses regularly. They were requested to wear the same glasses that were used for the control group (lens 3) for a 2-week period leading up to the experiment.

Before and after the experimental tasks were conducted, visual fatigue was assessed by calculating the CFF and by evaluating the answers to a questionnaire on visual complaints. The CFF value was measured using a Handy Flicker HF-II (Neitz Instrument, Tokyo, Japan). The mean CFF of 3 trials was recorded.

The 13-item questionnaire is shown in Table 3 (2 items with simple yes or no answers and 11 items with scale-based answers). A 5-point scale was used, with 1 representing "not at all" and 5 representing "yes, very much."

The dependent variables were CFF and scores on the subjective questionnaire. The independent variables were the types of glass lenses. To examine the effects of the independent variables, the data were analyzed using SPSS ver 18 (SPSS Inc, Chicago, Ill). P < 0.05 was considered to indicate statistical significance.

RESULTS

On analyzing the within-group differences in preexperiment and postexperiment CFF results, a statistically significant decrease in CFF was found in the lens 3 (control) group, whereas no significant decreases were observed in the lens 1 and lens 2 groups (Fig. 2).

DISCUSSION

In this study, we focused on the effects of blocking short-wavelength light on CFF, which has been said to be related to eye strain/fatigue. Subjects performed 2-hour tasks on the computer while wearing 1 of the 3 types of lenses. These tasks required continuous attention. The lenses differed primarily in terms of their ability to block short-wavelength light. Various methods have been used to measure eye fatigue, including the CFF, visual acuity, subjective ratings of visual fatigue, accommodation power, pupil diameter, eye movement velocity, and task performance. Among these methods, CFF, visual acuity, and subjective ratings of visual fatigue have been used most extensively for the measurement of visual strain in tasks involving

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### TABLE 1. Demographics of the Study Participants

<table>
<thead>
<tr>
<th>Lens</th>
<th>Age Range, y (Mean ± SD)</th>
<th>Sex, M</th>
<th>Sex, F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lens 1</td>
<td>28–34</td>
<td>31.36 ± 2.01</td>
<td>3</td>
</tr>
<tr>
<td>Lens 2</td>
<td>30–39</td>
<td>33.36 ± 2.23</td>
<td>7</td>
</tr>
<tr>
<td>Lens 3</td>
<td>28–38</td>
<td>34.64 ± 3.32</td>
<td>7</td>
</tr>
</tbody>
</table>

SEX M indicates male; SEX F, female.

### TABLE 2. The Characteristics of the Lenses Used in the Experiments

<table>
<thead>
<tr>
<th>Lens</th>
<th>Blue Range Cut, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lens 1</td>
<td>High blocking</td>
</tr>
<tr>
<td>Lens 2</td>
<td>Low blocking</td>
</tr>
<tr>
<td>Lens 3</td>
<td>Control</td>
</tr>
</tbody>
</table>

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### TABLE 3. Thirteen Questions in the Questionnaire

Yes/No Questions

- Dry eyes
- Irritated eyes
- Scale-based questions (1-5)
- Difficulty in refocusing the eyes
- Polyopia/double vision/blurred vision
- Photophobia (when outdoors)
- Photophobia (when staring at the computer monitor)
- Itchy eyes
- Eye strain/fatigue
- General fatigue
- Mental stress
- Sleepiness when working
- Neck/shoulder/back/waist pain
- Finger pain
FIGURE 1. Lens spectra. The spectra of the lenses were analyzed based on the British Standard Specification for sun glare eye protectors for general use (BS 2724: 1987). The major difference was the cut rate for short-wavelength light. A, lens 1 (high cut rate), (B) lens 2 (low cut rate), and (C) lens 3 (control lens).
VDTs. We therefore chose to examine CFF and subjective questionnaire responses. The results of our study showed that the type of lenses tested affected the CFF (Fig. 2) but not subjective answers to the questionnaire. Nevertheless, the answers to 2 of the 13 items suggested that the cut rate may partly explain the observed reductions in eye fatigue (Fig. 3). Other studies have established that reductions in CFF are positively correlated with the duration of VDT use. In this study, a significant difference was observed in the CFF values measured in the lens 1 and lens 2 groups after 2-hour computer tasks. We found that the greater the reduction in the transmission of short-wavelength light, the lower was the reduction in CFF values.

Numerous studies have reported that good lighting contributes to improved work performance and decreased accident rates. Jusleine et al. also found that increased industrial lighting intensities lead to increased productivity. Bommel et al. showed that increasing the lighting intensity from the minimum 300 to 500 lux leads to an increase of more than 8% in productivity. Offices typically use bright fluorescent lights, light-emitting diode lights, and LCD monitors, which are bright and emit more bluish light than incandescent lamps and cathode ray tubes. On the other hand, bright light has been found to cause ocular discomfort and/or pain. Okamoto et al. identified a novel reflex circuit necessary for bright light to excite nociceptive neurons in the superficial laminae of the trigeminal subnucleus caudalis (Vc/C1). These findings support the hypothesis that bright light activates trigeminal nerve activity through an intraocular mechanism driven by a luminance-responsive circuit and increased parasympathetic outflow to the eye. Viola et al. showed that blue-enriched white lighting in offices has beneficial effects on daytime alertness, performance, mood, and eye strain, as well as on nighttime sleep quality and duration.

The precise effect of wavelength on the judgment of CFF has been a controversial issue for many years. Giorgi performed a systematic investigation in which the intensity of the light source was controlled by means of neutral tint filters and an optical wedge. Eight wavelengths covering most of the visible spectrum were used, and the CFF thresholds were obtained at 7 different luminance levels for each wavelength. On the basis of their results, the authors suggested that the wavelengths at the opposite ends of the spectrum are the ones that show a greater degree of difference. The wavelengths in the middle regions of the spectrum, as a rule, are not significantly different from the extremes or from other wavelengths in the same region. Apparently, the greater separation between the wavelengths is the probability of significance. The flicker instrument we used (Handy Flicker HF-II; Neitz Instrument, Tokyo, Japan) has 3 light sources (yellow, green, and red), and we used the yellow light source, which has been used for fatigue evaluation. The yellow wavelength is not at the extreme end of the visible light spectrum.

This study only recruited participants who worked during normal office hours (8:30 AM to 4:45 PM). In reality, however, many people work overtime under blue-enriched light for a longer duration during the day and even late at night. With regard to age, increased illumination has been shown to improve rest-activity rhythms in the elderly population and in those with dementia. Interestingly, the magnitude of the increase in melatonin secretion in the elderly population paralleled the improvement in sleep.

Exposure to blue-enriched white light may also lead to stronger pupil constriction than would standard white light, which in turn may contribute to the improvements in visual comfort that are noted with blue-enriched white light. However, some researchers suggest that blue-blocking intraocular chromophores do not reduce clinical disability glare because they decrease target luminance in the same proportion as does veiling stray light. Furthermore, they do not significantly improve contrast sensitivity because contrast transfer at mid-to-high
spatial frequencies occurs at wavelengths between 500 and 600 nm, which are essentially unaffected by yellow chromophores.48 In addition, light stimuli around 470 nm are thought to trigger migraines.39

Our study results may make readers think that blue light causes only hazardous effects, but this is not our point. Both basic and clinical investigations suggested that we have to get along with lights properly in terms of quality and quantity. From clinical standpoints, blue light or shorter wavelength light is broadly used in phototherapy for neonatal jaundice, depression, skin problem, depression, sleep problem, and so on.

This study has several limitations such as the small sample size and the low representativeness of the sample, which gives results that may not be representative of the general population. The experimental conditions were very different from the actual working conditions. This study involved 2-hour-long attention-intensive tasks performed using a bright monitor. The demographics of the 3 groups were relatively comparable; however, each participant may have been exposed to a different work environment in his or her daily life. Although a few workers may have been accustomed to severe VDT conditions, others may not have been. In addition, the age range of the workers may have been selected to test for fatigue of the central nervous system.

Therefore, to address these limitations, more data must be accumulated in future studies using a larger, strictly age-matched population under conditions that more closely simulate real life. We performed this study using several glass lenses, but of course, lens change is not the only option for eye strain relief. Eye fatigue is multifactorial and is a part of CVS. This CVS can be reduced by repositioning the monitor (eg, tilt, gaze position); adjusting color, brightness, and contrast; or by using a low-glare monitor/filter, screen hood, and/or lighting reflecting on the monitor.35,54,55

Because many individuals have CVS, the subjective and objective reductions in eyestrain, mental stress, and musculoskeletal pain achieved through the use of light-blocking computer glasses are worth the associated costs.

REFERENCES


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