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Purpose. The purpose of this study was to determine whether subjects who wear short wavelength–blocking eyeglasses during computer tasks exhibit less visual fatigue and report fewer symptoms of visual discomfort than subjects wearing eyeglasses with clear lenses.

Methods. A total of 36 healthy subjects (20 male; 16 female) was randomized to wearing no-block, low-blocking, or high-blocking eyeglasses while performing a 2-hour computer task. A masked grader measured critical flicker fusion frequency (CFF) as a metric of eye fatigue and evaluated symptoms of eye strain with a 15-item questionnaire before and after computer use.

Results. We found that the change in CFF after the computer task was significantly more positive (i.e., less eye fatigue) in the high-block versus the no-block ($P = 0.027$) and low-block ($P = 0.008$) groups. Moreover, random assignment to the high-block group but not to the low-block group predicted a more positive change in CFF (i.e., less eye fatigue) following the computer task (adjusted $\beta = 2.310$; $P = 0.002$). Additionally, subjects wearing high-blocking eyeglasses reported significantly less feeling pain around/inside the eye ($P = 0.0063$), less feeling that the eyes were heavy ($P = 0.0189$), and less feeling that the eyes were itchy ($P = 0.0043$) following the computer task, when compared to subjects not wearing high-blocking lenses.

Conclusions. Our results support the hypothesis that short-wavelength light-blocking eyeglasses may reduce eye strain associated with computer use based on a physiologic correlate of eye fatigue and on subjects' reporting of symptoms typically associated with eye strain.

Keywords: eye fatigue, eye strain, blue light, VDT, CVS

Blue light has the most energy of all light in the visible electromagnetic spectrum. Although there is irradiance of blue light from the sun at the Earth's surface, our society's increasing use of technology has led to a significant increase in daily exposure to this short-wavelength light. For example, the majority of today's computer screens and televisions use liquid crystal displays (LCDs), which emit far more blue light than cathode ray tube (CRT) displays. In addition, the now-popular light-emitting diodes (LEDs) and fluorescent lights also emit more short-wavelength light compared to their incandescent predecessors. Of concern, past studies have reported that short-wavelength light has a greater and often more hazardous effect on human physiology compared to visible light of other wavelengths.[1,2]

Light toxicity to the retina is well established and occurs when excess light exposure causes photochemical, photomechanical, and photothermal damage.[3] Some groups have reported that short-wavelength light may be particularly hazardous to the retina. For example, Kuse et al.[4] found that visible light-induced damage in photoreceptor-derived cells is wavelength-dependent: short-wavelength light in the blue spectrum had a more severe toxic effect compared to either white or green light. These findings are consistent with other studies showing that retinal damage induced by LEDs in animal models show similar wavelength dependence.[5] Other groups have shown that this phototoxicity can be attenuated by blocking blue light in cell models[6] and in animal models.[7] Although human exposure to short-wavelength light generally is chronic and subthreshold rather than acute and suprathreshold, as is typical for most these animal models, these studies implicate short-wavelength light as pathologic. Future studies not only will explore the effects of chronic exposure to blue light but also will identify the characteristics of blue light that yield these toxic effects.

Some human studies have shown that chronic subthreshold exposure to blue light may, indeed, have clinically relevant consequences. For example, although short-wavelength light also has been shown to be important for setting circadian rhythms,[8] excessive exposure to blue light also has been suggested to be a major cause of eye strain.[9] Consistently, Isono et al.[10] reported that short wavelength-emitting devices contribute to visual fatigue. In fact, prolonged use of short-wavelength light-emitting devices can result in a constellation of symptoms, which are now recognized as Visual Display

Table 1. Demographic Information of Study Subjects

Demographic Variable	No Block	Low Block	High Block	*P* Value
Age, mean ± SD	23.25 ± 0.75	24.58 ± 1.38	25.00 ± 2.73	0.012*
Sex, *N*				
Male	9	5	6	0.232†
Female	3	7	6	
Race/ethnicity, *N*				
Caucasian	11	11	11	1.00‡
African-American	0	1	0	
Asian	1	0	1	
Contact lens use, *N*				
Yes	6	5	8	0.458†
No	6	7	4	
Sleep/night, mean ± SD	7.25 ± 0.87	6.96 ± 0.81	7.58 ± 0.79	0.193§
Computer use/wk, mean ± SD	37.58 ± 19.29	40.67 ± 16.88	39.92 ± 14.10	0.897§

N, number of subjects in each category.
* Significant by 1-way ANOVA with Welch correction; Games-Howell post hoc test revealed that the no-block group was significantly different from the low-block group.
† Nonsignificant by the χ^2 test.
‡ Nonsignificant by the Freeman-Halton extension of the Fisher exact test.
§ Nonsignificant by 1-way ANOVA.

Terminal (VDT) Syndrome and Computer Vision Syndrome (CVS). Numerous groups have explored the possibility that lenses that block short-wavelength light may reduce these health hazards. Ayaki et al.[11] demonstrated that wearing short-wavelength light-reducing eyeglasses when using electronic devices at night improves sleep quality and increases overnight melatonin secretion. Similarly, Ide et al.[12] found that wearing short-wavelength light-blocking eyeglasses during intensive computer tasks reduces eye fatigue and symptoms of eye strain.

Nonetheless, no study to our knowledge has tested this question rigorously in a North American population. In this study, we performed a single-center, randomized study to determine whether North American subjects who wear short-wavelength light-blocking eyeglasses during a 2-hour computer task exhibit less visual fatigue and report fewer symptoms of visual discomfort than subjects wearing eyeglasses with clear lenses.

Materials and Methods

Subjects

We recruited 36 subjects at the College of Optometry at University of Missouri–St. Louis. Demographic characteristics are shown in Table 1. All participants gave written informed consent. All procedures conformed to the Declaration of Helsinki and were approved by the Institutional Review Board of University of Missouri–Saint Louis. The inclusion criteria included being a healthy (no known significant health problems) volunteer, being male or female of any ethnic group between 21 and 39 years of age, having uncorrected vision or contact lens–corrected vision of 20/30 or better with both eyes open, not having performed VDT work for at least 1 hour before testing, and not having known visually significant ophthalmic pathology, such as cataracts, macular degeneration, glaucoma, eye surgeries, or injuries based on self-reported history. Subjects were excluded if they were <21 or ≥40 years of age; had uncorrected vision or contact lens–corrected vision worse than 20/30 with both eyes open; self-reported a concurrent eye injury or disease; had photosensitivity, which would preclude them from comfortably performing 2 hours of VDT work; had been diagnosed with epilepsy; or had previously suffered a seizure. We confirmed that all subjects had binocular visual acuity of 20/30 or better with a Snellen chart.

Critical Flicker Fusion Frequency (CFF) Measurements and Eye Strain Questionnaire

The primary outcome measure was the difference between the pre- and posttask CFF, i.e., change in CFF after the task. A reduction in CFF is associated with eye fatigue.[11,13,14] We measured CFF before and after the task with the Handy Flicker HF-II (Neitz Instrument, Tokyo, Japan), which emits a blinking light whose frequency can be varied from 1 to 79 Hz. We measured ascending and descending thresholds and averaged these values to calculate the pre- and posttask CFF for each subject. Study subjects did not wear the eyeglasses during CFF measurements to ensure that the study personnel taking these measurements were not biased by knowledge of group assignment.

Additionally, we evaluated symptoms related to eye strain with a 15-item questionnaire (Appendix A), adapted from a previous study.[12] Subjects reported their responses on a Likert scale (1, never; 2, rarely; 3, cannot say either way; 4, a little; 5, very much) and were permitted to respond with noninteger responses. We calculated the difference between the pre- and posttask responses, such that a positive change in score corresponds with an increase in eye strain, while a negative change in score corresponds with a decrease in eye strain. Although we also included two yes/no questions to assess eye dryness (Question #6) and the sensation of a foreign body in the eye (Question #7), we did not include these questionnaire items in our analysis due to significant nonresponse by the participants on these questions.

Computer Task

Subjects were assigned randomly based on a predetermined schedule to one of the three lens groups: control lenses, low-blocking lenses, and high-blocking lenses. Since the blocking lenses can be identified potentially by their tint/color, the manufacturer packaged the eyeglasses in opaque boxes that

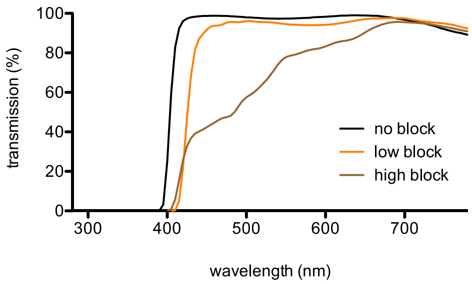

FIGURE 1. Transmission spectra of the no-blocking, low-blocking, and high-blocking lenses as measured according to the EN ISO 12311:2013 and EN ISO 12312:2013 testing standards.

were marked with only a serial number to permit proper randomization. We tested the lenses according to standard EN ISO 12311:2013 and EN ISO 12312:2013: the transmission spectra for each of the three lenses based on these testing standards are shown in Figure 1, and the blue-range cuts are shown in Table 2. Eyeglasses with these particular low- and high-blocking lenses are available commercially from JINS CO., LTD as the JINS Screen Clear and JINS Screen Night models, respectively. Because all study subjects had uncorrected or contact lens-corrected vision of 20/30 or better, the eyeglasses did not correct refractive error. Study subjects were blinded to their group assignments until completion of all data collection.

For the computer task, subjects were instructed to place the glasses over their eyes and to continuously use a laptop computer VDT for 2 hours to view videos or to engage in games. The examination room and testing conditions were standardized for all subjects: the same laptops were used, which all had the same 1366- × 768-pixel screen resolution with a 60 Hz refresh rate; and the ambient room illumination was set at 350 lux. Study personnel monitored subjects to ensure compliance with the protocol and to time each session. We tested all subjects in late morning through early afternoon to minimize confounding effects of the time of day.

Statistics

We used G*Power 3.1[15] to perform an a priori power calculation to determine the appropriate sample size. To detect a significant difference between the groups at the two-sided $\alpha = 0.05$ level with an estimated effect size f of 0.8 based on a previous study[12] and 95% power, we calculated that we needed to recruit 30 subjects. To account for up to 20% drop out, we recruited 36 subjects in total; that is,12 per group. We performed statistics with GraphPad Prism 5.0 (La Jolla, CA, USA) and IBM SPSS Version 18.0 (Armonk, NY, USA). To compare categorical variables, we used the χ^2 test of Independence. For race/ethnicity, we used the Freeman-Halton extension of the Fisher exact test to account for sparse expected cell values. To compare three means, we used the 1-way ANOVA with Tukey HSD post hoc test. To compare the changes in the scores after the task on the questionnaire items, we used the Mann-Whitney *U* test. As needed, we assessed the

TABLE 2. Blue-Range Cut (%) of Lenses Used in This Study as Measured According to the EN ISO 12311:2013 and EN ISO 12312:2013 Testing Standards

Level of Blue Block	Blue-Range Cut (%)
No block	3.2
Low block	24.2
High block	60.0

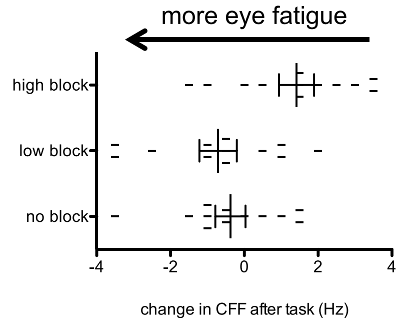

FIGURE 2. Subjects wearing high-blocking eyeglasses had a significantly less negative change in CFF (negative change = more eye fatigue) after the computer task compared to subjects wearing either the no-blocking or low-blocking eyeglasses. *Horizontal tick marks* denote individual data points; *vertical lines* depict group means ± SEM.

normality of the data graphically and with the Kolmogorov-Smirnov test. To determine whether variables significantly differed from 0, we used the 1-sample *t*-test or the 1-sample Wilcoxon signed-rank test. To determine whether wearing low-blocking or high-blocking eyeglasses during the computer task attenuated eye fatigue as measured by the change in CFF after computer use after adjusting for possible confounding variables, we generated a multivariable linear regression model. Our model included forced entry of the following predictor variables: age, sex, contact lens use (dichotomized as yes or no), and lens group assignment (dummy-coded as two dichotomous variables to indicate assignment to one of three groups). We considered $P < 0.05$ to be statistically significant.

RESULTS

There were no differences among the three groups based on sex or race/ethnicity (Table 1). Although subjects were randomized to each lens group, post hoc testing revealed that there was a statistically significant difference between the ages of the subjects randomly assigned to the no-block and low-block groups ($P = 0.024$), but no statistically significant differences in age ($P > 0.05$) between any other pairs of groups (Table 1). Furthermore, there were no differences between the groups with regard to their average number of hours of sleep per night, their average weekly computer use, or whether they wore contact lenses (Table 1).

We calculated the change in CFF after the computer task for each subject by subtracting the pretask CFF from the posttask CFF such that a negative change in CFF corresponds with an increase in eye fatigue. There was a significant difference in the change in CFF after the computer task among the three lens groups ($F_{2,33} = 6.035$, $P = 0.006$). Although there was no difference in the change in CFF between the no- and low-block groups ($P = 0.869$), the change in CFF in the high-block group was significantly less negative than in the no- and low-block groups ($P = 0.027$ and 0.008, respectively; Fig. 2), indicating that the high-blocking eyeglasses indeed attenuated eye fatigue associated with computer use. In fact, our secondary analysis revealed the change in CFF after the computer task was significantly greater than 0 in the high-block group ($t_{11} = 2.976$, $P = 0.013$), suggesting that subjects wearing high-blocking eyeglasses had even less fatigue after compared to before the task. These findings supported our hypothesis that blue-blocking eyeglasses reduced eye fatigue associated with excessive blue light exposure.

Although we randomly assigned subjects to each of the three lens groups, we observed a statistically significant

Table 3. Beta Coefficients From Multivariable Linear Regression With Predictor Variables of Age, Sex, Contact Lens Use, and Lens Group, and the Dependent Variable of Change in CFF Following the Computer Task (More Negative Change in CFF = More Eye Fatigue)

Predictor Variable	Adjusted β	95% CI of β	*P* Value
Age	−0.398	−0.684 to −0.112	0.008
Sex, 1 = female	0.306	−0.759 to 1.370	0.562
Contact lens use	0.607	−0.427 to 1.640	0.240
Lens group			
Low-block	0.145	−1.193 to 1.484	0.826
High-block	2.310	0.959 to 3.661	0.002

difference in baseline CFF when comparing subjects assigned to each of the lens groups ($F_{2,33} = 6.827$, $P = 0.003$): subjects in the high-block group had lower baseline CFF compared to subjects in the low-block group ($P = 0.002$). These findings suggested that confounding variables may affect our results. To adjust our results for potential confounding variables, we generated a multivariable linear regression model to determine whether assignment to the low-block or high-block lens groups was associated with more positive changes in CFF after adjusting for age, sex, and contact lens use. After controlling for these covariates, assignment to the high-block group was still a significant predictor of a more positive change in CFF (adjusted β = 2.310; 95% confidence interval [CI]: 0.959 – 3.661; $P = 0.002$; Table 3). In contrast, assignment to the low-block group was not a significant predictor of the change in CFF (adjusted β = 0.145; 95% CI: –1.193 – 1.484; $P = 0.826$; Table 3). Our final model had an R^2 of 0.457, indicating good explanatory power. Overall, these findings supported our assertion that high-blocking glasses do, indeed, appear to attenuate eye fatigue associated with computer use, even after controlling for confounding variables, such as age, sex, and contact lens use.

Additionally, we collected pre- and posttask information on symptoms of eye strain (Appendix A). Since there was no statistically significant difference between the no- and low-block groups based on CFF changes, we pooled these subjects for further analysis to determine whether the significant change in CFF scores in the high-block group corresponded with improvement of symptoms of eye strain. For each subject, we calculated a change in symptom score by subtracting the pretask symptom score from the posttask symptom score such that a less positive change in symptom score would indicate a reduction of eye strain associated with computer use. Of interest, the high-block group exhibited a significantly more negative change in symptom score on three of the questionnaire items related to pain around or inside the eyes ($U = 70.50$, $P = 0.0063$; Question #11; Fig. 3A), the eyes feeling heavy ($U = 79.50$, $P = 0.0189$; Question #14; Fig. 3B), and the eyes feeling itchy ($U = 66.00$, $P = 0.0043$; Question #15; Fig. 3C). In fact, secondary analysis revealed that the change in score for two of these questionnaire items (Questions #11 and #15) was significantly less than 0 in the high-block group ($P = 0.034$ and 0.006, respectively), suggesting that subjects wearing high-blocking eyeglasses reported less pain around or inside the eye and less feelings of itchy eyes after the task compared to their baseline.

Moreover, although not statistically significant, there were clear trends ($0.05 < P < 0.10$) for three other questionnaire items with the high-block group being associated with a less positive change in score, indicating "less" eye strain, including those related to the eyes feeling tired ($U = 91.50$, $P = 0.0669$; Question #1; Fig. 4A), finding it hard to focus eyesight when doing work at the desk or at the computer ($U = 99.00$, $P = 0.0862$; Question #2; Fig. 4B), and feeling tired when doing work at a desk or at a computer ($U = 97.50$, $P = 0.0656$; Question #5; Fig. 4C). There were no statistically significant differences or trends for the other questionnaire items (Figs. 4D–J). Cumulatively, these findings supported our hypothesis that short wavelength–blocking eyeglasses may reduce specific symptoms of eye strain associated with computer use.

Discussion

The results from our randomized study suggested that high-blocking eyeglasses reduce eye fatigue associated with computer use as measured quantitatively by the change in CFF after the 2-hour computer task. Moreover, subjects wearing high-blocking eyeglasses also reported fewer symptoms associated with eye strain after computer use compared to subjects not wearing the high-blocking eyeglasses. These findings not only validated past studies that have reported that short-wavelength light-blocking eyewear may attenuate eye strain,[11,12] but also extended these findings to a North American population. In addition, although a formal double-blind study design is impossible given the nature of the experiment, our rigorous study design, including careful control of experimental conditions (e.g., monitoring subjects for the duration of the task, standardizing testing room conditions, testing subjects at roughly the same time of day), minimized the risks of potential confounding factors.

We did not find a statistically significant improvement in eye fatigue when comparing the eyeglasses with low-blocking lenses to those with the control lens, despite the fact that our a priori power calculations suggested that our study was

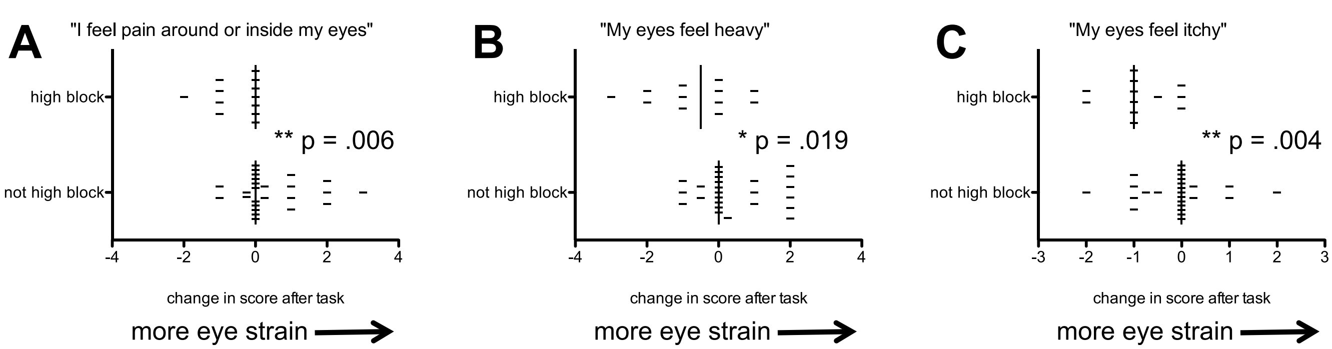

Figure 3. Subjects wearing high-blocking eyeglasses during the computer task had a significantly less positive change in symptom score (positive change = more eye strain) on questions related to pain around or inside the eye (**A**), heaviness of the eyes (**B**), and itchiness of the eyes (**C**), compared to subjects not wearing the high-blocking eyeglasses. *Horizontal tick marks* denote individual data points; *vertical lines* depict group medians (**A–C**).

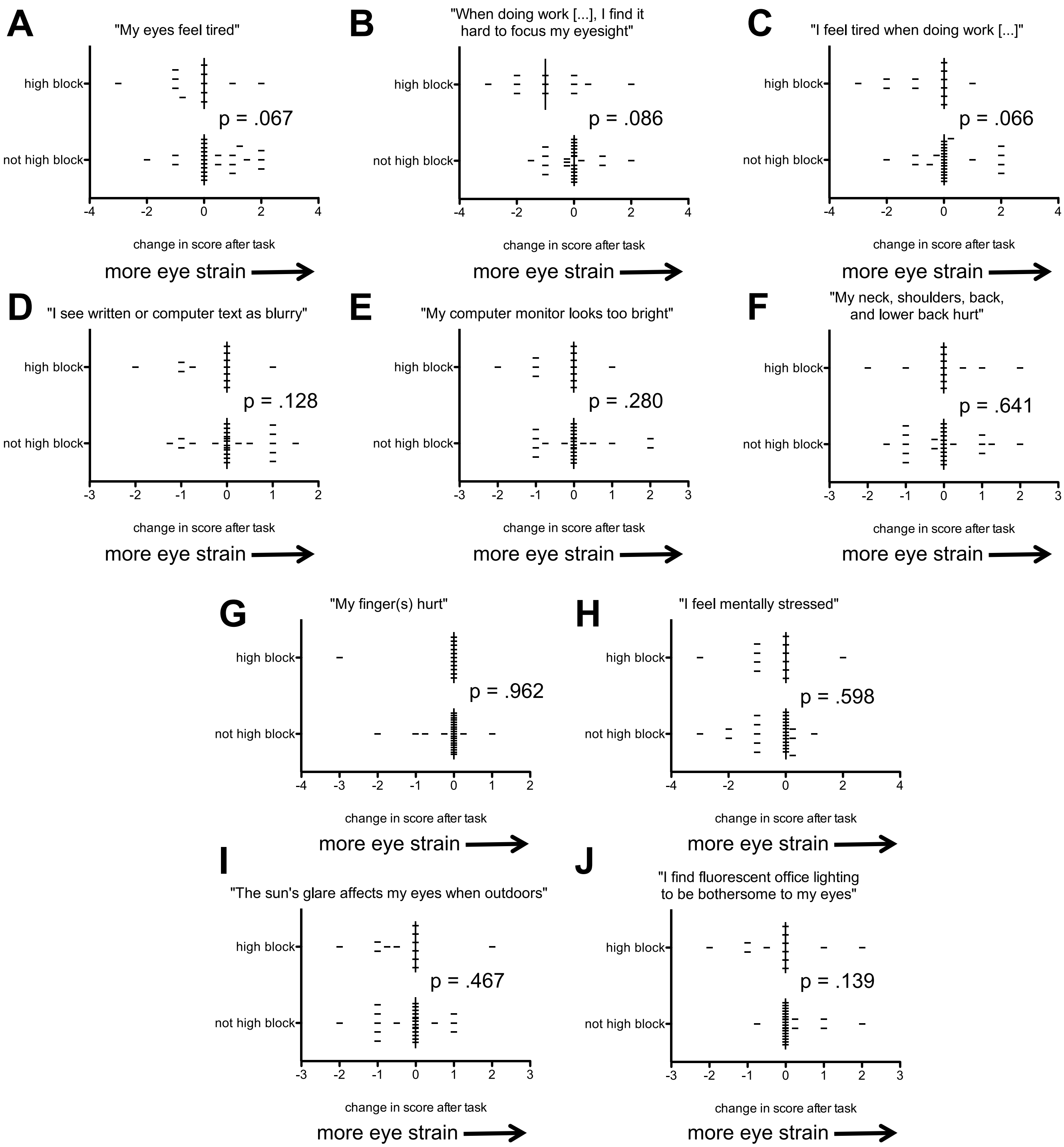

FIGURE 4. There were clear trends ($0.05 < P < 0.10$) with subjects wearing high-blocking eyeglasses having a less positive change in symptom score (positive change = more eye strain) on questions related to tiredness of the eyes (**A**), difficulty focusing eyesight when doing work at a computer or at a desk (**B**), and tiredness when doing work at a computer or at a desk (**C**). (**D–J**) There were no significant differences or trends for the remaining questionnaire items. *Horizontal tick marks* denote individual data points; *vertical lines* depict group medians (**A–J**).

sufficiently powered to detect such a difference if it existed. However, it remains possible that low-blocking lenses have a beneficial effect that would have become apparent if subjects were challenged by a brighter short-wavelength light stimulus or a longer duration of exposure. Further studies are necessary to explore the proper level of short-wavelength light attenuation to minimize the health hazards associated with blue light while permitting sufficient blue light transmission to allow it to perform its normal physiologic functions.

Although study subjects did not wear the eyeglasses during the CFF measurements to ensure study personnel were masked to group assignments, we cannot rule out the possibility that the subjects themselves may have noticed the visual appearance of their glasses. Although the control eyeglasses with the no-block lenses were constructed in a way to make them as similar as possible to the eyeglasses with low- and high-block lenses, the high-blocking lenses have a brown color, and the low-blocking lenses have a subtle blue-light reflection especially when viewed under the light, making it impossible to completely mask the subjects. However, given that the subjects were not provided an opportunity to compare their eyeglasses to those provided to the other groups, it is unlikely that this limitation would have affected our results.

Moreover, although we randomized the subjects to each lens group, we had a serendipitous difference in age in the low-block group compared to the no-block group. In addition, the baseline CFF in the high-block group was lower than that of the low-block group, suggesting that randomization may not have been sufficient to account for all confounding factors. To account for this possibility, we generated a multivariable linear regression model to adjust our results for age, sex, and contact lens use. These adjusted results confirmed our findings by showing that assignment to the high-block group still predicted a more positive change in CFF after the computer task after controlling for these covariates. Nonetheless, future studies with a larger sample size and/or studies using a "within-subjects," repeated-measures study design may be necessary to completely eliminate the possibility that unidentified confounding factors affected our findings.

As with any study of this size, it is difficult to generalize broadly based on our results alone. However, our findings provided a strong foundation for future work more carefully characterizing the benefits associated with short-wavelength light-blocking lenses. Additionally, it will be important to extend these studies to subjects of a greater age range. The aged human lens is known to become less able to transmit short-wavelength light,[16] which not only can be protective in reducing potential phototoxicity but also can be deleterious by interfering with circadian rhythms. Studying the effect of attenuating short-wavelength light given these competing interests will provide much-needed clarity.

Cumulatively, our findings support our hypothesis that short-wavelength light-blocking lenses may reduce eye strain based on a physiologic correlate of eye fatigue and subjective reports of eye strain. Given the increasing number of sources of short-wavelength light in our environment, these findings have wide applicability and may inform the development of devices that modify potential hazards associated with excessive blue light exposure.

Acknowledgments

JIN CO., LTD. provided the lenses used in this study, prepared the randomization schedule, and masked the investigators to the lenses used in each pair of glasses.

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Disclosure: **J.B. Lin**, None; **B.W. Gerratt**, None; **C.J. Bassi**, JIN CO., LTD (F); **R.S. Apte**, JIN CO., LTD (C, F, R)

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Appendix A

1. My eyes feel tired.
2. When doing work at my computer or at my desk, I find it hard to focus my eyesight.
3. I see written or computer text as blurry.
4. My computer monitor looks too bright.
5. I feel tired when doing work at my desk or on my computer.
6. My eyes feel dry from time to time.
7. I feel as if there is something in my eye.
8. My neck, shoulders, back, and lower back hurt.
9. My finger(s) hurt.
10. I feel mentally stressed.
11. I feel pain around or inside my eyes.
12. The sun's glare affects my eyes when outdoors.
13. I find fluorescent office lighting to be bothersome to my eyes.
14. My eyes feel heavy.
15. My eyes feel itchy.