Effects of Virtual Reality-Induced Eye Strain on Visual Acuity and Contrast Sensitivity

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Candidate for the degree

Bachelor of Sciences

Submitted in partial fulfilment of the requirements for

College Honors

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Abstract

The current study is concerned with two main factors: understanding the effects of blue light emission on vision and determining how its filtration could ease negative symptoms and vision changes following usage of a head-mounted virtual reality (VR) system. This study has the potential to explore the possible impact of VR, a relatively new technological development in the mainstream commercial market, on short term visual ability and health. Low-wavelength blue light is constantly being emitted from widely used viewing screens, including cell phones and computer monitors. Anterior structures of the human eye, such as the cornea and lens, are effective at blocking ultraviolet rays from reaching the retina, however, virtually all visible blue light is able to pass through these structures to reach the back of the eye. With the advent of VR, viewing distance from eye to screen is decreased and could put greater demand upon ocular convergence and accommodative mechanisms of the eye and lens. Higher-energy, low wavelength light, such as blue light, can also cause damage to the retina and underlying neurons. Therefore, finding ways to mitigate these effects could improve eye function in long-term VR users. Here, participants took the Freiburg Vision Test to obtain a baseline measurement of visual acuity and contrast sensitivity. Following, participants engaged in a 20-minute- VR experience, playing the game *Vox Machinae* or *Waltz of the Wizard*. They then retook the Freiburg Vision Test. There were two groups: one with a normal VR headset and one with the same headset containing blue light filtering lenses. Results suggest little difference in visual acuity change between individuals who wore the blue-filtering lenses while engaged in VR compared to those who did not. However, contrast sensitivity appeared to worsen slightly after usage of the blue-filtering lenses. We interpret these results to suggest that blue light filtering lenses may have a negative effect on vision in short term use. Knowing the potential benefits of blue light filtration in the long-run, companies and users would have to learn that the lenses may not make the VR experience easier initially but will be best for their eyes over time.

Introduction

The current study is concerned with understanding the effects of blue light emission on one's visual acuity and contrast sensitivity. It also seeks to determine if the filtration of said light could ease negative symptoms and vision parameter changes following usage of a head-mounted blue light-emitting device. The blue light-emitting device in question is Oculus Rift virtual reality headset.

Light is a form of electromagnetic energy which portrays a dual wave-particle nature. Light that interacts with our eyes exists on a spectrum including wavelengths between ultraviolet (100-400 nm), visible light (400-760 nm), and infrared (760-10,000+ nm). The cornea, crystalline lens, and macular pigment absorb electromagnetic radiation up to and below about 400 nm, while visible spectrum light is readily propagated by the vitreous gel inside of the eye; the remaining propagated light radiation between 400 and 1400 nm is commonly referred to as the retinal hazard region. Macular pigments, such as zeaxanthin, lutein, and meso-zeaxanthin, are thought to confer additional protection to the retina through their ability to absorb relatively high-energy blue light. However, these pigments are only estimated to filter approximately 40% of visible blue light (Youssef et al. 2011). This leaves a majority of blue light with access to the interior of the eye.

Visible blue light can induce the formation of reactive oxygen species in human retinal pigment epithelium mitochondria, which could lead to retinal apoptosis. *In vivo* modeling in rats has shown such results after 11 to 28 days of 12-hr dark/12-hr light cyclic routines. The retina is a high oxygen environment with high oxygen tensions close to 70 mm Hg. Exposure to blue light can increase the vulnerability to oxidative stress through generation of hydroperoxyl ($HO_2\cdot$) and noxious hydroxyl ($OH\cdot$) radicals (Shang et al. 2017). The defense function in the retina to convert radicals creates high oxidative stress, which makes the retina more susceptible to retinal photochemical injury.

In the course of the 21st century, people are exposed to blue wavelength light from a much wider array of sources compared to in the past. Many modern professions require long hours working at computer screens, and cellular phones are present on and readily used by a large portion of individuals. Screens, such as computer monitors and cell phone screens, emit blue light during use. With the advent of new technology, such as VR headsets, and more advancements on the horizon, understanding the possible effects of blue light on eye health would be beneficial to the longevity of people's vision.

The current study has the potential to explore the usage of virtual reality, a relatively new technological development in the mainstream commercial market. Rapid advancements in virtual reality progression have increased the application of computer programs, such as in the head-mounted devices. The device's relatively small size and ability to display on large screens presents the possibility of displaying different three-dimensional images (Ha et al. 2016). Head-mounted displays are currently available for purchase from a variety of retailers and are readily used for both video viewing and gaming purposes. While using head-mounted displays, images are presented to users at a short distance; this distance is comparable to that seen during reading and smartphone usage. Therefore, the near vision system of the eye is stimulated during such activities. Suh et al. (2012) previously reported that three-dimensional images with cross-disparity induce a greater degree of near work-induced transient myopia than two-dimensional images. Since head-mounted display images are presented at a close distance in order to show a clear image, these images may affect accommodation and convergence within the eye.

Demands being made on the convergence/accommodative system is possibly a great source of binocular stress during head-mounted VR usage. To allow fusion of the observed screens in the headset, manufactures have placed the screens within the focal length of the compound lens. Since the crystalline lenses are powered at about +36 diopters, this means that the user must accommodate around 3 diopters of power to produce a clear image (Mon-Williams et al. 1993). This level of accommodation is likely the reason for esophoric shifts, which can result in symptoms such as eyestrain and blurred vision, experienced by subjects using the head-mounted VR devices.

Visual acuity and contrast sensitivity can be affected through the usage of head-mounted screen devices. Mon-Williams et al. (1993) noticed that 20% of the participants who experienced 10 minutes of engaging VR usage had a transient reduction in their binocular vision by one Snellen line following use of the VR headset; the addition of -0.25 D binocularly was enough to restore the previous level of vision. Seventy five percent of the participants who experienced reduction in acuity also reported blurred vision and difficulty focusing after the VR. Furthermore, high error rates in distinguishing a target's contrast levels in reference to a background have been seen in users who wore head-mounted augmented reality devices (Livingston et al. 2009). This information has led us to think that visual acuity and contrast sensitivity would be supportive representations of vision parameters that could be applied to eye strain and fatigue following VR usage.

The present research aims to investigate changes in visual acuity and contrast sensitivity following usage of a head-mounted VR device in relation to filtration of blue wavelength light. Understanding the effects of blue light on one's eyes could lead to better preservation of vision in a modern era of frequent screen exposure. We hypothesize that those who wear the blue light-filtering lenses will experience fewer symptoms of eyestrain and have less of a negative change on visual acuity and contrast sensitivity following usage of the Oculus Rift headset compared to those who did not wear the lenses.

Methods

Participants

Participants were 48 adults between the ages of 18 and 21 years old (M_{age} = 19.19 years, 6% Asian, 24% Black, 9% Hispanic, 57% White, 4% Mixed). The total group consisted of 31 females and 17 males. From the initial group, 9 females and 2 males were excluded due to inability to complete the virtual reality experience. All individuals were gathered from the Albright College Community, and 46 of the participants received extra credit in psychology courses at the discretion of the professor; the other 2 participants volunteered but received no compensation. Participants gave informed consent and were debriefed after the experiment was completed. If feelings of nausea or discomfort became too apparent during the virtual reality experience, participants were informed that they would be allowed to stop and still receive class credit if applicable.

Oculus Rift

The Oculus Rift, developed by Oculus VR (Menlo Park, CA), is a head-mounted virtual reality device that is placed over the eyes to simulate three-dimensional space. The Development Kit 2 (DK2) and Consumer Version 1 (CV1) were the models used for experimenting. For the DK2, the display resolution was 960 × 1080 per eye with OLED technology; it also included gyroscopic, accelerometric, and magnetometric sensors. A third-party gamepad was used as a controller during gameplay with the DK2. The CV1 per-eye displays were running at 90 Hz with a higher combined resolution than the DK2; integrated audio and 360-degree positional tracking are also notable upgrades from the DK2 model. Oculus Touch, a pair of tracked controllers, were used with the CV1 model to give hands presence and interaction during gameplay.

The initial wave of participants played the game *Vox Machinae* while in the DK2 headset. *Vox Machinae*, developed by Space Bullet Dynamics Corporation (Vancouver, B.C, Canada) is a free-roam game where players pilot a mechanical walker on the surface of an unknown planet. Shooting controls allow the player to engage in low-intensity fights with enemy robots. After receiving the new CV1 headset, we had to switch to a new game, *Waltz of the Wizard*, developed by Aldin Dynamics (Sudurlandsbraut, Reykjavik, Iceland), as the previous firmware was removed following the update. *Waltz of the Wizard* is also a free-roam game, but players take the role of a wizard in his workshop as he conjures and casts an array of spells. The two games were chosen for this study due to their low learning curve, abundance of space to explore, and relatively objectiveless gameplay.

Blue light-filtering lenses

Oculus rift Blueguard lens-inserts, developed by Blue Light Defense (Ocala, FL), were used to filter blue light emission during virtual reality usage. Blueguard lenses reflect harmful blue light instead of shifting the observed color spectrum; according to Blue Light Defense, the lenses block over 99% of waves between 400-420 nm and a good portion up to 450nm. The lenses fit comfortably into the oculus rift headsets without obstruction to the user.

Freiburg Vision Test

The Freiburg Vision Test is a free computer vision test program that uses anti-aliasing and psychometric methods to produce a self-paced and automated measurement of visual acuity and contrast sensitivity (Bach 2007) (Figure 1). It includes a progression of optotypes (i.e. Landolt ring) that adapts according to the performance of the participant. For example, participants doing worse will be given easier trials which are taken into account in the final result. Participants took one test of visual acuity and two sets of contrast sensitivity tests (Landolt ring and Grating). The visual acuity and contrast Landolt test had 8 choices while the contrast Grating had 4 options; every option was based on the orientation of the Landolt ring or grating lines. Answers were recorded from a number pad on a keyboard with the omission of the 0 and 5 keys. The tests provided results in units of visual acuity decimal (VAdecimal) for acuity, %weber for the contrast Landolt ring, and grating threshold for the contrast grating. The participants were sat two meters away from a computer monitor with one pixel equating to 0.48 arcmin; this meant that the maximum observable acuity allowed by the resolution of the monitor would be 1.86 VAdecimal, or between 20/12 and 20/10 Snellen vision. In these units, high scores of VAdecimal indicates better acuity while high scores of %weber and grating threshold indicate worse contrast sensitivity.

Figure 1: Example trials of visual acuity (left), contrast Landolt (middle), and contrast Grating (right) from the Freiburg Vision Test.

Procedure

The current study was conducted in person in a laboratory setting. Participants were randomly separated into two groups: one in which participants wore the headset normally and one in which participants also wore the blue light-filtering lenses inside of the headset. The order of vision tests and grouping of participants was counterbalanced in order to eliminate any confounding effects on performance or response. After signing a consent form informing them of the study, participants took the Freiburg Vision Test to obtain a baseline measurement for their visual acuity and contrast sensitivity. Participants then put on the Oculus Rift headset and began playing either *Vox Machinae* or *Waltz of the Wizard*. They were free to engage in the game however they like for 20 minutes. Following the 20 minutes, participants removed the headset and retook the Freiburg Vision Test. After completion, they were given a demographic form and questionnaire to complete as well as a debriefing form detailing the purpose of the experiment.

Results

Of the 37 participants who completed the study, those in the blue lens group and the no lens group were 21 and 16 respectively. From the initial population, 3 blue lens participants and 8 non-blue lens participants dropped out of the study. For measures of visual acuity, we noticed that scores tended to decrease after usage of the VR headset; however, the blue filtering lenses did not significantly aid in reducing the magnitude of this decrease. We performed a mixed ANOVA to determine if there was significant difference between the pre-VR and post-VR assay measurements of the blue lens group and the no lens group. There appeared to be no interaction between the groups in the visual acuity test $F(1,35) = 0.00$, *ns* (Figure 2); however, the interaction between the groups in the contrast Landolt test approached significance $F(1,35) = 3.124$, $p = 0.086$ (Figure 3). Those who wore the blue light lenses had worse contrast sensitivity following VR usage compared to those who wore no lenses.

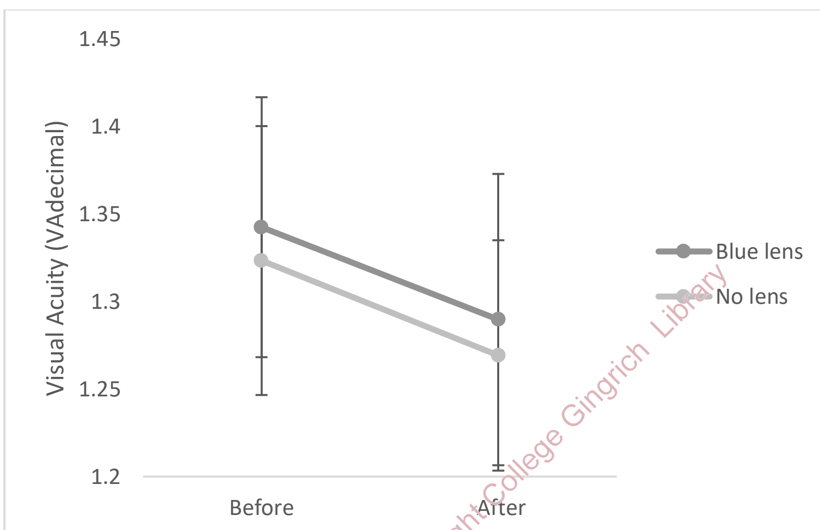

Figure 2: Mean scores of visual acuity before and after VR usage between those who wore the blue light-filtering lens and those who did not.

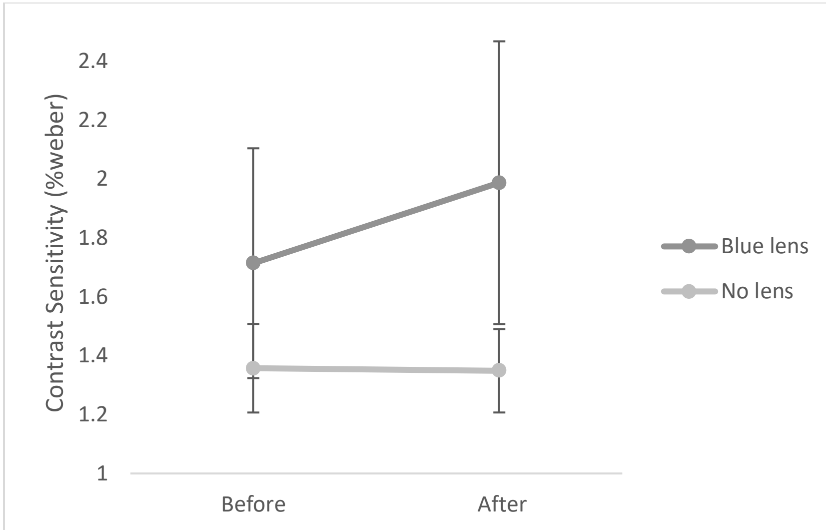

Figure 3: Mean scores of contrast sensitivity (Landolt ring) before and after VR usage between those who wore the blue light-filtering lens and those who did not.

The contrast grating test had a noticeable ceiling effect that was mentioned in the test manual. For both contrasts tests, a score of zero would be the highest recordable score. In the grating test, 9 individuals were able to obtain a score of zero either in the pre-VR or post-VR measurements. The test did not yield significant results in interaction or main effects, *p*s > 0.05.

Doing a 2-way ANOVA between gender and pre-VR and post-VR assay measurements revealed a significant interaction effect between the groups. Males tended to do better on the contrast Landolt test following VR usage while females appeared to perform worse afterwards $F(1,35) = 5.41$, $p < .05$ (Figure 4). This significance was not present in the visual acuity and contrast grating assays, *p*s > *0.05*. Because of this potential gender difference, we wanted to make sure participants of both genders were proportionally represented in all conditions; a Chi-squared analysis of male and female drop-out rate between conditions revealed no significant relationship $p > 0.05$. Therefore, it is unlikely that this gender difference in visual performance affected our final results.

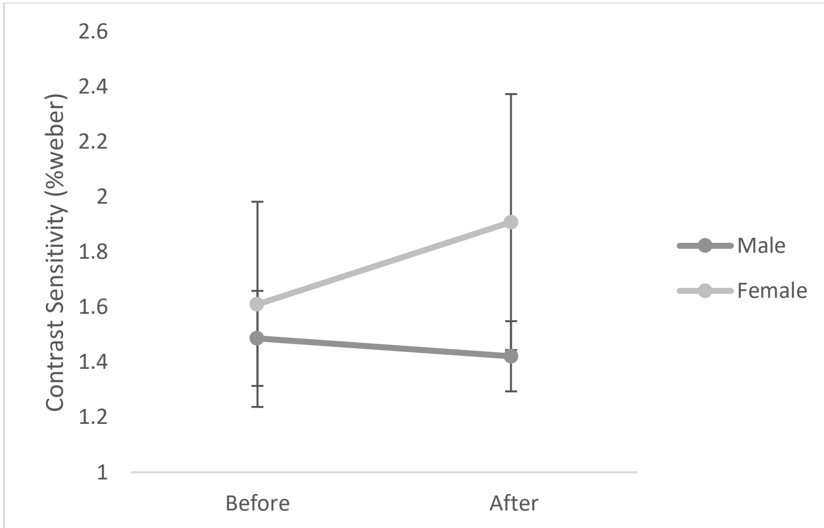

Figure 4: Mean scores of contrast sensitivity (Landolt ring) before and after VR usage between males and females.

Discussion

Our hypothesis was that the blue light-filtering lenses would aid in reducing symptoms of eyestrain while lessening the magnitude of worsening in visual parameters as measured through visual acuity and contrast sensitivity. The results did not support our primary hypothesis. The lenses offered no additional assistance with the visual acuity tests and actually produced negative results in the contrast Landolt tests. From previous studies, it is known that blue light-filtering lenses reduce incoming high-energy blue light from reaching the retina by at least 10.6% to 23.6% (Leung et al. 2017). The long-term effects of blue light and head-mounted displays have been studied quite substantially and generally point towards a negative impact on the eyes (Mon-Williams et al. 1993 and Livingston et al. 2009). Our results suggest that users may experience slight worsening of vision and potential discomfort following short-term usage of their virtual reality device. However, awareness would need to be spread to consumers that these short-term decreases in visual ability are to be expected, and wearing these blue-filtering lenses will be beneficial to eye health over the long-term.

Our results revealed a significant interaction effect between males and female before and after VR usage in the contrast Landolt test. Since there was a difference, a chi-square test was performed to examine if there was a disproportionate allotment of males and females in the conditions and who dropped out. The test revealed no significant relationship. Therefore, disproportionate gender allotment was not a confound for this study. It nevertheless is an element that could be further investigated in future studies: why might there be a gender difference in virtual reality vision?

Limitations of the current study include a small sample size and higher than predicted drop-out rate. Issues involving the participant pool could possibly be attributed to the relative size and gender ratio of psychology students at Albright College seeking extra credit through participation in studies. In order to address these issues, a larger pool of participants would need to be recruited from more concentrations or from a broader population outside of the college. Relating to the drop-out rate, a less stimulating game could be used in future studies; less intense movements and on-screen activity could help ease those who easily feel nauseous or experience motion sickness.

Another limitation presented during the study was having to switch games partway through the study. We had an unexpected software update for the Oculus Rift which required us to switch to the new CV1 headset over the DK2 headset; there was no other computer that would be able to properly run the older DK2. Future work would ideally maintain the same experience across all participants.

Future research may include a longitudinal study of repeated head-mounted VR usage. We can only anticipate to see so much of an effect following only 20 minutes of VR experience. Future work could look at the long-term effects of blue light emission from head-mounted devices on the eye and compare that to long-term usage of blue light-filtering lenses to see if a significant trend appears after repeated uses. Work could also be done to see if usage of augmented reality devices, which recreate a real-time environment, have similar effects to VR devices in terms of effects on vision and production of negative eyestrain symptoms. Since this technology has been gradually moving towards the mainstream market, research in these areas would be important to ensure the longevity of people's vision after consistent use of such devices.

The experiment did not find a significant benefit of blue light-filtering lenses during head-mounted VR usage. This suggests that these blue light lenses would not be effective at reducing negative effects on vision immediately following a session in the Oculus Rift. A significant decrease in contrast sensitivity following use of the blue light lenses may suggest a point of awareness for businesses and users that the short-term effects of these lenses may not be pleasant; but longer-term studies may reveal that repeated use of the lenses may be better for one's eye over time.

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