Motion sickness related aspects of inclusion of color deficient observers in virtual reality

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ABSTRACT

Color blindness is one of the most common forms of disability. Virtual reality (VR) development has increased recently, and it is important not to exclude people with impairments or other limitations. Visually induced motion sickness (VIMS) can be worse due to color versus black, white and gray environments. Can non-color factors in dynamic environments be excluded by performing color deficiency impacted tasks and comparing them to the equivalent static and dynamic tasks performed by a color-sighted person? Would a color-based experiment causing VIMS produce different results for a color deficient observer (CDO)? This paper advocates a novel approach to color blindness and motion sickness in VR based on psychophysical experiments. The aim is to find solutions and develop recommendations that will improve accessibility of VR for the colorblind.

1. INTRODUCTION

Color blindness is one of the most common and widespread forms of disability in humans. The total frequency of color vision defects reaches up to 8% in males (Deeb, 2005) and at least 0.5% in females (Sharpe et al, 1999). The term *color blindness* in itself is covering several types of color deficient observers (CDOs), predominantly those affected by the so-called *red-green blindness*, also known as *anomalous trichromats*, along with some *dichromats* and rare *monochromats*. It has been estimated that ~2% or almost 6.5 million people in all age categories of the 2002 U.S. census have a non-severe visual impairment that affects gameplay (Yuan et al, 2011). This is not surprising, given that the most common inherited color defects are the aforementioned red-green ones (Pease, 2006), and more than 75% of red-green colorblind individuals experience some difficulties with daily tasks (Steward and Cole, 1989).

Some game developers, such as Rockstar North (Grand Theft Auto IV) and Epic Games (Unreal 4) have incorporated colorblind accessibility solutions into their products (Ellis et al, n.d.). However, the renewed interest in virtual reality (VR) exposes an area where accessibility remains relatively unexplored. In particular, it becomes important to find out if motion sickness in VR affects CDOs differently than it does viewers with normal trichromatic vision, given that color-sensitive cones concentrate heavily near the middle of the field of view in the retina. Two prior studies (Bonato et al, 2004; So and Yuen, 2007) disagreed as to whether color plays a role in the phenomenon of motion sickness in VR, so this more general issue has to be addressed as well.

Bonato et al (2004) reported that motion sickness onset was faster and more severe when observers were shown chromatic stripes, as opposed to showing black, white, and gray stripes only. The performance of a CDO is not purely a function of the color, but also influenced by other factors that are not yet fully understood. Can non-color factors in dynamic environments be excluded by performing color deficiency impacted tasks and comparing them to the equivalent static and dynamic tasks performed by a color-sighted person? A related question is: would a color-based experiment causing visually induced motion sickness (VIMS) give different results for a CDO?

2. MOTIVATION AND BACKGROUND

Surprisingly many CDOs remain unaware of their color defiency until tested, usually with color differentiation and so-called *color confusion lines*, which are simplified descriptors in a static environment. This suggests that the CDOs use some forms of visual input other than color to help or augment their color distinction and differentiation. Color deficiency and color confusion lines are very good descriptors in an aperture mode view of color, meaning a scenario where two pure color sensations have to be matched. Many static tests exist, among them the well-known Farnsworth-Munsell 100 Hue Color Vision Test (Farnsworth, 1943), the RGB Anomaloscope (Nagel, 1907), or the Ishihara test (Ishihara, 1917). The latter one is the most widely used test for color deficiency, unless one counts simple tests administered to prospective drivers. All of these static tests are repeatable and their results are stable. This reproducibility seemingly presents a stark contradiction to the relatively low level of awareness among the CDOs.

The explanation proposed by Eschbach et al (2014) is that, in realistic viewing situations, CDOs compensate for their disability by utilizing other available cues. In that work, it was shown that a simple modification of the Ishihara plates led to a strong change in the ability of CDOs to identify the colors. In their examples, Eschbach et al did not modify the color per se, but merely changed the spatial arrangement and edge formation of the colors. This modification did not allow a higher cognitive level to enter the experiment. No higher level objects or knowledge could be used, since the actual plate still consisted of dots of given colors at quasi-random position. The result strongly suggests that there are additional sources of information that a CDO makes use of and that these sources are not well known or understood. Thus, complex static environments already challenge several aspects of the extension of standard color deficiency models, such as the popular one based on replacement colormaps and developed for the relatively narrow purpose of evaluation of display legibility (Viénot et al, 1999). Complex dynamic environments such as VR are therefore likely to show even stronger effects leading us to better understanding of the color and VIMS phenomena and toward improved utilization of the VR technology.

3. OPTOKINETIC DRUM AND SPHERE SIMULATION

Simulator sickness (nausea, headache, disorientation etc.) experienced by the observer poses a serious challenge to VR developers. Some people are significantly more susceptible to simulator sickness than others, the factors in play including age, ethnicity, gender, and experience with the simulator (Kolasinski, 1995). The most widely accepted explanation of simulator sickness is the theory of cue conflict (McCauley and Sharkey, 1992). In line with this theory, simulator sickness can be classified as VIMS. Two tentative hypotheses are: 1) The reaction of CDOs to the signal is muted, and thus motion sickness sets in at a later stage; and 2) Additional information that seems to be used by CDOs will be amplified and thus create a stronger motion sickness.

3.1 The Simulator

Bonato et al. (2004) studied visually induced motion sickness using an *optokinetic drum*, a rotating instrument in which a test subject is seated facing the interior wall of a cylinder covered with patterns. A similar instrument of a different geometrical shape is known as an *optokinetic sphere*. As Bonato et al (2004) did not investigate the color blindness aspect of the problem, two of the co-authors of this paper contributed to the development of a VR simulator designed to study the effects of color and color blindness on motion sickness using head-mounted displays (Gusev et al, 2016). The VR simulator included both an optokinetic drum and sphere, using a popular HMD (Samsung Gear VR). Stripes and checkerboard patterns are used. Gusev et al (2016) describe the details of the design, including the method of selecting colors so that when they are viewed through a color blindness simulator, the colors become indistinguishable from each other. In addition to the normal color vision mode, eight types of color blindness are simulated, based on the color mapping approach of Viénot et al (1999).

3.2 The Psychophysical Experiment

The psychophysical experiment that is currently underway at the Envision Center of Purdue University is designed as follows. The goal of the psychophysical experiment is to collect the subjective visually induced motion sickness detection and assessment data for measurement of the effect of color and color blindness on VIMS in VR. Before the experiment, the subject is asked to do a standard Snellen visual acuity test and an

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Ishihara color blindness test. Both colorblind individuals and those with normal color vision are included in our observer pool. People who do not have normal visual acuity (corrected to be 20/20 Snellen acuity) or are not able to understand the instructions are excluded from subject pool. The subject is also asked to fill out a preliminary questionnaire aimed at assessment of the subject's susceptibility to motion/simulation sickness. The experiment is conducted in a controlled lab. Oculus Rift DK2 and Samsung Gear VR units are used. During the experiment, the subject is asked to perform tasks in a VR simulation of an optokinetic drum (or sphere). As the drum rotates, the subjects observe a moving visual field while their bodies remain stationary. With the subjects that have normal color vision, up to 9 simulation modes can be used. Stripes and the checkerboard pattern are tested. The VR optokinetic drum controls allow the observer to speed up rotation, slow it down, or stop entirely at any time. The observer responses are recorded in the simulator sickness questionnaire (Kennedy et al, 1993).

4. THE PATH FORWARD

Even as the current experiment is progressing, we feel the need to deviate from the approach of Viénot et al (1999) as the sizes of color stimuli in VR may far exceed those involved in evaluation of display legibility. Indeed, one of the more common mistakes made by people with normal color vision when they select paint color for painting walls of a room is to look at the relatively small color samples available at a store, possibly even hold the sample cards against a wall, and select a color that's too bright, chromatic, or saturated. Once the whole room or a sufficiently large area of its walls is painted in that color, the bold color comes across as too strong/harsh. This may seem counterintuitive, given that color perception changes across the visual field so that it is best in the fovea and declines in the periphery. Moreover, sensitivity to red-green color variations declines more steeply toward the periphery than sensitivity to luminance or blue-yellow colors (Hansen et al, 2009).

However, one should bear in mind that human vision system has an *averaging (integration) property* that acts as one of the noise-reducing mechanisms that aim to reconstruct a more faithful representation of the stimuli (Lombrozo et al, 2005). Sometimes, these mechanisms fail and contribute to such optical illusions as Mach bands (Ratliff, 1965). We suspect that these mechanisms are at least partly responsible for the color selection mistake discussed above, as they reduce the signal-to-noise ratio (SNR) for the large stimuli, even despite the reduced color sensitivity in the periphery. Some CDOs may be able to see the color once the stimulus is large enough, despite the inability to pass the Ishihara color blindness test, with its small colored blobs. What this also means is that the simple static color mapping should fail to correctly simulate color blindness for large color stimuli in VR. Hence one natural follow-up to the ongoing experiment is to either vary the widths of the stripes and sizes of the checkerboard squares, or allow the observer to get closer to the moving wall in the VR simulator.

5. CONCLUSIONS AND FUTURE WORK

Examining CDOs in complex dynamic settings is important for three separate, but equally fundamental reasons: 1) In contrast to the color-sighted viewers, CDO performance is a function of the static vs. dynamic environment. In a virtual environment, certain natural cues or information channels may be omitted or misrepresented. This might have had minimal effect on a color-sighted person, since other signals were stronger, but muting the other signals then exposed the deficiency of the virtual environment. In a sense, the virtual environment may have created a new barrier for CDOs. However, without having all cues identified and classified, it is impossible for the creator of such environments to avoid these pitfalls; 2) Identifying cues that differentiate the CDO, one can postulate that at least a small effect of these cues is also present for the color-sighted observer. In a virtual environment, we then have the conscious and controlled option if we want to emphasize or de-emphasize such cues in order to enhance or diminish effects for the color-sighted observer; and 3) If we make the determination that colorblind people can complete some tasks in VR that normal viewers cannot due to VIMS, it will represent a major step forward in our understanding of the complex interrelationship among color, color blindness, and motion sickness. Indeed, some colors, such as red, are commonly perceived as more "aggressive" than others, and certain "psychedelic" color combinations reportedly help cause motion sickness and nausea in video games (Far Cry Primal Forum, 2015). We expect this effect to be even more pronounced in VR.

With these three reasons in mind, we plan to expand the psychophysical experiment to cover a second type of VR systems, in addition to the HMDs, — the CAVE projection-based immersive environment with walls. The properties of these two types of VR with respect to task completion were reported to be different by Kim et al. (2012), and we want our results to be as general as possible. We also intend to use realistic virtual environments, in addition to those specifically designed to cause VIMS. We believe that the results of this future work will have positive impact on the design process of modern VR games and simulations so as to broaden participation of people with such disabilities as motion sickness susceptibility and color blindness.

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