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Myopia in Head-Worn Virtual Reality

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Abstract

In this work, we investigate the influence of myopia on the perceived visual acuity (VA) in head-worn virtual reality (VR). Factors such as display resolution or vision capabilities of users influence the VA in VR. We simulated eyesight tests in VR and on a desktop screen and conducted a user study comparing VA measurements of participants with normal sight and participants with myopia. Surprisingly, our results suggest that people with severe myopia can see better in VR than in the real world, while the VA of people with normal or corrected sight or mild myopia is reduced in VR.

Index Terms: Computing methodologies—Computer Graphics—Graphics systems and interfaces—Perception; Computing methodologies—Virtual reality—;

1 Introduction

In spirit of an inclusive society, immersive technologies should be accessible to everyone – healthy people as well as people with physical or cognitive disabilities or vision impairments. Sectors like education, training and entertainment can benefit from virtual reality (VR). However, one of the major shortcomings of most head-worn displays (HWDs) is the resolution of the display, which is significantly lower than the resolution of the human eye, as well as the small field of view of the HWD. Consequently, people with normal or corrected sight (wearing contact lenses or glasses) experience a reduction in visual acuity (VA) in VR, when using HWDs, comparable to a mild vision impairment [5]. A low resolution in VR, resulting in blurry or pixelated images, diminishes the experience of users in the virtual environment (VE). For people with vision impairments, this can be an even greater issue, because it is not always possible or comfortable to wear glasses inside an HWD, and some people cannot tolerate contact lenses. Furthermore, eye trackers, which are increasingly used in modern HWDs for techniques such as foveated rendering, often do not work for people wearing glasses.

According to the World Health Organization (WHO), more than 1.8 billion people worldwide are affected by refractive errors such as presbyopia, myopia or hyperopia. This is a large part of our population that we should enable to access novel immersive technologies and have the same experience as everyone else. In order to develop any kind of vision aids for HWDs (special lenses, computational vision enhancement methods, magnification filters, etc.), we need to understand the influence of vision impairments on VA in VR. In this work, we present a **user study that investigates the influence of myopia (nearsightedness) on VA in head-worn VR**. We implemented a refined version of the eyesight test of Krösl et al. [4, 5] with *Unreal Engine 4*. Our **tool provides a VR mode (for HWDs) and a 2D desktop mode for VA tests**, allowing us to measure the perceived VA of every participant in VR and in the real world.

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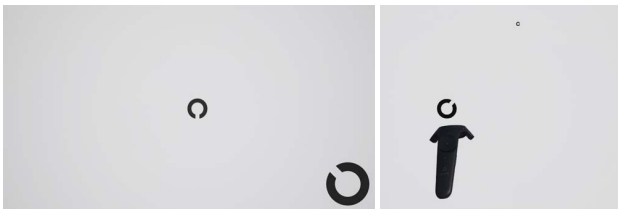

Figure 1: (left) 2D VA test with test symbol in the center and user-selected orientation in the lower-right corner. (right) VR VA test (using a head-worn display) with test symbol in the distance and user-selected orientation above the controller.

2 Background

Visual acuity (VA) is a term used to describe the capability of the eyes to recognize small details from a certain distance. VA is commonly measured by asking a subject to identify different alphanumeric symbols, called optotypes (such as the *Landolt C* used in Fig. 1), on an eye chart, positioned at a certain distance. The standard is 20 feet or 6 meters, but other distances are used as well. VA is often given in minutes of arc (*arcmin*), and "normal vision" is defined as a VA that allows people to recognize an optotype subtending an angle of 5 minutes of arc from 20 feet or 6 meters away. To measure VA, a test subject is asked to read the optotypes on an eye chart from top (biggest) to bottom (smallest) until they cannot recognize the optotypes anymore. The smallest correct line ($> 60\%$ correct) represents the VA score for the tested eye [2].

3 Methodology

To investigate the effects of VR displays on VA, we implemented a VA test in VR (using an HWD) and on a 2D desktop screen and conducted a user study with myopic and normal-sighted participants. The study uses a "between-subjects" design, comparing results of each subject's VR test to the results of the 2D test (once with and once without glasses for myopic participants), and a "between-groups" design, comparing the results between myopic and normal-sighted participants. To validate the correctness of our VA tests, we additionally let some users conduct a well-known and established online VA-test [1] and compared the results to ours. In contrast to common eyesight tests used by ophthalmologists to measure the VA of each eye, we measure binocular and not monocular VA. This better approximates the normal usage of VR HWDs, given that content inside VR HWDs is usually experienced with both eyes.

4 User Study

We conducted the user study with 15 participants (4 female and 11 male between the age of 19 an 63, with an average of 32.). 5 people had normal vision, the remaining 10 had myopia with a deficit in diopters between -1.5 and -6. All participants performed the test once in VR and once on the 2D desktop screen, and myopic people did each test a second time without glasses. All participants performed the 2D test first and then proceeded with the VR version. We did not test for a learning effect. However, our VA tests are similar to the VA tests conducted by Krösl et al. [4], whose evaluations showed no learning effect after multiple VA tests.

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4.1 Test Protocol

A Landolt C is displayed at 3 meters distance with its gap randomly set at 1 of 8 possible positions: up, down, right, left and diagonal positions in between. A second, large Landolt C (representing the selection of the user) is displayed in the lower-right corner of the screen (in the 2D desktop mode) or above the Vive controller (in VR). Participants have to indicate the orientation of the gap by rotating the second Landolt C, via trackpad of the Vive controller, to match the orientation of the test symbol. Upon pressing the trigger, the input is confirmed, and the gap's orientation of the test symbol changes. After a test sequence (a certain number of symbols of the same size), the size of the test symbol is decreased or increased, depending on the number of correct inputs. The relative reduction in size from one test sequence of Landolt Cs to the next decreases the smaller the test symbols become. If a participant does not recognize more than 50% of the symbols in the current sequence, the Landolt C is increased again to a size between the current and the last correct sequence. This transition between sizes proceeds until reaching a threshold, i.e., when the difference between the last correctly recognized size and the tested one is too small. The last correctly recognized size (in minutes of arc) identified by each participant is recorded and converted to decimal acuity by calculating the reciprocal of the minimum recognizable gap width of the Landolt C [2]:

$$decimal\ acuity = \frac{1}{[gap\ size\ in\ arcmin]} \tag{1}$$

4.2 2D Visual Acuity Test

The 2D test uses the test protocol described above and is implemented using UE4 and its widget class to project the two Landolt Cs on a 2D desktop screen (see Fig. 1(left)), which allows us to adjust the dimension of the elements in pixels before starting an experiment. To make sure that the size of the displayed optotypes corresponds to the correct size in centimeters, the screen size and resolution of the monitor have to be taken into account when calculating the initial size and scale for the optotypes based on the visual angle. We conducted our experiments with participants standing at a distance of 3 meters to the screen.

4.3 VR Visual Acuity Test

The implementation of the VR version is based on the work of Krösl et al. [5], but uses our own test protocol (described above) that does not end a VA test after one failed test sequence, but uses a psychophysical approach to "zero in" on the VA of a person, by transitioning between test sizes. Using UE4, the dimensions of virtual objects in the VE correspond to the same dimensions as in the real world. Consequently, the size of the Landolt C can be specified in centimeters is positioned 3 meters away from the player in the VE. The second Landolt C, representing the selected orientation of the recognized test symbol, is positioned above the virtual model of the Vive controller, as shown in Fig. 1(right).

5 Results

To test for statistical significance of our results, we used a two-sample *Kolmogorov-Smirnov test* on the decimal VA values.

Normal vs. Corrected Sight. We compared VA values measured of normal-sighted people to the results of myopic people wearing glasses and did not find any statistically significant difference (with $\alpha = 0.05$) between these sample groups (2D: $p \sim 0.540$; VR: $p \sim 0.267$).We conclude that people with normal vision and myopic users that wear corrective lenses experience a VE similarly.

VR vs. 2D (for Normal or Corrected Sight). The results for all 15 participants with normal or corrected sight (wearing glasses) show a lower VA in VR when compared to the 2D test ($p < 0.001$). This supports the findings of Krösl et al. [4] that the hardware of the HWD itself causes the user to experience a mild vision impairment.

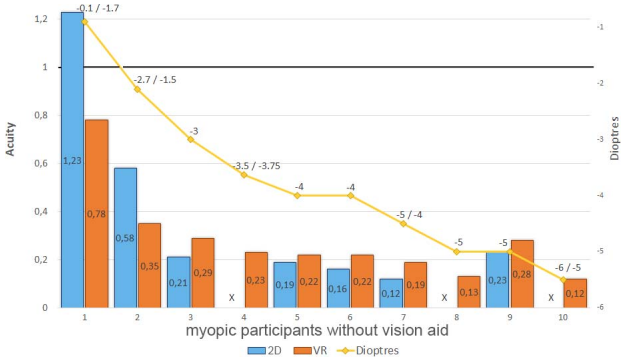

Figure 2: VA scores of myopic participants in VR and 2D tests without glasses. X marks the participants who were not able to identify the correct position of the gap in the Landolt C at the initial size of 70 arcmins ($\sim 6.1cm$) in the 2D test.

The Impact of Uncorrected Myopia. As expected, myopic people not wearing glasses perform significantly worse ($p \sim 0.003$) than normal-sighted people in the VR and the 2D VA test. However, our results indicate that their reduction of VA in VR is not necessarily worse than in the 2D test, as one might assume. Without glasses, only 2 out of 10 myopic participants, both with a dioptric defect less severe than -3, had a lower VA in VR when compared to their 2D test result. All other myopic participants had a dioptric defect of -3 or worse and reached better VA values in VR (see Fig. 2). A possible explanation for these results could be the fact that the display inside an HWD is in very close distance to the eyes of the user. Since myopic people have abnormal amplitudes of accommodation [3], this limited distance between eyes and displays could affect their VA in VR positively.

VA Test Validation. To validate the correctness of our vision tests, we asked 9 of our participants to also take the Freiburg Vision Test ('FrACT') by Michael Bach [1] and compared the results to the VA values from our 2D test. Our analysis did not yield any statistically significant difference ($p \sim 0.828$), which supports the validity of our VA tests.

Acknowledgments

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References

[1] M. Bach. Freiburg vision test ('FrACT'). `https://michaelbach.de/fract/index.html`. Accessed = 2019-02-10.

[2] International Organization for Standardization. iSO 8596:2009 Ophthalmic optics - Visual acuity testing - Standard optotype and its presentation. Iso, International Organization for Standardization, Geneva, CH, July 2009.

[3] D. J O'Leary and P. Allen. Facility of accommodation in myopia. *Ophthalmic & physiological optics : the journal of the British College of Ophthalmic Opticians (Optometrists)*, 21:352–5, 09 2001. doi: 10.1016/S0275-5408(01)00002-3

[4] K. Krösl, D. Bauer, M. Schwärzler, H. Fuchs, G. Suter, and M. Wimmer. A vr-based user study on the effects of vision impairments on recognition distances of escape-route signs in buildings. *The Visual Computer*, 34(6-8):911–923, 2018.

[5] K. Krösl, C. Elvezio, M. Hürbe, S. Karst, M. Wimmer, and S. Feiner. ICthroughvr: Illuminating cataracts through virtual reality. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces*, pp. 655–663. IEEE, mar 2019.