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Incidence of Stereo Blindness in a Recent VR Distance Perception User Study

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Abstract

Estimates of stereo-blindness, the inability to see in 3D using stereopsis, often sit in the 5-10% range. At the Curtin University HIVE visualisation facility, we regularly show stereoscopic content. During those demonstrations we routinely show a test random dot stereogram and it has been our casual observation that the incidence of stereo-blindness amongst visitors has been much lower than the 5-10% figure, perhaps as low as 2%. Our thought was that perhaps eye care has improved since the time that the original stereo-blindness studies were performed. A virtual reality (VR) based user study was recently run in the HIVE, as part of a PhD project, with an aim to study distance perception in underwater virtual heritage experiences. Distance perception is facilitated by a range of visual cues, including stereoscopic vision, and as a result we formally screened all participants for stereo-blindness. Using a standardised stereo test, we found approximately 5% of participants reported as stereo blind.

Keywords

Stereopsis, Stereovision, Stereo-blindness, Virtual Reality

Introduction

Stereoscopic vision (also known as stereovision and stereopsis) is the ability to perceive the depth of objects based on visual cues provided by binocular disparity [1]. This ability provides a sense of volume, a feeling of three-dimensionality, to the world. Stereovision is not managed by a single neural system but is instead composed of several subsystems. They include, amongst others, a system for processing both convergent and divergent disparities [2][3], systems to process disparities inside (fine disparities) or outside (coarse disparities) Panum's fusional area [4][5], and systems to process disparities in a single eye fixation or across multiple eye fixations [6]. Stereovision also relies on visual acuity to detect disparities at various levels of sensitivity, with each person having a level of stereo-acuity correlated to their visual acuity.

Stereo-impairment (also known as stereo-deficiency) is a partial dysfunction of stereovision and can be caused by a full or partial dysfunction of a specific subsystem. For example, individuals may have a stereo-impairment in crossed disparities but not uncrossed disparities [3], or an impairment in fine disparity processing and not coarse disparity processing [7]. As a result, stereo-impaired individuals can occasionally compensate for their impairment by adjusting their fixation to enable their visual input to be processed by other stereovision subsystems [2].

Within the academic community, stereo-blindness has varying definitions and various types of stereo-impairment are described as stereo-blindness [7]. In common use, stereo-blindness is generally described as total absence of stereovision. Stereo-blindness and stereo-impairment are commonly caused by amblyopia, a condition where the vision in one or both eyes is significantly impaired. This impairment is most frequently the result of strabismus [8], a condition where the eyes are misaligned and don't focus on the same object at the same time. These conditions most often appear at a very young age and cause the images from both eyes to be poorly correlated, compromising the development of stereovision [9]. Stereo-impairment and stereo-blindness can also be caused by age related eye disorders such as macular degeneration. These issues become particularly prevalent in adults over the age of 50 [7][10].

Stereovision provides a very strong cue for depth perception, but it is only one of many visual cues that provide depth information [11]. When stereovision fails, other visual cues will generally provide sufficient information to allow stereo-impaired individuals a limited understanding of depth and distance of objects in their environment. Those with stereo-impairments and stereo-blindness generally experience deficits with visually guided operations, such as hand to object movements, walking up and down stairs, and operating vehicles, but they are often unaware of the stereo-impairment until they are tested for it. They may understand they have some functional deficits in their motor skills, but not understand what is causing them, and learn to live with them [12]. This has led some organisations to adopt stereo-acuity testing as part of their recruitment [13]. Stereo-blindness also has a significant impact on the use of technologies that utilise binocular disparity to create an artificial sense of depth, such as 3D cinema, 3D TV, large screen stereoscopic visualisation displays, and VR headsets. For the stereo-impaired and stereo-blind, these technologies provide reduced or no benefit, and may even be a detriment over similar 2D technologies.

Testing

Stereo-blindness has been tested in studies from the 1970's [3] [14] [15] and today there is a large number of well validated tests available. These stereovision tests (also commonly known as "stereotests") present slightly different images to each eye, most often with the use of anaglyph or polarised glasses, and observers are asked questions about what they are seeing.

Two of the most common tests used today are the Titmus Fly stereotest and the Randot stereotest [16] (see Fig. 1 & Fig. 2). The Titmus fly test provides an image of a fly, and a series of circles with varying degrees of disparity. Unfortunately, due to the contour-based nature of the images, both the fly and the circles provide significant monocular cues that enable stereo-blind observers to defeat the test [17]. The Randot stereotest was developed in response to the concerns with the Titmus Fly test. It provides a series of random dot stereograms [18] and requires observers to report a series shapes contained within them. Studies on the use of random dot stereograms within the Randot stereotest verify a lack of monocular cues, improving its reliability over the Titmus Fly test [7].

Figure 1. *Titmus Fly stereotest [19].*

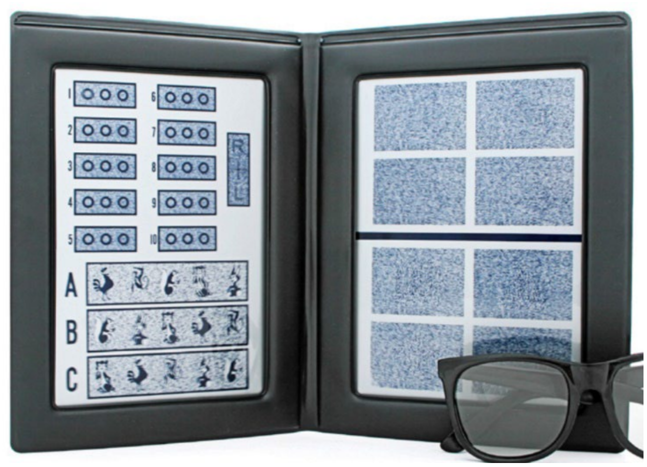

Figure 2. *Randot stereotest [19].*

A variety of stereo tests have been used in stereo-blindness prevalence studies over the years, each testing differing aspects of stereovision under varying environment conditions [7]. As a result, there is no standard definition or standard test for stereo-blindness. Stereotests generally provide images at different disparities allowing for testing of stereoacuity. Some organisations prefer to report on stereoacuity only and avoid the term stereo-blindness altogether [13][20]. Most commonly though, for the Titmus Fly and Randot stereotests, observers are classed as stereo-blind when they fail the test with the largest disparity.

Prevalence

One of the earliest studies on the prevalence of stereo-blindness was performed by Whitman Richards in 1970. The study estimated the prevalence of stereo-impairment in either crossed, or uncrossed disparities at 30% of the population, with a resulting estimate of complete stereo-blindness at 2.7% of the population [3].

Chopin et al.'s [7] review of studies on stereo-blindness between 1970 and 2016 shows estimates range from 1% up to 64%. These wildly divergent estimates are largely due to differing operational definitions for stereo-blindness, varying experimental conditions, and varying sampling methods across the studies. Summarising the studies, the review estimates that 7% of the population less than 60 years old is stereo-blind.

The Curtin University HIVE (Hub for Immersive Visualisation and eResearch), the University's visualisation facility, utilises active shutter 3D glasses to display 3D visualisations on multiple large-screen displays. To test the 3D glasses are turned on and functioning correctly, a custom dynamic random dot stereogram is routinely displayed in advance of visualisation content [21] (see Fig. 3). The random dot stereogram displays a random number that participants report on verbally, providing a quick, simple test in advance of screening content.

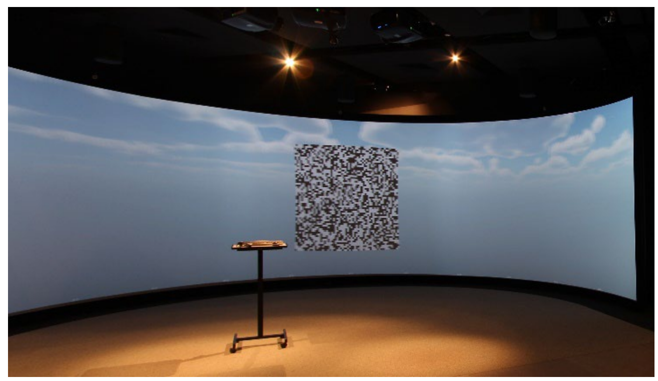

Figure 3. *Custom dynamic random dot stereogram displayed on the Cylinder screen in the Curtin HIVE.*

While primarily intended to test the hardware, participants occasionally report not seeing the content of the random dot stereogram despite the 3D glasses functioning correctly. This has provided the HIVE with an informal measure of stereo-blindness in the participant population. The casually assessed incidence of stereo-blindness reported by participants in this test has generally been very low - much lower than expected from previous reviews of studies on stereo-blindness. Prior to the VR user study, the common belief has been that the prevalence in the HIVE visitor population could be as low as around 2%.

VR User Study

A VR based user study was recently run in the HIVE to study distance perception in underwater virtual heritage experiences. This user study is part of a PhD research program being undertaken by the lead author, which in turn is part of a larger Australian Research Council Linkage Project "Photogrammetric Reconstruction for Underwater Virtual Heritage Experiences" (LP180100284) led by Curtin University. The primary objective of the PhD is to determine the impacts of adding a realistic environment around photogrammetry in virtual reality based underwater virtual heritage experiences. This includes impacts on experiences created for VR headsets and large screen immersive displays. The study was the first of three user studies planned for the PhD.

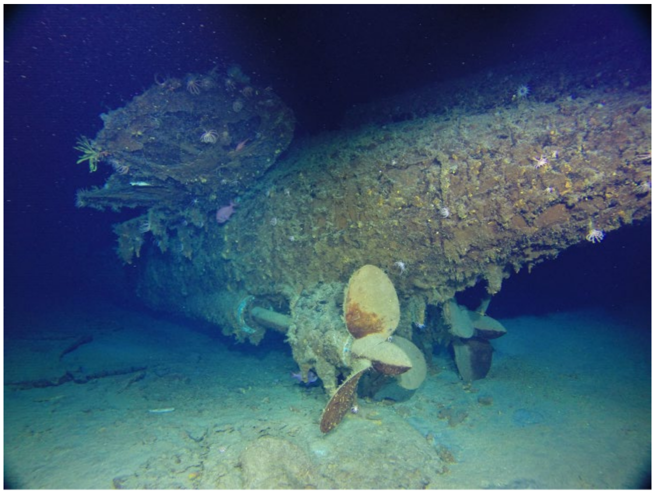

Figure 4. *A photograph of HMAS AE1 shipwreck (Image courtesy of Paul G. Allen, Find AE1, ANMM and Curtin University. © Navigea Ltd).*

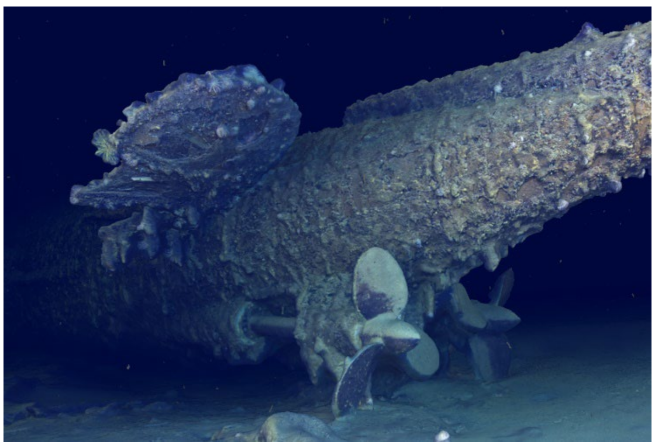

Figure 5. *A screen capture of shipwreck recreated in VR for the user study (3D Model by Curtin University from images courtesy of Paul G. Allen, Find AE1, ANMM and Curtin University. © Curtin University).*

Figure 6: *A screen capture of options available in VR for manipulation of shipwreck scene used in the VR user study (3D Model by Curtin University from images courtesy of Paul G. Allen, Find AE1, ANMM and Curtin University. © Curtin University).*

The aim of this particular user study was to investigate how modelling marine snow and light attenuation in a VR experience of a shipwreck impacts judgement of distance when viewed on a Meta Quest 2 VR headset (see Fig. 4, 5, 6). Distance perception is facilitated by a range of visual cues, including stereovision, and as a result participants were screened for stereo-blindness.

A total of 81 participants completed the user study. The participants were a convenience sample from the student population at Curtin University. The average age of the participants was 21 years old. The participants included 21 males, 59 females, and 1 nonbinary individual.

We used a Randot stereotest to screen participants for the study. The instructions that came with the stereotest were not explicit on how to classify stereo-blindness. As a result, we decided to classify as stereo-blind anyone who failed any of the four random dot stereograms situated on the top right of the chart (all at largest disparity at 500 seconds of arc). A total of 4 out of 81 participants (~5%) failed one or more of the four tests and were classed as stereo blind.

Discussion

The VR user study demonstrated a higher prevalence of stereo-blindness than anticipated from the informal testing previously performed in the HIVE. We regard the user study testing to be more reliable for the following reasons:

1. The Randot stereotest is well validated, and more established than our custom random dot stereogram.
2. The informal testing in the HIVE has usually been performed with groups of participants, asking people to speak up if they have issues seeing the stereogram. It may be that some individuals are staying quiet on their condition.
3. We suspect there are some minor monocular cues visible in the custom random dot stereogram allowing some people to defeat the test even if they are stereo-blind.

The incidence of stereo-blindness in this VR user study was lower than estimated by the review performed by Chopin et al. [7], though still within the range described by the confidence intervals in the estimates used to reach that conclusion. It is possible that the low age of the study cohort contributed to the difference. The study included students between the ages of 18 and 47, with 95% of the participants less than 30 years old. In contrast, the review encompassed adults up to the age of 60, and there is a significant increase in stereo-blindness in the adult population over the age of 50 [10].

Our study also had a relatively low number of users, possibly limiting the reliability of the results. This was the first of three user studies planned for the PhD, with each study including a test for stereo-blindness. We expect the combined results from the three studies to provide a more reliable estimate for the prevalence of stereo-blindness.

As stated, stereo-impaired and stereo-blind individuals are often not aware they have this condition. In the VR user study, none of the four participants that tested as stereo-blind were aware of their condition, though some knew in advance they had developed strabismus or amblyopia as a child. A few of the participants expressed concern at the outcome of the tests. This provided an opportunity to not only educate them on their condition but also provide some hope for a remedy, including referring people to the book “Fixing my Gaze” by Susan R. Barry [12].

Recent research indicates that people retain some neural plasticity in their visual cortex as adults [22], providing the opportunity to recover their stereovision even after a diagnosis of stereo-blindness. Susan R. Barry is one of the most well-known cases of recovering from stereo-blindness. She recovered her stereovision at the age of 48 and subsequently wrote a book describing joyous experiences after the recovery by herself as well as others who had corrected their vision as adults [12]. Understanding the prevalence of stereo-blindness can help us identify opportunities to help more people enjoy the benefits of stereovision and the technologies that utilise stereovision.

Conclusion

Stereovision is an important part of many daily actions and interactions, and for the use of technologies that utilise binocular disparity to provide depth to simulated environments. From our informal testing in the Curtin HIVE we had considered the prevalence of stereo-blindness to be around 2% to 3% of the adult population, lower than estimated in most academic studies. Our recent VR user study suggests the prevalence of stereo-blindness to be higher than we expected, at around 5% of the adult population. Taking into consideration the relatively low age of the study participants it’s likely the general visitor population to the HIVE has a higher incidence of stereo-blindness than recorded in our study. The results indicate there may be some limitations to the informal testing of our visitors, and that there could be opportunities available to improve assessment and provide additional support for those that are stereo-blind.

The usage of virtual reality and other 3D technology has increased significantly in recent years. The prevalence of stereo-blindness indicates a significant proportion of the population is set to stand at a disadvantage when utilising developments offered by these technologies. Understanding rates of stereo-blindness, establishing reliable tests for stereo-blindness, and developing treatment for stereo-blindness should be an area of growing importance.

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Associate Professor Andrew J. Woods is a research engineer and manager at Curtin University, where he manages the university's HIVE visualisation facility and is a research engineer with the university's Centre for Marine Science and Technology in Perth, Western Australia. He has over 30 years of experience working on the design, qualification, application, and evaluation of stereoscopic video equipment in teleoperation, marine, archaeology and entertainment applications.

Dr Hugh Riddell is a post-doctoral research associate at the Curtin School of Allied Health. He has contributed to research on various topics from the field of psychology, including visual perception, cognition, and motivation.