ASSETS: U: Insights for More Usable Virtual Reality Games for People with Ambylopia

Ocean Hurd
Computer Engineering
Advisor: Sri Kurniawan
Computational Media
UC Santa Cruz, USA
ohurd@ucsc.edu

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Abstract
Amblyopia, or "lazy eye", is the world's most common neurological eye disorder. Yet, very little has been done looking into how to make virtual reality (VR) more usable for people with Amblyopia. Furthermore, a trend of using VR for Amblyopia therapy has arisen, making such a study more essential than ever. Our study asks our user base of people with Amblyopia questions through two surveys, verbal feedback, and interviews about their experience with our VR video game therapy. We found patterns encoded in this information, which we use to create preliminary hypotheses for making VR experiences as usable as possible for people with Amblyopia.

BACKGROUND AND RELATED RESEARCH

Background

Amblyopia is the most common neurological eye disorder worldwide, impacting 1-5% of the population [23]. Amblyopia affects the connection between an eye and the brain, where the affected eye will have significantly reduced visual feedback. Due to this, the non-Amblyopic eye becomes dominant and processes visual information more clearly and dynamically, causing the brain to weaken the connection to the Amblyopic eye. Symptoms include reduced visual acuity, reduced or lack of depth perception, blurry vision, susceptibility to the visual crowding phenomenon, and double vision in severe cases [23].

The loss of vision in one eye, which people with Amblyopia suffer from, has been shown to lead to poor eye-hand coordination [25, 13]. It impacts academic performance as most people with Ambylopia have difficulty with reading [13, 18], and writing [9]. In fact, a topic of very hot debate in research has been if it is a possible correlate of Dyslexia [11, 1]. Dyslexia is a very common learning disorder that makes reading difficult. It is not debated whether Amblyopia and Dyslexia have the same symptoms when it comes to reading performance with similar severity[5]. In fact, a study comparing the two disorders points out that there is a gap in legislation for people with Amblyopia that does not entitle them to the same reading accommodations people with Dyslexia or other related learning disabilities get. The author points out this is a gap in legislation because people with Ambylopia have struggled with the same issues while reading and with the same or even greater severity than people with Dyslexia[5]. The legislation not reflecting the need for accessibility for Amblyopia may be accountable for the lack of research done on Ambylopia accessibility, which will be expanded on later.

Ambylopia has actually had a very effective therapy called "occlusion therapy". Occlusion therapy has been around for 250 years [12], but was first formally recorded in a 1936 British medical journal [24]. This therapy entails wearing an eye-patch over the non-Ambylopic or strong eye to encourage the brain to reforge the connection to the Amblyopic eye but leaving one visually impaired since the strong eye is occluded. However, occlusion therapy has infamously low compliance or follow through with therapy [8]. This has been attributed to many different aspects of a limited design, which causes discomfort to those who use it and was initially expected to be done for hours each day. In the 1990s and 2000s, there were many studies that paired some form of media (watching movies, games, and the like) with occlusion therapy, many with an increase in user compliance but still leaving plenty of room for improvement. There has been a very recent explosion in the use of virtual reality (VR) for an alternative rehabilitation for Amblyopia [22, 17, 2, 3, 27, 10, 6, 26, 19], many of which have been successful in one measure or another. This is a logical step in Ambylopia therapies as mixing traditional therapies with media mediums was the only thing that almost made occlusion therapy viable. Furthermore, VR offers unique factors compared to previous media mediums that make it perfectly suited for Ambylopia therapy.

VR is binocularly manipulatable, meaning you have the opportunity to burden or manipulate the vision only one eye while keeping the other unchanged. By the nature of Ambylopia, this is critical in all forms of Ambylopia therapy. Additionally, most virtual reality headsets commercially available today are

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able to track data. This allows the potential for seeing performance fluctuations and even logging of when users participate in their therapy game. Data tracking could -has in VR therapies for other medical conditions- help increase compliance with therapy or give insights otherwise hidden by non-VR therapy options. On top of these factors, VR is immersive.

Immersiveness has been proven time and time again to distract from discomfort. VR's ability to distract from discomfort is best illustrated by a recent academic study that became internet viral. For this study, researchers from the University of Washington created a VR game called "SnowWorld," which stimulated an icy terrain for burn victims in the ICU. They found that their VR therapy was just as effective as morphine in reducing pain and discomfort[14]. Lastly, VR video games as a therapy offer gamification.

Gamification is where a non-game related concept or goal is translated into a gaming format to encourage user engagement and continued use. Gamification has been used in many different settings, including teaching, safety training, and therapy. Studies have been done which show gamifying therapy increases compliance, which is perhaps not surprising as getting to play a game for an hour a day is much more stimulating than a repetitive task with no objectives besides completing the therapy. All of these factors come together to make VR therapy result in a better chance for compliance and a more effective therapy for Ambylopia.

Related Research

We discovered during our literature review that there was no research to date which outlines Amblyopia usability for game design. This is surprising as Ambylopia is very similar to Dyslexia. In fact, it even has a larger breadth of symptoms and can be of equal or worse severity, yet there is plenty of studies conducted on Dyslexia and similar disorders. What was found in our search for any work on the topic is outlined as follows. One paper reviews different systems of administering VR therapy, but only explores "accessibility" through the lens of affordability and widespread access to a system [19].

In terms of usability, the only research we found was a paper which discusses the usability of a rehabilitative computer game they created [4]. This paper mostly talks about usability in terms of the physical system, like using 2 screens as opposed to 1, and it measures success in terms of vision tests and that users did not have accurate mouse skills and kept trying to physically move the mouse. However, this study mentions design usability observations that we were able to consider and build upon in our study. This study notes that users responded better to non-busy spaces, with non-textured floors and walls. We found a similar pattern in our own work, but we specifically hypothesize that it is due to known side effects of Amblyopia, and propose preliminary methods to overcome these issues.

PROBLEM AND MOTIVATION

Overall, the work being done on this topic as a whole is very overwhelmingly focused on being assistive technologies and either proving their effectiveness in correction or the soundness of their concepts. Based on these metrics, most of the VR therapies studies have proposed and tested have been very successful in one measure or another and show much more promise than occlusion therapy. In fact, a handful of these studies have even put patents on their work with at one of them became recently available to use in clinics. The way research has been progressing on this topic, it seems VR gaming will be the future of the therapy.

Yet, while conducting a literature review, it was found by in our research that a non-trivial number of these studies had glaring game design flaws. Our research team had three people with Amblyopia on it at this point, so these design flaws or strengths were easy to notice. However, we identified that our observations could possibly be an anomaly, or we could be biasing one another. Thus, we programmed our own VR game therapy and conducted a user study to see if a group of people with Amblyopia would observe their own issues or strengthens with different aspects of VR therapy game design in patterns. Using their observations, it would be easy to find patterns and make guidelines for intelligent game design for people with Ambylopia.

Having intelligent game design is essential for play-ability for general audiences. For people with Amblyopia and similar disorders, intelligent game design is *critical* for the game to be usable. If these VR therapies are not designed with certain things about the demographic in mind, then follow through with therapy will stay low. For example, it would not make sense to make a website for people with Dyslexia that is text-based, so why did some of the studies have equivalent factors that may make their games less usable and comfortable for people with Ambylopia?

Without taking such factors into account during the design process for these VR therapies, their long term compliance may be poor, which makes them not an improvement over occlusion therapy. With the rise of VR games and the new interest of using VR for Amblyopia therapy, it is the best time to start a conversation on what makes VR games more usable (and therefore comply-able for therapy) for people with Amblyopia. With this study, we are hoping to start that conversation on what methods could be added to VR game designs to make them optimally usable. We explore the barriers experienced by our users and theorize how to best overcome those barriers.

UNIQUENESS OF APPROACH

Protocol

Our VR game therapy for Ambylopia entails our having our users play a VR video game we programmed for at least 3 sessions. The game structure and design is based on, and similar to, other VR therapy's video games. The game uses blur that reduces visual acuity on the dominant eye of a person with Amblyopia. The game we created is played like Fruit Ninja, if Fruit Ninja were in virtual reality. It is only different in the aesthetics, as you are a miner in a cave and you catch gems with an ax rather than slicing fruit. The specifics of the software, programming, and hardware will be expanded on in the technical section of methods.

Survey data was collected before using our VR game and then once more after completion of all VR sessions. We wanted to understand the opinions users had on their Amblyopia before knowing about the VR therapy. It was essential to see how the user's perception of Amblyopia treatments changed before and after the game. Having users take surveys before and after also gave us insight into what their compliance was with previous Ambylopia therapies versus what they would expect it to be with our game and why. Additionally, users were encouraged to "think out loud". We asked them to "think out loud" as opposed to a "talk aloud", during each gameplay session to get more earnest data.

We additionally gave users an interview post-therapy. During the interview, we asked about their observations on game design and were able to hear more expansively than in the questionnaires on any problems they did or did not have. Our pre-therapy survey had 23 questions, focusing on users' history with their Amblyopia, compliance with previous Amblyopia therapies, and previous experience with VR. The post-study survey contained 15 questions. These questions were aimed at gaining an idea of the user's experience with our VR therapy, opinions on different aspects of the game, and their compliance with our VR therapy.

Our game design includes a factor of visual crowding, as most VR experiences and video games would. Visual crowding is the inability to recognize objects due to visual clutter or too many objects in their line of sight [28]. Visual crowding is something people with Amblyopia struggle with severely[7, 28]. Therefore we felt testing different levels of visual crowding would be telling of what level is considered acceptable for people with Amblyopia in a game. Another factor we tested was the amount of movement required for the game.

Movement is necessary for increasing neuroplasticity [16, 20, 21], and VR encourages this movement. However, movement can imply the need for competent depth perception and eye-hand coordination, something people with Ambylopia struggle with. Based on this fact, we felt testing movement would also be revealing as to what is appropriate for people with Amblyopia. Our layout for what the virtual environment set up looked like in Unity's metrics is shown in Figure 1. The playspace is the range users could and would need to move around in. To test movements, we altered this play range and the gem spawn range to be scaled to different sizes such that they were farther away or closer in the real world.

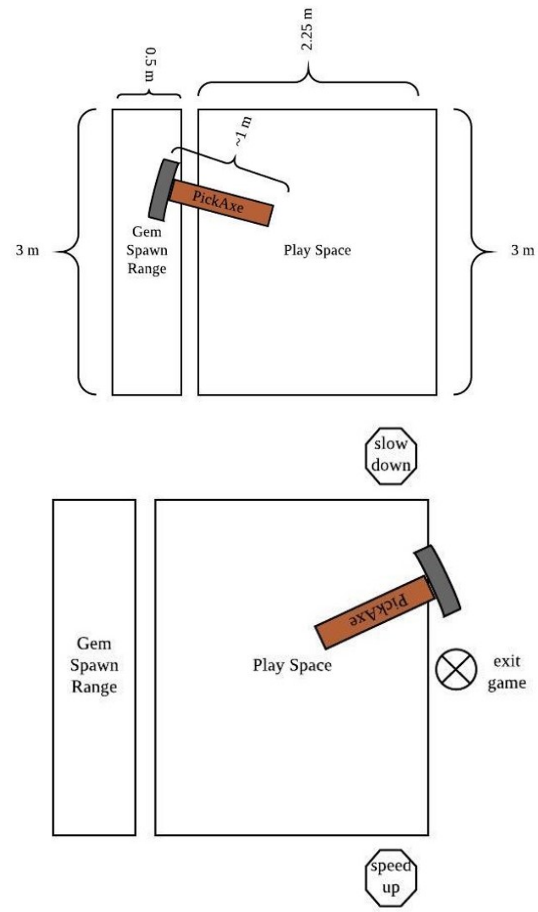

Figure 1. Shown above is the main physical layout of our game to demonstrate how movement is required and manipulated.

Technical

This study used an HTC Vive virtual reality system for user sessions. The HTC Vive system has a refresh rate of 90Hz. Usually, to avoid motion sickness, 60Hz, or more is required. Therefore the HTC Vive is fast enough that it ensures no one will get motion sickness. The HTC Vive comes with a headset and controllers which are tracked via infrared sensors. These infrared sensors send pulses 60 times per second. According to the HTC Vive official website, this many pulses per second with an infrared sensor allows them to get within sub-millimeter precision tracking. The features the HTC Vive system offers are useful to the study since users will not have to experience motion sickness or image lagging due to a slow or outdated system. Having a high-quality virtual reality system allowed us to isolate user feedback on game design without having hardware faults, which could alter their experience.

For our study, the HTC Vive controllers were programmed through the Unity software to appear in virtual reality as an ax. To program a VR game that would be playable via the HTC Vive, we used the Unity game developing platform and game engine. In Unity, we created C# scripts to program the virtual gems spawning, the speeding up and slowing down of spawning time, the collisions between the gems and the controller, and the phasing between the instructional scene, the gameplay and the game over scene. We also wrote scripts to change the visual crowding, which was represented by particles, as shown in Figure 2. We programmed the spawning to happen closer or farther away to manipulate how far a person would need to move in real life to catch a virtual gem to manipulate movement.

User Demographics

Our data is based on 9-10 participants. 10 users filled out the pre-study survey. Only 9 users filled out the post-study survey and attended the interview. 4 users were tested using different settings for visual crowding and kinematic requirements. All users had Amblyopia: 6 users with Amblyopic left eyes and 3 with Amblyopic right eyes. Of the 10 users, 6 were women, and 4 were men. Of the 9 users, 5 were women, and 4 were men. Seven of our users were age 21 to 23, two were 25 to

27, and one user was age 48. 5 users reported having used VR previously to our study.

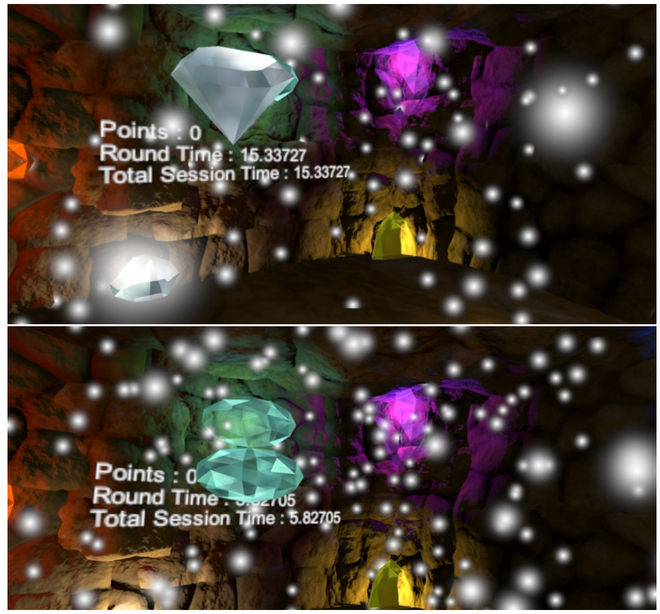

Figure 2. Shown above is our game with different levels of visual crowding.

RESULTS AND CONTRIBUTIONS

Analysis

This section has been divided into subsections. Each subsection corresponds to a symptom of Ambylopia. We analyzed the user feedback and interpreted what feedback we received that was a pattern or significant. Once we found the pattern of behavior, we then placed it into the section we felt appropriate.

Depth Perception

The size of the spawning ranges determined how much the user was going to have to move to catch the same amount of gems. We found that 3 out of 4 users rated a 4.5ft range un-doable. Participants reported moving at this range to be much more difficult in the forward and backward direction then from side to side. Users reported that they felt that the targets that spawned on the outer corners were far away from them, and they had to rely more heavily upon their depth perception. Making a range this small not only depleted the physical activity required for increasing neuroplasticity, but it was also not as fun. This created a loss of fun accessibility since a player with Amblyopia would not have as much fun as a person with healthy vision. We found the 3.5ft range on the x-axis (side to side movement) to be the most optimal for preserving play-ability and game integrity for people with Amblyopia. At this level, users did not have to rely as heavily on depth perception or keen visual acuity.

In one therapy session, our speaker was broken, and the game audio was not able to play while a user did the therapy. Though this case was taken out of the main study for not being consistent due to loss of audio, one interesting observation we had was that the user was more irritable and impatient than in their previous sessions. They scored below their typical average and were quieter during gameplay, implying that they were focusing more but achieving less. Other users said they felt the audio added to the immersion and helped them know when they touched a gem. Thus we credit our one user's low performance without audio to be due to loss of audio confirmation when they touched a gem, which would usually compensate for their loss of depth perception as a person who has Ambyopia. Furthermore, four users explicitly said without prompting that they would like it more if they had haptic feedback, more commonly known as vibration, when they touched gems on top of the audio. An even better addition would be using some recognizable beam coming out of the controller with a sphere that sits on the surface of an object to further confirm the distance of an object, as exemplified in a Microsoft paper on a Unity plugin for those with low vision [29].

Visual Crowding

Initially, we hypothesized visual crowding might actually be a good way to challenge and train people with Ambylopia. However, this hypothesis was based on the user's game scores, and with a more thorough look at our interviews with users, we found that this was not the case. Users reported that the more visual crowding we had in our game, the harder it was for them to perform accurately. Many users reported difficulty due to "over-stimulation" and not being able to distinguish important objects from unimportant ones.

One way we found that overcame this was making our main targets (being gems) large, brightly colored, and glowing to stand out among the white puff-like particles. Users reported that the neon-colored gems were easier for them to notice. The most accessible design for people with Amblyopia is to use minimal visual crowding. However, if jeopardizing the integrity or immersion of the game is the cost, it is important to find a healthy balance, so the game is not unplayable. We found an effective way to help users overcome the crowding phenomena was using targets or objectives that are easily distinguishable from the normal setting, as using aesthetically distinctive targets can trick the brain into giving them specific attention in the case of crowding for people with Amblyopia [15].

Reading

A frequent theme users reported while "thinking out loud" was that they liked that our game had an instructional scene with animated examples below the instruction shown. Another common theme from user commentary was that they liked that the informational scene was not timed at all (as it contained reading components). During the post-therapy interview, one user added on to this idea, saying that they had played games with tutorials where they could not keep up with the reading expectations.

User feedback patterns translated

The following game design tactics to improve usability has been created from patterns in user feedback. Based on our user study, we feel that those who wish to create games that are usable to people with Amblyopia should read over the

Figure 3. Shown is a screenshot of our game with instructions paired with examples.

following design recommendations. We have translated the main takeaways into more digestible guidelines. We have sectioned it off into sections that are easier to read for VR game designers, for easier access to what they should include and consider while designing their games.

Visuals

- Having minimalistic visual crowding
- Having targets or objectives be large (at least the size of a small dinner plate) and aesthetically distinct (ideally bright and colorful)
- Download this Unity plugin created by Microsoft for those with low vision and use the depth perception tool, which applies nicely to people with Amblyopia [29].

Audio and Haptics

- Having haptics and audio associated with touch, as it offers confirmation of a collision and assists with poor depth perception.

Structure

- Required movement should rely more heavily on side to side movement, keeping objectives around the same distance in the forwards and backward direction
- If, by the nature of the game, movement has to be in the backward and forwards direction, then try to reduce it as much as possible
- Instructions via example rather than text-based (especially, if the text were to have a time constraint)

Text

- Having few to no time constraints in the context of reading expectations
- Pair text with examples, animations or audio to demonstrate concepts

Taking these tactics in mind when designing a VR video game will render a more usable game for people with Amblyopia. As VR becomes increasingly popular for entertainment and Amblyopia therapies, these observations can steer conscious designers, especially those aiming to use VR for Amblyopia therapy, to design more intelligently.

Limitations

Though the research in this study points to the design tactics we have outlined, we were limited by our amount of users. We could benefit from more users in follow up studies to confirm the patterns we found. We encourage follow up studies to see if similar patterns are observed, so a more solid set of standard guidelines, like those in the Web Content Accessibility (WCAG), can be established.

Broader Implications

In her 2017 study, Birch points out that Amblyopia does not get the recognition it warrants in legislation considering its symptoms and severity[5]. In our search for work on usability for people with Ambylopia, we felt that this was echoed. Ambylopia is often overlooked as it only impacts one eye and the other eye usually overcompensates, which can make overall vision appear normal at first glance. There is very little work available on how to make game design more suited for people with Ambylopia. The fact that there is a lack of work to educate designers is even more problematic when VR games have become the future for therapy for people with Ambylopia. Just as one would not create a text-based homework website for people with Dyslexia, it is critical that game designers practice intelligent and educated design tactics. In the context of being used for Ambylopia therapy, if intelligent design is not used, follow through with therapy is likely to improve, meaning these fancy VR therapies are as useful as occlusion therapy.

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