# Virtual Reality Video Game Paired with Physical Monocular Blurring as Accessible Therapy for Amblyopia

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## ABSTRACT

This paper discusses a virtual reality (VR) therapeutic video game for treatment of the neurological eye disorder, Amblyopia. Amblyopia is often referred to as lazy eye, and it entails weaker vision in one eye due to a poor connection between the eye and the brain. Until recently it was thought to be untreatable in adults, but new research has proven that with consistent therapy even adults can improve their Amblyopia, especially through perceptual learning and video games. Even so, therapy compliance remains low due to the fact that conventional therapies are perceived as either invasive, dull and/or boring. Our game aims to make Amblyopia therapy more immersive, enjoyable and playful.

The game was perceived by our users to be a fun and accessible alternative, as it involves adhering a Bangerter foil (an opaque sticker) on a VR headset to blur vision in an Amblyopic person's dominant eye while having them play a VR video game. To perform well in the video game, their brain must adapt to rely on seeing with their weaker eye, thereby reforging that neurological connection. While testing our game, we also studied users behavior to investigate what visual and kinetic components were more effective therapeutically. Our findings generally show positive results, showing that visual acuity in adults increases with 45 minutes of therapy. Amblyopia has many negative symptoms including poor depth perception (necessary for daily activities such as driving), so this therapy could be life changing for adults with Amblyopia.

**Index Terms:** Visual acuity—Visual stereopsis—LogMAR—Crowding

## 1 INTRODUCTION

Amblyopia is the most common neurological eye disorder worldwide, affecting approximately 1-5 percent of the population [4]. Being a neurological eye disorder, Amblyopia entails a weak connection between the eye and the brain. As a result, the weak eye processes visual input drastically weaker and slower. This allows the strong eye to become exceptionally dominant and process visual input more clearly and dynamically, causing the brain to shut down the weaker eye.

Some of the symptoms of Amblyopia include reduced visual acuity, reduced or lack of depth perception, blurriness, and double vision in severe cases [23]. Such symptoms have been shown to lead to inadequate eye-hand coordination [8, 25] and is commonly misdiagnosed in children as dyslexia, as it tends to lead to difficulty reading [8, 16]. Thus, the side effects of Amblyopia include impairments in one's physical, academic, and possibly phonological skills [11]. Due to the imbalance of the eyes, Amblyopia very often

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leads to strabismus, an eye misalignment, which is more commonly known as a "lazy-eye" [8].

The traditional therapy for Amblyopia has been occlusion therapy, where one wears an eye-patch over their dominant eye to force their brain to use their weak eye to strengthen the neurological connection. This therapy was only expected to work on children [19]. Therefore, children would have had to have been diagnosed at a very young age, when Amblyopia is more difficult to detect. Although this therapy was found to be low cost, easily accessible, and effective as a permanent treatment, the compliance among Amblyopes is very low [6, 24, 27]. There are multiple intertwining reasons why this happens. For a start, the patch is aesthetically unappealing and not discrete. Secondly, since those with Amblyopia rely on their strong eye for vision, taking it away can feel very uncomfortable. Additionally, many are unconvinced that it can make a drastic enough difference to take the time to wear the patch.

Although traditional therapies have been shown to be more effective when applied at younger age [25], it has been shown that more non-traditional therapies have also been proven to be effective as treatment, even in adulthood. In fact, one recent paper reported that physical activity in conjunction with short term occlusion on the Amblyopic eye improved adult Amblyopes' visual acuity and stereopsis [15]. Until recently it was thought that Amblyopia was only correctable through therapy in children due to their high neuro-plasticity, particularly in the visual cortex. However, these therapies of the past did not entail use of VR. VR has been more recently popular among researchers for neurological disorder and damage rehabilitation. This is because VR has demonstrated to increase in neuro-plasticity adults of all ages [13, 20, 22].

Utilizing VR's binocularity has started to be a subject of interest among Amblyopia researchers. Some recent studies suggests that having a burden on the strong eye, but not completely occluding the eye and instead making the eyes work together is more effective than the traditional complete occlusion technique [31]. Other researchers have designed VR or binocular games or media that only have certain key visual components in the users' weaker or stronger eye [2, 3, 7, 10, 28, 29, 31]. These methods have had some forms of success[1] with treatment even in adults. Additionally, the issue of compliance with Amblyopia therapy started to disappear with the VR video games. With VR video game therapy, the exercises are more engaging and fun, there is no patch to be aesthetically unappealing and the users vision is not completely impaired. Additionally, the media or video game can serve as a distraction from the visual manipulation or impairment.

Although VR video games designed as therapy for Amblyopia seem very promising, most of these games are not available to the public at this time. Of those that are available, a few have been patented and are exclusively available under supervision of an eye care specialist (e.g., https://www.seevividly.com/) and a trained eye care specialist is required to oversee the therapy. The handful of games that are accessible by download via public digital VR video

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[1]increase in visual acuity or stereo acuity

game distribution platforms[2] are very limited in quantity, variety, enjoyability and gameplay length. They tend to be more amateur in their design and production, as they are presumably created by individuals with more limited resources then big VR video game companies. Additionally, some games advertise that they are for Amblyopia but do not have any citations or research to back up their methods.

For our game, we focused on the use of the physical blurring via a Bangerter foil and studying which -if any- occlusion level was optimal for Amblyopia treatment. We choose the Bangerter foil because, in opposition to full occlusion patches, one can still see through the foil and therefore can still utilize VR. Bangerter foils are found to have better compliance than patching therapy for Amblyopia [5, 9]. Additionally, they tend to be kind of as effective in terms of visual acuity improvement to patching, in children [5]. Bangerter foils have levels of occlusion, which is created by micro bubbles. The closer together the micro bubbles, the less contrast and more spacial frequency there is [18]. Seeing as how the highest level Bangerter foil is the closest to a full occlusion patch, which has proven itself time and time again as the most effective treatment for children [5] and penalizes the dominant eye the most, we compared the stronger (more blurred) Bangerter foils, which "stimulate" 20/200, 20/100 and 2/70 vision. It was necessary for us to try different levels of blurring because we needed to balance user comfort with effectiveness. We expected that the strongest foil would prove the most effective with the game but would be too uncomfortable for the player to wear. However, in our study, we were delighted to find that the strongest Bangerter foil was a hindrance at first, but was completely unnoticeable to users during gameplay. Based off user feedback, we hypothesized that this is due to the immersion and therefore distraction of the VR environment. User's game scores support this, as there was not a significant difference in their scores when they played with a stronger foil versus a weaker one.

Additionally in our game, we included a factor of visual crowding in the game via a particle system that imitates crowded visual stimuli, as Amblyopic people have consistently been found to struggle greatly with visual crowding. Visual crowding is where one cannot recognize objects due to visual clutter or too many objects in their line of sight [30]. We also tested what level of visual crowding works the best with the physical blurring to optimize the video game's therapeutic qualities, without making the player frustrated. Manipulating crowding is very important as it has been suggested that the reason Amblyopic people are poor at reading is due to poor visual crowding rather than poor visual acuity [12]. Much like with the Bangerter foils, we found through user feedback and scores that the more crowding did not disadvantage a player significantly.

Besides immersion, a big upside of VR video games as Amblyopia therapy, as opposed to wearing a Bangerter foil while watching a movie, is kinetic manipulation. On top of VR alone being able increase neuroplasticity [13, 20, 22], studies often argue that brain disorders benefit from physical activity [14, 17], because it seems to improve neuroplasticity. Neuroplasticity is very much lacking in adult Amblyopic people, making it the biggest hurdle to treating Amblyopic adults, and is why Amblyopia treatment was only believed to work on children in the past. Additionally, multiple studies on rats with Amblyopia found that physical exercise improved visual acuity [1, 21, 26]. Another study on Amblyopic adults found that physical activity increases brain visual cortical plasticity in the short term, which could allow for adults with Amblyopia to more viably be successful in therapy [14]. A very new study went even further by testing Amblyopic human adults via short term occlusion accompanied with physical exercise and found very positive results in improving visual acuity and stereopsis longterm [15], implying again that physical activity may aid Amblyopia treatments. Based on these studies, we felt it necessary that have we have made sure

the game require as much physical movement as possible while still being comfortable to the users, to optimize any therapeutic qualities and take advantage of virtual reality's user movement manipulability.

## 2 DESIGN ITERATIONS

### 2.1 Version One: Ambly-Olympics Game on Mobile Platforms

#### 2.1.1 Design Features

Our first game design, shown in Figure 1, was loosely based off the popular game Temple Run. We chose this game because it was critical to us that the the game was endless so users would not stop playing the game after a final level was complete. In this iteration of the game, we designed it to be compatible with mobile platforms so we could download a copy of the game on each user's phone. Each week, We instructed each user to play the game when they had time, with a minimum of 10 minutes a week, over the course of a month.

We designed the game to be endless by writing scripts that randomized the spawning of obstacles, coins and power ups. The game sped up over time so it never got monotonous. However, the "speeding up" mechanic plateaued at the end. When the player died, it would cut to an end screen and ask the player if they wanted to restart or quit the application. Unlike Temple Run, there were no sharp turns. We felt the sharp turns may induce nausea. The visual aesthetics were based off the Olympic hurdles, thus the name Ambly-Olympics.

We chose mobile VR platform for our game for the affordability and accessibility of mobile VR headsets and because there are plenty of headsets that can accommodate glasses of larger sizes. This was important because we would like to enable our users to wear correction glasses while playing the game if they wish (we should note that around 40 percent of our Amblyopic users wear glasses as their primary form of correction).

#### 2.1.2 Research Focus

In addition to the high level future goal of improving Amblyopia therapy compliance, the focus of the study reported in this paper is to explore the effects of physical blurring. We were particularly interested in the physical blurring option which, in theory, mixes the positives of traditional therapy like effectiveness, affordability and at home accessibility with the positives of non traditional therapies: effectiveness in adults and higher compliance. We carried this focus into our second iteration because if physical patching is effective then a person with Amblyopia could buy the patch on-line and adhere it to any VR headset and be able to play any of the hundreds of thousands of games available on VR platforms. We upgraded our Unity version to Unity 2018.1.7f1 for the development of MMC so we could more easily run it on a virtual reality system called the HTC Vive[3]. We downloaded the Steam VR plug-in. This plug-in links Unity with the HTC VIVE so testing games developed in Unity on the HTC VIVE is as simple as plugging it in and and pressing start (in Unity), assuming the VIVE's cameras are already set up.

We mounted our cameras early on in development so we would only need to set them up once to save unnecessary effort during game testing. Setting up our game to be played on one platform in one location while maintaining a consistent device setup streamlines our development process. Furthermore, both Unity and SteamVR are open source so we can readily acquire these two tools. Both have extensive libraries and plenty of on-line documentation presence, making learning them easy. They have resources for both Javascript and C#, although our game is written exclusively in C#, the language our developers were more comfortable with. Switching to HTC VIVE made our development process more efficient than other platforms.

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[2]i.e. Google Play, Steam VR, Apple's App Store

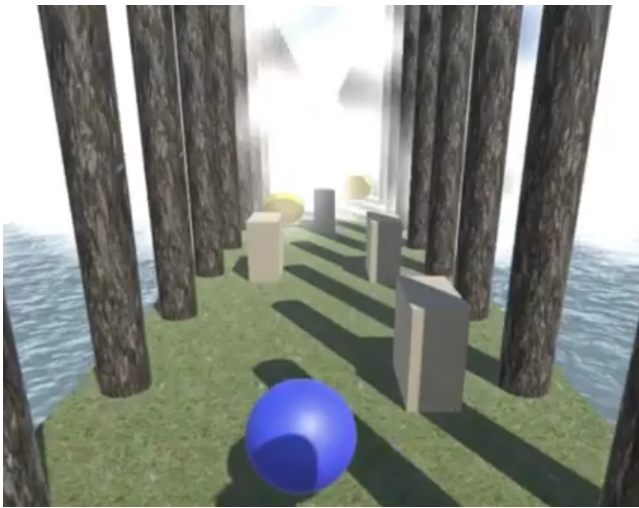[3]the standard HTC Vive, not the HTC VIVE Pro

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Figure 1: Ambly-Olympics gameplay. The blue ball is the movable player and the game camera is constantly moving down this long, endless passageway. The beige blocks are the hurdles and the yellow in the back are coins.



Figure 2: MMC sample beginning instructional scene.

Another advantage to the HTC VIVE is that it has motion capture at a 60Hz refresh rate using over 50 various sensors. These sensors consist of photo sensors, accelerometers and MEMS gyroscopes, while integrating pulse modulated infrared laser sweeps. The Vive headset itself runs at a 90Hz refresh rate and has a 2160 x 1200 pixel resolution. These features were specifically designed to minimize any motion sickness. On top of this, the HTC VIVE comes with its own "Chaperone" system. The Chaperone system warns the player about the boundaries in their virtual setting. This is particularly important, particularly for our older users and those who are technologically frail. Additionally, we found this system makes players feel more immersed in VR and gets rid of anxiety in those who are skittish about virtual reality.

Every user completes therapy sessions in our lab. This has the upside of testing in a controlled environment where the subjects are under constant observation. Constant observation of their gameplay has led to improvements on the game that would not have been done if we could only observe the subject through their pre-recorded data. The improvements led to the second game that deals with visual crowding described below.

The second game, Magic Mining Cave (MMC), is loosely based off the popular game Fruit Ninja[4], a projectile slashing endless game with points, obstacles and power ups. We chose for the game to be endless spawning for the same reasons as the Ambly-Olympics game. The endless-ness allows users to continue playing as long they wish without ever "finishing" the game or the final level.

The game starts in an instructional scene where looking around your environment shows text instructions on how to play and the "magical" abilities of each gem paired with visuals of said gems. Once they are done in this scene, they can start the actual gameplay by slashing a gem that says "Start Game". However, the user always has the ability to go to this scene in game by hitting an "Instructions" gem on the back wall of the Cave. We thought it was important for them to always have access to the instructions due to the range of both age and familiarity with video games within our user pool. Our users range from 18-55 years of age and some have reported to never have played modern video games before this study, let alone VR video games.

The main gameplay takes place in a cave surrounded by gems of various colors with small twinkling star-like particles rising through the cave floor and out of the ceiling. Aesthetically speaking, this gave the game a more magical, otherworldly fantasy atmosphere. However, we decided to include this particle system and vast array of colored gems to test visual crowding. Visual crowding is the inability to recognize objects visually, due to the brain being overwhelmed by too many objects being inputted. Since people with Amblyopia especially struggle with not being able to recognize individual objects due to crowding, we could explore if crowding was helpful or hurtful in the context of therapy. It would be easy to compare the users' scores and time spent without dying to the percentage of particles we included in each frame.

The main mechanic of the game is that the player holds one VIVE wand, that looks like a pick-axe in game, and uses it to slash gems that are propelled up from the floor. The gem spawning is randomized and different gems have different abilities or point values. One reason we did this was so users could not then memorize any patterns. Most gems (orange, yellow, turquoise and purple gems)[5] are worth one point, but the diamond is worth ten points as it moves at a higher velocity than other gems. These factors were meant to encourage a player to move as much as possible during gameplay. We want to encourage movement and light physical activity because during the development of MMC, we ran into a study that suggests that doing physical activity is effective in increasing visual acuity and stereo acuity in Amblyopic adults [15]. We found this particularly interesting because we could easily design our game to require more movement to induce some natural physical activity. The green gem or "emerald" speeds up the spawning rate of all the gems by 15 percent of a second. The red gem or "ruby" slows down the spawning rate of the gems by 15 percent of a second. These abilities were designed to cater to the skill level of the player. A player can adjust the settings by turning 60 degrees to the left, for green gems, or right, for red gems, away from the usual gem spawning place, to hit these gems to turn up or down the spawning speed of there game. We programmed the game so that after a certain amount it can not be sped up or slowed down anymore to avoid unplayable spawn times. Additionally, we programmed the game so even if they die, the spawning speed setting they input stays so they do not have to reset it the next time.

The game ends if the player touches a black hole gem. This gem is designed to look like something from a science fiction film and has rainbow neon particles spewing out of it so that it looks unstable. These particles also make the black hole gem eye catching and therefore easier to detect and avoid. Outside of gems, there is a stick of dynamite. The dynamite takes away 10 points from the users score, although the players score is programmed to stop at zero

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[4]TM

[5]or amber, citrine, aquamarine and amethyst, as they are called in game

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and never become negative. Once the game has ended, it switches to the end scene where the user has the option the slash the "Restart" gem.

## 3 METHODS

### 3.1 Visual Acuity and Stereo Acuity User Testing Protocol

Our users consisted of 4 women, 4 men and 1 non-binary person. 5 users were born female and 4 were born male. We had 6 users with weak left eyes and 3 with weak right eyes. 6 of our users were age 21 to 23. 2 users were 25 to 27. 1 user was age 48. 7 of our users were white, 1 was Hispanic and 1 was Asian.

It should be noted that the users in our study were self proclaimed Amblyopic people. We did not have access to their medical records, although most users reported that they had been formally diagnosed with Amblyopia and were told to do occlusion therapy. We did test our user's visual acuity and stereo acuity to see if they fit the expectations for a person with Amblyopia. If they did not fit the expectation for someone with Amblyopia, they were excluded from the study.

Exclusions include:

1. Not a drastic enough difference in visual acuity between the two eyes

2. Eye misalignment due to outside factors, such as an eye infection, rather than neurological factors

3. Ptosis[6] with no actual signs of Amblyopia

The person in our group who administered these tests has interned under two optometrists and is currently applying to optometry school. She also consulted the optometrist she works under for opinions on the study or user data.

We administered the tests before the user starts the VR video game therapy and directly after 3 sessions of VR video game therapy. We choose to use two different types of visual acuity charts to get a more comprehensive idea of the users' vision over time, much like how actual optometrist do. Our protocol included 3 different tests:

1. *Long distance visual acuity test*[7], often called the logMAR[8] chart. This chart tests user's vision clarity which is dependent on optical and neural factors. This test was hung in the same place for before and after tests. The users read the letters from 20 meters away, with one eye blocked with a paddle eye occluder. We asked them to block the strong eye and read with the weak eye first. Additionally, we alternated asking them to read lines left to right and right to left. We did this so they would not just memorize the letters while reading with their better eye, which would make the weaker eye appear stronger. Users were consistently given half a point if they guessed correctly and then switched to a similar letter.

2. *Short distance visual acuity test- numbers*. This chart also tests user's vision clarity. Using both long and short distance tests gives us a more holistic evaluation and is more likely to get rid of any outliers. The chart was held 16 inches away from the user's face and they were asked to read off the chart with one eye occluded. Again, we asked them to block the strong eye and read with the weak eye first. Alternating between reading left to right and right to left was also used. Users were consistently given half a point if they said correctly and then switched to a similar number.

3. *Stereopsis test*[9]. This test evaluates stereo acuity, more commonly known as depth perception. Naturally, for this test the user uses both eyes together. They wear special 3D glasses and are asked to identify what letters or shapes pop out at them. The test was held at 16 inches away from the face, level with their gaze. Users were consistently given half a point if they guessed the correct circle, instead of knowing it was correct.

Every test was administered in the same room before and after to ensure the same lighting and background environment. These tests are intended to be our primary source of quantitative data.

### 3.2 VR User Testing Protocol

All therapy sessions were done using the HTC VIVE. All users were asked to wear their corrected lenses or contact lenses to sessions.

1. *Amblyopia Optometry History and First Impressions Survey (Pre-Gameplay)*. We had our users fill out a survey explaining their history with Amblyopia, Amblyopia therapies in the past, what they expect to get out of virtual reality therapy and theoretical questions about compliance with virtual reality therapies. This survey was composed of 24 questions, 21 of which were mandatory to answer. We used this survey to collect qualitative data as there were only 9 users, making quantitative statistical analysis less meaningful.

2. *Virtual Reality and Magic Mining Cave Training*. We familiarized our users with the HTC VIVE wands and how to adjust the headset for maximum comfort. We emphasized that there is a knob on the front of the headset that allows one to adjust the distance between the eyes. If this adjustment is not on the right setting, one's vision can seem blurry. We then ran them through how the Magic Mining Cave game works.

3. *Gameplay Therapy Sessions* We had at least 3, 15 minute gameplay sessions with each user over the course of a week to 2.5 weeks. Users were encouraged to come in consecutive days. Before the session started, a researcher would adhere a 0.1 level Bangerter foil on the lens that the strong eye would be seeing through. Each user had finished 45 minutes of testing at this time, although we would like to continue these sessions in the future. Additionally, for our new users in the study we would like to see how an increase changing factors like occlusion level, crowding, brightness and physical activity impact the outcomes of the therapy. During gameplay, another way we received our quantitative data was from tracking players points, deaths and dynamite catches and game speed.

4. *Post Gameplay Survey* After they finished 15 minutes of gameplay, users were asked a series of questions and to fill out a survey documenting their feelings towards the therapy, virtual reality and theoretical therapy compliance. This survey was 15 questions long, with all questions but one being mandatory for them to answer. These surveys were used for qualitative data.

## 4 RESULTS AND ANALYSIS

It should be noted that some users participated in testing variations of settings (for different levels of occlusion, crowding and physical activity) that became the control settings for the study. Consequently, there is a discrepancy between the amount of users through out the result subjects.

From our observations, we noticed our users learned how to play the game very quickly. Users affirmed that they understood how to play the game after a verbal debriefing from a researcher. Even after this verbal debriefing, users entered an introductory scene that displays the instructions as you look around. The users swift learning

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[6]Ptosis is the drooping of an eyelid due to lack of or damage done to the eyelid's muscle, this will look like a "lazy eye" but subjects may actually have normal vision

[7]Grafco 1240 Snellen, Non- Reflective

[8]Logarithm of the Minimum Angle of Resolution

[9]Randot Stereo Test

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could be in part due to the relatively simplistic nature of our game and also due to the mostly younger demographic, who predominantly reported verbally being mild to avid gamers. Most users did need a game or two to get used to the controls but understood the objectives.

## 4.1 Interaction Optimization

### 4.1.1 Impact of Different Levels of Occlusion

We tested out multiple levels of blurring for the Bangerter foils to see what was the highest level users could comfortably handle. We worked our way up from the 0.3 blurring level, which is equivalent to seeing with 20/70 vision, to the 0.1 level, which has blurring so strong that it is equivalent to having 20/200 vision. In between we had users try the 0.2 level ( 20/100 vision). We only had the first 4 users try all these patches before it became apparent via user feedback that the higher level patches (0.1) were just as comfortable to wear during gameplay. From then on out we asked the next 5 users only if the 0.1 patch was comfortable during gameplay.

For 0.3, 0.2 and 0.1 patches 4 of 4 users reported on our post-session questionnaire as well as verbally that the patches were not distracting after a few minutes of game immersion, despite the level of blurring. Our questionnaire had users answer if they felt the patch's blurriness was distracting rating it 1 to 5, where 1 was completely unnoticeable and 5 was very noticeable. All users felt it was not noticeable. When prompted why they felt this was the case, users credited it due to being focused on playing the game and the immersive environment. After our first 4 users rated every level of occlusion not distracting after a couple minutes of gameplay, we only tested the strongest patch (0.1) from then on out. We then asked the next 5 users if they noticed the blurring of 0.1 foil once they starting playing the game. We received feedback via post-session questionnaire as well as verbally that these users also did not feel it was distracting after a couple minutes of gameplay.

Though we got positive feedback from users, we also wanted to check how their performance differed from one patch to another. Data was recorded every time a player died, tracking their average score (in points) and the time it took for them to die. The data from these user's scores was not a substantial change in points scored because their scores were changing by an overall average of 144 points per individual game between playing with the 0.3 and 0.2 level patch versus the 0.1 patch. This change was on par with the 257 points average difference we saw users endure between games while wearing the same patch (0.1). Since there was not a significant difference in their scores when they played with a stronger foil versus a weaker one, we hypothesize that once users pass a certain level of more intensive blurring in their dominant eye, their brain switches over to rely more heavily on their weak eye.

### 4.1.2 Crowding in Video Game

During this test, we used only the 0.1 level blurred patch and had users find the spawning speed they liked in the beginning and then did not change it to keep the environment controlled.

We observed that when we set the particle's rate over time to 400, distributing over a 20ft (width) by 16ft (length) by 9ft (height) cubical environment, 4 users scored an average of 629 points over the course of 110 seconds. We increased the crowding by setting the particle system to 800 particles. The average was 545 between them over 109 seconds. Considering we typically see an average of 257 points difference between each persons score between games, this score change is not drastic. Therefore, we decided to stick with the 800 particle per second system. All users reported they felt the more crowding there was, the more difficult. However, they felt having more particles was a part of the challenge and immersion of the game.



Figure 3: be The comparison between two levels of crowding: 400 particles on the top figure and 800 particles in the bottom figure.

### 4.1.3 Physical Activity in VR Video Games

During this test, we kept the particle system spawning at the same rate, used only the 0.1 level blurred patch, had users find the spawning speed they liked at the beginning of each session, and then did not change it in order to keep the environment controlled.

We had 4 users who tested out various spawning ranges. 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 found a 4.5+ meters range too large and uncomfortable. We found 4 out of 4 players felt 2.5 meters or less was either too easy or boring. Additionally, from observation, this setting was not optimizing movement in users.

We choose to use a 3.5ft range in the x-direction (which requires moving side to side) with a 1.5ft y-direction. This range requires forward and backward movement and upward arm thrusts. This translates to moderate movement required or light physical activity. We decided on this setting because based on feedback, users did not notice how much effort they were putting in physically to slash gems.

## 4.2 Visual Data

In this section, we present the results from people who did 3-5, 15 minute sessions where the settings were:

1. Level of occlusion: 0.1 level Bangerter foil

2. Crowding in game: a rate of 800 particles

3. Physical Activity in game: The spawning has a 3.5ft range in the x-direction (require moving left to right and vice versa) with a 1.5ft y-direction (requires forward and backward movement and arm thrusts) range. The gems are randomized and can spawn anywhere in this range.

We allowed users to choose their own gem projectile speed to maximize comfort with users of all skill levels and ages.

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**(Amblyopic Eye) Average Long Distance Visual Acuity Before and After Therapy**
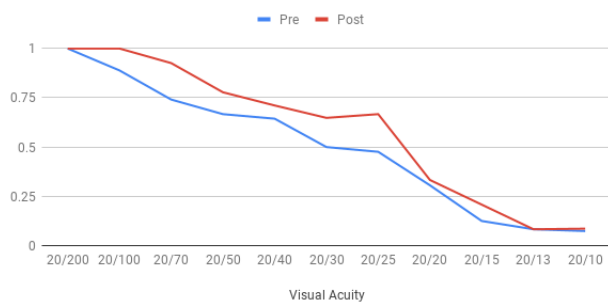


**(Amblyopic Eye) Average Short Distance Visual Acuity Before and After Therapy**
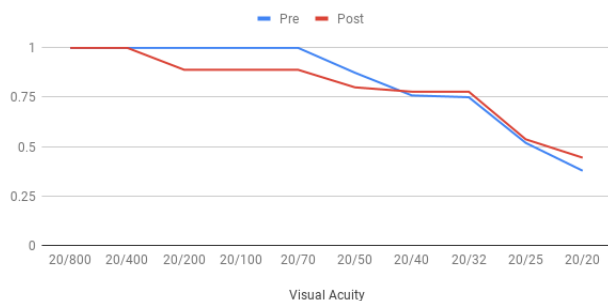


Figure 4: This data is from 9 users. One means they got it correct, zero means they did not get it correct. In between means they got that percentage of the visual acuity line correct. For example 6 out of 8 letters correct in a line would be 0.75. This is the average of the user base before and after playing our VR video game with a Bangerter foil.

### 4.2.1 Visual Acuity

In Figure 4, you can see there is a consistent increase in long distance visual acuity (post therapy) at almost every level. Only one user had no increase in this test. This increase translates to an average increase of a 15 percent of every single line. If a diagnosis were to be applied to the before and after averages, it would go from 20/70 to 20/50, which is entire line increase. An improvement in visual acuity implies that the therapy is effective at getting the weak eye to focus on a specific object in their view. These results also imply that with regular use over time, VR video games paired with a Bangerter foil might be a suitable therapy for Amblyopia visual acuity correction.

In Figure 4 and 6, one can see that our data from the short distance visual acuity test is not quite as consistent as the long distance; one user dropped over an entire three lines. This user improved on the long distance visual acuity test and we feel other factors may have encouraged them to want to leave testing abruptly. Consequently, we have presented the short distance test with and without them included.

With the outlier not included, there is an average increase of a 3 percent of every single line. This is significantly lower than the long distance visual acuity data. We feel this is because this chart is more polarized in its number sizing. The first half of numbers are very large and even our most visually impaired users were able to read all the way up to 20/70. After 20/70, the numbers get very small and are even blurred. For this reason, we feel that the long distance test

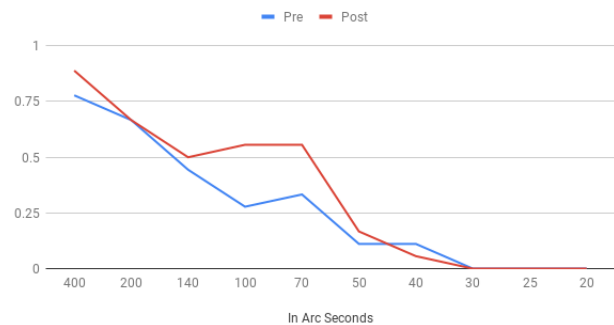**Average (Randot) Stereopsis Test Before and After Therapy**



Figure 5: This data is the average from 9 users. One means they got it correct, zero means they did not get it correct. This is the average of the user base before and after playing our VR video game with a Bangerter foil.

may have been a better signifier for visual acuity change. That being said the average increase per line between the long distance and short distance visual acuity was 9 percent, which is not insignificant. Based off the optometrist that advised us on this study, this translates to a half of a line increase in visual acuity in a full diagnosis of the average performance.

### 4.2.2 Stereopsis Test

Figure 5 shows the average results for the stereopsis test, As the figure shows, the results were positive overall. We argue that this positive result could be due to the Bangerter foil's minimization of contrast and increase of spatial frequency. These results imply that the Bangerter foil is helping increase binocular summation by suppressing the dominant eye. These results support the findings of our references on Bangerter foil therapy in adults, particularly

### 4.3 Theoretical Therapy Compliance

As studies had shown, therapy compliance is a problem with Amblyopic people. One of the most important finding of this study was how eager our participants were to participate in our therapy. We asked a number of questions centering around if they would continue this therapy on their own and what would keep them from doing so. We found that all users felt they would keep doing the therapy, if they had access to the system. They also stated that the game was so much more fun and enjoyable than their exercises were. We could conjecture that this means that we could expect a higher compliance rate with long term use of our game compared to the traditional therapy method.

## 5 CONCLUSION

### 5.1 Discussion

Virtual reality video games have the potential of being an alternative therapy for Ambylopia. VR games can require the physical movement necessary for opening up short term neuroplasticity in adults. VR games are completely manipulatable visually. Many VR games are already manipulated visually to include visual crowding as an aesthetic choice. VR is completely immersible and interact-able, allowing users to forget the exertion they are doing and the burden on their dominant vision. Based on user feedback that we received, the enjoyability of VR video games could encourage Amblyopic people to comply with therapy. On top of this, using a Bangerter foil could turn any VR video game into Amblyopia therapy, making this therapy very accessible and relatively low cost. And we found

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(Amblyopic Eye) Average Short Distance Visual Acuity Before and After (Excluding Possible Outlier)
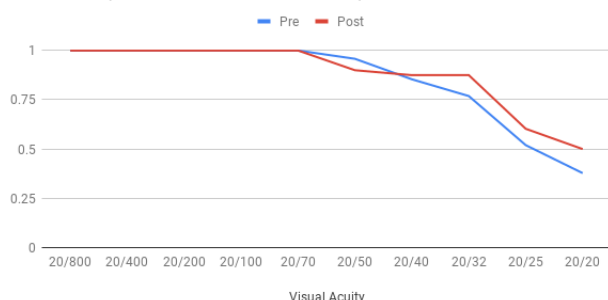
Figure 6: This is the short distance visual acuity test, excluding the possible outlier's data. As you can see, the post therapy values are more consistently higher.

that this therapy improves visual acuity in our user base of 9 after 45 minutes of gameplay.

To summarize, this study has shown that virtual reality video games are arguably a great therapy for Ambylopia, as they are equipped with multiple aspects that aid in the treatment of Ambly-opia. Even in a very short application of the therapy in our study, this therapy has shown to aid in visual acuity and stereopsis. We further argue that this therapy could be life changing towards adults with Amblyopia through improving eye-hand coordination, depth perception and reading skills. Additionally, this therapy is fun, discreet and largely age-friendly, maximizing theoretical compliance.

## 5.2 Future Work

Although this study is very promising, more diverse users would help us see if the patterns found in this study is consistent. Additionally, a follow up with users to see if their visual improvements have stayed long term is necessary.

Additionally, we have some MMC based changes we would like to implement. Based upon on user feedback and evaluation of our quantitative data, our study could be improved upon a number of ways:

1. Include haptic feedback

2. Start using the eye trackers to see if there is any change in eye movement velocity

A more fundamental change is that we would like to branch out to manipulate our VR video game such that we could digitally blur it. We want to digitally blur the game in the dominant eye to force the weak eye to work harder. Then we will explore the results and compare digital versus physical occlusion, to ensure that physical blurring is just as effective. Moving forward, it will be particularly interesting if the physical blurring was just as effective as digitally blurring the game for treatment of Amblyopia, since buying a physical patch is so much more accessible than having a digital manipulation included in your game.

In our future work, we would also like to isolate and increase the physical activity in MMC to see how more intensive physical activity could work in conjunction with out Amblyopia therapy. We would make physical activity the changing factor and explore the implications from the tests. However, this study is a first step in understanding the role of VR games for Amblyopia therapy, with promising results.

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