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Using Virtual Reality to Improve Sitting Balance

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USING VIRTUAL REALITY TO IMPROVE SITTING BALANCE

A Master's Thesis

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In Partial Fulfillment

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Master of Natural and Applied Science, Computer Science

By

Alice K. Barnes

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ABSTRACT

This thesis focuses on using virtual reality (VR) to enhance sitting balance and core strength. It is a study in how to create a VR exercise program which is interesting enough to keep players/patients motivated, but comfortable to play and not overwhelming to the senses. The software used for this study was written with the hope that a later version of it might be used with occupational/physical therapy patients one day. For this master's thesis, the initial testing has been done with healthy volunteers. The software incorporates what developers know thus far about designing for VR, and it is hoped that later software developers will benefit from knowing the results of this initial round of testing. All of the 39 test participants agreed that the game was fun, with 82% indicating "strongly agree" in the questionnaire. The enthusiastic responses indicate that the game probably has recreational value beyond therapy patients.

KEYWORDS: virtual reality, sitting, balance, benefits, drawbacks, core strength, occupational therapy, physical therapy.

This abstract is approved as to form and content

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Lloyd Smith, PhD
Chairperson, Advisory Committee
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IMPROVING SITTING BALANCE WITH VIRTUAL REALITY

By

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INTRODUCTION

Several challenges present themselves to occupational therapy patients and their therapists. Working through pain and tedium are high on this list. Pain and tedium in turn contribute to the overarching challenge of motivation. Many patients give up doing their exercises before reaching their full potential [1]. This thesis explores using virtual reality (VR) to make occupational/physical therapy and exercise in general more fun and motivating.

Some of the programs in the past intended for therapy patients and billing themselves as VR programs have been programs that supply an avatar for the patient and provide interaction with a conventional two-dimensional screen. As an example, if one views an OmniVR demonstration video, it is clear that the patients are working in front of a conventional screen [2]. This experience is not nearly as immersive as one involving a head-mounted display in which, no matter where a player looks, she/he is surrounded by a seamless world that appears three-dimensional. A better description of VR with a conventional screen would be "a conventional video game with an avatar." For this thesis and accompanying project, VR means using a head-mounted device (HMD) so that no matter where the player/patient looks, they see and interact with a seamless three-dimensional virtual world.

True immersive three-dimensional (3D) VR research dates back almost 20 years to studies with burn patients, in which it was shown that VR can be more effective than opioids in controlling pain [3]. Pain, of course, is an obstacle for occupational and physical therapy patients, and to a lesser extent for people in general who wish to get a great deal of exercise to attain or regain health. With opioid addiction now a broad-spectrum social concern, it is evident that less addictive pain relievers are needed. VR usage in both therapy and general exercise may be part of the answer.

While there is potentially great benefit in VR, care must be taken in the design of programs and gameplay. Players can become overstimulated or overwhelmed with conflicting sensory input quite easily and unintentionally by poor or under-informed design [4]. Designing for good 3D VR gameplay presents different challenges versus designing for traditional two-dimensional (2D) gameplay on a conventional flat screen [5].

This thesis and test results of the sitting balance game project aim to expand and better solidify the body of knowledge regarding 3D VR game design, especially with regard to its use in rehabilitation. After a literature review and accounting of the basic principles upon which VR operates, this study will present the methodology and strategy used for designing the therapy game and then review the test results. The following section considers comments and suggestions posed by test participants in relation to how the game might be further developed based on initial feedback. In the concluding section, the trajectory of the larger augmented reality (AR) and VR industries combined as a whole is examined, as well as its implications for VR/AR use in therapy. Presented last are implications and concluding remarks of the study.

LITERATURE REVIEW

Attempting to survey virtual reality literature is challenging. First, because definitions of what constitutes virtual reality vary, and second, because the technology has changed so rapidly and lacked standards in the beginning. Therefore, it is sometimes impossible to know exactly what caused experimental outcomes in the past. For these reasons, this literature review will focus on publications of the last decade (2007 to 2017), but will mention earlier publications where they seem relevant.

First, for the purposes of this thesis, virtual reality is intended to mean an immersive experience in which objects appear to be three-dimensional and the scene is continuous. No matter where the player looks—left, right, up, down, forward, behind—the player is surrounded by a seamless virtual world. Some commercial programs today, including commercial rehabilitation software such as that offered by OmniVR [2], bill themselves as virtual reality programs, but they are 2D video games delivered on flat screens, usually with an avatar supplied to represent the player. This is a very different experience from having a 3D world appear all around you, no matter where you look.

As of 2017, the state of the art experience for immersive 3D VR that offers a high level of interaction with the virtual environment requires a head mounted display (HMD) tethered to an entry-level gaming computer with a high-performance graphics card. Oculus Rift (utilized for this thesis study) recommends either an NVIDIA GTX 1060 or better or an AMD Radeon RX 480 or better graphics card [6]. Recommended CPUs are Intel i5-4590 or better; alternatively, AMD Ryzen 5 1500X or greater. A minimum of 8 GB of RAM is required, but more is preferred.

While there are head mounted holders into which a smart phone can be inserted, and this will allow one to view a 3D environment, interaction is very limited. For now, a cable (tethering) is required in conjunction with a special headset and graphics-intensive computing capability of a desktop or high-end laptop to facilitate immersive interactive VR. This thesis is concerned only with immersive, interactive 3D VR.

Development of 3D VR

The basic idea behind 3D virtual reality is that if each eye has a slightly different 2D picture of a 3D scene, approximating the way one's eyes have slightly different views in everyday life, one's brain will construct a 3D perception that mimics everyday reality. It is a very simple concept at its core for viewing still scenes, but comes fraught with many technical challenges if the person viewing the scene is to "move about" within it.

VR has some of its roots in Sir Charles Wheatstone's stereoscope invented in 1838 [7]. According to a Denver Post article, Sawyer's, Inc. took the basic idea of the stereoscope, combined it with an idea of organ maker William Gruber's [8] and developed the View Master which millions of children (myself included) enjoyed during the 1900's. According to the biography of Mr. Gruber, he is "the inventor" of the View Master [9].

These basic methods for viewing a 3D scene only allowed the viewer to see one still scene from one perspective. However, in the 1950's Morton Heilig invented the Sensorama, patented in 1962 [5]. Heilig shot stereoscopic movies for his device, which not only showed 3D movies to the viewer, but also had a vibrating chair, fans, sound and a smell generator to give the audience multi-sensory input. Viewers had to remain seated and could not move around to change their viewpoints within the 3D movies, but the other sensory input features along with the 3D movies were a step in the virtual reality direction.

The first head mounted display connected to a computer and displaying computer-generated graphics was invented in 1968 by Ivan Sutherland and his student Bob Sproull. It was a very cumbersome device that needed to be suspended from the ceiling because of its weight. This earned it the name “The Sword of Damocles” [5].

Though his most notable work in virtual reality employed large-scale (8 ft. X 10 ft.) wall projections of graphics, rather than HMDs, Myron Krueger is also worth mentioning [10]. Krueger’s Videoplace, developed in 1985, did not require gloves or handheld controllers to interact with the virtual world. The participants interacted with each other as shadow avatars in the “artificial reality” (Krueger’s term) [11] by using their bare hands. Today (2017) the leading manufacturers of VR provide handheld controllers to interact with their virtual worlds. However, Leap Motion has followed Krueger’s lead and developed technology (still in beta testing) that can allow a user’s hands to interact directly in the VR environment [12].

Thomas A. Furness is another important pioneer in virtual reality devices. Arguably, he may be the most important for his long-term contributions. He has worked in VR for 50 years, and is sometimes referred to as the “grandfather of VR” [13]. Furness began his career while working on helmet-mounted displays for the Air Force in the 1960s [14]. After his military service, he founded the Human Interface Technology Lab at the University of Washington. Furness has co-authored numerous papers on VR over the years and been responsible for new ground-breaking technology, including the virtual retinal display co-invented with Joel Kollin [15]. Magic Leap is now refining and miniaturizing that technology with the hope of eventually bringing it to the consumer market. Furness also co-authored one of the earliest studies in using VR to mitigate pain perception in burn patients [3].

Medical Uses of VR

Older than 10 years, but very valuable for its pioneering effort into the exploration of medical uses of VR, is Hoffman et al's work [3] using VR to ameliorate pain perception in burn victims. This study was published in the year 2000.

At the onset of a wound care session, the patient was given either a conventional 2D Nintendo game to play during the procedure, or was given a virtual reality experience during wound care. After wound care, the patient was asked to rank their pain and anxiety intensity levels. Effectiveness of playing conventional 2D Nintendo games as an analgesic was compared to that of experiencing 3D virtual reality during the procedure. VR effectiveness was dramatically better.

The scientists' theory for why VR works is as follows: "If patients become engrossed in stimuli such as VR, that draw heavily upon conscious attention, there will be less of this cognitive resource available to devote to the evaluation of nociceptive input, and patients will subjectively experience less pain" [3].

In simpler terms, this theory is something that practically everyone understands intuitively from childhood. Most of us, at one point or another, managed to skin a knee or an elbow while we were having a terrific time at play, but we were having so much fun that we didn't even notice the injury until after the blood dried. Burn victims still feel the pain of wound care, but engaging them in a highly immersive fun activity reduces the experience of pain.

More recent research along the lines of what might be called “distraction therapy” [16] include 2009 articles by Mahrer and Gold [17] on pain control and an article on chronic pain control by Shahrbanien et al [18]. In 2010 another study specific to burn patient pain control was published by Morris et al [19]. Hoffman et al. (2014) [20] published a case study using a Developer Kit version of Oculus, almost certainly the DK1 which was released in 2013. Note that this is the same H.G. Hoffman who was a part of the original HMD burn patient study in the year 2000. All of these articles give evidence of the great potential of using VR to control pain.

Hoffman et al’s 2014 work employed an “articulated arm mounted Oculus Rift.” The system is implemented via a floor stand with attached metal arm which in turn holds the HMD. This allows the patient to look into the HMD with little or no pressure against his or her face. This configuration is very important for patients with facial burns. The standard Oculus Rift HMD incorporates a dual spring mechanism to press and hold the HMD securely against the participant’s face. While the reviews of the Oculus Rift rate the HMD as relatively comfortable to wear [21-23], it does leave pressure marks on the face after wearing it for only a few minutes. This would be excruciating for a burn patient with burns on his/her head. The articulated arm for Oculus Rift therapy is a great innovation for patients.

The program/game used with the case study patient was SnowWorld. It was developed by Hunter Hoffman and David Patterson. One can view the use of this program with an earlier HMD that was used in a U.S. soldier’s rehabilitation [24].

Patients “throw” snowballs in the virtual world via a wireless mouse or, in certain situations, through head tracking. Functional magnetic resonance imaging (fMRI) scans showed marked reductions in pain-related brain activity when patients used SnowWorld. In addition to the article’s illustration, one can view additional scans at University of Washington Human Photonics Laboratory’s website [25]. The site also describes a “water friendly” VR system aimed at patients who need to receive care in a hydro tank. There is also a link to an NBC news story regarding a 2011 military study using SnowWorld in which researchers and patients found that “SnowWorld worked better than morphine [26].”

Lee et al [27] showed significant improvement in patients using VR for bi-lateral upper extremity training versus patients employing conventional therapy. This article is relevant because it focuses on upper body exercise. However, this version of VR was implemented with a conventional monitor, not with an HMD.

Relative to 3D VR employing an HMD, Foran in “Learning from experience” [16] points out “One problem is the lag time often present between the user’s movements and the visual input or response from the virtual environment.” While this may have been true five years ago, it is hardly true for the state of the art systems introduced in 2016. VR has undergone vast improvements in the last five years. The system used for this project is an “entry level” gaming system. It is nowhere near top of the line, and yet, commercial games play well. On rare occasion the system drops a frame and a split-second delay is barely noticeable. However, gameplay is usually quite smooth.

Robert, Ballaz and Lemay [28] studied the effects of VR on balance. They used the Oculus DK2, the second generation of Oculus which was made available to developers and which preceded the release of the consumer model. The consumer model tested for this thesis has somewhat better resolution (2160 X 1200 vs. 1920 X 1080) and refresh rates (90 Hz. vs. 75 Hz.) [29], but the headsets are roughly comparable. The researchers used the seven-item short Berg balance scale developed by Chou et al [30] to test balance. However, as the Oculus Touch controllers were not available at the time of their experiment, the researchers modified the reaching forward and reaching down to the floor to pick up an object portion of the test, as they did not yet have a way to represent the participant's hands in the virtual environment. The virtual environment was created by filming the Marie Enfant Rehabilitation Centre, CHU Sainte-Justine with a 3D camera. Thus, the Oculus Rift and attached computer could recreate a very realistic environment, rather than having to rely on 3D modeling.

Robert et al [28] found that VR did not significantly affect static balance. However, it did adversely affect dynamic balance. The authors did not define the meanings of static and dynamic balance. Taber's Cyclopedic Medical Dictionary gives "static equilibrium" as the synonym for static balance. Static equilibrium is defined as, "The ability to maintain a steady position of the head and body in relation to gravity; it is integrated with the equilibrium of movement, or dynamic equilibrium [31, p. 2197]." Taber's CMD give the definition of dynamic equilibrium as, "The sense of balance while the body or head is in motion. This is maintained by coordinating data from postural (stretch) receptors in the limbs with data from the inner ear and cerebellum [31, p. 798]."

The researchers noted that while there seemed to be no significant difference in balance for HMD wearers vs. non-HMD wearers when eyes were open, there was a difference when participants stood for a period of time with eyes closed. Perhaps the weight of the headset is easily compensated for when eyes are open and the visual sense of balance is integrated, but without visual sense, it can become a slight challenge. The researchers did not offer the latter explanation, but it is nonetheless a logical hypothesis.

The researchers theorized that sensorimotor conflict might be the most influential factor affecting balance and cautioned that more thorough testing needed to be done before attempting to use it as therapy for those with postural control deficits. They also saw a need for further research to determine whether or not there could be any detrimental effects if children or teenagers used VR. The researchers found that in these simple tests, there were no significant differences between men and women as to how their postural control was affected. However, other research indicates that as VR experiences become more intense, their effects on men and women do differ, as will be discussed later in regard to cybersickness.

Kim et al [32] found in their research that the Oculus Rift DK2 provided a good experience for Parkinson patients and older adults walking on a treadmill. Prior to the experiment, the authors were concerned that the Parkinson patients' challenges of postural instability might be exacerbated with exposure to a VR environment.

Thirty-three individuals participated in the test, 11 healthy young adults, 11 healthy older adults, and 11 Parkinson's disease patients. Participants walked for 5 minutes with short breaks between each 5-minute jaunt, for a total time walking in VR of 20 minutes. The participants on the treadmill "passed through" the virtual scenery at a rate locked to the treadmill rate, which was in turn determined by each participant. Kim et al. report that "No participants verbally reported any symptoms of simulator sickness." Additionally, "Postural sway, as measured by CoP area, was not affected by VR exposure in any of our groups." CoP stands for center of pressure. In all groups, participants were calmer or found they were less stressed after VR. They also walked faster.

Recall that Robert et al. detected an adverse effect of VR on dynamic balance. In contrast, Kim et al., measuring just after VR exposure, found that their particular VR simulation caused no significant change in dynamic balance. One can see how VR and medical research might be moved forward by having the same groups of test subjects evaluate different simulations.

VR presents new possibilities to test and rehabilitate a combination of physical and cognitive skills [33]. For instance, crossing a street safely requires a combination of skills [34]. Driving requires a higher level of these combined skills. VR is a safer test for these situations than physical reality. The simulation can simply be reset if a car crashes in VR. Physical reality is not so forgiving. Stroke patients are one example of a patient group which can benefit from being tested in VR simulations to assess the likelihood of their navigating physical reality well. If more practice is needed, that can be accomplished in VR before the more consequential test in physical reality [35].

Augmented Reality

Augmented reality (AR) marries the real world to the VR world. In AR, VR is overlaid onto physical reality. Some brain surgeons now use the Surgical Navigation Advanced Platform, an AR-based tool which allows them to construct a 3D brain model from patient-specific scans, including MRI scans. This aids the surgeon in figuring out exactly the best way to remove a tumor for a particular patient [36].

While Google Glass did not fare well in its debut in the mass consumer market, it has found at least one use with Parkinson Patients [37]. Dance for PD ™ is a nonprofit organization offering dance therapy classes to Parkinson Disease patients in 20 different countries [38]. This nonprofit organization resulted from a collaboration between the Mark Morris Dance Group and the Brooklyn Parkinson Group. Besides dance classes with live instructors, it also offers portable AR instruction called "Moving Through Glass." This is available to Parkinson sufferers who are willing to participate in testing the "Moving Through Glass" technology and application. The testing includes gyroscope and accelerometer wearable sensors to record data related to gait rhythm and step coordination [37]. Dance for PD ™ hopes to release a commercial version of the software in 2018. However, since the original Google Glass is, at this time, no longer for sale, the application might have to be rewritten for a different AR device.

While the usefulness of state of the art high-definition VR is being explored in several different therapies, including Parkinson patients, certainly it is preferable for someone to be untethered when trying to follow their virtual instructor's dance movements. It would also be preferable to see the physical environment in which he/she is moving. The resolution of Google Glass is 640 X 360 [39], much lower than current VR standards, but untethering and using AR, rather than just VR, facilitates using dance for patient therapy. Research in Parkinson dance therapy has shown "beneficial effects on endurance, motor impairment, and balance [37]." Participants in a Washington University School of Medicine study also reported "Improvements in mood, cognition, and quality of life [37]."

Visually Induced Motion Sickness (VIMS), Cybersickness, Simulator Sickness

"The challenge is that people's sensitivity to motion and simulator sickness varies wildly," according to Evan Suma, assistant professor at the University of Southern California [40]. The terms cybersickness, simulator sickness, and motion sickness have all been used to denote the unpleasant feelings that users of VR sometimes experience when their vision in VR tells them that they are moving, but the rest of their body's senses tell them they are standing still. Participants may feel nauseous or experience vertigo in VR.

In reviewing the literature, one finds that much of the research to date has warned about visually induced motion sickness (VIMS). However, it seems that many, if not all, of the VR simulations which led to VIMS in testing would cause motion sickness if the activities tested were conducted in physical reality. Therefore, is it accurate in these instances to say that VR induces motion sickness, or is it more apropos to say that if an activity induces motion sickness in physical reality, it is likely to induce motion sickness in VR?

Cheng-Li Liu has studied VIMS in a VR shopping scenario constructed for the elderly [4]. However, even though the publication claims that the study is of the elderly interacting within a 3D virtual store, the contents of the article indicate that while there is a 3D model of the store in the computer, what is actually displayed to the participants is on a 2D screen. Page 797 of the article states that the screen used was 22 inches. This is obviously too large for a head-mounted display. In any case, the experimental findings regarding tolerance for rotation (as used to move through the store), and the employment of "a fuzzy warning system" to predict cybersickness might one day be stepping stones in further research and problem solving for movement through full 3D environments.

Teleporting technology was probably unknown to C. Lieu. Teleporting is accomplished by pointing to an area of a VR scene and pressing a button to go to that point in the scene. What happens in the computer is that the VR scene is instantaneously rendered anew from the new perspective. There is no sense of one's being moved through the scene to experience the sensory conflict of the visual movement in VR conflicting with the vestibular sense in physical reality that one is standing or sitting quite still. One simply "appears" at a different point in the VR scene. I have tested multiple VR environments incorporating teleporting and found it to be gentle on the senses. I have also experienced being "moved" through a virtual scene by the computer and felt my muscles instantaneously stiffen and my arms fly away from body as though I suddenly found myself on a piece of ground that began moving without warning. If this is the method of movement that Liu used, there is no mystery as to why some of his test subjects experienced visually induced motion sickness (VIMS). There would have been sensorimotor conflict.

The technical problems of VR have been lessened with advancements in technology that include faster refresh rates (currently, 90 Hz is state of the art in high-end headsets), better resolution, and smaller inter-pixel distances that lessen the screen door effect caused by magnifying pixels. However, the fact remains that for simulated movement in VR, a person's vestibular system is going to conflict with the visual sense in instances where they are moved through the virtual scene but do not have corresponding movements in physical reality. This is sensorimotor conflict, and the experience of it can vary widely from person to person.

At the Consumer Electronics Show International in Las Vegas held in January 2016, shortly before the consumer release of the new VR systems by the big three manufacturers, Oculus and Sony posted warnings for people wanting to try their systems that participants could experience "motion sickness, nausea, disorientation and blurred vision [40]." Note, also, that among the game experiences offered were Eve Valkyrie, an action-packed space adventure in which the participant is a fighter pilot zooming, rolling, and turning at sometimes high simulated speeds through asteroids and other objects in outer space—lots of action that could induce motion sickness in real life, not just in VR. (I speak from the experience of having played this game).

Studies show that postural sway increases before motion sickness, for both standing and seated test subjects [41-44]. Therefore, in my experiment, participants were observed closely, with periodic verbal interaction, even though participants were seated. Additionally, the program was constructed so that all of participants' movements in the virtual scene correspond to movements in physical reality. Thus, avoiding sensory conflict. The expectation was that without sensorimotor conflict, participants would have an enjoyable experience.

Munafo, Diedrick and Stoffregen [45] found that motion sickness induced by VR afflicts women more than men. For their first experiment, the researchers used the *Balancer Rift* game. Subjects tilted their heads to control movement of a marble through a virtual maze. I was unsuccessful in finding either video of game play or a consumer version 1 (CV1) to view details of the game. From the single snapshot available on the Internet [46] it appears that the maze takes up most of the field of view, and there is no ground plane. The maze lies against a black background. This means that there is no fixed anchor point to aid visual stability. If the entire maze is tilting, taking up most of the field of view, and controlled by constant head movements, one can easily see how this could cause motion sickness in physical reality. Between the constant head movement and lack of a ground plane to provide a sense of visual stability, it should be no surprise that a significant number of test subjects experienced cybersickness. Six of 18 women (44%) and two of 18 men (11%) reported motion sickness.

Munafo et al's second experiment employed the game *Affected* [45]. The authors say, "…participants navigated an environment of hallways and rooms. The goal was to reach a designated end point to the virtual layout." What the researchers fail to say in their article is that this is a horror game with creaking doors, screams and scary things popping up to startle the participants. This fact seems very relevant, as test subjects are likely to jump and jerk as scary things constantly confront them along the way. A sampling of these intense experiences can be viewed on YouTube [47]. Participants' adrenal glands are likely to be hard at work, adding to any predilection they may have to experience cyber-sickness. Participants move themselves through this game via XBox button controls. Therefore, when "moving" through the virtual environment, their visual sense tells them they are moving, conflicting with their vestibular sense which tells them they are sitting in one place.

The rates of motion sickness were much higher in this second test. The overall rate of sickness was 56%. Six of the 18 men (33%) became ill, compared to 14 of the 18 women (78%). Three of the six men who quit early (before 15 minutes had passed), stated that they were not motion sick, but that they did not wish to continue because of general discomfort. All of the 12 women who quit early reported that they were motion sick. Two of the 12 sick women stayed in the game for the full 15 minutes.

Oculus Rift has a 3-tier system to give the average user some idea of his/her cyber-sickness/discomfort potential which, though it might not be perfect, is a good place to start. The three Oculus categories are 1) Comfortable ("appropriate for most people"), 2) Moderate ("appropriate for many"), 3) Intense ("experiences aren't appropriate for most people, especially those who are new to VR") [48].

The version of *Affected* updated for the consumer version (CV1) of Oculus Rift carries a comfort level rating of "Moderate [49]." Footage from multiple YouTube videos [47, 50] clearly demonstrates that this level of intensity is too great for most therapy patients, and may be too intense for the average person. Some of the teenagers in the first video [47] seem reluctant to play the game until the end. Judging from the video footage, an "Intense" rating might be just as appropriate as Moderate.

While the games the researchers chose might not have had official ratings at the time, better descriptions of game intensities should have been given. From information gleaned in a Google search, it is very reasonable to say that "Moderate" would describe the first game and "Intense" might have been more apropos than the official "Moderate" ranking of the second.

Designers of VR programs need a sense of what various groups of people can tolerate when it comes to VR stimulation. Some groups tolerate and, indeed, enjoy intense VR programs that will simply cause other groups of people to be sick. VR environments used for therapy should be constructed so that they minimize, or better yet, eliminate sensorimotor conflicts. There is good reason to believe that if a VR therapy program is constructed in such a manner and makes the patient exercises fun, the patient will make better therapy progress, have fun, and experience a reduced amount of pain.

For the foreseeable future, conflicting sensory input will continue to be a challenge to VR development in general. However, it can largely or entirely be avoided with careful planning. It should be noted that, while motion sickness is more easily induced in VR because of its immersive nature, even console video games using conventional screens carry significant risk of motion sickness [51].

The VR Cyber-Race of 2016-17

The first commercially available HMD was made by VPL Research more than 30 years ago and sold for $100,000 [52]. As mentioned earlier, Hoffman et al's 2014 experiment [20] used an early development model of the Oculus Rift, and the article noted that "several regional burn centers" used the Rockwell Collins SR80 "goggles" (headset) which sold for $35,000. Though SEGA and Nintendo made attempts to enter the wider consumer VR market with their own HMDs back in the 1990s, the experience was still primitive compared to today's standards, and the attempts failed [7]. With HMDs from three major players bearing price tags in the hundreds, rather than tens of thousands of dollars, 2016 was the year the VR market share race became serious and heated.

There are three major players in the 2016-17 high-end VR market: Oculus, HTC, and Sony. HTC released the Vive with its distinctive hand controls on April 5, 2016 [53]. For the Vive setup, each hand has a separate controller with accompanying tracking for the individual hands. As a result, the participant's hands are able to move independently to manipulate virtual objects.

While the Oculus Rift headset was released March 28, 2016 [54], at the time it employed a single Microsoft Xbox controller as a shared controller for both hands, in lieu of a pair of controllers. This gave the HTC Vive a competitive edge over the Oculus Rift in the beginning. Oculus later released its hand specific Touch controllers on December 6, 2016 [55]. The majority of online reviewers found the Oculus Touch controllers to be superior to the Vive controllers, but most early adopter customers who had already purchased the HTC Vive were not willing to purchase an additional system at an approximate cost of $798.

Both systems require a gaming computer with substantial computing power and a good graphics card. An entry-level computer might be purchased for $800, with a more expensive computer being preferable for these systems.

Sony also released a VR headset in 2016 [56]. Its 1080p headset was released in October. The headset's resolution is not as good as its competitors, but consumers already owning a PlayStation 4 do not have to buy an expensive computer to run it, and the headset's introductory price of $399 made it less expensive than its competitors. Sony also offers its own version of independent hand control, dubbed Move controllers. So far, Sony appears to be the winner in the VR market, as measured by the number of headsets sold [57].

The Oculus Rift with Touch controllers was chosen for this thesis experiment because it offered the most realistic VR experience of the top three competitors. It is unclear whether or not "being the best" in the moment will enable it to become the VR sales leader in the next couple of years, but with Facebook backing it and the partnership with smartphone maker Samsung in the mobile VR market, Oculus certainly has potential to become the leader [58].

THE OCULUS RIFT

The Basics

The front of the Oculus Rift headset is almost flat and black. Behind this (closer to the viewer's eyes) sits an OLED screen with 2160 X 1200 resolution. Behind this sit two magnifying glasses, one for each eye. Each half of the screen is devoted to the corresponding left/right eye of the viewer. Each eye is presented with a slightly different image. Viewed close up through the magnifying lenses, the images appear to merge into a single image which the brain interprets as three-dimensional. The division of the screen yields a resolution per eye of 1080 X 1200 [59]. The HMD incorporates a gyroscope, accelerometer and magnetometer to facilitate head tracking [28].

The headset, weighing 470 grams (a little over a pound), is tethered (connected via cable) to a computer which generates the graphics displayed on the headset. A secondary image is displayed on a conventional computer screen as part of the interface. Using the conventional screen facilitates game startup and also allows onlookers to see a 2D representation of what the HMD wearer sees. The headset also incorporates built-in headphones.

Why Oculus Rift?

Upon initial release, the consensus among Internet reviewers was that the HTC Vive was the best in VR headsets. This had a lot to do with two main factors: 1) The HTC Vive had separate hand controls for each hand and 2) the Vive accommodated movement around a room better than the Oculus Rift. Mark Zuckerberg, founder of

Facebook (the parent company of Oculus) had originally thought that people would nearly always be seated to play VR games, but the longer lines at trade shows of people wanting to try out the Vive proved otherwise.

So, upon initial release, the HTC Vive was the consensus winner. However, once the Oculus Touch controllers were released, reviews said they were superior to the Vive's controllers. They are ergonomic, well-balanced, and provide a believable interface whether you are playing an old west six-shooter game or using them as the joystick for flying a spaceship. Also, the Touch controllers include capacitive sensors for thumb and forefinger, meaning that the controller can "sense" whether those digits are resting on the controller without pressing a button or completely off of the controller. If the game the player is using incorporates a fully functional hand avatar, this allows the player to, for instance, give a "thumbs up" sign or "point" in the virtual world.

METHODOLOGY

Objectives

Currently, the graphics in untethered VR and augmented reality (AR) are inferior to those in tethered VR. The processing power of untethered VR is simply not as great as that in tethered VR. Therefore, the experience is less immersive. A less immersive experience would likely be less fun, less motivating, and have less pain reduction influence. Additionally, it is expected that the tethering would be less of an obstacle in a seated vs. unseated game for therapy patients. There seems to be little or no research regarding sitting balance games involving VR. All of these factors played into the choice and formation of this project and accompanying testing.

The software was designed with three primary objectives in mind: 1) Make reaching and leaning (exercise) fun via a VR program created for the Oculus Rift and Touch controllers. 2) See if this can be accomplished with a very simple game. 3) Do this in a manner which induces no simulator sickness (a.k.a., cybersickness).

As described in the literature review, if therapeutic exercises are perceived as "fun," patients have a tendency to experience less pain and make better progress in their recovery. If it is possible to construct a fun game which is also simple and does not require a great deal of artistic talent, then there is the possibility to make many variations on games, providing variety and potentially maintaining interest longer. Being able to produce game variations quickly, in turn, could lead to low-cost programs, potentially making game therapy more accessible to more people in the future. As to the third objective, it is of course desirable to have no adverse effects. Avoiding any sensorimotor conflict and creating a game that would stimulate, but not overstimulate the senses, was expected to yield a healthful and beneficial game for participants. However, for the time being, HMDs can cause short-term eye strain and do tend to leave pressure imprints on the face after a few minutes. It was hoped that the game would be overall enough fun that these minor inconveniences would not override the overall experience.

General Design and Best Practices for VR

From the "Oculus Best Practices" manual [5]:

> "Because VR has been a fairly esoteric and specialized discipline, there are still aspects of it that haven't been studied enough for anybody to make authoritative statements. In these cases, we put forward informed theories and observations and indicate them as such. User testing of your content is absolutely crucial for designing engaging, comfortable experiences; VR as a popular medium is still too young to have established conventions that address every aspect of the experience." [5, p. 4]

VR headsets, while displaying a more realistic scene in 3D, do make the wearer more susceptible to simulator sickness than TV/computer monitors [5, p. 6]. However, the experience is more immersive because of the feeling conveyed by being completely surrounded in a virtual world with virtual objects which can be picked up, tossed, moved around, and otherwise manipulated.

Flatter textures and solid-colored objects tend to be gentler on the player's senses [5, p. 6-7]. Avoid large areas of repeated patterns, especially bold patterns, such as stripes.

The ground plane appearing in the virtual scene should also closely approximate the floor in the physical world so as not to be disorienting. The occupational therapy consultant noted this early in the project's game development. Also, for the general public, avoid undulating horizons, as might be seen from a ship on the sea. Undulating horizons are thought to be an underlying cause of seasickness [60]. Couple this with sensorimotor conflict (discussed earlier), and many users are likely to have an unpleasant experience. Put the user in control of his/her own movements through the scene as much as possible, and scale the virtual world so that the player's movements there match their movements in the physical realm.

Equipment and Software

The computer used was an ASUS G11CD-B13 with an NVIDEA GeForce GTX 1060 graphics card containing 6 GB of onboard memory. The system had 16 GB of RAM. The processor was an Intel core i5-6400. The Oculus Rift consumer version 1 (CV1) was used in conjunction with the Oculus Touch controllers to facilitate interaction with virtual objects.

The system used a Windows 10 operating system. The Unity 3D game engine along with the Mono Develop integrated development environment (IDE) was used to write and test the C# code used for scripting. The Oculus Rift software development kit (SDK) for PC was imported into Unity 3D for game development.

Strategy in the Game Design

One challenge at the forefront of creating this game was creating something that was both fun and simple. As novelty often enhances interest, could a simple game be created that would also be novel in some way? The solution to this question was to simulate a weightless environment. While this might not be novel in another 10 years, playing in a weightless environment is certainly uncommon now in 2017. The Unity3D physics engine facilitates weightless objects and their interactions quite nicely, once one knows where the gravity setting is, how to apply it to objects, and how it interacts with other physics.

A secondary choice related to novelty was to create a wide open vista, giving the impression that the player can see for many, many miles. Views like this are uncommon for urban dwellers (Fig. 1). The figure below illustrates game play. Several game balls have been tossed and have collided with objects. Some of these are now tiny dots in the distance because they have traveled so far.

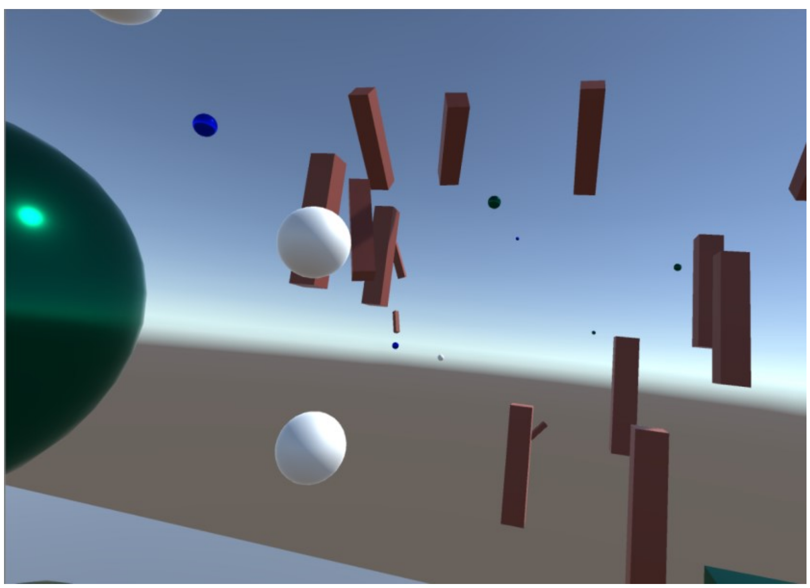

Figure 1. Far-Reaching View

While some therapists, as noted earlier, have incorporated games into their patients' rehabilitation regimes, measurement of the activities during game play can pose a challenge. The occupational therapy consultant related that therapists who use games will often record the amount of time that a patient plays said games, but this time measurement offers little information as to the patient's progress other than, perhaps, the patient's ability to play the game for longer periods as therapy continues over weeks or months. This time measure gives no real information as to increased speed or facility of the patient's movements. For this reason, a scoring system was employed which is geared toward the therapist's needs of having some better measure of the patient's progress.

In the game, virtual balls are arranged in concentric semicircles floating in space. The outside balls, possessing a bright blue metallic color and sheen (akin to that of Christmas balls) require the furthest reach to grasp. These balls are scored the highest. The semicircle of balls just inside this possess a shiny metallic teal color. They are worth a lesser number of points. Balls of the inner circle are easiest to reach, and they are colored a plain white. The shiny metallic colors of the outer balls were intended to make the balls more attractive and further incentivize stretch and lean.

The scoreboard keeps track of the number of each color of ball grasped and which hand captured it (Fig. 2). The scoreboard is placed behind the floating game balls so that it is partially obstructed from view. This is to encourage the player/patient to lean right and left in order to change his or her perspective and peek through the game balls to see the various parts of the scoreboard.

In order to generate more interest and activity for the player, many unscored "targets" are suspended in the atmosphere surrounding the participant. After the player picks a ball out of the air, he or she can then throw it at another object elsewhere in the virtual world and watch it tumble outward into space.

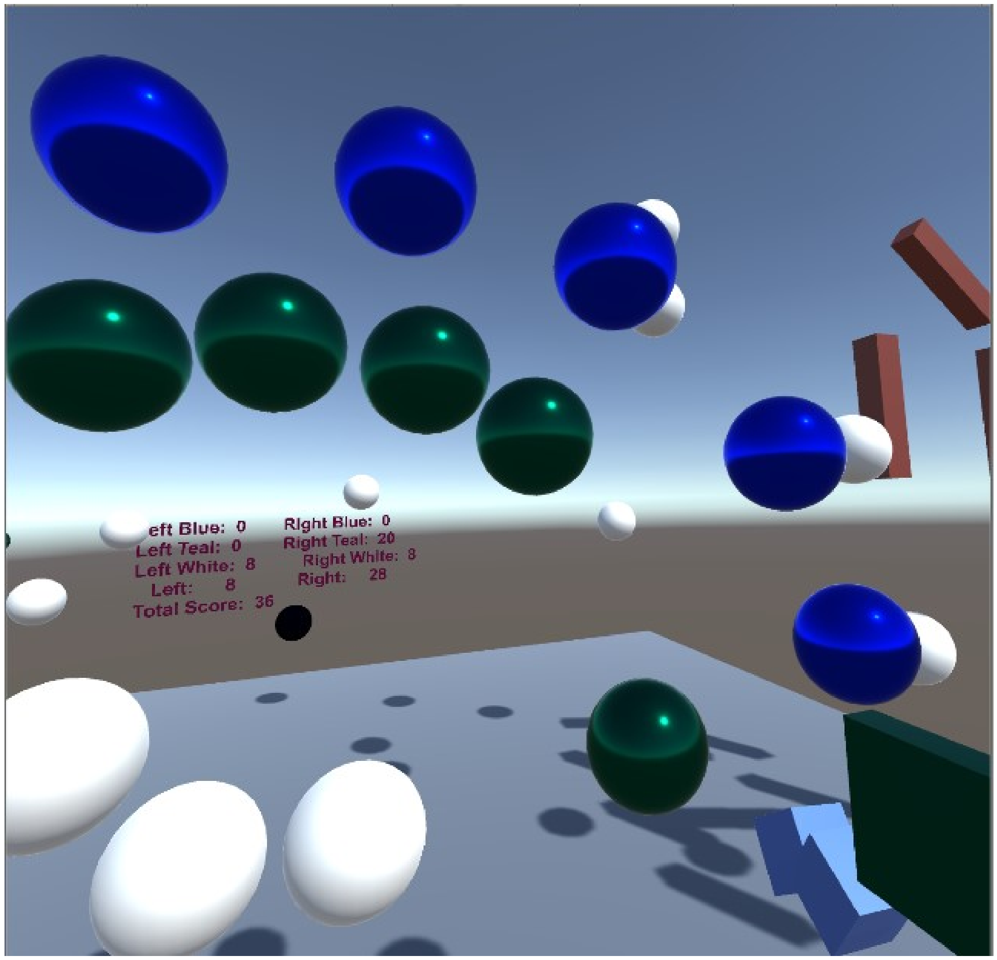

Figure 2. Metallic Balls for Scoring

As one objective was to create the game without hiring an artist, the author was faced with the problem of how to create an environment that was attractive, or at least interesting, with easily created shapes such as spheres, cubes, blocks, etc. Color palette becomes important to this end to give interest to basic geometric shapes. Earth tones were chosen, along with shiny metallic blue and teal colors for the balls requiring the most stretch and lean. This seems to have been a good choice, as test subjects later comments included, "…relaxing…fun…nice color choice…"

Experiments

Testing was conducted in the Plaster Student Union of Missouri State University. A space adjoining a high traffic area was chosen and passersby were offered the opportunity to play the game in exchange for filling out a short questionnaire. The testing was conducted September 25 and 26, 2017 after IRB approval had been obtained (see Appendix A). The questionnaire can be found in Appendix B. A Likert scale is used for questions 1, 3 and 4. Participants are asked to identify as male or female in question 2. Questions 4 and 5 prompt for comments, and question 6 is a 2-part question, asking if the participant considers himself/herself a gamer, and if so, does the participant play more VR or conventional 2D games.

Volunteers were asked to play the game for five minutes. The occupational therapy consultant advised that this was enough time to gain therapeutic benefit, while at the same time being a short enough test period to encourage volunteers to try the game and give feedback. Volunteers were told that the whole process might take 15 minutes between explanation of the game, getting the equipment adjusted, playing the game, and answering the survey.

RESULTS

The program was received enthusiastically by participants, and a few even asked if it was possible to acquire the game or if there were some way for them to check on the project's progress at a later date. Tables 1 through 3 show responses for the three questions which were measured on a 5-category Likert Scale, rated from 1 "Strongly Disagree" to 5 "Strongly Agree." Sixty-two percent of participants identified themselves as "gamers" (people who play a lot of video games). With regard to Table 1, one person, a non-gamer, did not respond to question 1. The rest of the participants agreed or strongly agreed that the game would make therapy more fun. Table 2 shows the responses for question 3 regarding discomfort. All but one of the participants disagreed or strongly disagreed that they experienced discomfort. The one participant who agreed that he experienced discomfort indicated in his comments that this was mild discomfort caused by wearing glasses inside the Oculus Rift HMD.

Table 1. Q1 Responses on a Likert Scale: Therapy More Fun? (%)

	No. of Participants	1	2	3	4	5	No Ans.
Gamers	24				8	92	
Non-Gamers	13				38	54	8
Undecided	2				50	50	
Total Participants	39				21	77	3

Table 2. Q3 Responses on a Likert Scale: Experience Discomfort? (%)

	No. of Participants	1	2	3	4	5	No Ans.
Gamers	24	75	21		4		
Non-Gamers	13	62	38				
Undecided	2	100					
Total Participants	39	72	26		3		

Table 3. Q4 Responses on a Likert Scale: Good Experience? (%)

	No. of Participants	1	2	3	4	5	No Ans.
Gamers	24				4	96	
Non-Gamers	13				46	54	
Undecided	2					100	
Total Participants	39				18	82	

Question 4 asked if the participants had a good experience overall. Seven participants (18% overall) gave a “4” rating (agreed, Table 3). Thirty-two participants (82%) gave a “5” rating (strongly agreed).

Eleven females (28% of total participants) and 28 males (72%) tested the game and took the survey. It was hoped that by conducting the experiment in a public place where the pool of participants would be roughly equal in both genders that the volunteers might be divided more or less equally. However, there were simply more men than women willing to volunteer for the testing. Figure 3 gives a graphic representation of the number of responses to question 4 by gender.

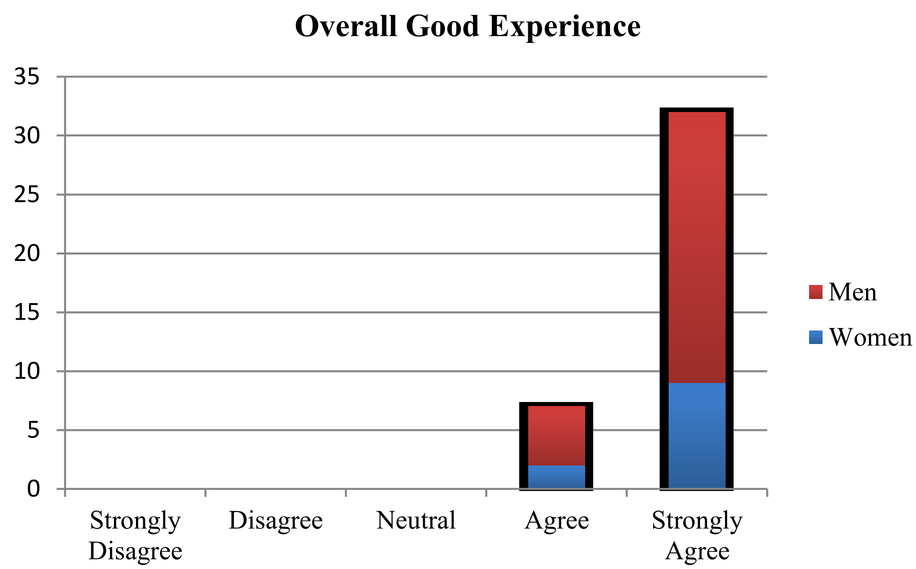

Figure 3. Overall Good Experience

In addition to the Likert Scale questions, participants were asked to comment on their experience and offer suggestions for improving the game. Comments can be found in Appendix C. Eight of the 11 women offered suggestions. See Appendix D for list. Twenty of 28 men offered suggestions. See Appendix E for list. The most numerous type of comment related that the game was fun and/or interesting. The most common suggestion theme was related to targets—adding more or different ones. There were also several suggestions to add sound effects or music. No significant difference was noted in the kinds of comments offered by gamers versus non-gamers. A discussion of the results follows.

DISCUSSION

Most of the answers to the questionnaire were straightforward, addressed in the previous Results section of this thesis, and do not warrant further discussion. Two areas that do warrant discussion are discomfort and user suggestions. Therefore, the discussion will center around discomfort. User suggestions will be addressed in a separate section.

Ten of 11 women gave a "1" rating (strongly disagree) that they experienced discomfort (Fig. 4). However, one of these participants did report a minor headache. It is unclear whether or not this was caused by the VR session, as she did give a "1" (strongly disagree there was discomfort) rating. Another of the 11 women gave a "2" rating (disagree) that she experienced discomfort, but wrote "uncertainty" in the comments. The exact meaning of this is unknown, as there was no elaboration. Both women who commented in question 3 gave a "5" rating (strongly agree) in question 4—Overall, did you have a good experience playing the game? Therefore, it seems that any faults or irritation were indeed minor and interfered only slightly with the experience for women.

Of the 28 men, one rated his discomfort a "4" (agree that there was discomfort) and relayed in his comments, "My glasses caused mild discomfort." However, he still rated question 4 (Did you have a good experience playing the game?) a "5." Again, it does not seem to have interfered much with his having a good experience, but might have in a longer session.

The rest of the men rated discomfort a "1" (strongly disagree there was discomfort), or a "2" (disagree there was discomfort). No one rated discomfort a "5" (strongly agree there was discomfort).

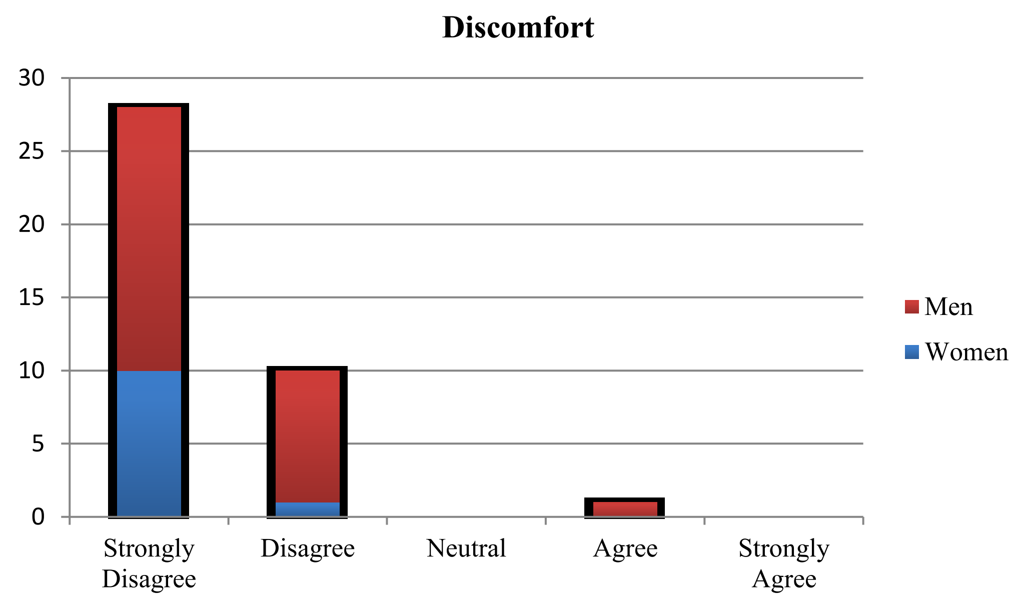

Figure 4. Discomfort

Even though, with the single previous exception, all men rated discomfort as a "1" or a "2," there were eight other comments to indicate that either something actually was a little uncomfortable or that something could have been made more comfortable. Their comments follow.

"A little dissoriation and slight strain of eyes, however I wear glasses and its very little discomfort." Dissoriation probably means disorientation. Disorientation may be accounted for by the very different scenery of looking out at floating objects placed in an endless expanse in the VR game versus the relatively small area of the cubbyhole underneath the staircase where the testing took place in physical reality. The two environments can feel like very different places because they are so visually different and yet are experienced without moving from the chair. The participant still gave his overall experience a "5" rating. Two other comments which may be related were "Slight spatial disorientation," and another participant reported "Slight dizziness (readjustment)." These participants rated their overall experiences as "4" and "5," respectively.

One person reported "Only mild visual disconnect." This last comment may indicate that the computer dropped a frame or two, causing a split-second delay in expected virtual object movement. This had been observed on occasion in testing. Again, the system used was a lower-end gaming system. A high-end system might avoid this, but the cost would be greater (perhaps, double).

Slight eye strain is common in VR. While glasses can be worn under the HMD, the pressure exerted on them by the HMD can make the setup uncomfortable in extended use. If the makers of Oculus Rift would incorporate a focusing apparatus, this would make the device more comfortable for those who wear glasses. In theory, as binoculars can be purchased for under $50 and include such mechanisms, adding focus capabilities would not be expensive in theory. However, the amount of weight it would add to the device is unknown. Addition of a focusing apparatus would certainly facilitate more widespread use for therapy in nursing homes, as many residents there do wear glasses. The other comment regarding glasses was: "The headset could be a bit more comfortable. I'd like space for my glasses."

"Not related to the VR, stretching high, I felt it in my back a little. I'm 34. Getting old!" This comment indicates that the program is serving its purpose of encouraging stretching and may have some health and exercise benefits outside of strictly "therapeutic" settings.

"I just got sweaty around where the headset fit." This is one reason hygiene masks were used.

"Slight irritation on the forehead." This may have been caused by the hygiene mask and/or Velcro attached to the HMD slipping out of place. The Oculus Rift does not come with these accessories, but some method of employing a hygiene mask is desirable when dozens of people wear the same equipment on their face. The masks were tested by the game creator prior to trial. Elastic bands supplied with the masks were supposed to hold them in place over the ears, but the masks moved too much when putting on the HMD. Therefore, Velcro strips with sticky backs were attached to the HMD, allowing the soft hygiene masks to be lightly attached to the HMD via the Velcro. The masks were far easier to align with the HMD using this method, but friction caused by repeatedly putting on and taking off the HMD did occasionally cause the Velcro to lose some of its stickiness, move, and require replacement.

TAKING NOTE OF THE SUGGESTIONS

Level One

The program tested was envisioned as level one of a larger program, but testing needed to be done on this level to make sure that, indeed, the approach was generally a good one—to wit, make sure the experience is fun while encouraging exercise, does not cause sensory overload or conflict, provides an inviting environment, is easy to understand, etc. Overall, as shown by the predominant rankings of "5" (strongly agree), this was accomplished.

Sound was considered as an initial component, but was ultimately left out because the developer was not sure what sound to include. Objects do collide in the game, but sounds of clunking and explosions may not be good sounds for therapy. However, multiple comments suggested that sound would be a good addition. On further thought, sounds generally considered soothing, such as a random wind chime from a set well-tuned to a pentatonic scale might be good for sonic feedback on collision in this level one game. This would add a sound effect and a somewhat musical quality without venturing into the myriad problems of trying to choose music that would be generally liked by a wide variety of people and further adding to the cost of the program by having to pay royalties.

"A seeable scoring system" was suggested by one person. This undoubtedly refers to the scoreboard. Its view is partially obstructed by the floating game balls on purpose. The reason is to encourage players to lean right and left in order to view various portions of the scoreboard by peeking through the spaces between the balls. Thus, the current scoreboard placement supports the therapeutic objectives of the game, and there is no intent to move it.

To score collisions or not to score collisions? Scoring is based upon the player reaching and grabbing balls in concentric semicircles. The outer balls for which they have to reach and lean the farthest give the most points, and the points become progressively smaller to the easiest to reach balls. The scoring is geared toward the therapist. This is because therapists are challenged to measure their patients' progress. Both the game creator and the therapy consultant were satisfied with this non-competitive scoring, but several of the participants testing the game wanted the collisions scored. The desire for this scoring may stem from a person's innate tendency (or lack thereof) to be competitive. One solution would be to offer collision scoring as an option. It should be noted that 62% of the participants consider themselves to be "gamers," and this is far higher than the number of gamers in the general population. According to one survey, 10% of Americans identify as "gamers" [61]. Non-gamers (such as the game creator and her therapy consultant) may prefer to "have fun" without keeping score of the number of objects they hit. To this end, a level 1 and level 1A are proposed in which level 1 stays pretty much the way it is as an introduction to players and then level 1A would incorporate options including a second scoreboard for objects struck, as well as choice of collision sounds or wind chimes or silence when objects collide.

A timer or timed game was suggested by two people. This, in conjunction with a "game over" message, could be incorporated into level 1A. The individual's therapist should decide, based on his or her competitive nature and physical abilities, whether to allow the patient to engage in a timed version of the game. It could be implemented as a menu choice of 5, 10, and 15 minutes with a default time of 5 minutes. If more than 5 minutes is offered, a button to replenish objects to aim at should also be incorporated. These additions were planned in the early stages of the project as later additions, but again, the author wanted to test the most important concepts in the prototype before going too far into incorporating the details.

During testing, when initializing the game for an individual, a gasp followed by an exclamation was often heard when the 3D game scene appeared to the player in the HMD. This is one indication that there is plenty of stimulation in the first level, at least, for an initial experience. It is probably more advisable to build a few separate scenarios, rather than add very much to the first game and risk overstimulation in the very beginning.

Other Levels and More Options

Several people suggested targets or more targets. On occasion, verbal clarification was added by participants to their written comments. There was a desire expressed for "classic" targets which incorporate concentric circle scoring. This could certainly be added, though it does not keep with the theme of the level one game tested. It would be more appropriate to set up a different scenario with targets. It would take more programming/object-constructing skill than the simple shapes of the game tested, but could probably be done by a programmer without having to employ an artist.

Another request was for moving objects. A few moving objects could be employed for targets, but again, this would need testing. As this is a therapy game, patients may be more susceptible than healthy people to overstimulation. A few moving objects might enhance the game, but too many moving too fast could overstimulate. One participant suggested an arcade style game. Some arcade style duck targets could be made to move around one or two areas of the game and scored when hit. This would best be offered after someone had tried the level 1 and level 1A games and felt that they wanted to try incorporating animated objects.

A desire was expressed for “Different objects that do different things to the bricks. Spheres knock them [unknown word], cubes blow them up, etc.” This is a good suggestion that should not be difficult to implement. Cubes can easily be interspersed among the spheres as additional objects to toss. Though, for a therapy game, it might be preferable to “dissolve” the floating targets, rather than explode them. One participant suggested “a hoop or a basket to aim at for bonus points.” This can also be implemented with little difficulty. “Confetti for high points” should also be an achievable addition.

“Motivation reward” and “reward animation” including using a bell sound when objects collide were suggested. Bell sounds such as one would hear in an arcade, however, are not likely to be conducive to a “calming” environment. Other participants appreciated and commented upon the calming effects of the current game. Some therapy patients may like the bell sound, but others may find that it detracts from the experience. The bell sounds would probably best be reserved for an arcade-style experience which certain participants may want, but it would not be well-suited for those therapy patients who most enjoy a calm environment.

A game of two players was also suggested. This is in theory possible, but the amount of effort required to write, test, and debug a two-person game is unknown. With constant two-person testing required, it would certainly take more than a single person to create this kind of game and so, is beyond the scope of this thesis. The purpose here was to “test the waters,” so to speak, to see if a single programmer could create a game for therapy patients which would be both fun and help them in their recovery process. However, a two-person game could be quite useful in therapy. While the therapist could play in this environment with the patient, perhaps even more benefit could be gained by therapy patients playing with each other. Comradery in the game could potentially be a motivating factor in the recovery processes. If both patients had access to the equipment and software at home, they could set “play dates” without having to physically travel to the same location.

CONCLUSIONS

The Possible Near Future of the VR/AR Industry

What is likely to take place in the VR/AR (augmented reality) industry in the next handful of years? Tesselation, that screen door effect from looking at magnified pixels, may disappear or only continue to exist in old and low-end VR. Magic Leap already has prototypes for this technology, the foundation of which was co-developed by Thomas Furness and Joel Kollin [15]. It is being developed for the consumer market and is reported to be more realistic than Oculus Rift and other high-end technologies [62].

We are likely to see more augmented reality (AR, or mixed reality). This is the overlay of computer graphics (sometimes 2D, sometimes 3D) onto our view of the tangible world. Prototypes already exist in Microsoft’s HoloLens [63] as well as Magic Leap’s technology [64]. Developers can purchase a HoloLens now, but at a cost of $3,000, it is not yet priced for the general consumer market. The first Google Glass was an attempt at wearable computer technology which, despite the hype, was still buggy upon its release and failed as a wide-spread consumer product. However, the newly revised Google Glass Enterprise Edition incorporates AR, is aimed at businesses, and is currently being used in some U.S. factories [65].

There are several AR “smart glasses” aimed at the consumer market and tentatively scheduled for release in the upcoming year [66]. Among them are smart glasses developed specifically for cyclists and tested by the USA Olympic cycling team [67].

While the current VR and AR technologies already provide good potential for therapy use, athletic enhancement, a variety of business uses, and far more interactive virtual "hands on" learning opportunities, further development in the next few years may open up new possibilities which have not yet even been conceived. As VR and AR become untethered and we become able to reach our bare physical hands into the virtual world and interact with virtual objects, the potential to create, manipulate and experiment in the virtual world before realizing the creations in the physical world should help humanity avoid many mistakes and wasted materials in its processes of learning and creation.

If the technology for virtual reality and its cousin, augmented reality, progresses to the point that it can be worn as a pair of glasses, and our bare hands are freed to interact with the virtual as well as the physical world, this technology will likely become every bit as life changing as smartphones have been; perhaps even more so. Microsoft's HoloLens ventures in this direction [63]. However, it still needs refinements and a price reduction for mass appeal [68].

As VR/AR technology develops, designers, especially those designing for "practical" uses whose primary objective is something other than entertaining, should be keenly aware of designing to avoid sensorimotor conflict. Else, the public is likely to gain a poor impression of this new technology, refuse to adopt it, and its immense potential benefits could be lost. With careful design, however, VR and AR are likely to become integrated into daily life much the way that other mobile devices are now.

The Future Role of VR/AR in Therapy

VR and AR hold tremendous potential benefit for many therapy patients. VR and AR may never be appropriate for everyone, but the results of this study and others performed in the last handful of years indicate that the use of this technology has potential to become pervasive in therapy as the technology transitions to becoming wireless, hardware costs are reduced, and more software is developed especially for use by therapy patients. VR and AR are not replacements for a therapist, but they can certainly be great tools when used to motivate and encourage optimal recovery.

Another potential benefit of VR/AR therapy games for patients is that they can be expanded to multiple player games. This would accommodate an additional social interaction aspect not generally seen in conventional therapy. In theory, two therapy patients with a good Internet connection and the same software could play catch or compete in a game, even if they were separated by half a world. This would require more sophisticated programming than was needed for the game tested, but it is possible.

In AR, one can still see physical reality. There is simply an overlay of one or more objects onto physical reality. In the long term, AR will be more important in therapy than VR because one can still see the physical world and the play/therapy space will not have to be cleared of all obstructing objects as in VR. As AR technology becomes more affordable and lightweight, we could see elderly people playing catch with virtual balls in nursing homes. They would not have to worry about knocking over a lamp or chasing down a missed ball. They could simply make a ball-creating hand motion, create another ball out of “nothing,” and continue their play. Leap Motion has already pioneered object creation gestures in VR [69].

Many younger people would probably also enjoy such a game of catch. Why not toss a baseball, or a glowing orb, or a dragon pup for that matter to your friend in Brazil while you are in Canada? If you are in an appropriate physical space, why not play VR “off-world” in some alien landscape, or even in the depths of the deep blue sea?

As VR/AR technologies advance, the possibilities for therapy, general exercise programs, and practical uses throughout daily life expand tremendously, and hopefully, imaginatively.

Concluding Remarks of This Study

In this study, participants unanimously agreed that the simple therapy game tested was fun and that they had an overall good or very good experience. This initial outcome is a positive indication that the game is ready for testing with patients to verify its therapeutic value. However, as was noted in the discussion section, a game clock and a few other minor modifications might be made if patients and therapists also desire these changes.

The responses indicate that even simple games can have entertainment and therapeutic value, if they are well-constructed. This opens the possibility that a small game creation shop consisting of only one or two programmers may be able to produce commercially viable games with a dual purpose. The games would not only make therapy more enjoyable, but could also serve a larger market as fun recreation that incorporated some health benefits.

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APPENDICES

Appendix A. Human Subjects IRB Approval

Study # IRB-FY2017-777

This project was approved for human testing by the Institutional Review Board of Missouri State University September 6, 2017. Testing was conducted Sept. 25 & 26, 2017.

Researchers Associated with this Project:

PI: Lloyd Smith

Primary Contact: Alice Barnes

Other Investigators: Alice Barnes

Approval Date: Sept. 6, 2017

Expiration Date: Sept. 4, 2018

This study was reviewed in accordance with federal regulations governing human subjects research, including those found at 45 CFR 46 (Common Rule), 45 CFR 164 (HIPAA), 21 CFR 50 & 56 (FDA), and 40 CFR 26 (EPA), where applicable.

Appendix B. VR Sitting Balance Questionnaire

1. If you were a therapy patient, do you think this game would make the exercise experience more fun?

Strongly Disagree --- 1 --- 2 --- 3 --- 4 --- 5 --- Strongly Agree

2. Part of the purpose of this study is to understand the differences in virtual reality (VR) experiences in women vs. men. For this reason, please tell us your gender:

Male Female

3. Did you experience any discomfort?

Strongly Disagree --- 1 --- 2 --- 3 --- 4 --- 5 --- Strongly Agree

- If you did experience discomfort, please describe it:

4. Overall, did you have a good experience playing the game?

Strongly Disagree --- 1 --- 2 --- 3 --- 4 --- 5 --- Strongly Agree

- Comments:

5. One of the reasons for keeping this game simple and calm is that earlier studies have found that when the VR experience is intense (as in a very fast and steep roller coaster simulation) players can have unpleasant side effects.

With the limits of simplicity in mind, and the wish to avoid over stimulation, do you have any suggestions to make the game more motivational as a means to encourage reaching, leaning and stretching?

6. Do you consider yourself to be a “gamer” (someone who plays lots of video games)? Yes No

- If yes, do you play most of your games in VR or conventional 2D?

Appendix C. Comment Responses to Question #4

Spelling and misspelling, punctuation and lack thereof are preserved. Drawings are described in brackets.

- It was simple yet interesting.
- The game was a lot of fun and I definitely felt the core stretching
- Collision when attempting to grab balls will encourage more deliberate and slower actions.
- It got blurry sometimes, so I had to adjust a bit. Didn't want to tighten it anymore because it was already snug.
- No motion sickness
- Very interesting and useful for multiple applications
- SUPER NEAT!
- I got better at hand eye coordination/controlling my movements.
- It was fun [smiley face]
- A lot of fun!
- Targets [Drawing of traditional concentric circles target]
- Very interesting, fun, and calming while testing my motor skills.
- Simple but interesting.
- Simple but entertaining
- Enjoyed the physics.
- New to V.R. Fun interactive
- Yes I enjoyed myself. I know the game is supposed to be simple, but having set targets to toss at would be fun.
- Never tried it and loved it
- Some ricoche off the targets might improve the fun factor.

- It was fun, and it’s a good way to make me stretch
- Fun and easy to learn.
- This game is very good for therapy patient
- Very relaxing. Nice color use.
- So fun!

Appendix D. Women's Comment Responses to Question #5

- Moving objects, more difficult levels
- Achievements, and fun challenges that aren't too hard. And fun music.
- Maybe include targets to throw the balls at. Still a lot of fun!
- Maybe make the points scored more prominent and like a motivational reward for scoring.
- I thought it wasn't too simple but not too overstimulating. Maybe a little more things to throw balls at.
- Perhaps being able to put balls in baskets? - Organization and different movements
- Maybe create another objective to make it more fun. Like having a timed game to see how many of something you can get or creating harder obstacles.
- Is any music going to be added? Or other ball colors?

Appendix E. Men's Comment Responses to Question #5

- A seeable scoring system
- Give them targets to hit.
- Maybe some kind of reward animation when colliding with pins. A bell and a "+10" or something like that might jazz it up a little. See Khan Academy.
- Giving a more targetal or arcade experience.
- Have 2 people do the exercise together. Keep track of score. VR interconnectivity.
- blue > green > white; earn points: more red blocks hit with one ball = more points
- Possibly some more targets of variety and possibly physical objects for balls to bounce off of.
- Different objects that do different things to the bricks. Example: Spheres knock them [????], Cubes blow them up, etc.
- Time limit, and more integrated points. Rewards for such as well (maybe confetti for high points and such).
- More colors.
- Possible puzzle game with switches on a dashboard
- Positive, yet calming sounds for actions
- Create a target-centered boss that moves and challenges people to make larger reaches.
- Sensitivity of the controllers is a little high, as well as the release speed
- Maybe rather than just a score, you can also give the player either a hoop or a basket to aim at for bonus points.
- Sound effects
- You could try moving the balls around.
- Have a scoring system possibly.

- If you could add sound effects it would make the experience unbelievable.

- The ball replacement buttons can be placed toward bottom sides to encourage reach and lean. More 'targets' behind and above also.