# Distraction Therapy Using Virtual Reality for Quadriplegic Patients

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**Abstract--Virtual Reality (VR) is an expanding technology that has the potential to play a major role in emerging healthcare practices and treatments. In this study, researchers and developers evaluated the usefulness of VR-based therapy for Spinal Cord Injury (SCI) patients that suffered from neuropathic pain. Individuals suffering from neuropathic pain experience acute discomfort and pain in areas of their body in which they either have little or no feeling. Doctors may commonly employ distraction-based therapy techniques in addition to medication, to alleviate the pain and discomfort experienced by these patients. Distraction therapy works by "distracting" the patient from their pain, in contrast to target the root cause of the pain. This study aims to expand on this traditional therapy by incorporating a VR gaming experience that may help distract and therefore relieve the patient suffering from neuropathic pain. For this study, a traditional tower defense game has been developed to create a sense of immersion for the patient. This game will utilize VR gaming technology in order to be hands free, with the intention of accommodating the most severe cases of SCI. This study will quantify results based on feedback from two surveys, the Immersive Tendencies Questionnaire (ITQ) and the Presence Questionnaire (PQ).**

***Index Terms*—Neuropathic pain, Nociceptive pain, Spinal Cord Injury, Unity, GoogleVR, Android**

## I. Introduction

According to *Spinal Cord Injury: Facts and Figures at a Glance*, published by the National Spinal Cord Injury Statistical Center, up to 17,000 people in the U.S. are diagnosed with SCI per year [15].

Many SCI patients suffer from muscle weakness and abnormal painful sensations. There are different types of pain in SCI. According to *Managing Chronic Pain after Spinal Cord Injury*, presented by University of Washington Medical Center, pain can be classified as either nociceptive or neuropathic. Nociceptive pain, such as musculoskeletal and visceral pain, are caused by irritated undamaged nerve endings. In contrast, Neuropathic pain is caused by spinal cord damages which interrupt the communication between the brain and the body [13].

Currently there are a wide variety of pharmacological treatments for neuropathic pain but determining which treatment is the most appropriate is challenging due to the many complexities involved with treating chronic pain. There are varying degrees and types of neuropathic pain, as well as other subtleties such as a patient's treatment history that may contribute to the efficacy of a given treatment. In addition to these concerns, doctors must also consider "tolerability and safety" when determining which treatment to recommend [4].

In the article: *Recommendations for the Pharmacological Management of Neuropathic Pain: An Overview and Literature Update* the adverse effects of many pharmacological treatments are expanded upon. One adverse effect noted for opioid treatments is that "All patients treated with long-term opioid therapy develop physical dependence". This negative implication for a chronic illness like neuropathic pain is paramount because the treatment only targets the symptoms and therefore the illness may persist rendering opioids a poor choice as a long-term solution [4].

Like opioid treatments, distraction therapy only targets the symptoms, of the problem this case neuropathic pain for SCI patients. The benefit of VR treatments is that they may provide similar results over a longer period and without the adverse effects that are commonly found with pharmaceutical treatments. The longevity of these solutions alone is compelling when considering these problems are chronic and may be lifelong.

Technical advances in healthcare provide new and alternative means to treat patients suffering from SCI. Most recently, Virtual Reality (VR) has been used to engage SCI patients in an enjoyable environment and ease their pain. However, past studies suggest that while VR-based training may improve lower limb-motor function in SCI patients, it still provides only a minor reduction of pain. The developers in this study will create a new VR application that expands upon the previous studies to examine new approaches towards pain reduction.

The VR application will be a tower defense game that utilizes GoogleVR. GoogleVR was chosen due to the wide range of Android devices and headsets that can adequately support the application, two of which are included in Figure 1 below:

headset like Google Daydream on top and the Google Cardboard on the bottom.


Fig.1 VR Headset similar to Google Daydream and Google Cardboard

As individuals living with an SCI vary in their ability to use these headsets, the design choice taken was to assume that the patient will have assistance from a care provider to properly place the headset on and off. Aside from this, any SCI patient that can move their head will be able to play this game and participate in this study.

## II. LITERATURE REVIEW

Neuropathic pain is a debilitating condition that commonly accompanies spinal cord injury. To date, few effective therapies exist for managing neuropathic pain long-term. Recently, an increasing number of clinical centers have started adopting VR technology to treat and manage pain. Many studies have turned to the utilization of VR technology to distract patients from pain. It is believed that VR distraction therapy "can reduce pain for patients with mild to moderate fear and anxiety" [22].

When assessing whether a treatment is appropriate, it is important to address what to focus on, that is, the cause of neuropathic pain or treatment of the pain itself. If the latter is chosen, implementing a distraction therapy would be the focus.

Alternatively, if the root cause of neuropathic pain can be targeted, this research would seek to assist the brain in building new connections to the affected areas of their body. This is known as neuroplasticity. In this case, this research would show that VR may potentially be used to increase the rate of neuroplasticity on affected patients. Aside from this, VR has also shown great potential as a distraction therapy and has been used in Exposure therapy, Treatment for PTSD, pain management, surgical training, phantom limb pain, brain damage assessment and rehabilitation, etc.[11]

### *A. SnowWorld*

Regarding pain management, many studies have utilized VR games as a form of distraction therapy to help patients who have sustained various injuries in relieving their pain. One such example is a VR game called SnowWorld which was designed by Hoffman and Patterson from University of Washington. The game's intent is to relieve pain for burn victims during wound treatment by engaging their senses through VR immersion in an attempt to help them ignore their pain. The representation of an icy 3D world exposes the patients to a seemingly cool virtual environment meant to distract the patients from the pains of their treatment and burns. Using a VR headset and a controller, a player can move through an icy canyon and shoot penguins with snowballs all while listening to music. The architecture of this game exposed the patient to a scenery that was designed to take their mind off the source of their pain, and by allowing the patient to interact with creatures in a playful manner [8].

Fig. 2 Snow World Game

SnowWorld has also been used by the military. A study was conducted with attempts to discover if immersive VR could be able to reduce excessive pain for the patients during a wound debridement treatment. Soldiers who were injured by explosive devices received two subsequent treatments. Twelve of the patients received half of the standard treatment (6 minutes) involving opioids and the other half of the treatment utilizing SnowWorld.

The results of this study were quantified by using the following measures: "Pain unpleasantness", "Worst Pain", and "Time spend thinking about pain." For the first measure (pain unpleasantness) the pain rating was reduced from 6.25 to 2.83 on a scale of 1 to 10, in other words, the pain unpleasantness for the patient became mild descending from moderate. For the second measure (worst pain), the result suggested that the VR game was particularly effective for those who suffered from more severe burn damage or unbearable pain. The pain intensity was reduced from 6.25 to 4.50 on average. For the third measure (time spent thinking about pain), with VR the percentage of the patients spending time thinking about the pain during the treatment dropped down from 76% to 22%. Not only did Snow World manage to distract patient from thinking about the pain, but it also increased the patient's level of comfort [8].

Study results showed that SnowWorld had better results than the standard opioid treatment for a statistically significant number of soldiers involved in the study. Moreover, unlike opioids treatment, SnowWorld generated little risk and few side effects.

### *B. Virtual Gorilla*

Aside from SnowWorld there are many other games that were created to investigate utilizing VR as a distraction therapy. One notable study was conducted by J. Gershon, this study used a game called "Virtual Gorilla" and was used to test the feasibility of VR to reduce pain associated with an invasive medical procedure for cancer patients [1].

Virtual Gorilla is a virtual gorilla exhibit, where the player visits a zoo and can see a gorilla. The game's focus was to capture primate behavior and to be used as an educational tool to raise awareness for this endangered species. When playing the game, the user will be placed in side of a Virtual Visitor Center where they can observe the gorilla's behavior from behind a glass window as they would in a zoo (See Fig3).

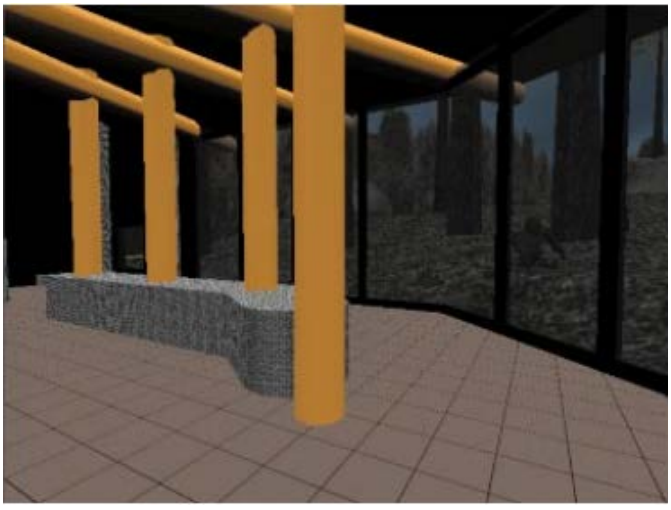

Figure 3. Virtual Gorilla Visitors' Center [1]

The experience is akin to viewing a television program allowing the player to view a family of exotic animals interacting with each other. The difference is that in this game the player is free to look around making the experience closer to visiting the zoo. This adds a level of immersion to the experience that a television program alone cannot yet capture. The player has no interaction with the environment itself and is relegated to viewing only. Included below is a screenshot of one of the tours showcasing a herd of elephants in their habitat (Fig 4).

Figure 4. Virtual Gorilla [1]

This study used pulse rate to measure the effectiveness of Virtual Gorilla as a distraction therapy. It was observed that "reductions in pain and anxiety were found for children who used the virtual reality distraction in comparison with the no distraction condition as evidenced by lower pulse rate and reports of pain by nurses." Whereas no significant differences were discovered in the control subjects not using Virtual Gorilla.

### *C. VR as Distraction Therapy*

One major benefit of using VR to assist with neuroplasticity is that it can be programmed to fit the exact patients' needs as expressed in more detail in *Virtual Reality for Physical and Motor Rehabilitation, Virtual Reality Technologies for Health and Clinical Applications.* It is believed that VR technology may potentially play a more significant role in cognitive assessment and other treatments in the near future. Therefore, the studies and researches done on incorporating VR technology to refine rehabilitation and treatment processes have been proven to be reasonable [9].

Although this is quite notable and there is evidence to warrant further research for VR as an aid with neuroplasticity, VR does have its short comings as well. When attempting to generalize the VR solution, the results may not prove to be better than traditional real world therapies. "Larger clinical studies are required to establish the efficacy of using VR in sensorimotor rehabilitation in different clinical populations.

Additionally, to date there is little information on the generalizability of the training effects of VR to the corresponding physical environment in general, and the VR training parameters associated with optimal transfer to real-world functional improvements remain yet to be elucidated. Furthermore, it is unclear whether advantages of VR over real-world training exist" [9].

## III. PROJECT REQUIREMENTS

The subjects tested in this study must be currently suffering from Spinal Cord Injury related pain or discomfort. Additionally, the subjects should have sufficient vision and hearing to be able to respond to the stimuli of a VR application. The VR application developed for the purposes of this research must be comfortable enough to wear on the head without additional support from the hands or a 3rd party. The application should be accessible to individuals regardless of their ability to use their arms, speak, or walk.

To facilitate the creation of this application, a code repository and version control process must be in place. A process must be defined for the deployment of the application to the devices usable by subjects for testing. Any software licenses, such as for Unity 3D, must be acquired and applied before subjects can be tested.

## IV. METHODOLOGY

The goal of this research paper is to create a fully-immersive Virtual Reality application in order to examine the potential for use of VR in distraction-based therapy.

The VR application will be developed within Unity 3D, a 3D game engine that has the ability to deploy to multiple formats. Source code for the application will be written in C#.

The application must deploy to Smartphones running Android 4.3 O.S. or higher, for use within VR headsets such as Google Cardboard/Daydream and Samsung VR.

Fig 3. Adult using GoogleVR headset

Subject candidates will be tested for vision and hearing before being trained to use the application. A guided training session of the application will occur before the user is allowed up to 15 minutes of unguided, but observed, use of the application.

After a candidate has completed a session with the VR application, the individual will fill out a questionnaire. Subjects will be asked to rate their experience in the following areas:

- Ease of using the application
- Interest in the application
- Immersiveness of the application
- Comfort of the VR headset
- Level of pain or discomfort when VR session begins
- Average level of pain or discomfort during VR Session
- Level of pain or discomfort when VR session ends
- How well the application helped the patient cope with pain

### *A. The Virtual Reality Tower Defense Game*

The goal involved designing a game with a sufficiently engaging environment to distract the player. The major limitation in the design process was that the game needed to be playable by patients suffering from more severe SCI (only capable of moving their head). One of the major benefits of a basic tower defense game is that the engagement of the player is based more on carefully thought out strategic positioning and planning instead of fast reflexes.

The tower defense game presents the player with a large map that can be navigated by "gazing" – this is a term that we use to describe when the player is looking in a specific direction for a set amount of time. This same gazing concept is used as a substitution for clicking that would be common in a typical tower defense game. As the player navigates over the landscape they can interact with certain objects by gazing at them. The most prevalent object they can interact with is called a node. These nodes are predefined locations on the map where the user can choose to build a tower. The placement of towers as well as the type of towers that are placed will provide different strategic advantages and costs.

In the alpha release of this game there are two different types of towers with a respective associated cost (see Fig. 4). Based on how well players adapt to these game concepts and mechanics will allow the developers to expand on different tower options and upgrade paths in order to make the game more engaging and subsequently distracting in the future.

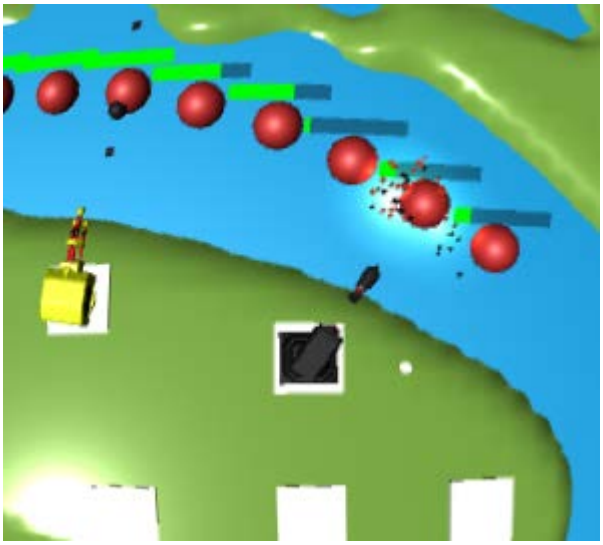

Fig 4. Two different towers options

The tower defense game includes an opening scene containing a menu to allow the player to either start the game when ready or exit out accordingly. In the picture below, the menu is displayed along with the crosshair (see Fig. 5) that will help the player orient themselves and avoid motion sickness.

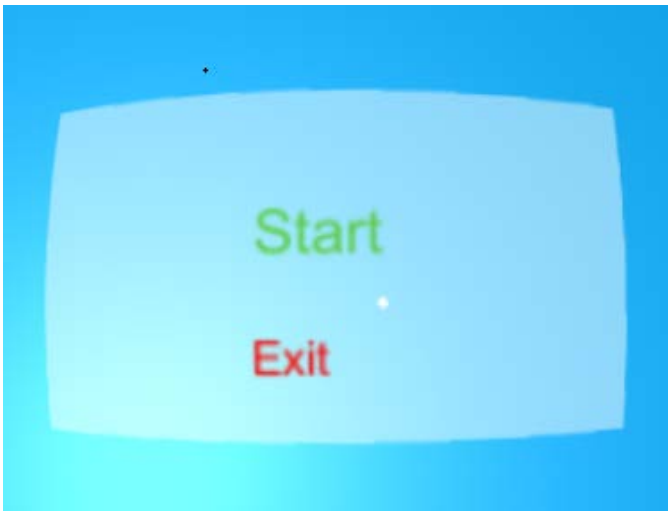


Fig 5. Start menu and crosshair

If the player chooses to the start the game, a new scene will open presenting the player with a top down view of a forest landscape, including trees, rivers and other aesthetic objects. On two opposing corners of the map there the player will find a spaceship and a castle. The spaceship represents the spawn location of the invaders and the castle represents the players' home base which they will need to defend.

Fig 6. Entire Map

After a short countdown, the game will begin and "enemies" will start to spawn from the spaceship. Similar to the towers in the alpha version, there are only two different types of enemies which may be expanded upon after preliminary results have been received. Currently each enemy has two basic attributes, speed and health. With these two attributes, the developers intend to make interesting combinations of enemies that will require the player to adjust their defense strategy accordingly. Enemies will spawn in set waves; these waves increase in difficulty as the game progresses and contain increasingly difficult combinations.

### *B. Programs and Implementations*

The primary program used in designing this game was Unity. Unity is a cross-platform game engine developed by Unity Technologies. This game engine has been used to develop video games for computers, various consoles, and various mobile device operating systems, but for the scope of this study the game will be developed specifically for Android. Although the game is being developed specifically for Android, the potential for scaling out to other platforms is there and should not require a large amount of effort as Unity supports this.

When developing a VR game for Android the designers chose to utilize the GoogleVR packages available for Unity, as well as various other Software Development Kits (SDK) as necessary. The environment was created largely from scratch using some assets that were freely available through the Unity asset store.

## V. Preliminary Results

### *A. Planning*

Quantifying results for this study were done over 2 major releases using four surveys. The first release is the alpha version of the tower defense application, with a test population of adults who are not suffering from SCI. The purpose of this first test is to determine the readiness of the application and complete basic quality assurance before proceeding to the second release. The second release is focused on testing with a patient suffering from SCI. The focus of this release is to determine the effectiveness of the VR application in successfully distracting the patient and reducing their perceived level of pain.

The four surveys that were used in this study are:

- Visual Analog Pain Questionnaire
- Immersive Tendencies Questionnaire (ITQ)
- Presence Questionnaire (PQ)
- System Usability Survey

The Visual Analog Pain Questionnaire was given before the participant plays the game, it is a single question intended to gauge the level of pain the patient is feeling. The ITQ survey was also given to the patient before playing the game. This particular survey was developed by Witmer and Singer and is intended to capture how susceptible the participant is to immersive environments. After the patient, has played the game they are given the Visual Analog Pain survey again to determine how effective the therapy has been. The second pain survey is followed by the Presence Questionnaire and System Usability Survey. These last two surveys are very similar in that they both measure how good or bad the players experience was. The Presence Questionnaire was also developed by Witmer and Singer – this questionnaire focuses on how naturally the user interacted with the gaming environment. Lastly, the system survey aims to determine if the application was easy to use. Based on the results from these surveys the game will be modified to increase immersion/playability for the second release. This is extremely important because patients suffering from SCI may have varying physical restrictions and a certain level of playability must be attained for this therapy to be effective.

Fig. 7 Wong-Baker Faces Pain Rating Scale[16]

The alpha version of the tower defense game aims to deliver 10-20 minutes of game content, and filling out the surveys should take approximately 5-10 minutes using Qualtrics. The results will be given to Burke.

### *B. Results*

During the alpha testing phase a variety of individuals were tested, including university students and working professionals ranging from ages 17-35. In total, 15 surveys were administered and feedback was provided. The overwhelming majority of the alpha testers were not patients and do not have any pre-existing conditions such as neuropathic pain. Therefore, the results showed that the nearly all of the test subjects reported "No Hurt" or "Hurts Little Bit" before playing the Tower Defense game.

When analyzing the results of the Immersive Tendencies Questionnaire, the bulk of individuals participating in alpha tests fell into the "occasionally to often range" indicating a propensity to immersive environments.

When discussing the Presence Questionnaire, the feedback was generally positive, although some participants indicated there was difficulty understanding what to do.

Based on the feedback received in the alpha testing we have realized that the test subjects who had previous experience with Tower Defense games could pick up the game easily and had a relatively enjoyable experience. The participants without this background were struggling with the learning curve.

## VI. Conclusion

### *A. Future of Tower Defense (Beta)*

The alpha test of this application proved to be a successful proof of concept in that a typical tower defense game can be ported over to a hands-free VR environment. For the beta version of this application the developers will seek to address the concerns noted during the alpha test. Developers will create more levels to the game allowing for gradual exposure to the concepts necessary to successfully play a Tower Defense game. This new content will focus on the learning curve of a tower defense game and make it easier for new players.

Aside from onboarding content, developers intend to increase the gameplay time and depth of the game by introducing more difficult content, upgrade paths for turrets, and more interesting turret types.

### *B. Future of VR and SCI*

This study among many others has shown that there is great potential for VR technology to be utilized as a distraction therapy. Although these are positive additions to the field there are many other potential applications for this technology and SCI patients. Using a VR headset in conjunction with new software, SCI patients may have a new way to access technology such as the internet or other applications we take for granted.

Although these are not distraction therapies per say the quality of life for an SCI patient can change dramatically by providing them with more independence. It is possible to imagine that an SCI patient could use this technology to browse the web independently, play their favorite video game, or even simply turn the pages of a virtual book. These simple applications may increase the quality of life for an SCI patient and potentially even be considered a form of distraction therapy.

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