Immersive Virtual Reality for Individuals with Spinal Cord Injuries

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***Abstract* - Immersive Virtual Reality (VR) is an emerging technology with the potential to have a major impact in healthcare. Immersive Virtual Reality is the best way for patients who are incapable of doing a certain task for their rehabilitation, to engage in a fun and enjoyable environment that will help them. The clinicians at Burke Rehabilitation Hospital have found spinal chord injury patient interaction with the Virtual Reality environment challenging due to the nature of spinal cord injuries and the degree in which individuals with them can move. Due to some survivor's limited range of motion, it has been proven difficult to easily start virtual reality therapy without the use of hands hitting a button on the side of the Samsung Gear VR. Developers working on this study will create an application that may provide a solution to the current problem, so that patient and clinician interaction with the virtual reality environment is seamless and accessible. Patient and clinician interaction is very important when dealing with Virtual Reality applications, because knowing a patients condition and reaction to specific environments is important. It will also help developers with knowing what to add to the application. By looking at certain research such as lag motion sickness, mirror neurons, neuroplasticity and gaming software developments, this gives coders and clinicians the upper hand. In order to assess how the survivors with spinal chord injury and clinicians are receiving the immersive virtual reality solution, this study will use the Presence Questionnaire and the Immersive Tendencies Questionnaire for feedback.**

***Index Terms* – Avatar, Immersive Tendencies Questionnaire, neuropathic pain, Presence Questionnaire, rehabilitation, virtual reality, motion sickness, Gear VR, Unity, Unreal Engine.**

I. INTRODUCTION

Technological advances in healthcare provide new and alternative means to treat patients. The use of immersive virtual reality (VR) to improve symptoms and reduce pain has great potential. For spinal cord injury survivors (SCI), 81% report experiencing pain which is difficult to treat with common practices [13]. Using an immersive VR environment, individuals will be able to simulate certain therapies, like picking up an object or driving, to potentially improve motor functions and reduce pain.

This study aims to provide a mixture of resolutions to improve SCI survivors' neuropathic pain using a virtual environment with Gear VR headsets. Using this gear, Burke Medical Research Institute is already presenting rehabilitation videos to individuals suffering from SCI and has reported that this technology is helping the individuals' symptoms. However, due to the logistics of putting on the headset and controlling the environment, the efforts of pain reduction are diminished in the process.

Individuals with SCI vary due to the type of injury they suffer from. If an individual suffers from an acute SCI, they cannot move their head down to control a virtual environment [25]. Due to this, there are certain requirements that must be met when developing an application to help survivors and caregivers.

Fig. 1. Samsung Gear VR Headset

This study is done in two phases. Phase one will focus on developing a universally designed interface between a tablet and aforementioned headset. The Gear VR headset will be controlled from a tablet so that clinicians can manually control when the VR technology is turned on or off. The point of view and what is being displayed to the user will also be seen through the tablet for ease of use. Phase one will focus on the impact to the clinicians, as they will be the ones interacting with the application. Phase two will focus on the individual with a SCI, and creating a more adaptive environment. This study attempts to create an environment where survivors can create avatars in Unity that resonate with them in order to increase the immersive experience. During the first two phases, improvements will be implemented based on the feedback provided by the clinicians and individuals.

This paper is broken down into the following sections: introduction, background information, research methodology, application development, patient and clinician VR interaction, results, conclusions, future work and references.

II. BACKGROUND INFORMATION

A. Literature Review

Survivors with SCI often suffer from neuropathic pain, which the American Chronic Pain Association describes as a complex, chronic pain that is usually accompanied by tissue injury. Damaged nerve fibers send incorrect signals to other pain centers which causes a change in nerve function at the site of injury and surrounding areas ultimately causing pain to the individual [2]. Since there are currently no restorative treatments for individuals affected by SCI, research on VR environments to help improve patient conditions is being conducted [3]. SCI not only affects physical aspects of an individual but also psychological and emotional aspects, depending on the level of disability caused by the injury [17]. For these reasons, the research and results of using an immersive VR can improve SCI survivors' physical, mental and emotional health, as well as their overall quality of life.

In previous studies, SCI survivors reported reduced pain and increased duration of pain relief when using immersive virtual reality therapy for a period of 12 to 16 weeks [13]. Figure 1 represents some of the questions researchers should ask when developing and implementing a VR system to achieve optimal results.

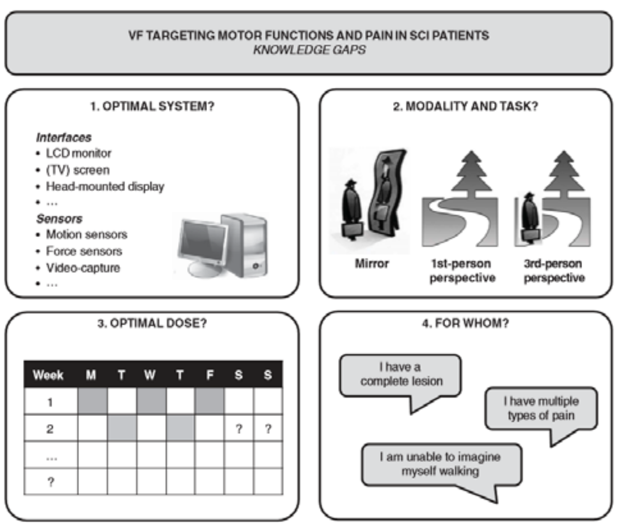

Fig. 1. Proposed questions when coming up with a VR system [7].

Most VR systems being used to treat individuals with SCI are goal oriented, where the user has to complete a certain task [13]. The immersive environment allows individuals to feel as if they are completing the tasks themselves which stimulates their senses. It is the purpose of this study to provide tasks for survivors to accomplish, measure the success of these tasks over a period time, and come up with an optimal solution to improve survivor pain and quality of life.

There have been different approaches to avatar creation in past studies. Some research suggests that survivors who are able to create an avatar that represents themselves has a greater impact on the success of the VR therapy, while other studies suggest that there is no correlation between the two [1,5]. Currently Burke Rehabilitation Hospital does not have a personalized avatar experience. This study intends to create an environment where individuals can create an avatar, and feedback will be collected

B. Lag and Motion Sickness

Jet lag or sleeping sickness is experienced by people who quickly travels through multiple time zones. This is a temporary sickness. It happens because the internal clock, or circadian rhythms of a human body is synchronized with the local time zone and they give signals to the body about sleeping time, awakening time and other human routine functions and when a person quickly travels to the other time zone, which has significant difference in time, then body needs time to get synchronized with new time zone and that person suffers Jet lag or sleeping sickness.

Motion sickness is caused by moving environments like cars, airplanes, funfair rides, boats, space, and virtual reality. Anyone with a healthy functioning vestibular system can be made motion sick. "Motion sickness occurs most commonly with acceleration in a direction perpendicular to the longitudinal axis of the body, which is why head movements away from the direction of motion are so provocative. Vertical oscillatory motion (appropriately called heave) at a frequency of 0.2 Hertz is most likely to cause motion sickness" [15].

Primary functions of vestibular system are spatial orientation, maintenance of balance, stabilization of vision through vestibular–ocular reflexes etc. Additionally it also functions as a "toxin detector" that recognize any disturbance of regular or expected patterns of vestibular, visual, and kinesthetic information and take it as failure of central nervous system assuming that the body has ingested a neurotoxin and start vomiting as a defense mechanism. "The key observation is that the physical intensity of the stimulus is not necessarily related to the degree of nauseogenicity" [7]. For example, a person sitting in cinema in front of a wide screen experiences self-vection and 'cinema sickness' because there is no motion in physical world but the visual system is signaling the movement or self-vection.

Motion sickness in Virtual Reality is known as VR or Simulator Sickness. Motion sickness is quite different than simulator sickness though both of them feature very identical symptoms. Motion sickness creates a sense of post movement afterwards whereas simulator sickness leaves a feeling of dizziness.

TABLE I
RULES LEADING TO MOTION SICKNESS

Rule	Name	Definition/ Effect
1	Visual–vestibular	Motion of the head in one direction must result in motion of the external visual scene in the opposite direction
2	Canal–otolith	Rotation of the head, other than in the horizontal plane, must be accompanied by appropriate angular change in the direction of the gravity vector
3	Utricle–saccule	Any sustained linear acceleration is due to gravity, has an intensity of 1 g and defines 'downwards.'

Stott (1986) proposed a useful set of simple rules which if broken, will lead to motion sickness: [1]

"The cause of these symptoms is due for two reasons. First, the brain receives conflicting cues namely from the visual cortex, posture and vestibular system and secondly from erroneous data the brain believes the user has ingested or absorbed based on conflicting processed data from the perceptual, vestibular, postural and visual system". [18]

METHODS FOR DEVELOPERS TO RUDUCE MOTION SICKNESS:

1. Making sure the 3D rendering and shades in every scene are setup perfectly. Providing users an option to access full adjustment of their eye configurations. Making sure that everything is optically correct.
2. Making walking speeds slow. Making sense of jumping and awareness as close as possible to the real world.
3. Making a fixed or solid reference point for user to focus on and keep a track of the movement and understand the environment mentally. In our case, it is a small star which moves in the direction of user's head movement.
4. Using darker textures makes a scene comfortable to look at and causes less irritation than bright and illuminated objects.
5. Using a proper sense of scale. For e.g. a user will feel very small compare to the environment if the scene is moving faster than user's head movement.

C. Mirror Neurons

Mirror neurons were first found in research where macaque monkeys were implanted with electrodes. "Building on research in animals, researchers have conducted brain imaging studies that reveal a possible mirror neuron "system" in humans, as well" [19]. It is so believed that mirror neurons, which are a variety of visuospatial neurons, forms the basis for human behavior and social interaction. Mirror neurons respond to actions that we observe in others. Interestingly mirror neurons fire in a way as if we were performing the task by ourselves. "Rizzolatti recorded from the ventral premotor area of the frontal lobes of monkeys and found that certain cells will fire when a monkey performs a single, highly specific action with its hand: pulling, pushing, tugging, grasping, picking up and putting a peanut in the mouth etc. However, the astonishing truth is that any given mirror neuron will also fire when the monkey in question observes another monkey (or even the experimenter) performing the same action, e.g. tasting a peanut!" [18]. These neurons can enable us to imitate the movements of others and mime, in turn, providing an opportunity for rehabilitation.

Discovery of mirror neurons manifests that human beings understand each other by feeling and not by thinking because mirror neurons not only let us understand other's actions, but the intentions and emotions behind those actions. For e.g. we feel the pain and make an "ouch" face and voice when we see a person getting hurt by the door while walking out of the room. We don't have to think about whether to react or not. We experience the intensity of pain immediately and effortlessly. Mirror neuron research is therefore helping us to reinterpret the neurological foundation of social interactions. These studies are leading to new therapies which will help to regain lost movements of stroke victims [19].

D. Distraction v. Neuroplasticity

"Neuroplasticity: the brain's ability to reorganize itself by forming new neural connections throughout life. Neuroplasticity allows the neurons in the brain to compensate for injury and disease and to adjust their activities in response to new situations or to changes in their environment" [4].

Brain cells die or gets damaged on regular basis and it does not pose any serious threat to a person's mental health because "axonal sprouting" , a mechanism by which brain reorganization takes place, is a process in which healthy and unharmed axons develop new nerve endings to connect to the neurons whose links were damaged. It is neuroplasticity by which all permanent learning takes place in our brain, such as playing a musical instrument or mastering a different language. Indeed, the neuroplastic nature of the brain allows for it to restructure over time with training and practice. It is a lifelong process, which means, as long as the person is alive, the brain will compensate for damage. But in order to reconnect, the neurons need to be stimulated through activity. Thus, by proper and controlled rehabilitation process, it is possible to recover from stroke, get out of a depression, overcome birth abnormalities, autism, learning disabilities and other brain deficits.

From researches and experiments, Immersive VR has been a successful method of distracting the patient's attention from the pain or the part of the body being operated. According to studies, by controlling the sensory stimuli, almost all sorts of pain can be distracted. VR distraction therapy is not used for completely eliminating the pain but for distracting the patient's attention temporarily so that the intensity of pain is lowered eventually helping doctor as well as patient. The degree of success of distraction therapy depends on the degree the patient is distracted by the sensory stimuli provided by the VR system. A study was conducted in which a patient was operated for three minutes of physiotherapy without diverting their attention and another three minutes using virtual reality games. The visual analog scale was used to measure the pain intensity. "The result shows a reduction in the treatment time from 60 minutes to 14 minutes". [16]

Depending on the task, whether immersive VR is being used for pain therapy (temporary procedure) or for some longer-lasting effects, distraction and neuroplasticity plays their respective roles. Distraction will work for temporary situations whereas neuroplasticity will work for long duration procedures as brain reorganization is comparatively slow and longer-lasting process.

E. Environments

According to the School of Occupational Therapy at Hadassah-Hebrew University, "Injury or disease to the central or peripheral nervous systems typically results in a decreased ability to perform activities of daily living, due to the resulting cognitive and motor deficits." [17] Spinal cord injuries can be devastating. It disrupts the signals that are being sent between your brain and your body. A spinal cord is a bundle of nerves that are located in the middle of your back from your tailbone to your brain. Most spinal cord injuries begin with a blow that fractures or dislocates your vertebrae, the bone disks that make up your spine. [23] Unlike other injuries such as a broken arm bone, or a broken collarbone, a spinal cord injury does not always mean that the spinal cord has been cut. Most of the injuries, result in pieces of vertebrae torn into cord tissue or the nerve parts are being pressed on, so they can no longer carry signals to and from the brain. One of the most challenging things that therapists face with spinal cord injury patients is identifying which tools are effective in motivating and communicating their skills and abilities to be transferred during the rehabilitation to the "real" world.

Virtual Reality applications have been focusing on the development of the virtual environments and how they impact patients. For example, VividGroup's Gesture Xtreme VR System results show that the patients enjoyed the application with physical and cognitive impairment. In this study, the team looked at the way patients reacted to a series of stimulated functional tasks such as catching a virtual ball or swimming in a virtual ocean. A digital video camera converted the user's movements through a video signal using unique software. The use of video gestures was a success because it processed the user's image on the animation screen. This helped the patients engage in the virtual world and have a more realistic experience with the application.

The use of an avatar or image of the user, can be beneficial as well because it enhances the thought of actually being inside of the virtual reality world, instead of feeling as if they are just playing another game. While creating virtual environments, coders need to keep in mind the emotional and psychological state of their users. Creating virtual reality environments, means creating an application that could either help or completely devastate a patient, which is why it is so important to get to know what certain patients like and dislike. For example, a patient who cannot move their arms, but loves basketball, may or may not like an application that is centered around basketball because it may bring back memories which may cause the patient to discontinue the use of the application.

III. RESEARCH METHODOLOGY

This study consists of two parts. First, the Samsung VR headset should be controlled by a clinician from a tablet. The clinician should be able to replicate what the patient is seeing through a different medium. This control will allow the clinical to easily start and stop the VR simulation as needed, and ensure correct view. Part one will also include experimenting with the tilt of the headset so that SCI survivors unable to look down at their hands or feet will be able to see the same view as an individual that can. In order to accomplish these goals, the researches will look into ways to mirror the VR simulation to a computer or TV screen. Additionally, the researchers will develop an interface for clinicians to be used on a tablet.

Secondly, this study will develop two different VR simulations. There will be one sematic environment. This environment will consist of ambient scenery that individuals can explore. Unity will be used to create a virtual world that a camera can be ran through for the VR environment. Figure 3 shows an adult utilizing this technology and being immersed in a VR simulation. The use of 360 degree cameras can also be applied to this part of the process.

Two non-sematic environments will be created for this study. One environment will be for hand simulation, and one for feet simulation. Simulations will consist of SCI survivors doing activities that are nostalgic to them, and will be 5 minutes in duration. Some examples of these simulations will be: washing dishes, driving a car, writing a note, kicking a ball, and riding a bike. This study will also research ways to create user profiles where avatars can be customized to look like the individual that is using them. Data for this study will be collected using three different questionnaires:

1. Presence Questionnaire.
2. Immersive Tendencies Questionnaire.
3. Visual Analog Pain Questionnaire.

The visual analog pain questionnaire will be given to the SCI survivor before and after VR therapy, and the presence and immersive tendencies questionnaire will be given only after treatment.

Fig. 3. Older adult utilizing Samsung Gear VR goggles

IV. APPLICATION DEVELOPMENT

A. Unity v. Unreal

When conducting this study, developers had to choose between two different game software development applications, which were Unity 3D and Unreal Engine. Unity is a 3D game engine that was developed by Unity Technologies [21]. It is used to develop video games for mobile devices, PC websites and consoles. It is a user friendly development environment that can be utilized in creating 3D images. Unity, like most game development applications is free, but the Pro version is costly. The Unity application is a completely 3D environment that is suitable for laying levels, doing animation and writing scripts. It is a user interface that is well organized and customizable. The Unity scripts that are used are the following: UnityScript, C#, and Boo. Unity Script is similar to JavaScript and ActionScript, while C# is similar to Java. Additionally, Boo is similar to Python. Choosing a development language to use for this project was dependent on what background knowledge the developers had and the flexibility of the language.

Unreal Engine is a game engine that was developed by Epic Games as a complete set of game development tools. The language associated with Unreal Engine is C++. Unreal Engine is based on a high degree of portability [8]. It is designed for Windows, Xbox, OpenGL, Android, and JavaScript. Unrealscript another one of Unreal's scripting language, is the native language of Unreal. Unreal Script was created for simple high-level game programming. UnrealScript is similar to Java due to it being object-oriented.

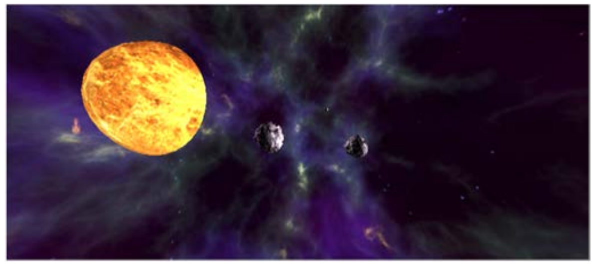

Fig. 4 VR environment for this study.

The developers in this study chose to program the VR environment in Unity. Unity provided more customization options as well as support. The developers also used GitHub to collaborate on their work to grow the VR environment. Figure 4 represents the VR environment that the developers have created for the purpose of this study. The researchers on this study decided on space because it was a creative outlook on already existing environments. Unlike an underwater theme, outer space has not been heavily researched in regards to VR environments. Space is a very abstract environment with an unlimited scope.

To build the environment in Unity, developers used online resources, programming knowledge, and Unity's asset store. The game was created with the target audience in mind. Since the individuals with SCI have limited range of motion the menu bar options are selected when a user holds a crosshair over the item for a duration of 5 seconds. The VR environment is made to be comfortable for users and fun. Users will experience a simulation as if they are flying through space while they have to destroy the meteors and other objects coming towards. This game provides a challenging and fun environment with different levels of difficulty as individual's therapy progresses.

B. Avatars

Avatars in virtual games are what make a game more interesting and relatable. If an individual can create an avatar that resembles themselves, it makes the VR environment more believable [9]. Individuals can choose what clothes, skin color, hair color, hand or feet size, etc. that best represents the user. These virtual games allow for us to be a lot more flexible in changing our appearance to the way that we want to look. Some studies suggest that individuals build avatars that represent a, "better" version of his or herself. Due to the personalization an avatar can greatly impact how a patient reacts to therapy. Due to the nature of neuropathic pain in survivors with SCI, it is important that a therapy session feels personalized and is successful. Avatars provide a meaningful relationship between patient and the VR therapy, so that patients believe they are moving their hands and feet, in turn reducing neuropathic pain. Studies suggest that the more immersed we become, the more we enjoy VR environments and that correlates with personal avatar representation [9].

VI. RESULTS

A. Planning

Results for this study will be obtained in three different phases. First, the alpha version of the virtual environment will be tested on Pace University students and staff. The alpha release will be a 10-minute demo with surveys before and after testing. The researches plan to obtain at least 50 completed surveys for preliminary analysis. After the results are analyzed a beta version will be released to Burke Rehabilitation Hospital to be tested on individuals with SCI. Results will be obtained from four different surveys that should take less than 5 minutes to complete. The first survey will judge individuals pain and will be given before and after interaction with the VR enviornment. Figure 5 represents the pain scale that will be used in this study. This survey will allow researches insight into how well this thearpy is working to reduce user pain. The second survey, which will be given before interaction with the enviornenment is the Immersive Tendancies Questionnaire, which indicates how susceptible a user is to immersive virtual enviornments. This study hopes to find a correlation between users with a high susceptibilty to immersive enviornments and pain reduction. After the user has undergone the immersive experience of this study, they will then fill out the pain rating scale for a second time, along with 2 other surveys. The System Usability Scale will be used to provide feedback on the ease of use of the envionment that has been created. This survey is essential for this study because survivors with SCI's have varying, limited ranges of motion. The ease of use will be directly related to how well the thearpy works. Additionally, the Presence Questionnare will be given to individuals to tell how natural the expierence went, and how interaction with the evniornment felt. All surveys will be filled out via Qualtrics and feedback will be implements in the Beta version that will be given to Burke for testing.

Fig. 5 Wong-Baker Faces Pain Rating Scale [24].

Burke Rehabilitation Hospital will test the enviornment on its individuals with SCI's for one week, and results will be analyzed for further modification to the enviornment.

B. Results

Students at Pace University, as well as co-workers and acquaintances of this study were able to test the alpha demo of the VR environment. A total of 50 surveys were completed and insightful feedback was provided to be incorporated in the beta version. Since most individuals tested did not have a pre-existing injury, no hurt was predominately selected according to the Wong-Baker Faces Pain Rating Scale. In regards to the Immersive Tendencies Questionnaire, most individuals fell into the occasionally to often range indicating that they are susceptible to virtual environments. Additionally, most people provided positive feedback in the Presence Questionnaire and interacted with the environment well. Figure 6 shows a positive response to virtual interaction.

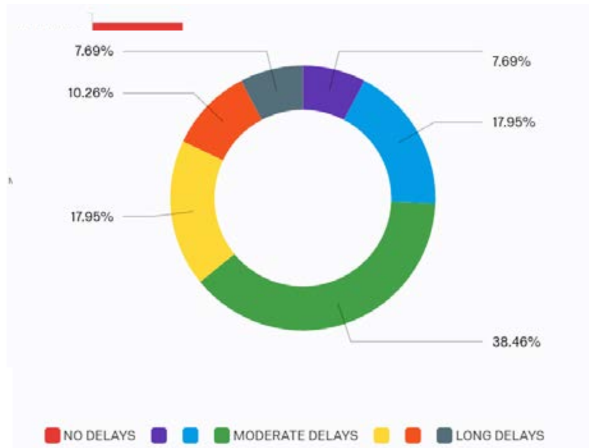

Fig. 6 Positive feedback regarding interaction with VR.

However, some responses indicated that interaction to the environment on performing specific tasks, like blowing up asteroids, proved difficult. Delays were also experienced within the VR environment that interfered with user's ability to perform tasks. Figure 7 visualizes the results of this.

Fig 7. Response to experienced delays on VR environment.

Based on this feedback and testing on one individual with SCI the following changes were made.

1. Narrow the field of view.
2. Make all of the asteroids destructible in a timely manner.
3. Change the cursor from a star to a crosshair.

VII. CONCLUSION

Virtual Reality for therapeutic purposes is only in the beginning stages of its potential. This research shows that VR is a viable way for SCI therapy, with great impact on pain management for survivors suffering from this injury. Since this study is in the beginning stages, the researchers hope to continue to develop the VR environment and find ways to improve the experience.

VIII. FUTURE WORK

A. User Profiles for Therapy

Burke Rehabilitation Hospital hopes to have unique user profiles based on patient therapy. It is the hope of this study to provide the foundation for this therapy. When a user comes in for therapy, they can log into their account and create an avatar that represents them. While doing therapy, users will be able to accomplish different tasks and complete levels. User profiles will be built upon level completion, so that therapy changes every time and keeps individuals engaged.

The low cost of some VR technologies make this type of therapy cost effective. As this technology emerges and becomes more wide spread, individuals can practice their therapy in the comfort of their homes as opposed to coming in for treatment. This will allow easier access to therapy, reduced costs, and reduced pain in survivors with SCI.

B. Samsung EKSO Project and HIMMS Proposal

The research team involved in this study is working with Samsung and Burke Rehabilitation Hospital on a proposal to continue this research with a brain-controlled robotic exoskeleton.

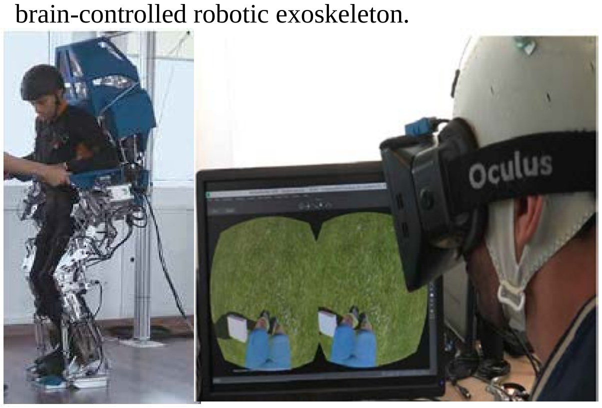

Fig. 8 Current research studies using exoskeleton and VR [1].

Figure 8 shows the type of technology they are using, along with the environment that the user sees. Already, this research conducted by Migul Nicolelis has seen drastic positive results. Survivors with no movement in their legs for a long time were expierencing sensation in their legs which changed their paralysis diagnosis [1]. Pace, Samsung, and Burke Rehabilitation Hospital hope to replicate this study at a lower cost. This will allow patients that cannot afford this type of thearpy access to it.

C. Additional Publications

The researches are planning on publishing this study in the following journals: Games for Health, which is a journal specifically oriented around the use of various gaming technologies such as the Xbox Kinect, for example, to showcase how modern technological advances in gaming could be used for health benefits in individuals with all kinds of medical diagnoses. In the course of this research, we are attempting to introduce virtual reality rehabilitative practices with a particular interest in a suspension of disbelief experiential event. For this express purpose, Games for Health includes editorials on gaming software like the newly released, Pokemon Go mobile phenomenon and a number of original article pieces including research done with the Nintendo Wii and cerebral palsy patients. With respect the researh being conducted in this study, developers have run the course of building a Samsung Gear VR space game whose focus is not so much on balance or anything of the sort as much as it is about the suspension of disbelief phenomenon. The research team finds that this end-goal suits this publication platform perfectly.

Additionally, this study will also plan on publishing an article in Neurorehabilitation and Neural Repair which is a paper that specifically targets the care of individuals who have suffered from various forms of neural damage. Injuries could range from spinal cord severances to burned nerve endings in the finger tips. This paper has a special interest in the use of a wide range of methods particularly to solve the complex issue of neurological rehabilitation through therapies of exercise or otherwise, through an experiential process that fools the brain into thinking that the injury is momentarily gone. Given that the very patients that Pace University is working with are those individuals with, in many cases, moderate to severe spinal cord injured patients, it is concluded that this research suits this publication platform especially well. In publishing for this paper, the researchers have planned slight alterations to the original paper for the express purpose of meeting paper obligations and deadlines, as such, the reader can expect to see slight variations in presented material as it relates to the work in the actual paper. For example, with respect to publication in Games for Health, we place a greater emphasis in work as it relates to the future of virtual reality experiences for individuals of all disabilities. In Neurorehabilitation and Neural Repair journal we place a greater emphasis on VR as a potential source of neurorehabilitation, particularly for patients with severe spinal cord injury as they are quite incapable of even minor movements of the head.

Lastly, the researchers are planning for publication in a third journal at this time; Spinal Cord. This paper covers generally, all research pertaining to the spinal cord. As with Pace Universitys partnership with Burke Rehabilitation Hospital, this study is expecting to be able to publish in Spinal Cord as well. Being that Spinal Cord magazine asks for the most content, and asks for very particular styling of the paper, this team finds it best to adapt the paper for Spinal cord and make minor adjustments for inclusion in Games for Health and Neurorehabilitation and Neural Repair.

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