Accessorized Therapeutic Game Experiences for Tablets

Alex Restrepo

Jonathan Engelsma

Thomas Parker

John Farris

Grand Valley State University

Author Note:

Alex Restrepo, Jonathan Engelsma, Thomas Parker, GVSU School of Computing. John Farris, GVSU School of Engineering.

The authors would like to acknowledge Alex Hastings, Cathy Harro, and the therapists at Hope Network and Mary Free Bed Hospital for their contributions to this study.

Abstract

In the world of physical therapy, a number of consumer gaming devices have been used with various levels of success. Most commercially available video games are designed for the general population and are, in most cases, overwhelming and difficult for traumatic brain injury (TBI) or stroke patients to use. Specialized therapeutic medical devices are not only expensive and non-portable, they also make limited use of gamification techniques to better engage and motivate the patient. This paper examines the use of inexpensive, portable handheld devices, together with a custom sensor accessory in order to drive a set of therapist designed and configured, short video games. Games have been designed that are intended to elicit specific therapeutic movements from the patient, are customizable by the therapist for a given patient's needs, and also produce clinical output for the therapists to use. The games have been evaluated in clinics by physical therapists who treat TBI patients, and the results indicate our approach addresses the shortcomings therapists have experienced with prior attempts at gamification in physical therapy. Moreover, game controllability by the therapist has been identified as a key component in successfully gamifying treatment of TBI patients as it allows the therapist to customize the game experience to suit a patient's individual needs.

Accessorized Therapeutic Game Experiences for Touch-Enabled Devices

Traumatic brain injury (TBI) has been referred to as the "silent epidemic", given its high level of incidence. (Goldstein 1990). Researchers have reported that the number of people in the United States being treated for brain and nervous system disorders exceed that of any other health problem. (Goldstein 1995). The Center for Disease Control and prevention estimates that the direct medical costs and indirect costs such as lost productivity of TBI totaled an estimated $76.5 billion in the United States in 2000 (CDC 2012).

The initial interviews our team conducted with physical therapists in a local hospital and clinic informed us that games were in fact being used in TBI therapy, but therapists and patients alike expressed dissatisfaction with the commercial off-the-shelf games available to them from a therapeutic perspective. The goal in this study was to identify the limitations of the current gamification approaches therapists were using, and devise an approach that was more effective for both therapists and their patients. In what follows we discuss the background of gamification in the context of physical therapy. We then describe our methodology for approaching the problem, and our solution. Finally, we report on our results to-date and summarize future directions for the project.

Background

Video games can motivate patients and help them with their motor skills, as well as serving as a distractor in pain management. Video games have been used in physiotherapy, occupational therapy, and psychotherapy (Annema et al 2010). In what follows, we discuss a variety of existing commercial approaches being used today by therapists. We also discuss the more experimental approaches still being explored by researchers and reported on in the literature, but not widely adopted by therapists to-date.

Commercial Approaches

Therapists use a range of devices in rehabilitation therapy, from commercial gaming consoles, to expensive medical devices. When it comes to commercial gaming consoles, those with active sensors to monitor the user are favored over those with just standard controllers. The Nintendo Wii system, with its Wii Fit sensor board is a favorite among therapists. The board is used to detect the movements performed by the user and use them as input for a variety of fitness-related exercises. "Wiihabilitation", or the use of the Wii in rehabilitation has been successful in motivating patients and encouraging body motions. Stroke patients showed measurable improvement on their balance, after a number of therapy sessions (Sugarman 2009 and Anderson 2010).

A more recent consumer device that has been gaining popularity in the therapy clinic is Microsoft's Kinect controller for the Xbox gaming console. This device uses an array of cameras and sensors to detect movements from players without the need of controllers or sensors in contact with the user; this frees the patient and the therapist from having to handle and secure controllers or sensors, as the input is merely motion based. Setups like Kinerehab (Huang 2011) from the Chung Yuan Christian University in Taiwan, found that users of the system exhibited an increase in motivation and willingness to interact with it; therapists also rated the system favorably.

The Trazer device (www.trazer.com) is a commercial fitness device with an array of sensors similar to the Kinect. It uses infrared sensors to detect the user's movements. Additionally to optical sensors, a system of cords can be used to modify the purpose and strength of the exercises. According to tests, the system improves muscle and mental agility, as well as motor coordination(Metairie 2010).

When it comes to medical devices, one that is commonly used to treat stroke patients is the Biodex Balance System. It consists of a balance board that measures how much the patient leans to a particular side. It can also be configured so it offsets the center of gravity of the patient, so that trunk control exercises can be modified and made more challenging (Wicks 2011). While the Biodex Balance System is generally more available due to its relatively cheaper price, NeuroCom's devices are regarded as the gold standard, when it comes to assessment / therapy devices in the TBI rehabilitation realm. These machines are designed to measure the limits of stability of a patient, using dynamic force plates to quantify the forces exerted while maintaining balance to measure the patient's center of gravity, while providing dynamic visual surround (Neurocom).

While all these commercial systems are useful for therapy, in various degrees, they were not designed as a therapeutic tool (except for the medical devices) so their success varies as games and activities can be challenging to stroke patients. In the case of the medical devices, while they provide good clinical feedback, they typically offer very little (if any) game content.

Experimental Approaches

There is a significant amount of activity within the research community in the use of games and game-related technologies in treating TBI patients. The success of games in physical therapy typically is attributed to increased motivation on the part of patients who otherwise view the therapy as mundane and repetitive. An early study for example, demonstrated that a simple "Simon" game elicited significantly more range of motion from TBI patients than rote exercise (Sietsema, Nelson, Mulder, Mervau-Scheidel, and White 1993). Racing games are a common theme in this area. One study demonstrated that patients with spinal cord injuries were motivated by a manual wheelchair interface called GameWheels. In this system, the patients could use their wheelchairs as input controllers to commercial games such as Need for Speed and Power Boat Racing (O'Connor et al., 2000). A more recent study used and add-on exercise hand crank device called GameCycle as an input device. It allows patients with spina bifidia and other spinal cord impairments the ability to participate in the commercial video game Need for Speed. (Widman, McDonald, & Abresch, 2006). In all of these examples, the game content used in the experiments was commercial off the shelf video games that were coupled with custom input controllers (with the exception of the Simon game). As we will discuss in later sections, our study found that existing commercial games were not adequate for therapy in that they are authored for the general population who do not have the motor and cognitive impairments that the typical TBI patient has. Furthermore, the game sessions do not produce any kind of therapeutic output that therapists can use to track progress, and better tailor individual treatment.

The use of virtual reality (VR) in rehabilitation of brain damage rehabilitation has been widely reported on in the literature (Rose, Brooks, & Rizzo 2005). The advantage of VR in cognitive rehabilitation is its ability to simulate a variety or real or imaginary circumstances providing a consistent environment and infinite repetition for training and assessment purposes. A major obstacle in widespread adoption of VR in rehabilitation is the associated costs (Rizzo and Kim 2005). In addition, most VR systems involve a multitude of sensor devices that greatly hamper end user usability. More simple camera-based systems do not always provide adequate accuracy for therapeutic use cases (Metsis, Athitsos, Iversen, Nasr and Makedon 2012).

Design Method

In order to better understand how to effectively utilize games in physical therapy, we adopted a participatory design method, which was used over a period of 12 months. In addition to the technical team (1 faculty member and student from Engineering doing hardware design, 1 faculty member and 2 students from Computer Science developing game software) the project involved a number of physical therapy domain experts, that included 2 physical therapists from a local hospital, 4 physical therapists from a local clinic, and a physical therapy professor from our university along with one of her doctoral students. All of the domain experts have expertise in studying and treating TBI patients.

At the start of the project, we conducted on-site initial interviews with the physical therapists in an attempt to identify what games and game equipment they were currently using in treating TBI patients and to learn how effective these games were in meeting their objectives. We then proceeded to rapidly produce low-fidelity game prototypes that were representative of the ultimate approach we felt would address the issues. Once these prototypes were presented to the therapists and validated (or corrected) we proceeded to create two high-fidelity prototypes in sequence. After each prototype was completed, we formally presented it to the therapists, trained them on how to use it, and then let them experiment with it for approximately for several weeks. At the end of each pilot session, the therapists responded to a survey, and then participated in a workshop in which we explored the results of the survey and elicited further feedback for improving the game.

Our goal in this first phase of what we hope is a more extended projected was to conduct a qualitative evaluation of whether or not our particular solution (running a configurable therapeutic game experience on a handheld touch-enabled device paired with an inexpensive sensor) would be positively received by therapists involved in TBI treatment. All of the results that follow were determined by the collective response of the therapists who participated in the design process and pilot studies. Patients were not directly involved in evaluating our solution in this initial phase.

Initial Findings

During the initial interview with our domain experts (the physical therapists), a number of currently available consumer-ready exer-game equipment (Wii-Fit, Kinect, Trazer) as well as specialized equipment designed for use in the clinic (e.g., Biodex Balance System) were identified and discussed. Based on the therapist's experiences with these available solutions, a number of limitations surfaced. In what follows, we discuss each of the shortcomings in turn.

Inadequate Game Content

Consumer video games are designed for the general population. Patients get frustrated, as sometimes they cannot perform well. Many of the patients have had experience with those same games prior to their injury and are frustrated when they no longer can play at the same level. Furthermore, modern console games offer too much visual stimuli, and TBI patients frequently become confused or distracted while playing them. Patients in early therapy require simple visuals, as they often struggle cognitively and the pace and intensity of modern games produces an information overload. In the case of specialized equipment designed for therapy, very little if any game content was available. Those games that were available on these platforms were found to be less than motivating to patients.

Inadequate Game Controllability / Customizability

According to the therapists we interviewed, the therapeutic value of consumer games is low. Some games are too easy, and some are too hard. In both cases, the games are not therapeutically accomplishing what the therapists want. A key issue is that there is not enough fine-grained control for setting competence levels and eliciting therapeutic movements for a given patient: Patients show great differences in their cognitive and motor abilities. The ability to tweak parameters and set goals tailored to each individual is key, in reaching therapeutic goals. A related issue is that some of the approaches require the patient to stand in order to participate in the game. This eliminates a large number of patients from using it. Patients in wheelchairs, or those who are not safe enough to be in a standing position cannot use the system. Also, in the case of some specialized clinical equipment, the standing platform can be quite elevated and therapists have reservations about some patients using it due to the possibility of falling.

Lack of Clinical Feedback

None of the consumer variety video games utilized provided adequate clinical feedback from the experience. These games have a general scoring system that was not designed to produce reports or track progress of patients engaged in therapy. Furthermore, what feedback is available is embedded only in the game content and can only be viewed by a therapist who is attending the patient while utilizing the game. In situations where the patient is utilizing the game for therapy unattended by the therapist (e.g. at home on their own), the therapist has no insight into their progress and therefore cannot directly intervene and adjust the experience when required.

Cost/Portability Limitations

Finally, a number of practical issues were voiced as well. For example, the lack of portability was a concern. Though gaming consoles are affordable and readily available, they are not portable in that they require adequate physical space and a larger screen. In the case of commercial exergaming equipment, and specialized clinical platforms, cost was a major issue. For example, the Trazer (typically found in health clubs and gyms) costs approximately $12,000. More specialized equipment can cost as much as $30,000.

Our Solution

Our project grew out of an earlier project that involved formally assessing the progress of TBI patients. When treating for rehabilitation of stroke and head trauma patients, physical therapists often find a need to measure the patient's control of the muscles in their torso. In order to measure this trunk control, therapists have traditionally used one of two methods. The first is a qualitative analysis performed by the therapist, which scores the patient based on predefined tests. The second is the use of large, expensive equipment that measures the patient’s balance and control.

In 2010, GVSU’s School of Engineering developed a low-cost sensor device: the Quantitative Trunk Control Measurement Device (QTCMD), whose goal was the evaluation of trunk control in stroke or traumatic brain injury (TBI) patients, by measuring angular trunk motion, in both the left-right and forward-backward directions, as compared to the vertical gravity vector. The original device, stored raw angular data on a micro-SD card which was then further processed on a computer, using a numerical analysis software package (Plotkowski et al 2010).

With the popularization of smartphones and tablets, high levels of portable computing power are now readily available. The fact that these devices include a wide range of radio technologies, enabling them to communicate with other devices has spawned a new market for hardware accessories that enhance the core capabilities of these devices. Using the QTCMD sensor as an accessory for a handheld device was a natural "next step" for the project. It also increased its portability and usefulness, since the therapists can easily access all the data registered by the sensor. On the patient side, an increased motivation to perform the therapeutic exercises can be obtained, using the sensor (and the patient's body) as the input controller for simple games that induce the patient to perform useful movements, defined by the therapist.

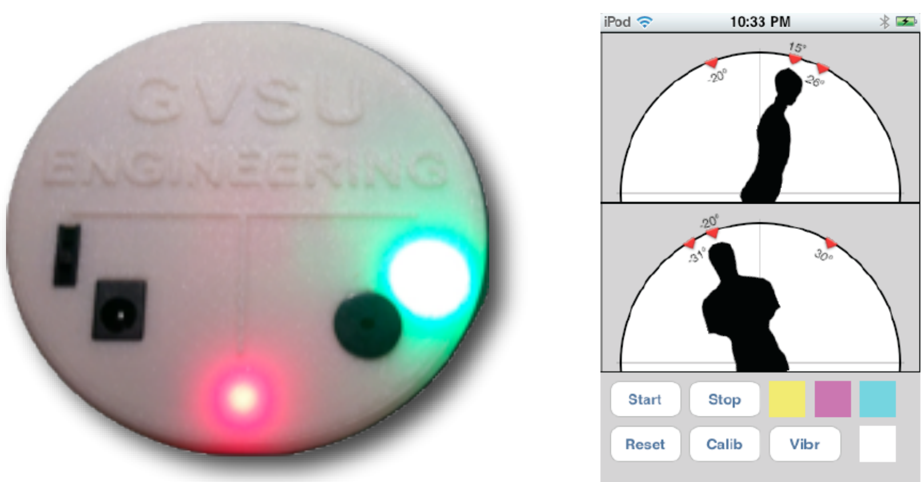

Figure 1. Custom QTCMD accessory, and its use in measuring a patients trunk control.

From these observations, we found the handheld-based experience intriguing. It seems to be in the "sweet spot" between dedicated gaming devices and expensive therapeutic machinery.

Intuitively, some of the reasons that make handheld devices attractive as therapeutic tools are as follows:

- They are relatively inexpensive and readily available: Prices range from $199 to $499 in the case of Apple's iOS systems.
- Highly portable.
- Can be used on a wide range of patients, as no special posture is needed to use them.
- Highly popular form factor, especially in the target patient demographic, which helps incentivize patient cooperation.
- Capable of providing clinical feedback: Reporting is one of the many things that regular mobile health applications have in common.
- Custom, Therapist designed experiences: Apps could be designed from the beginning with therapeutic goals in mind, instead of a game designed for the general population that is then used in therapy.
- Convenient: Patients could use the devices in their own environment and whenever it is convenient for them.
- Network capability for remote supervision: Monitoring studies and progress over time. Although not an exclusive feature of handheld devices, internet-ready handheld devices can constantly report progress to a cloud service, which can then be accessed anywhere.

During our initial meetings with the domain experts, they agreed that the experiences built around the handheld device / accessory system could potentially be helpful in a therapeutic environment, as both the patient motivational challenge could be addressed as well as the ability to configure the experience individually for a wide range of TBI patients. In addition, a custom solution utilizing these devices would allow clinical feedback to be provided to the therapists outside of the game context. Hence, the solution described below consists of an iPad tablet paired with the QTCMD accessory.

In order to develop a better understanding of the actual therapeutic methods used with TBI patients, we visited two different clinics and had therapists demonstrate the techniques they use when working with TBI patients. In each session one therapist would play the role of the patient, while a second therapist would demonstrate the different movements patients are asked to make in a typical therapy session. We videotaped these sessions and also attached the QTCMD device to the "patient" and recorded the actual accelerometer data for later reference during our subsequent game design phase.

Figure 2. Data acquisition with the therapists.

A number of game concepts were discussed with the therapists, as well as some basic requirements that they thought should be part of therapeutic games. Most patients enjoy, or used to enjoy sport-related activities; games that allow them to participate in sports that they once enjoyed but are now unable to play, these could provide a good incentive for therapy. However, not all patients are suited for sports games; older patients might not find them motivating. Also, as mentioned before, some patients may find, the graphical richness of a game overwhelming. Preferably, there should be a way in which these characteristics of the game can be modified to meet an individual patient's particular needs. Initially, for some patients, games must be simple, but details can be added once the patient makes progress.

With the insight provided by the experts, we determined that there are two types of patients for which the accessorized games can be developed: patients with poor stability, and patients with poor range of trunk motion. For patients with poor stability, a simple game where the patient needs to hold a "correct" posture for as long as possible was developed. For this game, the implemented prototype was a "walking" game in which the patient is presented with a screen resembling a straight walking path, and the idea is that the user, in this case the patient, stays on the path for as long as possible. The longer the patient holds their stability the faster the avatar will go

For patients with limited trunk motion, we developed a movement-eliciting game, in which the patient uses trunk movements as input for the game. The game uses a similar setting to the stability game, but instead of a walking path, a street or similar setting was simulated. The street will no longer be completely straight and the user will have to steer a car, or given a possible aversion to motor vehicles, any other vehicle or avatar, to keep the vehicle on the street.

A key discovery we made in our inquiry is that it is important for the therapists to be able to modify the different characteristics of a game to meet the specific needs of a given patient. There is a wide range of motor and cognitive impairments that need to be treated, and no two patients have exactly the same needs. Therapists identified this problem as their biggest frustration when trying to use off-the-shelf consumer video game consoles (e.g. Wii and Kinect) for therapy. To accommodate the specific needs of each patient we've identified two aspects of configurability that are key for a successful therapeutic game: control configurability and content configurability.

Control Configurability involves tailoring the way in which the patient interacts with the game. For example, fine control over settings such as percentage of right or left turns, maximum leaning angles and speeds. These settings are important since patients may have a weaker side that needs to be exercised more, as well as how far they can reach on any of the four directions. The values entered for these settings normalize the sensor input, so the experience is specific for each patient, and consistent across patients.

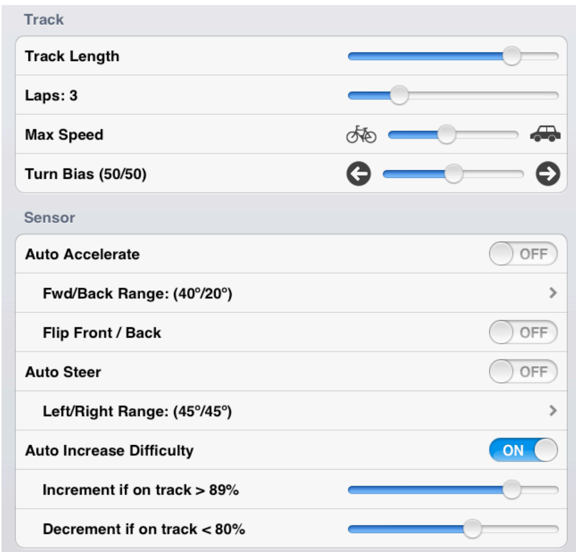

Figure 3. Control configurability.

Content Configurability involves tailoring the actual game content without modifying the movements elicited from the game.   For example, patients may have negative reactions to some themes, a car race, for example, may not be suited for a patient who was involved in a car accident. For these types of situations, different themes are needed for each game (e.g. changing the car for a bicycle or a marble).

Figure 4. Content Configurability: Movement Based game with different themes.

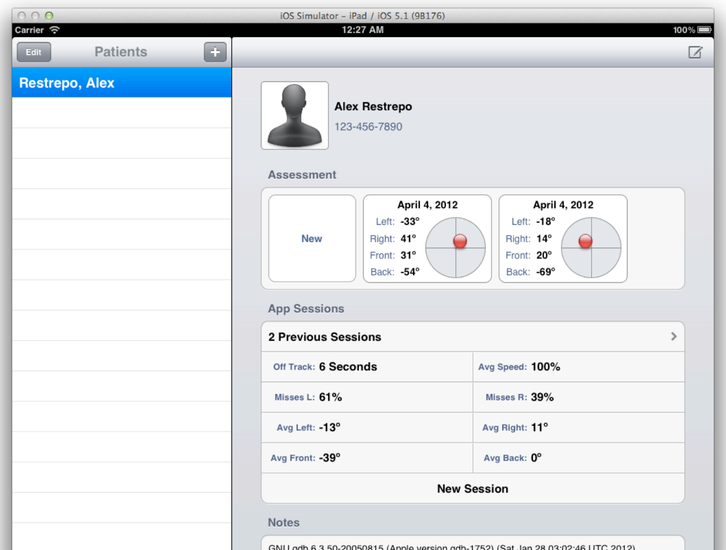

Figure 5. Patient profiles retain game and assessment feedback that therapists can access outside of the game.

Another distinguishing feature of our solution was to provide useful clinical feedback to the therapists outside of the game context. The focus of the second prototype was primarily in this area. This prototype established a profile for each patient (see Figure 5) that contained historical data of that patient's game sessions, as well as any formal assessments the therapist made using the application's ability to measure a patient's trunk control.

Figure 6. Therapists can measure a patient's progress using the application's assessment feature, which uses the same input sensor as the game.

Figure 7. Assessment data is gathered overtime and available for therapist to view.

The ability to actually assess the patient within the same game application as shown in Figure 6, was a feature the therapists strongly urged us to incorporate. One of the difficulties with using existing commercial video games for therapy is the difficulty to actually measure the progress the patient is making. In our solution, in addition to the game itself, an assessment feature allows the therapist to quickly take measurements within the same app, using the same game input sensor. Therapists can retrieve and view assessments overtime and adjust the game parameters for the patient as needed (see Figure 7.) From a research perspective, we anticipate this feature will also be useful in a future phase of the project when we hope to actually test our solution with real patients.

Results

Our platform was developed iteratively: a first prototype was developed in order to test the gaming component, its usability and motivational aspect. After a few weeks in which the therapists evaluated the prototype, and taking into consideration their feedback about the system, a second prototype was built. The second prototype focused on improvements to the game, game controls, as well as data collection and clinical output.

Each prototype included an online survey in which the feedback from the therapists was collected. The survey aimed to identify which features of the prototypes are more useful to the actual therapeutic process, as well as identifying the aspects that made the prototype interesting and viable as a possible product in the future. The overall results of these surveys were quite satisfactory, in each of the 6 different evaluated aspects: patient usability / interaction, configurability, ability to motivate and clinical output.

Patient Usability / Interaction

Therapists were asked to evaluate the prototype from a patient perspective, and from that point of view, 75% of the therapists found the device easy to interact with. A high score in ease of use, from the patient side is important in an application where patients can have major cognitive disabilities. Also, from the point of view of the patient, a

100% of the therapists agreed that the device was useful or very useful for therapy. In addition to ease of use of the game itself, the therapists also took into consideration how easy it was to pair the custom accessory to the iPad.

Configurability

The configurability of the game itself was a feature we believed key after our initial interviews with the therapists. At the same time, we realized that ease of use from the therapists' perspective (e.g. they are the ones that configure the game for patients) was going to be challenging, as the control knobs in a therapeutic racing game are quite different than the configuration settings in a commercial racing game (see Figure 3 above). In this area, 50% of the therapists indicated game configurability was very easy, and the other 50% indicated it was rather difficult. During the workshop discussions that followed the survey, we determined that therapists who participated more closely in the design were the ones who found the controls easy to work with, while those who were more peripherally involved in the design did not always find them so intuitive. Our experience to-date indicates that providing an intuitive set of game controls that allow the therapists to "design" a custom game experience that elicits a therapeutic movement from a particular patient is very challenging, and an area we hope to spend more time working on in future versions of our system.

Ability to Motivate

The motivation to use the system ranks higher on the therapist's scores, when compared to the motivation to use the conventional systems already in place, whereas 75% of the answers rank the system as good or excellent in terms of motivation, that same 75% ranks conventional systems as neutral when it comes to patient motivation. Also, 50% of the answers strongly agree that our system motivates the patients to move more than traditional systems do.

Clinical Output

The second prototype added patient profiles and a variety of screens that allows the therapist to view a patients' past history with the game, as well as assessment data. While most of the therapists indicated the output from the second prototype was "sufficient" and in most cases superior to what is obtained from commercial games, in our follow-up interviews we learned that therapists were less interested in game output per se and more interested in how well patients were progressing towards established therapeutic goals. Another finding was that the clinical output, while decoupled from the game itself, should also be decoupled from the iPad and made available and actionable in the cloud via some sort of web dashboard.

Based on these findings and our discussions with the experts, we believe that our prototypes show promise as effective therapeutic tools. This approach has a strong potential for the rehab market given its portability, low cost, ease of use, customization and intuitive gaming components.

Future Work

While the most important next step would be a formal study with real patients in order to quantify what we have found qualitatively with the therapists, there's also a lot of room for improvement in future prototypes. While we tried to implement as much of the suggestions given by the therapists, there are some that were simply out of scope for the given timeframe. The following are a series of features that we will be implementing and evaluating in the future:

- Richer, moving visuals:

Being able to gradually add visual elements such as moving backgrounds or random objects such as rocks, birds or traffic.

- Remote dashboard:

In the latest prototype, a patient profile and history was added to the application. The idea is to eventually have the same profile and information available online for the therapists to access anywhere. Profiles would be stored online so both, therapists and users, could simply login to any device and use it. The devices in turn, would sync the information back to the cloud. Therapists could even add preprogrammed settings for a patient to do at home.

- Bluetooth 4 Integration:

The current accessory uses WiFi as its networking technology, however, it is preferable to use Bluetooth for communication. By using WiFi, the handheld device needs to disconnect from any network it may be connected to, so it can connect to the accessory. This limits the flow of information, as the handheld device will need to switch to a standard WiFi connection in order to sync data. With Bluetooth, the handheld device doesn't need to switch networks, and can access the Internet while interacting with the accessory at the same time. Bluetooth 4 allows accessories to talk with iOS devices without having to be part of Apple's Bluetooth certification program, which is a cumbersome procedure.

- Programmable calibration:

Currently, the device can only be calibrated by setting its current orientation as its zero value on all axes. Being able to set that zero programmatically, in addition to the current calibration scheme, allows for finer control from the therapists, as they could potentially store calibration settings for each patient, and even adjust each calibration axis on the fly if needed.

References

Goldstein, M. (1990). Traumatic brain injury – a silent epidemic. *Annals of Neurology*. *27*(3), 327.

Goldstein, M. (1995). Brain repair (in forward). Stein, D., Brailowski, S., and Will, B. (Eds.). New York. Oxford University Press.

Center for Disease Control and Prevention (2012). Injury prevention and control: Traumatic brain injury. Retrieved from http://www.cdc.gov/traumaticbraininjury/statistics.html.

Annema, J., Verstraete, M., Vanden Abeele, V., Desmet, S., and Geerts, D.,. (2010). Videogames in therapy: a therapist's perspective. In Proceedings of the 3rd International Conference on Fun and Games (Fun and Games '10). ACM, New York, NY, USA, 94-98.

Sugarman, H.; Weisel-Eichler, A.; Burstin, A.; Brown, R.; , "Use of the Wii Fit system for the treatment of balance problems in the elderly: A feasibility study," Virtual Rehabilitation International Conference, 2009 , vol., no., pp.111-116, June 29 2009-July 2 2009

Anderson, Fraser, Michelle Annett, and Walter F Bischof. 2010. Lean on Wii: physical rehabilitation with virtual reality Wii peripherals. Studies In Health Technology And Informatics 154: 229-234.

Jun-Da Huang. 2011. Kinerehab: a kinect-based system for physical rehabilitation: a pilot study for young adults with motor disabilities. In The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility (ASSETS '11). ACM, New York, NY, USA, 319-320.

Clinic of Metairie, OrthoPtic Rehab 2010

http://www.orthorehabofmetairie.com/trazer-3d.htm

Andrew Wicks, DPT. Personal Conversation. November 2011.

NeuroCom's Smart EquiTest Product Page. Retrieved from http://www.onbalance.com/products/EquiTest/detail.php

Sietsema, J., Nelson, D., Mulder, R., Mervau-Scheidel, D., & White, B. (1993). The use of a game to promote arm reach in persons with traumatic brain injury. American Journal of Occupational Therapy, 47(1), 19–24.

O'Connor, T. J., Cooper, R. A., Fitzgerald, S. G., Dvorznak, M. J., Boninger, M. L., VanSickle, D. P., & Glass, L. (2000). Evaluation of a manual wheelchair interface to computer games. Neurorehabilitation and Neural Repair, 14(1), 21-31.

Widman, L., McDonald, C., & Abresch, T. (2006). Effectiveness of an upper extremity exercise device integrated with computer gaming for aerobic training in adolescents with spinal cord dysfunction. Journal of Spinal Cord Medicine, 29(4), 363–370.

Rose, F., Brooks, B., and Rizzo, A. (2005). Virtual reality in brain damage rehabilitation: Review. CyberPsychology & Behavior. 8(3). 241-262.

Metsis, V., Athitsos, V., Iverson, M. Seif-el Nasr, M., and Makedon F. (2012) Enhanced Therapy for Rheumatoid Arthritis (RPLAY). Retrieved from https://heracleia.uta.edu/wiki/tiki-index.php?page=Enhanced+Physical+Therapy+for+Rheumatoid+Arthritis+%28RPLAY%29.

Plotkowski, A., & Barakat, N. (2010). A new device to quantify human trunk-control measurements. Proceedings of the ASME 2010 International Mechanical Engineering Congress & Exposition IMECE2010, Vancouver, British Columbia, Canada.