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Accessorized Therapeutic Game Experiences for Touch-Enabled Devices

By
Alex Restrepo

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Computer Information Systems

At

Grand Valley State University
April 2012

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1. 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 thesis aims to study 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. The games are intended to elicit specific therapeutic movements from the patient, and also to produce clinical output for the therapists to use.

2. Introduction

When helping in the 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. This is called trunk control. In order to measure 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[4].

In early 2010, GVSU's school of engineering developed a low-cost sensor device: the Quantitative Trunk 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 the range from -70 to +70 degrees, in both the left-right and forward-backward directions, 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.

With the recent 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. In the health related field, these accessories are designed to measure everything from steps, such as the Nike+ sensor[15], to detailed logs of your sleeping cycles and eating habits [16]. The added advantage with these accessories is that the information gathered by them is readily available on the device it communicates with. Standard PCs are no longer required to access or sync the gathered information.

Using the QTCMD sensor as an accessory for a handheld device is a natural "next step" for the project. It will also greatly increase its portability and usefulness, since all the data registered by the sensor can easily be accessed by the therapists. 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, as defined by the therapist.

Many areas can benefit from the entertainment power of video games. One that has received some attention from researchers is that of games for therapy. 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[1].

3. Literature Review

3.1 Why Traumatic Brain Injury (TBI)?

TBI and Stroke patients have similar disabilities when it comes to trunk control. In our conversations with the therapists, TBI patients are usually younger, male individuals who were involved in some kind of accident. Younger individuals have a tendency to enjoy video games, making them an ideal target demographic for our accessory-controlled games.

3.2 What is a Stroke?

Each year, in the United States alone, approximately 795000 people are affected by stroke [5]. A Cerebral Vascular Accident (CVA) or simply “stroke” is defined by the World Health Organization as “a neurological deficit of cerebrovascular cause that persists beyond 24 hours or is interrupted by death within 24 hours” [6, 3].

A stroke affects brain functions due to the interruption of blood supply to the brain, resulting in altered motor and/or cognitive functioning. As a result, stroke patients are often unable to independently perform day to day activities, such as dressing or eating. This loss of autonomy leads to an overall decrease in quality of life [6].

A stroke is also a highly heterogenous condition; specific abilities that are affected depend on the location and size of the lesion, making each patient have its own specific combination of deficits [3].

3.3 Stroke Therapy

Difficulty to control upper body muscles is often associated with individuals recovering from a stroke or a traumatic head injury (TBI). This disability ranges from mild, in which patients have difficulty maintaining a correct posture, to extreme, where a patient may not even be able to sit up effectively, or at all. Currently, the only way to measure a patient’s recovery progress in this area is using purely qualitative methods, or using expensive clinical equipment that can cost more than $50000[4].

Stroke rehabilitation programs are strongly personalized and not generic: they are adapted to a particular patient, to regain as much function as possible. The most important re-gain of function takes place within the first six months after a stroke[3]. Therapy helps reverse disabilities caused by stroke. By encouraging the use of the affected parts of the body through exercise, the patient can slowly relearn the ability to use them again[2]. These exercises however, tend to be repetitive, and in order to be helpful, need to be performed several times a week, which can pose a challenge when it comes to motivate patients to perform the exercises as often as needed.

Video games are a powerful instrument to captivate, entertain and motivate people. They develop motor and cognitive skills and, in particular, when it comes to therapy, they can help motivate patients, and serve as a distractor in pain management [1].

Some research has examined the potential of existing commercial games for stroke rehabilitation. Existing console games with motion-based input devices, such as the Playstation 2 EyeToy [8] and Wii Sports [9], have been used in stroke therapy studies. While these games are promising for patients in the later stages of recovery, they were designed for users with a full range of motion and, consequently, cannot be used by the majority of patients recovering from a stroke, as they are usually too challenging [2, 8, 9].

In order to reach stroke patients in earlier stages of recovery, researchers have opted for developing their own games[2], which is the approach that we took on this project: to develop a suite of simple games, that can be used as therapeutical exercises.

3.4 Games for health / wellness in mobile devices

Health and wellness activities are getting more attractive, now that they can be measured, scored and shared with the help of mobile devices. According to Apple's app store, there are over 11000 apps in the health and fitness category, anything from pedometers to sleep monitors and everything in between. What makes some of these games motivating and fun is the fact that you can rank your fitness / health level with that of other players, all over the world. Competition and track of progress are big motivators when it comes to exercise. In fact, just by tracking an activity, the activity increases by 26% [16].

Perhaps the most successful wellness game available is the Nike+ app[15], where external sensors measure the amount of steps and distance traveled while running, stats from your runs can then be shared online and compare your performance with that of other athletes around the world. You can also challenge friends and leave comments (cheers) about their performance on their profile.

Figure 1: Nike+ app

Similar to Nike+, the app "Monumental" [17] uses the device's accelerometer to keep track of the steps needed to climb different monuments throughout the world. Once you reach the top, you can collect digital souvenirs as well as sharing your achievements via Facebook or Twitter.

Figure 2: UP Bracelet

The recently released UP bracelet [16] by Jawbone tracks all sorts of activities during the day, in particular, it tracks your steps and distance traveled and at the same time reminds you to move when you've been inactive for too long. It tracks your sleeping cycles and knows when you are in a deep or light sleep; the bracelet can then be set as an active alarm that vibrates on your wrist and wakes you up "at the ideal moment in your natural sleep cycle just before your desired wake time."

Gaming comes in the shape of "challenges" which can be individual or team based, and include activities like moving more or sleeping better. This social component supports not only competition and collaboration between friends, but also with other people that use the system.

4. Current devices used in therapy

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[10, 11]

Figure 3: Wii Fit board

A more recent consumer device that has been gaining popularity in the therapy room 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 [12] 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.

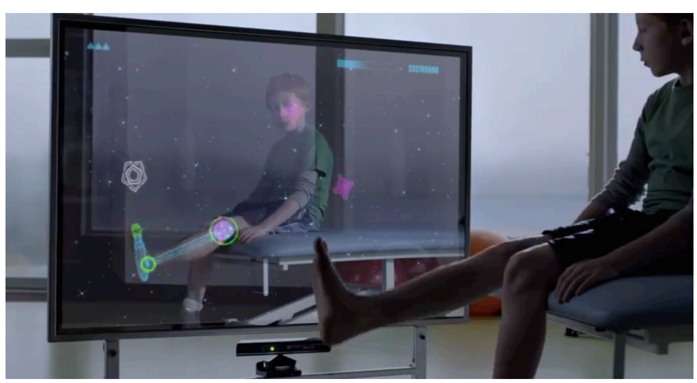


Figure 4: Kinect Sensor

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[13].

Figure 5: Trazer device

When it comes to medical devices, one that is generally 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[14].

Figure 6: Biodex Balance System (left) and NeuroCom's Balance Master (right)

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 [21].

While all these 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 section 5.3 a list of limitations, from the point of view of a team of therapists, is presented for these devices.

5. Background

Handheld devices are becoming increasingly popular, most of these devices work by using touch-based interfaces, and include most “smartphones” and “tablets” available in the market. These devices can communicate with a great range of hardware accessories that provide all sorts of services, from external input devices, to headsets and gaming controllers. In a way, accessories augment the handheld devices by providing them of capabilities beyond what they were designed for.
The Quantitative Trunk Measurement Device (QTCMD) is used in this study as an accessory for touch-enabled, handheld devices. In particular, iOS devices were used as the development platform for this study.

5.1 The Accessory Sensor

Development of the sensor began in early 2010 from a capstone project in the Analytical Tools for Product Design (EGR 301) class, in the GVSU School of Engineering [4]. The intent of the device was, and still is, the evaluation of trunk control in stroke or head trauma patients, measuring angular trunk motion in the range -70 to +70 degrees.

The original device consisted of a sensor that was attached to the patient using a system of straps and recorded information to a onboard SD Card.

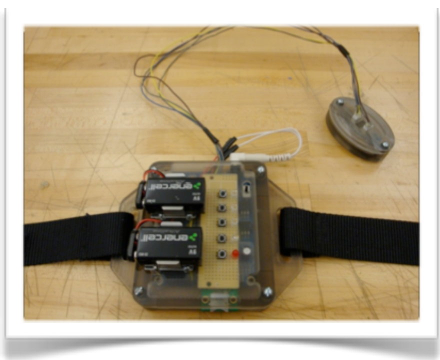


Figure 7: Original sensor

Based on the feedback received from the therapists, in 2011 a second version was created, incorporating most of the new requirements: making it a wireless device that could communicate directly with a PC (using a wireless dongle), all the straps were removed and the device was redesigned as a single unit so it could be attached directly on the patient using a double-sided medical tape.

Figure 8: Second generation sensor

These revisions made the device much more useful in a real-world scenario, as now therapists could simply connect their PCs to the devices wirelessly and start any number of tests, recording data directly on their PCs.

The wireless network between the device and the PC was established used a proprietary dongle, using the Zigbee radio protocol, for low power consumption. These dongles limited the use of the sensor to devices with USB ports and the required drivers.

In order to make the accessory work with touch-enabled devices, such as an iPad, a standard WiFi network needed to be used. Alex Hastings, member of Professor Farris' team, modified the sensor so it uses a standard 802.11 WiFi network instead of Zigbee, allowing the sensor to communicate with any WiFi capable device, which nowadays includes all smartphones and tablets.

Once the sensor included the new wireless hardware, iOS code was written to interface with the sensor. The sensor will create its own WiFi network to which the handheld device connects to. Once the sensor detects a connection, it will "pair" with that client and all further communication will be delivered to it. Communication is done using UDP packets, to make the communication as lightweight and fast as possible, at a steady frequency of at least 15 HZ.

The first proof-of-concept application simply displayed the angular data graphically on screen, already an improvement on the PC version which streamed raw data and required an external application to graph it:

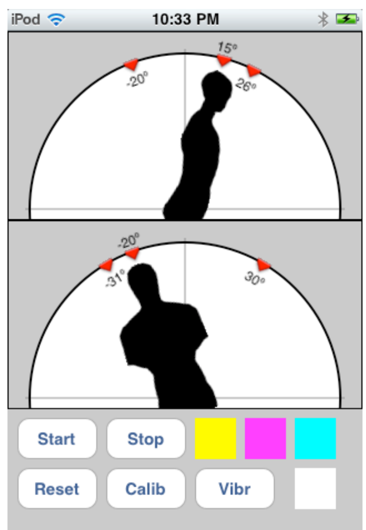


Figure 9: Accessory-Enabled App running on an iOS device

Code was also written for each of the control commands of the sensor, in charge of the color of the indicator light, the vibrators, as well as the calibration.

Our initial focus was to use the technology for assessment purposes only, this thesis aims to push the envelope by exploring its use for therapeutic purposes in the rehabilitation of TBI patients.

5.2 Data Collection.

Once the integration of the handheld device with the sensor was completed, a couple of data collection sessions were scheduled. In order to create a model of how the TBI patients interact with the device while performing therapeutic motions, a team of physical therapists from two separate hospitals agreed to use the sensor on themselves, as if they were patients.

In order to record the information gathered by the sensor, a computer program was written that allowed us to save the data to a file that could easily be replayed at a later time. With that program, a battery of different tests was filmed and data-recorded, on average, each team recreated 20 different exercises.

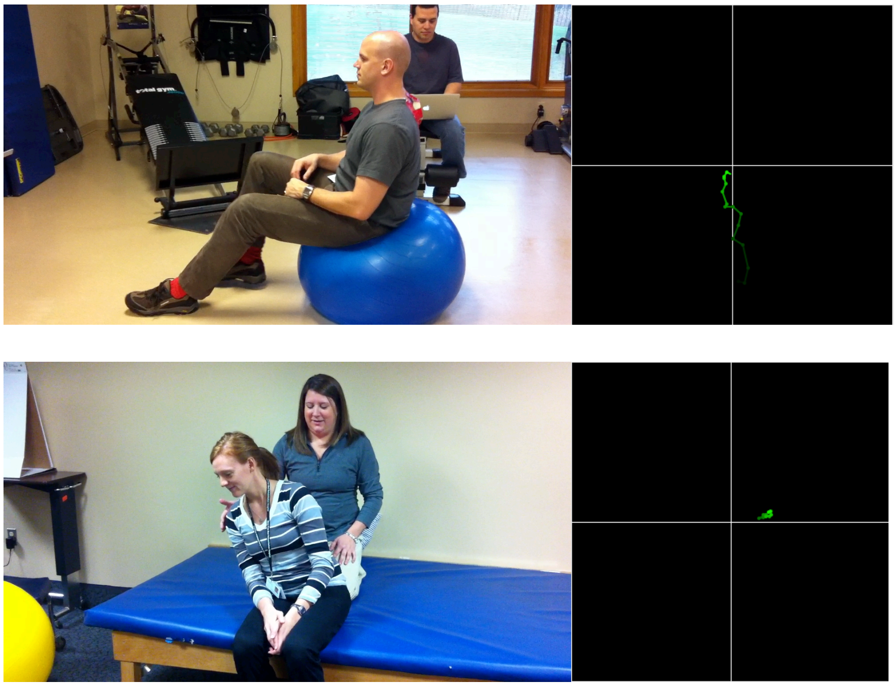


Figure 10: Therapists acting as patients in the data collection phase

5.3 Analysis of current systems

With the feedback obtained from the different therapists, an evaluation of their current therapy tools produced an interesting set of challenges to overcome:

5.3.1 Consumer Devices

With current consumer-ready exer-game equipment (Wii-Fit, Kinect, Trazer) therapists outline the following limitations that would need to be addressed:

- *No clinical feedback from experience:* Games have a general scoring system that was not designed to produce reports or track progress of patients engaged in therapy.

- *Modern console games offer too much visual stimuli:* TBI patients become confused or distracted. Patients in early therapy require simple visuals, they often struggle cognitively and the pace and intensity of modern games produces an information overload.

- Consumer *Games are designed for the general population:* Patients get frustrated as sometimes they can not 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.

- *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.

- *Therapeutic value of consumer games is low:* Some games are too easy, and therapeutically aren't doing what therapists want.

- *Lack of portability:* Though gaming consoles are inexpensive, ranging from $150 to just under $300, they are not portable as they require a dedicated area plus a screen.

- *Expensive in some cases:* Trazer is actually a specialized device that is expensive (around $12000), as well as non-portable. This type of equipment is more generally found in health clubs and gyms.

5.3.2 Clinical Equipment

Existing clinical rehabilitation equipment (Such as the Balance Biodex) also present an interesting set of limitations, but a clear advantage when it comes to reporting:

- *Very few games are available:* In the case of the Biodex, just one existing game is built into the system. However, the company claims to have plans to build more games in future.

- *Very expensive and non-portable:* Prices for the Biodex Balance System range around $12000 for new units and around $4000 for refurbished ones [18]. NeuroCom devices are even more expensive, with prices around the $30000 mark [22].

- *Requires the patient be able to stand:* 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 can not use the system.

- Its standing platform is quite elevated and and therapists have reservations about some patients using it due to the possibility of falling.

- *Has clinical feedback:* Reports can be created for each therapy session, as well as tracking of patient progress.

5.4 Opportunities

We found the handheld based experience intriguing, and the rest of this thesis confirms that the domain experts (therapists) agree. This approach seems to be in the “sweet spot” between dedicated gaming devices and expensive therapeutic machinery, where there currently is not a viable solution available. These make the proposed project, an interesting area to explore.

Intuitively, 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.

This thesis has confirmed these intuitions, born from early contextual inquiry, as therapists agree that the experiences built around the handheld device / accessory system can potentially be extremely helpful in a therapeutic environment, as it really helps with the perceived motivation and the wide range of configuration settings helps to taylor the experience to a wide range of patients.

6. Research Model and Viability Study

6.1 Experience Design

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, could provide a good incentive for therapy. However, not all patients are suited for sports games; older patients might not find them motivating. For example, they could find motivating cognitive-challenging games, such as navigating through a maze while providing familiar images as incentive.
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. Initially, for some patients, games must be simple, but details can be added once the patient makes progress.

With the insight provided by therapists, 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 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 patients with limited motion, we developed a movement-eliciting game, in which the patient uses trunk movements as input for the game. It was our goal to create a prototype game for both use cases, and then work with physical therapists to evaluate and refine them, to then determine the system’s feasibility.

6.2 Stability oriented game

For the stability game, the implemented prototype is a “walking” game. 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.

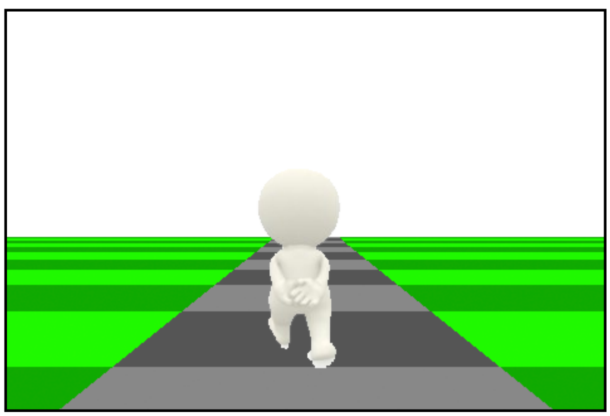


Figure 11: Stability oriented game prototype

There is audible as well as haptic (via vibration) feedback if the user starts leaning towards either side of the path. This should trigger corrections in posture, without having to explicitly tell the user that he/she needs to correct his/her posture.

6.3 Movement oriented game

For the movement game, a similar setting to the stability game is used, however this time a street or similar setting is 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.
The type of movement needs to be configurable, some patients will need to exercise one side more than the other, so the percentage of curves that make the user move to one of the sides, needs to be set beforehand by the therapist. In the actual prototypes, we called this setting turn bias.

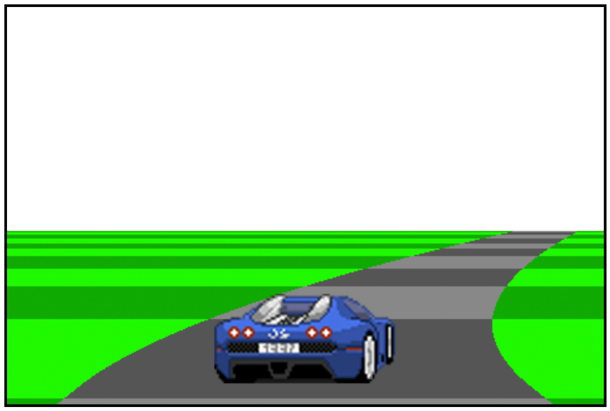


Figure 12: Movement oriented game prototype

In addition to these prototypes, an iOS - QTCMD communication framework has been developed, in order to speed up development of applications that wish to use the sensor.

6.4 Game Characteristics

It is important for the therapists to modify the characteristics of a game. To accommodate the specific needs of each patient we've learned that control and content configurability, are important features for a successful therapeutic game:

- *Control Configurability:* 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.

- *Themes:* 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).

6.5 Method of Evaluation

Based on our discussions with therapists, before the sensor and its games can be used with real patients, a feasibility study needed to be performed.
In order to study the feasibility of the system, the development and evaluation of the project was performed in a series of iterative prototypes:

- The prototype was created, and delivered to therapists at the Mary Free Bed and Hope Network hospitals for evaluation.

- After the therapists evaluated the system for a few days, their feedback was collected using an online survey and a personal interview.

- Starting from their suggestions, the prototype was refined for a second round of testing and feedback, in addition to the Mary Free Bed and Hope Network hospitals, the prototype was also delivered to a GVSU faculty member and a graduate student in physical therapy.

Our findings are collected and evaluated later in this document. This research is the first step towards a clinical trial with real patients.

6.6 Questions to Address

The specific questions this thesis investigates include:

- What are the characteristics of the ideal companion device / accessory for therapeutic games involving TBI patients? (e.g. sensory features, input / output modalities, battery life considerations, pairing procedures, etc.)

- Is it feasible to receive the appropriate regiment of therapy from a custom video game, running on a handheld device?

- Is it feasible that a game can be fully configurable for therapy reasons, and still be compelling to the patient? How does customizability affect gameplay.

- Is it feasible to motivate and engage patients to perform therapy, by using such a system?

- What are the facets of customizability that are needed for a therapeutic game in this context?

This thesis explores these questions via experimentation and collaboration with domain experts (e.g. physical therapists in a clinical setting). While the feedback from the therapists was primarily qualitative in this study, we (and the domain experts involved) believe it was sufficient to address the feasibility of this approach in a clinical setting and hence serve as a valuable foundation or launch pad for future studies involving human subjects

7. Prototype design and Implementation

Once the basic idea of the game was defined, the platform to develop it on was chosen. Given the popularity of iOS devices in medical environments and our familiarity with its development tools, an iPad application was selected as the optimal target for the prototypes.
An iterative prototype refinement approach was selected, since it allowed us to quickly come up with a prototype and then improve upon it given the feedback gathered from the test therapist. With these constrains in mind, two prototypes were scheduled to be released for testing by the domain experts.

The prototypes were written using Apple's iOS development tools, in particular, the prototype targets iOS 5, but should compile and run on any iPad running iOS 4 or better.
The game engine was adapted from an open source, MIT licensed, Javascript version by Selim Arsever [19]. This code was then ported to C and the iOS graphic libraries available in Core Graphics. Once the port was completed, it was extended to be highly parametrizable, in order to include all the settings required by the therapists.

Two versions of the prototype were developed throughout the semester. The first one was designed with just the game (and hence the therapeutic) experience in mind, as well as fully integrating the accessory sensor (and a library to communicate with it) into the app. For the second prototype, the feedback gathered from the first prototype was implemented into the experience. The second prototype was expanded to handle patient profiles, clinical output and clinical history.

7.1 The Accessory

The QTCMD sensor communicates wirelessly with the iOS device by creating its own ad-hoc Wi-Fi network, whose SSID is "QTCMD#", where # is the number of the sensor. Once the connection is established, a local network is created where the sensor has the static IP Address of 169.254.1.1. The address of the client device is not important, as the sensor will pick the first connected device from its client list as the recipient of the data.
Communication between the sensor and the iPad is performed using UDP packets on the port 29168.
The sensor has a simple text-based interface for all of its available commands, all commands are prefixed with the '#' character and terminated with the '>' character, in the following format:

#<command>[parameter(s)]>

where "command" is a required command from the list below, and "parameter" can be an empty set. Once a command is sent, the sensor will echo-back the last issued command, without the trailing '>', and any query results (if available).

7.1.1 Available commands

#S> Start sensor output: Starts streaming tilt angles for the X, Y and Z axes, but in practice, only the X and Z values are relevant.

#E> End sensor output: Stops the data stream.

#C> Calibrate: Calibrates the accelerometer by zeroing it to the current orientation of the device.

#B> Battery Voltage: Measures the voltage and sends it back in the echo response. Low battery charge has a direct effect on the range and performance of the device.

Voltage Range	Condition
> 3.2	Fully Charged
3.0 - 2.8	Half charge, charge soon.
< 2.8	Battery low, charge immediately, performance is inhibited

Operational Battery Ranges

Issuing a #B> command, will result in an echo-back with the format #B<voltage>\r.

#L<RGB>> LED Control: Controls the output of the RGB LED located on the front of the device. Values are 1 or 0 only, allowing for 3 bit color (7 colors + off). Values for the RGB output must follow the command L, for example, red would be #L100>.

#V<milliseconds>> Vibrate / Tone Control: Activates the vibrators and speaker for the specified duration, in milliseconds. The parameter must be in the range 0 - 999.

#G<0-1> G-Value Data: Enables or disables the output of the accelerometers as raw data (in G values). A 0 for the parameter disables the raw accelerometer data and the sensor outputs angles of inclination (this is the default setting), a value of 1 enables the raw data.

7.1.2 Accelerometer output

When data streaming is enabled on the sensor (using the command 'S'), the device sends the inclination data at a rate of 20Hz (though in practice it averages 15Hz, due to its limited processing power). The output is in the form of angles of inclination (in degrees), and follows the following conventions:

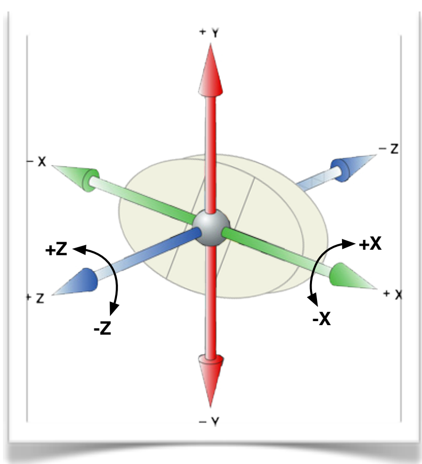


Figure 13: Accelerometer axes and signs

The angular data is streamed in packets containing the inclination angle for all axes, enclosed within the '<' and '>' characters and separated by a tab '\t' character like so:

'<' xangle '\t' yangle '\t' zangle '>'

Note that the yangle parameter is useless in our particular application, as the angle of rotation on y can not be determined using an accelerometer.

7.1.3 Accessory Objective-C Library

For the prototypes, a reusable Objective-C library to communicate with the accessory was created. The library wraps most of the functionality of the accessory in a single, easy to use class.

The class defines a protocol (interface) for the client classes to implement, it declares a couple of callbacks for the information being streamed from the sensor, one for the angular data (required) and one for the echo messages (optional):

```
@protocol QTCMDSensorDelegate <NSObject>
// sends the delegate the angular values received from the QTCMD Sensor
- (void) sensor:(QTCMDSensor *)sensor didReceiveXAngle:(float)xangle YAngle:(float)yangle ZAngle:
(float)zangle;

@optional
// sends the delegate any received echo message, as well as the command that issued the response
- (void) sensor:(QTCMDSensor *)sensor didReceiveEchoMessage:(NSString *)message forCommand:
(NSString *)command;
@end
```

There's also a number of methods that match, for the most part, the commands available in the accessory, as well as an init (constructor) function that defines the delegate object. A delegate object is a mechanism in which a host object (accessory) holds a weak reference to another object (its delegate) and periodically sends it messages when it requires to *delegate* it some sort of task. Host objects are usually generic classes that accomplish a single task in a generic way. The delegate is usually a custom class, that in coordination with the host, provide implementation-specific behavior at certain points of the lifetime of the application. Delegation makes it possible to modify or extend behavior without the need for subclassing[20].

```
- (id) initWithDelegate:(id<QTCMDSensorDelegate>)delegate;
- (void) startSensing;
- (void) stopSensing;
- (void) calibrate;
- (void) queryBatteryStatus;
- (void) setLedRed:(BOOL)R green:(BOOL)G blue:(BOOL)B;
- (void) vibrate:(int)millis;
- (void) setEnableGMode:(BOOL)mode;
```

7.2 First Prototype

The first prototype was focused on the game experience and on mapping the sensor/patient input into usable data for the game. As such, it implemented the basic game mechanics and configuration options that the therapists suggested in our initial discussions.

7.2.1 Main Screen

When launching the app, a simple screen appears that displays the name of the application (PT Racer at the time), while a simulated race is shown in the background. There is a single button in the middle of the screen to create a "New Session", sessions is what the application refers to as a therapy session:

Figure 14: Main Screen, Prototype 1

7.2.2 Settings

Once the “New Session” button is clicked, a session configuration window appears, in this window all the different configurable parameters for the game can be set, these settings are tweaked by the therapists as needed for each individual patient.

Figure 15: Session Settings, Prototype 1

The different settings are grouped into two sections, “Visuals” for content configuration and “Behavior” for control configuration.

The visuals group control the images and their intensity in the game, and contain the following settings:

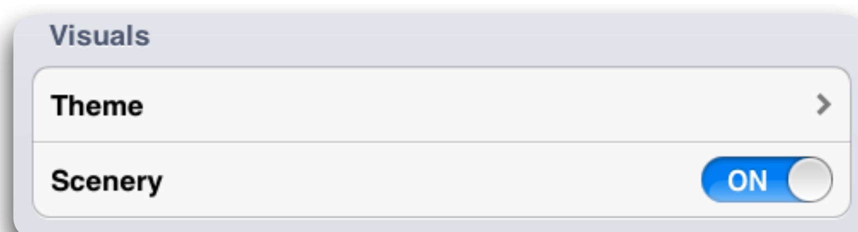


Figure 16: Visuals group

Theme
In our meetings with the therapists, they emphasized the importance of being able to change the theme of the game, due to specific aversions that some patients may have regarding the elements involved in the game. A car race may not be attractive to a patient who was just involved in a car accident, therefore, the ability to choose different themes is fundamental for a successful implementation. In this particular prototype, 2 different themes are available: a car race and a mountain bike. It is however, possible to add other themes while preserving the same style of game, such as a skiing game or a boat race.
By clicking on the theme option, a small list with the two available themes appear, from which the therapist can select the most appropriate one for the patient

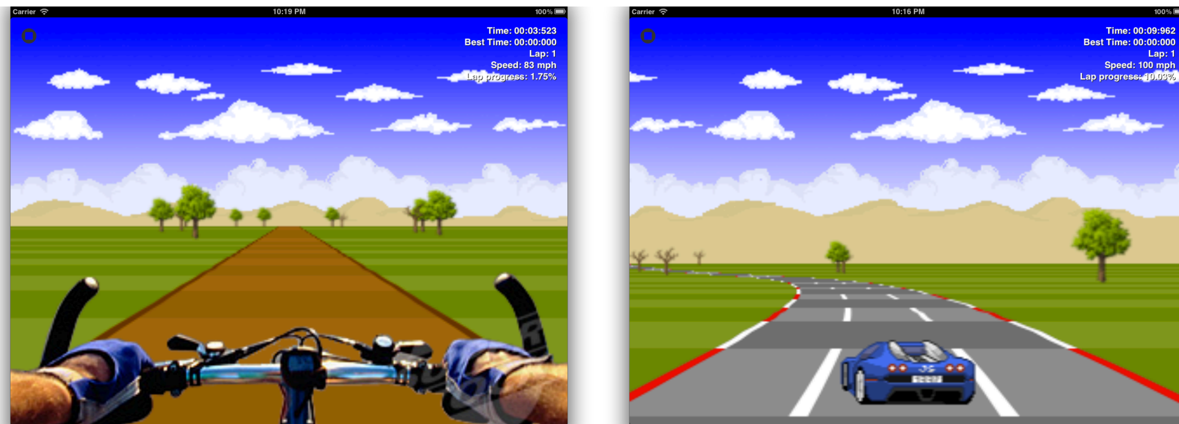


Figure 17: Game themes available

Scenery
Sensory overload is also an issue when it comes to off-the-shelf video games when used in therapy; It is important to be able to "simplify" the visuals shown to the TBI patient. This setting allows the therapists to turn on or off the "scenery" displayed in the game, in particular, this setting controls whether the background mountains and clouds, as well as the trees are displayed.

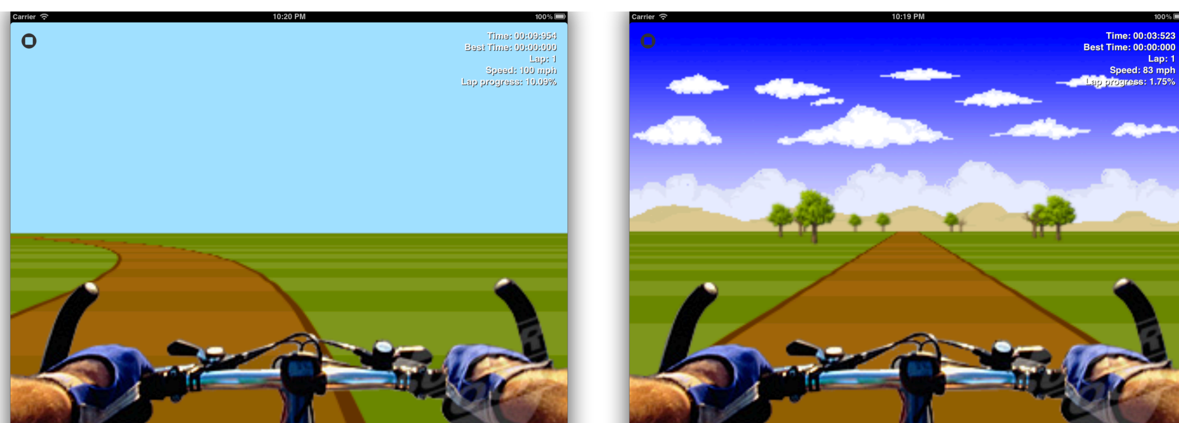


Figure 18: Differences between Scenery On and Off

The Behavior group control the mechanics of the game, and contains the following settings:

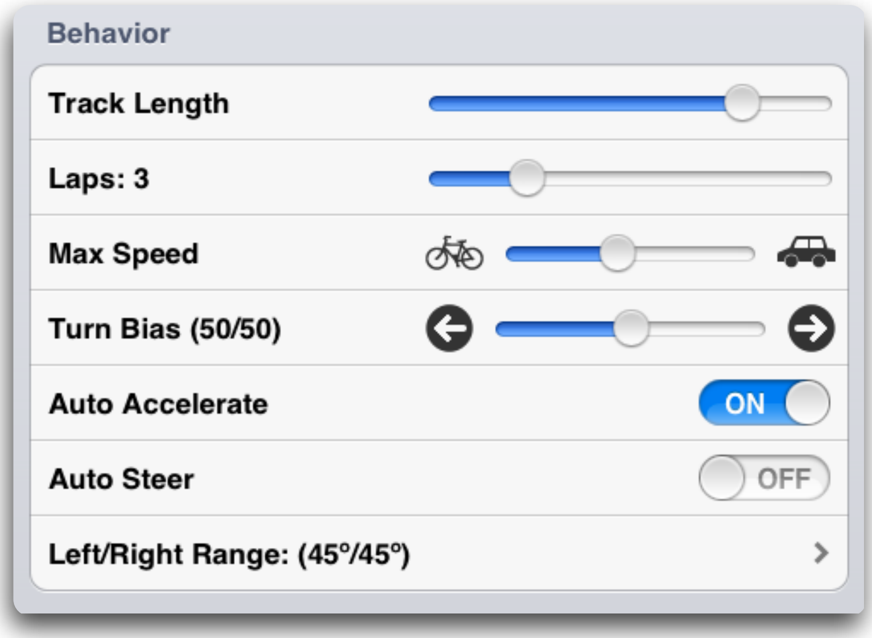


Figure 19: Behavior Group

Track Length
Specifies the length of a single lap, shorter tracks are achieved by sliding the knob to the left, longer ones by sliding it to the right. This setting directly affects the number of curves present in the generated track.

Laps
Number of laps in the current session, a range between 1 and 10 can be chosen by sliding the knob left and right.

Max Speed
The maximum speed that the car / bike can achieve in the current session. The faster the vehicle goes, the more information a patient has to process and also the harder it is to successfully navigate the curves. Patients with lower cognitive function may need slower speeds than those in a higher state of recuperation.

Turn Bias
Therapists may decide that a particular patient needs to favor one side more than the other, this setting allows them to set the percentage of left vs right curves that the current session will have. Tracks are still generated at random, but this setting changes the probability in which a side will be favored. Moving the knob to the left, favors left turns, moving it to the right, favors right turns.

Auto Accelerate
If enabled, the game will ignore the front / back readings from the sensor and will always accelerate automatically, if disabled, then the therapist can choose the maximum angles for the forward and backwards movements by selecting the forward / backward range option. Input from the sensor will then be normalized using these maximum values.
Auto Accelerate, along with Auto Steer, allow therapists to compartmentalize lateral and forward / backwards motions, enabling them to tackle just one set of movements at the time, if needed for patients with higher limitations.

Auto Steer
If enabled, the game will ignore the left / right readings from the sensor and will steer automatically. When disabled, the therapist can set the maximum angles for the patient by selecting the left/right range option:

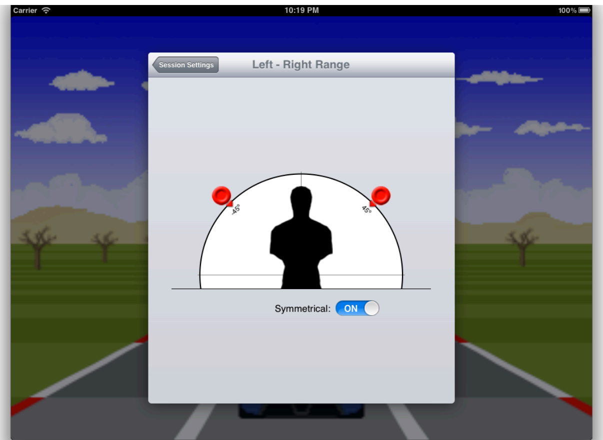


Figure 20: Lateral Range Selector Screen

In this screen (also available for the front/back measurements) the therapist can set the angles that the user can (or should) reach while in therapy. Steering and acceleration values are then normalized using these settings. By default, the values are set symmetrically, meaning that setting one side will automatically set the other side to the same, opposite angle. However, some patients may be able to use one side more than the other, to compensate for that, angles can be set independently, by simply disabling the symmetrical option.

7.2.3 Measurements
Given the emphasis on the actual game experience for the first prototype, only the most basic information, required to drive the game, was being recorded, though it was not being analyzed, beyond being normalized according to the settings established by the therapist. The inclination angles in all 4 directions were used simply as input to the game, forward - backward movement was used for acceleration, lateral movement was used for steering. The only scoring mechanism used in this prototype was the total time used and the best lap time, which was presented at the end of a session in a simple alert for the therapists to see:

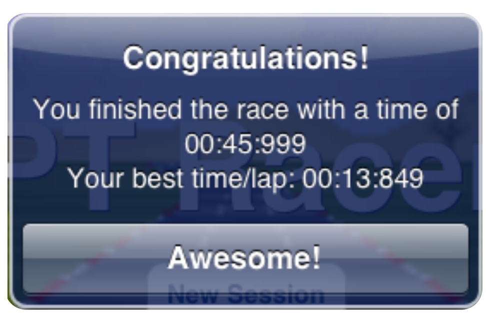


Figure 21: Score screen, prototype 1

7.3 Second Prototype
For the second prototype, emphasis was given to:
- Patient profiles and clinical output.
- Implementing an assessment tool to measure patient progress.
- Improving game experience developed in the first prototype and providing finer control options.

The feedback gathered after the therapists had a few weeks to play with the first prototype was taken into consideration and most of their suggestions were incorporated into the new prototype.

7.3.1 Main screen

Profiles are a fundamental part of the second prototype and they allow therapists to share devices among many patients, as well as to track progress over time on individual patients. They also open the possibility of sharing profile and performance data among devices.

As soon as the application launches, the screen will be divided into 2 parts: on the left, there's a list of patients whose profile is stored in the application. There are two buttons at the top of the list that allows the user to edit the contents of the listing: "edit" and "+":

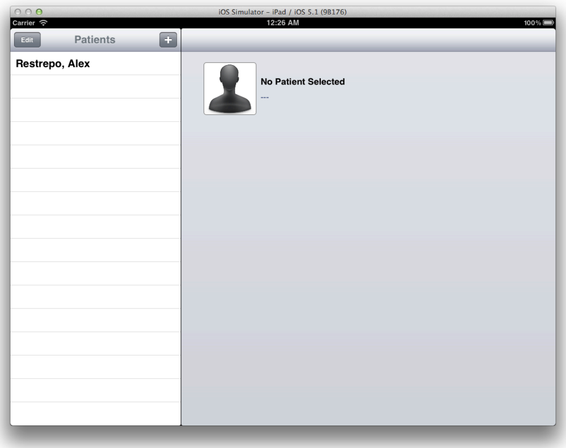


Figure 22: Main Screen, Prototype 2

Edit will allow you to permanently delete patients from the internal database, by switching the list into "edit mode"

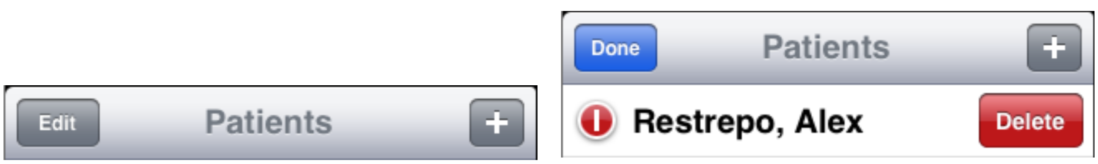


Figure 23: Patient List in Edit mode

The [+] button allows for the creation of a new patient profile, by clicking on this button, a new view to enter the basic details from the patient will be displayed:

Figure 24: Patient Entry Screen

The application will only create the profile if a First, Last name and telephone are provided, otherwise the application will not allow you to save the information.

7.3.2 Patient Summary

Once a patient is selected from the list, a patient summary will appear on the right. This view will display a quick summary of all the different assessments and "sessions" taken by the patient.

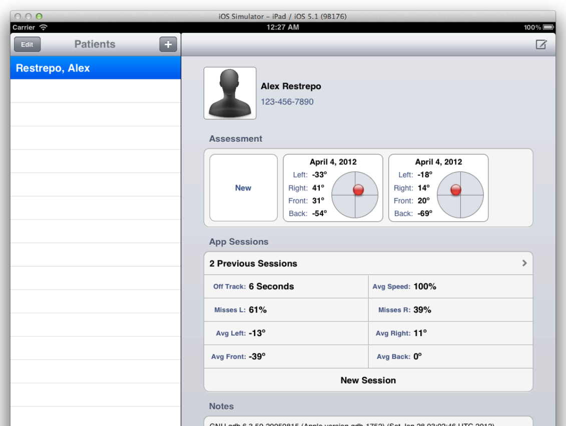


Figure 25: Patient Summary Screen

The summary is divided into 4 sections: User details, Assessments, App Sessions and Notes. At the very top, there's the user details section, where you can see the name and phone number of the patient (and in the future, his/her picture). At the very bottom, a notes section displays the notes for the patient profile, which can be edited by clicking on the "edit" button, at the top right of the patient summary panel.

The Assessments and App Sessions sections are more elaborated, and are described in detail below.

7.3.3 Assessments

As mentioned previously, the assessment section of the patient summary holds the history of the different assessments taken by the patient. An assessment is a combination of measurements of the trunk control of the patient, in this particular implementation, an assessment contains the initial (natural) position of the patient, as well as a measurement of the limits of stability, or how far can a patient reach in all four directions.

Figure 26: Patient Assessments

The circle with the red dot is a “top view” of the initial position of the patient, and gives a quick idea to the therapist of the default posture of the patient.
To take a new assessment, click on the “new” button on the left side, a “new assessment” window will appear:

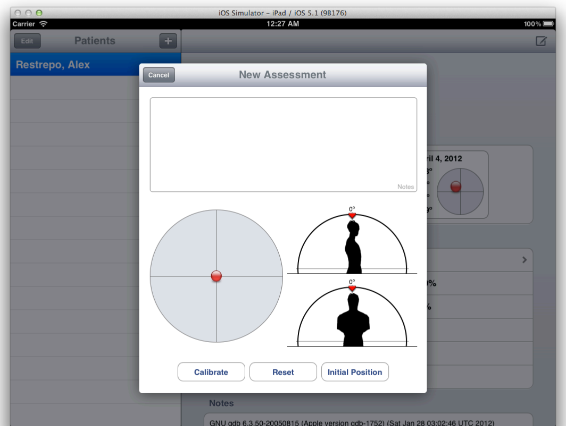


Figure 27: New Assessment Screen

In this screen, the therapist can enter notes for this particular assessment session (if desired), below the notes section. The output of the sensor is displayed, as seen from the top, the back and the side. The back and side views will record the maximum angle values for all 4 directions. In order to save an assessment, an “initial position” measurement needs to be recorded first, which can be done by clicking on the “Initial Position” button. Once the “initial position” is clicked the current measurements will be marked as the initial position for the patient. Then a save button will appear on the top-right corner. If needed, the therapist can reset the initial position value, as well as the currently recorded limits by pressing the reset button. The sensor can also be calibrated (mark its current position and orientation in space as its zero value) by pressing the calibrate button. Calibration should be done before the actual assessment takes place, by placing the sensor on a flat surface.
To delete an assessment, or to view its details (such as the notes taken for it), simply tap and hold on one of the assessment views, and a detail view will appear with the extra information:

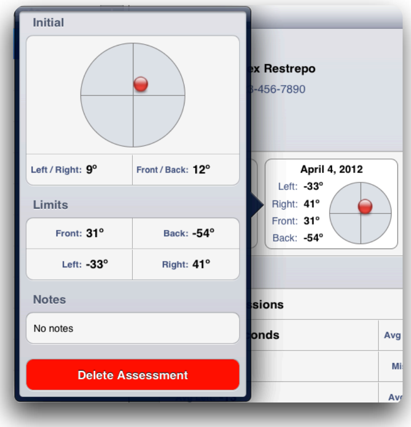


Figure 28: Assessment Details

Being able to perform assessments and store their related data will be a powerful feature in a future clinical study.

7.3.4 App Sessions

This section provides a quick summary of the measurements taken in all the sessions that the patient has finished. All the values displayed are the averages of what individual sessions measured, and include: average time off track, average speed, percentage of misses to the left and right (averaged) and the average of the maximum angles recorded for each of the 4 measuring directions.
This section also allow the therapist to go into the history of all previous session, or launch a new session.

Figure 29: App Sessions section

7.3.5 Session history (Previous Sessions)

Each session records a number of measurement from the patient, each one of those sessions can be accessed in reverse chronological order from the patient summary. Each session is displayed as a separate section, where each section contains: Date and time, total session time, time off track, maximum speed, average speed, maximum angles for all 4 directions, average angles for all 4 directions, and the percentage of misses to the left and the right, this percentage is from the total time off track.

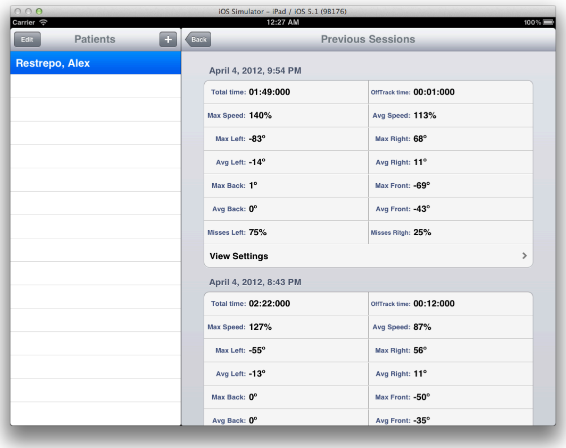


Figure 30: Session History

7.3.6 New session

The new session screen is similar to the one in the first prototype, but includes some of the requests made by the test therapists in their feedback, in particular, it now contains 3 sections (Visuals / Audio, Track and Sensor) and adds the following new control configurability features:

Audio Feedback

This prototype includes preliminary audio output. The effects currently supported are: audio from the car / bicycle as it accelerates / decelerates, a beeping sound when the “race” starts and a cheering effect every time a lap is completed.

Flip Front / Back

For some patients, it is needed to elicit movement to the back a lot more than to the front, enabling this setting inverts the input from the sensor, so leaning forward stops the vehicle, while leaning backwards accelerates it. This setting is only available while the Auto Accelerate setting is disabled.

Auto increase difficulty

Enables a simple heuristic that increases the difficulty of the game, as long as the patient exceeds a percentage of time on track. If the percentage is exceeded, at the moment the patient finishes each lap, the maximum speed is increased and a new track is selected; this new track was generated using a larger range for the generated curves, effectively making the game more difficult. Likewise, there’s a setting to specify a minimum percentage of time on track, if the patient can not reach this minimum percentage, the difficulty goes down, to the base level specified by the therapist (original session settings).
Currently the system uses 4 difficulty levels, the base level being the original session settings.

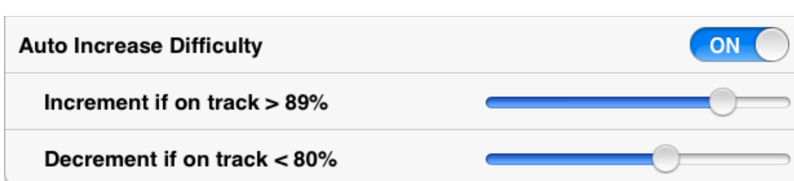


Figure 31: Auto Increase Difficulty Setting

It’s also important to note that the settings view now remembers the latest settings used for every patient, this way the therapists have easy access to the latest settings used, and can modify the current settings for the patient if needed.

7.3.7 Visual enhancements

A common complain with the first prototype was that the finish line was barely visible and that it was difficult to note when a lap was completed. In the second prototype, the finish line was replaced with a finish sign above the track:

Figure 32: Finish line in prototype 1 on the left, and prototype 2 on the right

7.3.8 Database

In order to keep record of the patient profile as well as the session history, including measurements and settings, a simple relational database is included with the application. This database is a SQLite database, which is a standard relational database available on most mobile platforms.

This database will also make the process of storing and syncing user profiles online a bit easier in the future, as a simple syncing mechanism could be written to keep all the devices in use by the therapists in sync. The database definition can be found as an appendix to this document.

7.3.9 Measurements

The second prototype records a large set of parameters, from the settings used in a given session, to the individual measurements taken during the session so the therapist can analyze them later

For each session, the following parameters are stored:

Theme: The theme that was used in this particular session, it is a integer with the values 0, for car race and 1 for the bike race.

EnableScenery: Boolean. Whether the session had the scenery turned on or off.

TurnBias: Float. A patient may need to exercise a side more than the other, this parameter changes the probability in which the track generation algorithm will select right vs left curves. The parameter has a range of 0 to 1, inclusive, where the probability of choosing a left curve is 1 - turnBias, and the probability to choose a right curve is turnBias.

MaxSpeed: Float. Value between 0 and 1, which stands for the percentage of the maximum absolute speed permitted in the game.

AutoAccelerate: Boolean. Whether the game auto-accelerates, ignoring front-back sensor input.

MaxForwardDOF: Float. The maximum forward inclination angle for the patient, all front inclination angles obtained from the sensor are normalized with this value.

MaxBackwardsDOF: Float. The maximum backwards inclination angle for the patient, all backwards inclination angles obtained from the sensor are normalized with this value.

AutoSteer: Boolean. Whether the game will auto steer, ignoring lateral input from the sensor.

MaxLeftDOF: Float. The maximum left inclination angle for the patient, all left inclination angles obtained from the sensor are normalized with this value.

MaxRightDOF: Float. The maximum right inclination angle for the patient, all right inclination angles obtained from the sensor are normalized with this value.

Laps: Integer. The number of laps used in the session, this number has a range between 1 and 10.

Length: Integer. The track generation algorithm uses a concept of “zones” to generate the track, each zone corresponds to either a curve or a straight segment, this value modifies the number of zones that the track algorithm will generate, from a minimum of 4, to a maximum of 14.

Notes: Text. Therapists underlined the need to have notes attached to each session, starting with prototype 2, sessions now have a notes section that the therapists can use. Notes are available on a per-session basis.

FlipFrontBack: Boolean. Whether the forward / backwards input from the sensor was flipped during the session.

AutoincrementDifficulty: Boolean. Indicates if the difficulty was incremented automatically during the session, based on the two following settings.

AutoincrementAfterValue: Float. The percentage of time on track that the patient needs to satisfy before the difficulty is automatically incremented.

DecrementBelowValue: Float. If a patient fails to be on the track at least this percentage, the difficulty is then reduced, up to a base value which is how the session itself started.

EnableAudio: Boolean. Whether the session included audio or not.

Additionally to all the settings used in the session, there are some specific measurements taken during the session, which are the actual therapeutic values useful for therapists, these values include averages and maximums achieved by the patient and can be reviewed at any time by accessing the session history view. Currently, these values are:

Timestamp: The date and time in which the session took place.

TotalTime: The total time used by the patient to finish all the laps.

BestTime: The fastest time in which a patient finished a lap.

TimeOffTrack: The total amount of time that the patient was off track.

MaxLeft: The maximum inclination angle to the left, achieved by the patient.

MaxRight: The maximum inclination angle to the right, achieved by the patient.

MaxFront: The maximum inclination angle to the front, achieved by the patient.

MaxBack: The maximum inclination angle to the back, achieved by the patient.

AverageLeft: The average inclination angle to the left, achieved by the patient.

AverageRight: The average inclination angle to the right, achieved by the patient.

AverageFront: The average inclination angle to the front, achieved by the patient.

AverageBack: The average inclination angle to the back, achieved by the patient.

MaxSpeed: The maximum speed achieved by the patient.

AvgSpeed: The average speed achieved by the patient.

MissesLeft: The percentage of the total time off track, in which the patient missed the track on the left.

MissesRight: The percentage of the total time off track, in which the patient missed the track on the right.

8. Results

Each prototype included an online survey in which the feedback from the therapists was collected, the survey, divided into 6 sections (Usability / interaction, Usefulness, Configurability, Motivation, Clinical Output and General), aims 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.
Before the therapists were exposed to the surveys, they had the opportunity to use the prototypes for at least one week, after being trained in the specifics on how to navigate and use the app. Followup interviews were then conducted with each participating therapist.

8.1 First Prototype

For the first prototype, a total of 4 therapists, from both hospitals, answered the survey. Their responses are summarized below.

8.1.2 Usability / Interaction

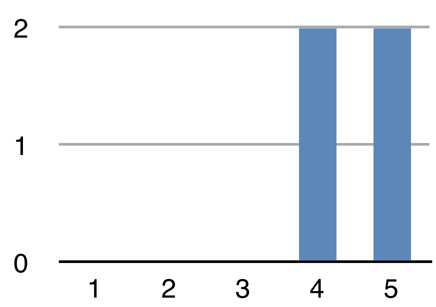
In general, all the test therapists found the device easy to operate, which is an important metric to strive for. Half of them rating it as very usable, while the other half found it just below the very usable mark, which still labels the prototype as an easy to use application.

In this study, the 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.

The pairing process is definitely an area of improvement, at least half of the therapists found the pairing process to be somewhat hard to execute, in part, it’s a limitation of the sensor itself given its limited processing power and the overhead of crating an ad-hoc Wi-Fi network.

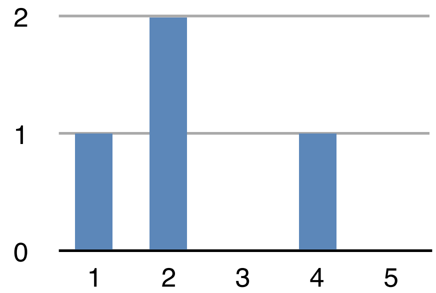
As far as the suggestions given on how to improve usability, some were implemented in prototype 2, in particular, the finish line is easier to see, as well as calibrating the device to the patient’s position when the session starts.

How would you rate the usability, or ease of use, of the device?



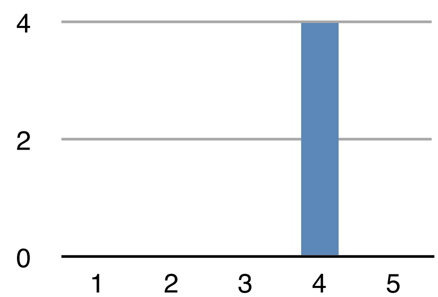
1 - Not Usable	0	0%
2	0	0%
3	0	0%
4	2	50%
5 - Very Usable	2	50%

Rate the ease of interaction between the patient and the device.



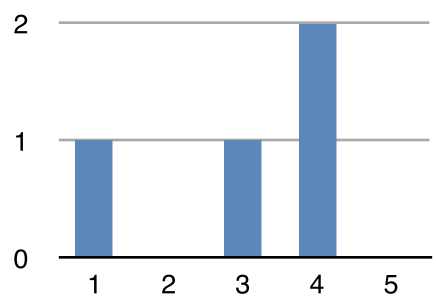
1 - Easy	1	25%
2	2	50%
3	0	0%
4	1	25%
5 - Hard	0	0%

How would you rate the sensor interaction / sensitivity with the device?



1 - Poor	0	0%
2	0	0%
3	0	0%
4	4	100%
5 - Excellent	0	0%

How would you rate the device - sensor pairing process?



1 - Easy	1	25%
2	0	0%
3	1	25%
4	2	50%
5 - Hard	0	0%

How would you improve the interaction between the system, the user and the therapist?

1. *"I would have the finish line stand out more, such as a black and white checkered line or flag poles of some type - it just blends in too much and can easily get missed w/ the vertical white slash marks when driving w/ the car.*
   If the device isn't positioned just perfectly (exactly upright) it greatly affects the sensitivity of the device. "

2. *"Have the data transferable for therapist use objectively"*

3. *"Ability for the sensor to calibrate at a set of data points (true zero or initial position of client)."*

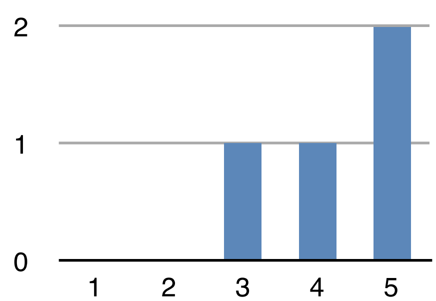
4. *"Developing a harness/vest system to secure the device to the patient to improve ease of use. More adjustability of positioning midline starting point to allow for improved sensitivity of shifting weight."*

8.1.3 Usefulness

Particular attention, in order to advance from prototype 1 to prototype 2, was given to this section and the feedback gathered from the therapists. Since it exposed the actual therapeutic value of the experience, most of the suggestions outlined here were indeed implemented in the second iteration. These suggestions were further emphasized when we met with the therapists for a feedback round after they were done using the device. It's also particularly interesting how some of their suggestions are remarkably similar.

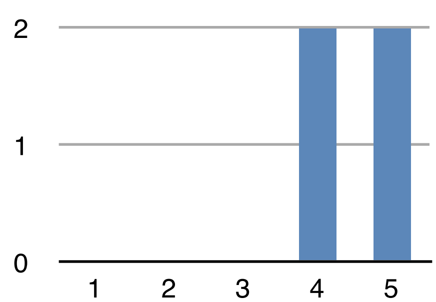
From these questions we can infer that the device can definitely be of help for both therapists and patients for real life therapy sessions. From the point of view of the patient, a 100% of the therapists agreed that the device was useful or very useful for therapy.

From your perspective, how would you rate the usefulness of the device, when it comes to therapy?



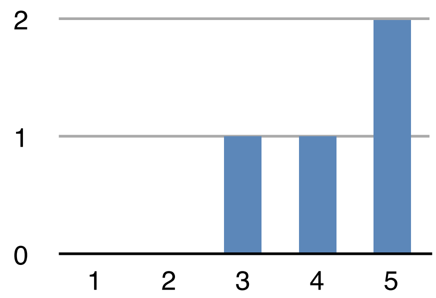
1 - Not useful	0	0%
2	0	0%
3	1	25%
4	1	25%
5 - Very useful	2	50%

From a patient perspective, how would you rate the usefulness of the device, when it comes for therapy?



1 - Not useful	0	0%
2	0	0%
3	0	0%
4	2	50%
5 - Very useful	2	50%

How would you rate the overall usefulness of the device, for therapeutic use?



1 - Not useful	0	0%
2	0	0%
3	1	25%
4	1	25%
5 - Very useful	2	50%

What do you think would make the system more useful in therapy? what could be added or removed?

1. *"see previous remarks."*

2. *"More variability such as even simpler background to moving objects in the background, other cars or maybe a dog crossing the street"*

3. *"Adding more objective information.*
   Examples:
   Percent of time on track versus off track;
   Percentage of success with R turns vs. left turns.
   Ability to save patient profiles.
   Ability to set acceleration to occur by leaning backwards.
   Ability to change relative ""midline"" to something other than 0 degrees.
   Variety of race tracks; having ability to set turns to be slow/smooth or sharp turns."

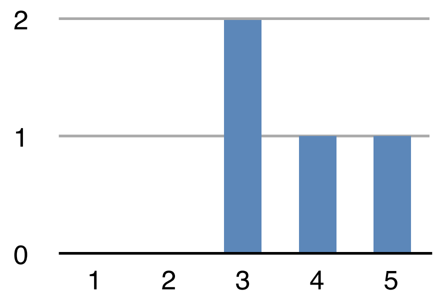
4. *"More adjustability in difficulty of turns, option to limit number of "beeps" when they go out of bounds as this was frustrating for one ct to hear continually, option to change which direction causes acceleration (backward rather than forward) Or have the option to lean to just the R (or the L) to accelerate with the auto-steering to force them to keep the weight to the R the whole time."*

8.1.4 Configurability

In order to differentiate the game from a regular game, and emphasize its therapeutic goals, a highly customizable experience was implemented.

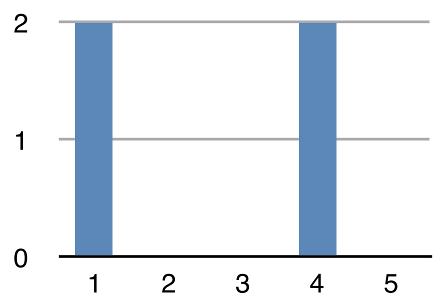
In general, therapists found the amount of configurability found in the prototype to be adequate, it is however, their answers to the open-ended questions, what helps us understand the real requirements for a truly customizable, therapy game.

How would you rate the amount of configurability available in the app?



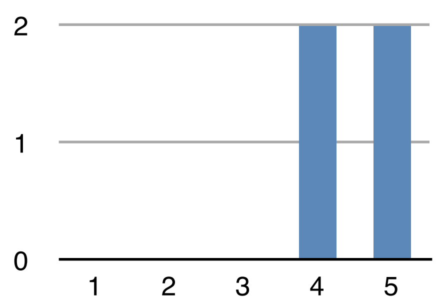
1 - Poor	0	0%
2	0	0%
3	2	50%
4	1	25%
5 - Excellent	1	25%

Are the controls easy to understand, navigate and operate?



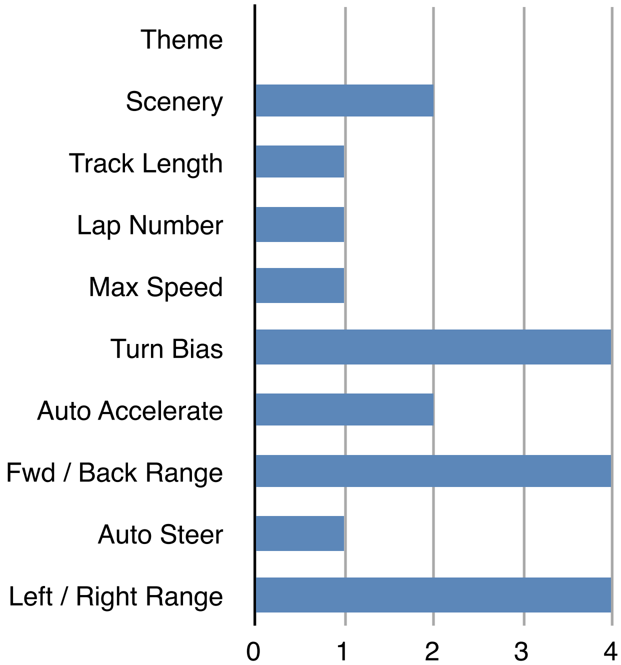
1 - Easy	2	50%
2	0	0%
3	0	0%
4	2	50%
5 - Hard	0	0%

Do the setting names accurately describe the function of what it does?



1 - Not at all	0	0%
2	0	0%
3	0	0%
4	2	50%
5 - Very much so	2	50%

What controls do you use the most? Check all that apply



Theme	0	0%
Scenery	2	50%
Track Length	1	25%
Lap Number	1	25%
Max Speed	1	25%
Turn Bias	4	100%
Auto Accelerate	2	50%
Fwd / Back Range	4	100%
Auto Steer	1	25%
Left / Right Range	4	100%

Between the bike and racing game, what one gets the most use? and why do you think it does?

1. *"Both are used about the same. Most people prefer the car."*

2. *"Bike- because a lot of people were in car accidents"*

3. *"No opinion due to limited time trying the unit. Only used car, but also liked the biking game. Biking game had less visual stimuli from road (pros and cons to this depending on treatment needs)."*

4. *"Racing; it's the default that comes up first so I tended to just use it. Also the view is looking at the whole car and keeping it on track vs the view as if you are riding the bike so it seemed easier for people to see where the car was going. I like having both options, though."*

What other game themes would you like to see added to the device?

1. *"Maybe a runner or some other type of sport game"*

2. *"One where the patient needs to stabilize self in a position"*

3. *"Would be neat to see ability to expand to being able to do games that aren't static standing or sitting...reaching and stepping to "catch" balls for example."*

4. *"Similar idea with other sports...skiing, steering a boat...*
   Also could have the option to add in even more ""real life"" distractions of people walking by, or a dog running into road, etc to force a reason to decelerate. "

What kind of control/configuration do you wish you had more of?

1. *"I think you hit it right on. I can't think of anything else that I would change."*

2. *"More background options"*

3. *"More variety in changing difficulty of course."*

4. *"Changing their midline point and biasing weight shifts all to one side vs mostly to one side. Also changing direction of weight shift for acceleration."*

What other settings do you find important that are missing, any that could be removed?

1. "I think all are necessary. *I wouldn't remove or add anything."*

2. *"sound on/off (different amount of business in sounds setting as well)"*

3. *"As addressed elsewhere in survey."*

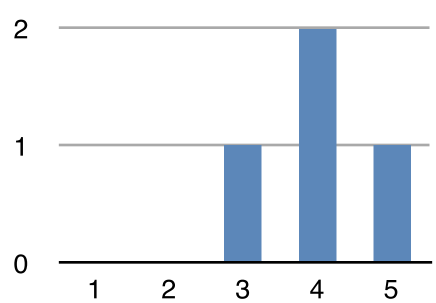
4. *"See above suggestions."*

8.1.5 Motivation

In this particular feasibility study, it is important to determine how motivated are patients are to use the system, the more motivated they are, the easier its adoption, and provided the actual therapy is beneficial, the better the results they will get from using the device.

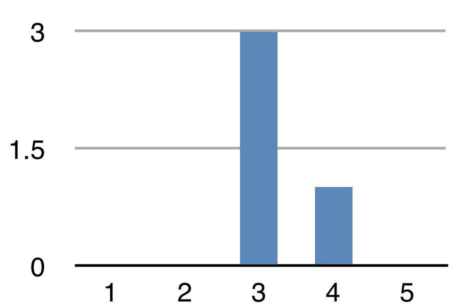
It is important to note how, comparatively, the motivation to use this system ranks higher on the therapist's scores, when compared to the motivation to use the conventional systems already in place, whereas 75% of the answers rank the system as good or excellent in terms of motivation, that same 75% 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.

How would you rate a patient's motivation to use the system?



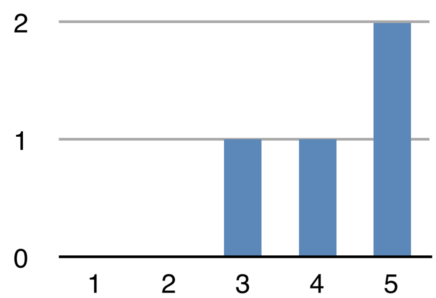
1 - Poor	0	0%
2	0	0%
3	1	25%
4	2	50%
5 - Excellent	1	25%

How would you rate a patient's motivation to use the current systems in place today?



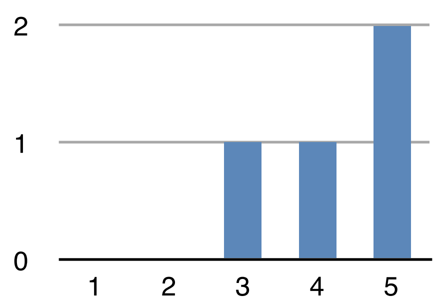
1 - Poor	0	0%
2	0	0%
3	3	75%
4	1	25%
5 - Excellent	0	0%

Would you agree that the system motivates patients to move, compared to more traditional methods?



1 - Do not agree	0	0%
2	0	0%
3	1	25%
4	1	25%
5 - Strongly agree	2	50%

How would you rate the patient's ability to learn to use the system?



1 - Poor	0	0%
2	0	0%
3	1	25%
4	1	25%
5 - Excellent	2	50%

Do you have any suggestions on how we can make the system more engaging for the users?

1. *"More challenges - possibly add in obstacles to avoid so it could be more difficult"*

2. *"I rated all at 3 because we have not been able to use the device on patients yet."*

3. *"Continue to increase variety of tasks, and levels of difficulty."*

4. *"Adding other types of activities (skiing, boating, etc)"*

Do you have any suggestions on how to make the system easier to use for a patient?

1. *"see remarks on 1st page."*

2. *"unsure at this time."*

3. *"Currently very easy.*
   I would have some concerns that if adding increased options as suggested in the survey, then the use may be more complicated for a patient.
   Ability for therapist to make settings then lock the settings would be important so that the patient only has to turn it on/off."

4. *"Adding a harness/vest system to secure the sensor in place"*

8.1.6 Clinical Output
There was no clinical output for the first prototype, however, we asked the therapists what kind of output they would like to see in place for prototype 2. Most of their suggestions were implemented as part of the

patient profile or the session history. Also, the notion of a possible online dashboard, where the therapists could have remote control over the sessions was introduced.

Now that you have had some time to play with the system, what would you like to see as output from a session?

1. *"Same data as discussed before - % of lean to R vs. L vs. anterior vs. posterior, % off track, approximate speed, if targets or obstacles were added % of obstacles hit."*

2. *"The extremes in motion they were able to achieve. accuracy staying on course-perhaps even what direction they most often went off course.*
   Some sort of calculated score taking into account, speed, background difficulty, extremes of motion, amt of time on track etc so as they progress and things become harder their score continues to rise for encouragement"

3. *"More data than just time to complete laps...suggestions provided earlier in survey."*

4. *"Total time, best lap, slowest lap, and number of times off the track and which side."*

What would you like to store in the patient's history / profile?

1. *"Same info as before plus environment"*

2. *"Last time's settings"*

3. *"Name, settings for game, scores"*

4. *"Settings that were used, all the info listed above as well."*

Would you find useful an online dashboard to set and control patient profiles and settings?

1. *"yes"*

2. *"i'm not sure"*

3. *"yes!!"*

4. *"maybe…"*

What kind of control would you like to have over the device online?

1. *"Same control as on the ipad just in case adjustments would be needed after a therapy session."*

2. *"Current controls seem good"*

3. *"Ability to see usage of the device, progress/scores, ability to change settings"*

4. *"Able to download their race results to my computer"*

Any other comments or suggestions on what the user should provide as output?

1. *“the finish line comes up too quick and you cannot tell you are reaching it”*

8.1.7 General
The final section of the survey focused on open-ended questions in which the therapists were asked for their opinions about the prototype, its feasibility as a finished product and any other comment that could be helpful for future iterations.
In general, there's a consensus that the prototype is feasible as a therapy option and has a lot of potential as a finished product, as well as the fact that it enables a wider range of patients to use it, since there's no requirement for the patient to stand on a separate device and the patient can easily use the device sitting or standing.

What are your thoughts on the system? do you think it could be a feasible option for therapy as a finished product?

1. *"Yes. great concept."*

2. *"I do think there's a lot of potential but would need to see it on actual patients to really be sure"*

3. *"I really like it.*
   Very impressed with the current product and see many innovative ideas for further improvements.
   In the beginning, I strongly felt that there lacked a therapy device that assisted with treatments for a wide range of clients (those who could only sit, vs. those who can only stand, vs. those who need work on balance during movement). I think this device is hitting a wide range of clients and could expand more to those who need balance training within the context of movement."

4. *"Yes, I think it's a great concept and my patients enjoyed using it as well. There are a lot of great features already in the product and I think creating even more adjustability as previously mentioned would be great. "*

Any other comments about the project?

1. *"Nice job with the development of the game so far. You have definitely taken our recommendations into consideration. It is very user friendly and a great tool."*

2. *"Great job with this first game!"*

3. *"I see potential for the device to be used outside of the "game" and used as a posture assist. Could have settings for how much lean is allowed and then worn by a patient--if they lean past the set parameters, then could beep/vibrate as a postural reminder."*

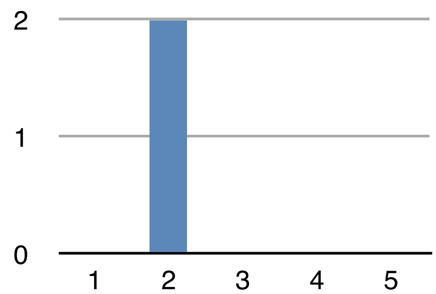
4. *"Nothing further than previously suggested. Can't wait to try it more!"*

8.2 Second Prototype
In addition to the teams at Hope Network and Mary Free Bed, the second prototype was also evaluated by a team of graduate students in physical therapy, as well as a faculty member.

8.2.1 Usability / Interaction
The experience with this prototype seems to be consistent with that of the first prototype, in general, the therapists agreed that the device is easy to use for both, patients and therapists.

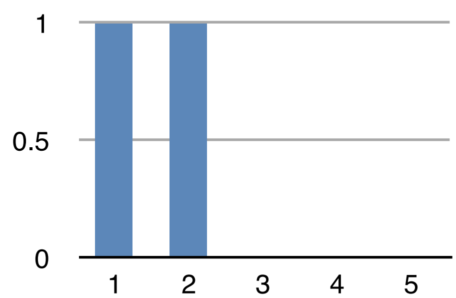
There was also a substantial amount of suggestions for improvements, which, along with previous unimplemented suggestions, are summarized in section 10 (Future Work).

How would you rate the overall ease of use of the new features in prototype 2 (patient profile, history, settings)?



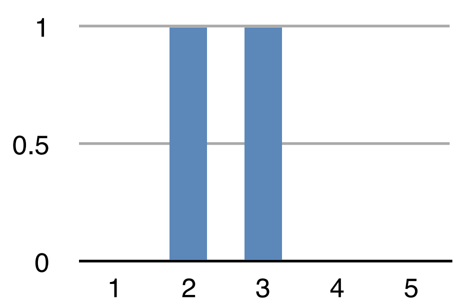
1 - Easy	0	0%
2	2	100%
3	0	0%
4	0	0%
5 - Hard	0	0%

How would you rate the ease of use of the patient profile?



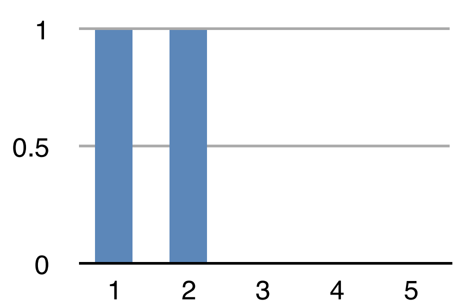
1 - Easy	1	50%
2	1	50%
3	0	0%
4	0	0%
5 - Hard	0	0%

How would you rate the ease of use of the patient assessment?



1 - Easy	0	0%
2	1	50%
3	1	50%
4	0	0%
5 - Hard	0	0%

How would you rate the ease of use of the patient session history?



1 - Easy	1	50%
2	1	50%
3	0	0%
4	0	0%
5 - Hard	0	0%

How would you improve the interaction between the system, the user and the therapist?

- *Ways to vary degree of challenge within program:*
  - *Determine number of turns per lap*
  - *Additional environmental visual stimuli*
  - *Determine amount of time one can see that the turn is approaching*
  - *Unexpected obstacles in path to avoid*
  - *Ability to turn off auditory and vibrational cue*
  - *Increase the amount of degrees that create movement*

- *Lost wireless connection fairly frequently*

- *Documentation or to be able to document in notes after a session. This would allow for documentation of things like physical assist or UE support needed to regain LOB X number of times. Also, would allow clinician to document the cues they provided the client. This would then allow for another clinician to access it prior to a session in order to understand what has been successful in the past.*

- *In regards to documenting physical assist/UE support needs: could we document while the program is running? Perhaps via a small icon that the therapist could tap when the event occurs. Perhaps, 2 icons, one for physical assist and one for independent UE support. This would then record what the challenge was that induced this and could be reported in the session summary.*

- *Have a choice to get a summary that tracks progress. This should be client friendly in order to serve as a motivator.*

- *When in the mode where acceleration occurs with anterior shift, one can accomplish this in a slouched position.*

- *Application in standing:*
  - *May need to experiment with the placement. With is being so cranial at T2, it allows the client to accomplish the goal without weight-shifting but rather with just movement of the upper body.*

- *In sitting, the placement of the device at T2 seems to be reliable in detecting true trunk movements.*

- *Anterior/posterior acceleration: I like the feature. I think it provides a client to perform more functional movement patterns (diagonal).*

- *Can accomplish goal without weight shift.*

- *Demonstrated a catch when using the anterior/posterior acceleration: seems to sometimes not respond to anterior acceleration if I go too far. I then have to come back to neutral and move anterior again.*

- *Could do on unstable sitting surface (tilt board) to increase challenge.*

- *Must ensure correct posture is preset at beginning of session. Anyway to not require this? Can the calibration during the assessment be sufficient? This would make it easier for home and independent use.*

- *Clinical skills needed:*
  - *Assessment skills and handling for weight shift and postural correction.*
  - *Decision making regarding challenges.*

- *Per our discussion at today's meeting, there are issues with the device calibration and responsiveness to A/P movement based on placement of the device on patient and anatomical alignment. We may have* *to consider an alternate spinal placement or some way to calibrate the initial position if the patient has kyphotic posture.*

- *Once a patient is way off the course, perhaps arrows to let them know which direction to head to get back on the course. Also, a method to move them back on the course after a set time period so they are not lost in the trees for the duration of the training session!*

- *The user friendly flexibility for the therapist to set directionally specific training goals is excellent.*

- *The summary on training session performance is good as well, love the idea of adding a graphic to show progress.*

- *If we were to use this in standing or with vestibular rehabilitation, it would be great to add more complex visual moving environments and moving obstacles across the path.*

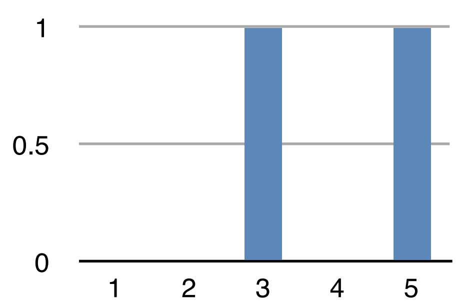
- *I like the idea of next generation using gyroscope so we can pick up vertical displacement in center of mass as well... will lend itself to more dynamic functional balance demands in standing.*

- *My last comment is to do away with the breathing for the bike sound... not sure what you would use, I thought motorcycle sound that reflects speed would be good. If they are a crash victim then therapist could just turn the sound off.*

8.2.2 Usefulness

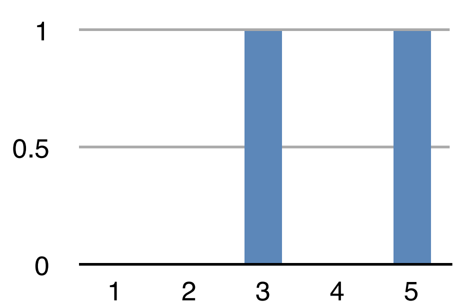
Again, prototype 2 maintains its high perceivable usability. All teams agree on the fact that the device is on the right track when it comes to provide useful information and more importantly, useful therapy.

From a patient perspective, how would you rate the usefulness of the device, when it comes to therapy, compared with prototype 1?



1 - Not Useful	0	0%
2	0	0%
3	1	50%
4	0	0%
5 - Very Useful	1	50%

How would you rate the overall usefulness of the device, for therapeutic use?



1 - Not Useful	0	0%
2	0	0%
3	1	50%
4	0	0%
5 - Very Useful	1	50%

What do you think would make the system more useful in therapy? what could be added or removed?

- *"See previous"*

- *"Most of my feedback on this system regarding recommendations, I included in that last section narrative."*

- *"Feedback on what made this system useful for therapy :*
    - *The assessment component in this new system is important and needed addition, as long as the data is valid and reliable.*
    - *The individual patient profiles and reports in this new system is a great addition.*
    - *The ability to customize the training session based on the patient's needs and specific balance impairments is a nice improvement as well."*

- *"Could add tighter turns, increased speed of responses as many of our clients are very delayed in their balance responses."*

- *"I think your team's idea of uploading the data from patient profile to the cloud is a worthwhile goal as therapists could download the data for progress reports or daily performance logs quite easily."*

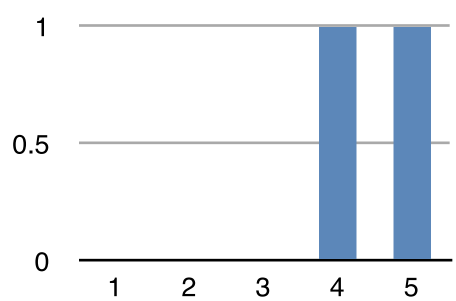
- *"Main improvements are needed in the device itself... smaller overall component, a leveling or stabilizing in vertical housing component, a way to secure it on the patient, and perhaps, addition of the gyroscope & bluetooth technology."*

- *"Great work team!"*

8.2.3 Configurability

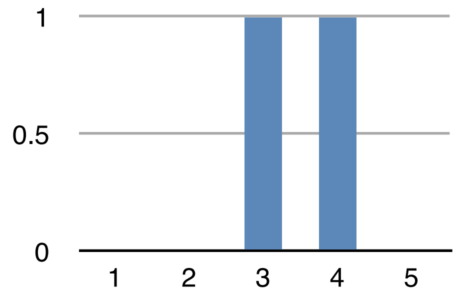
The overall amount of configurability available in prototype 2 appears to be sufficient for what the system is set out to do. Unfortunately, with the larger amount of available options, it became harder for the therapists to quickly setup the application and some options became unclear for them. The need for some sort of in-app help can address some of these concerns.

How would you rate the new configuration options available in the app? (audio, flip front/back, auto increase difficulty)



1 - Not Useful	0	0%
2	0	0%
3	0	0%
4	1	50%
5 - Very Useful	1	50%

Are these new controls easy to understand, navigate and operate?



1 - Strongly Disagree	0	0%
2	0	0%
3	1	50%
4	1	50%
5 - Strongly Agree	0	0%

What kind of control/configuration do you wish you had more of?

- *"See previous"*

- *"Already discussed my key issues with you at our meeting today."*

What other settings do you find important that are missing, any that could be removed?

- *"See previous"*

- *"Pause setting during the training session... for patients that you need to redirect their attention, or assist them back to safe upright position, etc.."*

- *"Arrows to tell the user where the track is when they are off in the woods."*

- *"Clear directions or cues in the first few seconds prior to training that the system is calibrating initial starting position.... very important for the therapist to know this detail."*

How would you rate, in terms of usefulness, the Auto Increment Difficulty, and its related settings?

- *"I think it is useful (3/5). See comments below."*

- *"Extremely useful."*

- *"It takes awhile to learn and play with these components in order to understand how they would be manipulated for specific patient needs, but overall good concept."*

- *"We would probably need a user manual with explanation of each variable that can be customized."*

What are your thoughts about the Auto Increment feature, do you find it useful as it is, or what would you add / change to make it more useful for therapy?

- *"I think it would be clinically useful. Clinical decision making, along with the increment difficulty, would allow for challenge to be varied appropriately. I think the auto increment feature is good but additional features (expanded on previously) should be added in order to allow a therapist to alter variables to create different challenges for a client."*

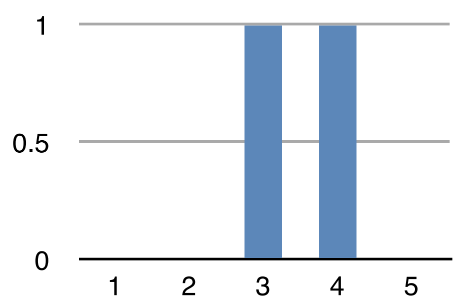
- *"Same comments as above."*

- *"I'd really need to play with it more now that I know that there is a forward lean limit that is greatly affected by the initial position of the device on the patient. I couldn't fully explore these other options* *until I got the device responding to my trunk movements consistently. I would like to explore further how this could be applied to standing balance retraining as well."*

8.2.4 Motivation

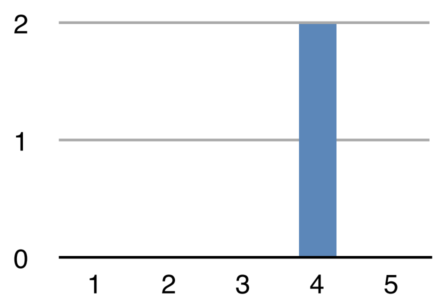
The perceived motivation for patients in prototype 2 remains high to very high, and more importantly, therapists agree that it motivates patients in a higher degree than traditional methods.

How would you rate a patient's motivation to use the system?



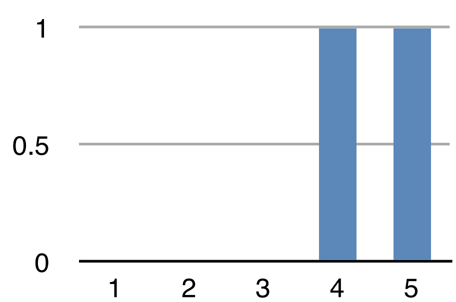
1 - Very Low	0	0%
2	0	0%
3	1	50%
4	1	50%
5 - Very High	0	0%

Would you agree that newer settings (such as audio) help motivate the patient to use the system?



1 - Strongly Disagree	0	0%
2	0	0%
3	0	0%
4	2	100%
5 - Very High	0	0%

Would you agree that the system engages patients to do therapy, compared to more traditional methods?



1 - Strongly Disagree	0	0%
2	0	0%
3	0	0%
4	1	50%
5 - Strongly Agree	1	50%

From the app perspective, do you have any suggestions on how to make the system easier to use for a patient?

- *"Provide summary of progression in training in client friendly format in order to improve client motivation. Easy to apply harness for device."*

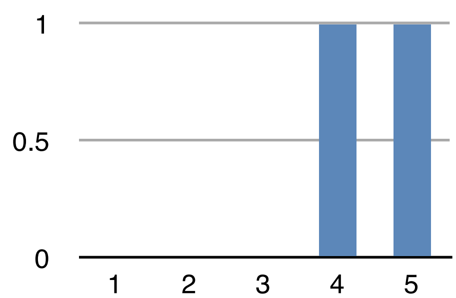
- *"I didn't get a chance to use it on patients yet so can't really comment on this from the patient's perspective."*

- *"I think the assessment piece can also be a "learning time" for the patients to see how their trunk lean can control the system. Perhaps in the training mode, a short warmup lap with a few turns would be helpful to teach them how to run/control the system with their trunk/com movements."*

8.2.5 Clinical Input - Output

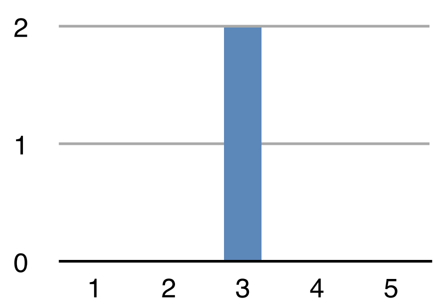
From the responses, we can see how the amount of session data recorded, as well as its presentation, seems to be adequate for our purposes, however the amount of information recorded for the assessments still could be improved. Adding graphs that correlate session information in order to see trending, whether positive or negative, seems to be a generalized request.

The patient summary screen presents a summary of previous sessions and assessments, how would you rate the overall amount of information present on this screen?



1 - Insufficient	0	0%
2	0	0%
3	0	0%
4	1	50%
5 - Sufficient	1	50%

How would you rate the amount of information available (and/or recordable) in a patient assessment?



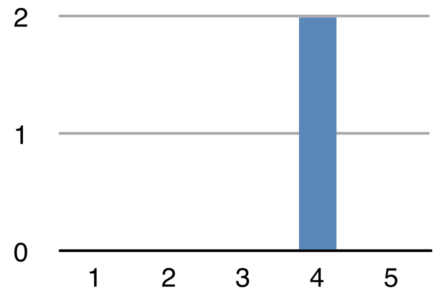
1 - Insufficient	0	0%
2	0	0%
3	2	100%
4	0	0%
5 - Sufficient	0	0%

What would you add to a patient assessment?

- *"See previous"*

- *"Concerns about validity and reliability... as we discussed. Ease of use is great... simple initial position and few click for r/l a/p maximal lean."*

How would you rate the averaged session information?



1 - Insufficient	0	0%
2	0	0%
3	0	0%
4	2	100%
5 - Sufficient	0	0%

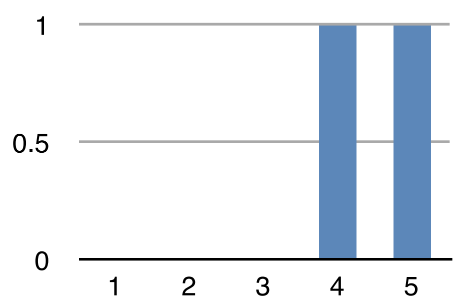
What other measurements would you like to see summarized in the average session information?

- *"See previous"*

- *"Graphics would be great to show progress over time."*

- *"Response time to error (off track)... when they recognize and start to make any correction would be helpful but not necessary."*

How would you rate the amount of information available in the session history screen?



1 - Insufficient	0	0%
2	0	0%
3	0	0%
4	1	50%
5 - Sufficient	1	50%

Each session completed by the patient is stored in the session history, besides the values already being recorded, what other values would you like to record on each session?

- *"See previous"*

- *"No further comments..."*

The patient profile contains just basic information, what would you like to add to the patient profile that is not already available?

- "I don't think the client profile requires anything additional."

- If this were stored confidentially in the cloud.. then the therapist could add more patient identification data such as age, sex, diagnosis, time post diagnosis/injury, training goals etc..."

If this data was to be presented in the form of a web dashboard, what kind of data would you like to see? How would you like it represented? ie: charts, graphs, tables, etc...

- *“I would like the option of a summary of training progression in order to track progress. A line graph could be useful for this.”*

- *“I am unclear as to what a web dashboard is.”*

- *“Charts with each training session and then summary data of training.”*

- *“Graphics of progress over "x" number of sessions”*

- *“Some visual of initial position relative to upright vertical with little graphic on maximal lean right/left, anterior/posterior”*

Is there any additional data you would like the web dashboard to display that the device doesn’t?

- *“See previous”*

- *“The opportunity for patients/clients to compete with one another in their gaming on this device would be a fun addition but not priority by any means.”*

8.2.6 General

Finally, the overall consensus from the test teams is that the system has a lot of potential as a finished product, it addresses most of the problems with conventional consumer games and clinical devices: portability, cost, ease of use and customized training.

What are your thoughts on the system? do you think it could be a feasible option for therapy as a finished product?

- *“I think this is a very feasible and marketable option for therapy. Especially if additional features were added that would allow the therapist to more greatly tailor the challenges of the intervention to the client's deficits.”*

- *“Excellent progress this past semester in making this device/system more therapist and user friendly. This system definitely has strong potential for the rehab market due to its portability, low cost, user friendly, customized training, and intuitive gaming components. We would probably need a few more game options on it to maximize its marketability, but this would sell to rehab facilities, outpatient offices, etc...”*

Any other comments about the project?

- *“See previous”*

- *“No, I think that about covers them. Great work Alex!”*

9. Conclusions

When we set out to study the feasibility of the system as a viable therapy device, we had just a vague idea of what could make a video game useful in therapy. In different meetings with experts, a number of features started to stand out as things that needed to be implemented.

As the prototypes were evolving, the answers to our initial questions started to emerge. Some fascinating results from the test therapists showed that the device has a great potential as a finished product, and that it highly motivates patients to use it. As for the questions that were defined as the basis for this research, we can now base our answers on the feedback provided by the experts that tested the system.

1. ***What are the characteristics of the ideal companion device / accessory for therapeutic games involving TBI patients? (e.g. sensory features, input / output modalities, battery life considerations, pairing procedures, etc.)***

After evaluating the prototypes, the feedback and the interviews, it is clear to us now that some of the fundamental characteristics that make an accessory-controlled therapeutic application are:

- *Configurability of content and control:*
  Patients vary enormously in terms of cognitive and motor abilities. It is extremely important for the therapists to be able to "fine tune" the look and behavior of the game, in order for it to be as useful as possible to a specific patient. This contrasts with consumer games, in which both visuals and controls are usually preset and offer very little or no configuration possibilities.

- *Ease of use:*
  Therapists need a system that they can easily configure and "deploy" to their patients, and at the same time, it needs to be easy to use for a patient, given their possible cognitive and motor disabilities. Therapists can make the games easier, in a way, by tailoring it to the specific needs of a patient. Consumer games can frustrate patients, as they may not perform as they would like to.

- *Portability:*
  Therapy devices, and even consumer video games require a dedicated setup that is not portable. A handheld device allows therapists and patients to engage in therapy anywhere without the need of a special, fixed setup. The accessory is also small enough that can easily be carried with the device. Additionally, the system allows a wide range of patients to use it, since the patient is not required to move to reach the device, on the contrary, the device can be brought to the patient.

- *Price:*
  Handheld devices are relatively affordable, and when compared to a dedicated therapy device, their price becomes even more attractive. A hospital can acquire several handheld devices for the price of a therapy machine. We have shown that a handheld and accessory system can be effective when it comes to therapy. Several patients can use different devices simultaneously, while a dedicated therapy machine is more expensive and can be used by only one patient at a time.

2. ***Is it feasible to receive the appropriate regiment of therapy from a custom video game?***

As far as the therapists are concerned, yes. They seem to agree on the fact that the system has a lot of potential, and can definitely help them when it comes to provide therapy to a TBI patient, however, they can only speak from their own experience while pretending to be an actual patient. Clinical trials with real patients are necessary to confirm what therapists have experienced in our tests

> - *"I do think there's a lot of potential but would need to see it on actual patients to really be sure"*

- *“I really like it.*
  Very impressed with the current product and see many innovative ideas for further improvements.
  In the beginning, I strongly felt that there lacked a therapy device that assisted with treatments for a wide range of clients (those who could only sit, vs. those who can only stand, vs. those who need work on balance during movement). I think this device is hitting a wide range of clients and could expand more to those who need balance training within the context of movement."

3. Is it feasible that a game can be fully configurable for therapy reasons, and still be compelling to the patient? how does customizability affect gameplay.

In our observations, the game seems to be as a motivation factor for patients to engage in therapy. Part of the reason for this motivation is that the game can be fine-tuned to the abilities of the patient, in such a way that it’s appealing to even patients with severe limitations.

4. Is it feasible to motivate and engage patients to perform therapy, by using our system?
It definitely appears to be so. When the therapists were asked about the apparent motivation to use the system, 75% of them ranked it as good or excellent in terms of motivation. Furthermore, they have excellent opinions about the concept of the system:

- *"Yes, I think it's a great concept and my patients enjoyed using it as well. There are a lot of great features already in the product and I think creating even more adjustability as previously mentioned would be great. "*

- *"Great job with this first game!"*

- *“...Can't wait to try it more!"*

5. What are the facets of customizability that are needed for a therapeutic game?
Throughout this study, two facets constantly emerged in our discussions as the basis for a successful therapeutic application:

- *Content Configurability:*
  Being able to target the sensory feedback to the appropriate level for the patient.

- *Control Configurability:*
  The ability to normalize and modify the patient input so different levels of disability can still get comparable levels of performance.

This research focused primarily on these two aspects when designing and implementing the prototypes, the initial, intuitive, settings where extracted from our informal interviews with the experts before the project started, but then were refined as the first prototype was delivered and therapists could actually see a tangible application working.

Is it feasible?

Based on our findings and our discussions with the experts, we can state that our prototypes were successful at providing therapeutic experiences, while delivering useful data for the therapists. We are confident that a full study with real patients will only confirm what the results on this document have shown.

- *“...This system definitely has strong potential for the rehab market due to its portability, low cost, user friendly, customized training, and intuitive gaming components...”*

10. Future work

There's definitely a lot of room for improvement for future prototypes, but there's also the danger of crossing a fine line between simple and useful and complex and useless. 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, some of these can be implemented as part of the next series of prototypes. The following, are a series of features that, we think, should be evaluated to be added 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.

- **Road Signs:**
  To be used as visual hints to the therapists and the patients, some may even have a "double" meaning valid only for the therapists, such a special one when the level goes up, or special events happen during the game.

- **Make the on track measurement be more forgiving the richer the visuals are on:**
  Having tons of visual stimuli can be challenging for a patient, so if all the visuals are enabled, the game should be a bit more forgiving about the percentage of time the patient misses the track or makes mistakes.

- **Being able to offset the zero value for the angles:**
  The sensor itself has a calibration feature, that gets triggered automatically when a session stats, however, in some occasions it can be helpful for the therapist to set the zero value for the device in any of the two supported axes, in a way, a programmable calibration for the sensor.

- **Some sort of backpack or harness for the unit:**
  One of the biggest complains about the usability of the sensor is about how hard it is to position and attach to the patient, a small backpack or harness should be designed so wearing the sensor is a simple procedure.

- **Preprogrammed tracks that vary in difficulty:**
  This idea came up when discussing with the therapists possible ways to make the prototype easier to use. The idea is basically to have 3 or 4 "Quick-Start" tracks, with different difficulties and preset settings, so instead of configuring the session for every use, the therapist could simply choose one of the preset tracks.

- **Variable track width:**
  Being able to set the width of the track, or have it be variable while in game, this to increment the difficulty in specific places, or to change the purpose of the session (from mobility to stability) by having a narrow straight section every once in a while.

- **Separate vibration from beeps**:
  Currently the accessory vibrates AND beeps at the same time, when it receives the vibrate command. Ideally, there should be two separate commands for each one of those events.

- **Remote dashboard:**
  In prototype 2, 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 sessions for a patient to do at home.

- **Comparative Graphs:**
Adding graphs to the session history, that way, app session data can be compared to show trends, and view progress (or lack of) in patients.

- **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.

- **Gyroscopes:**
The current device has a sensitivity of approximately +- 70 degrees, after that threshold, the sensor simply stops working and zeroes out all of its input. Given that some patients have a natural lean forward, it really limits the range in which the sensor will remain accurate. Exchanging the accelerometers for gyroscopes would solve the problem, and better yet, having both sensors, accelerometer + gyro, would make the device even more useful, since it would be able to detect lateral and vertical motion.

- **In-App Documentation:**
Being able to get quick help for the different options available in a particular window, in case the concept behind one of them is not completely clear.

- **Visual clues on how to go back on track:**
Some patients with severe limitations can get off track and may not be able to find it again. Adding arrows pointing towards the right direction, plus an auto-reset after a preset timeout in seconds could be useful.

- **Pause:**
Some patients may need some sort of assistance while a session is in progress, the ability to pause the session is important for such cases, instead of restarting the whole session.

- **Calibration screen:**
Have an option to calibrate the sensor visually right before starting a race, to make sure the patient and the sensor are in the correct position.

- **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.

- **Practice runs:**
Some patients may need training on how to use their trunk to operate the games. For such training, some sort of test run that is not saved to the patient history would be needed.

- **Leaderboards:**
For some patients, competition is a big motivation. Being able to compete against other patients, using some sort of leaderboard, can provide the competition aspect for the games.

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12. Appendix

12.1 Database Tables

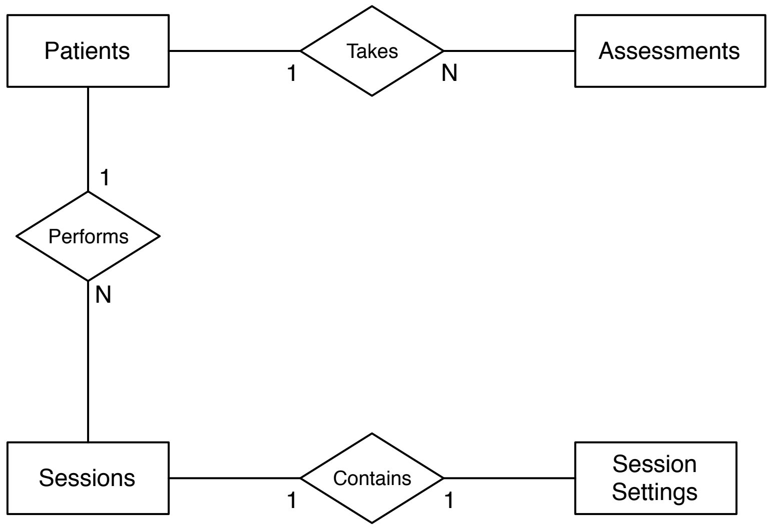
```
CREATE TABLE patients (
id integer NOT NULL PRIMARY KEY AUTOINCREMENT UNIQUE,
firstName text NOT NULL,
lastName text NOT NULL,
phone text,
notes text,
image binary)

CREATE TABLE assessments (
id integer NOT NULL PRIMARY KEY AUTOINCREMENT,
patientid integer NOT NULL,
"timestamp" date NOT NULL,
maxLeft integer NOT NULL,
maxRight integer NOT NULL,
maxFront integer NOT NULL,
maxBack integer NOT NULL,
initialLR integer NOT NULL,
initialFB integer NOT NULL,
notes text)

CREATE TABLE sessions (
id integer NOT NULL PRIMARY KEY AUTOINCREMENT,
patientID integer NOT NULL,
"timestamp" date NOT NULL,
totalTime real NOT NULL,
bestTime real NOT NULL,
timeOffTrack real NOT NULL,
maxLeft integer NOT NULL,
maxRight integer NOT NULL,
maxFront integer NOT NULL,
maxBack integer NOT NULL,
averageLeft integer NOT NULL,
averageRight integer NOT NULL,
averageFront integer NOT NULL,
averageBack integer NOT NULL,
maxSpeed real NOT NULL,
avgSpeed real NOT NULL,
missesLeft integer NOT NULL,
missesRight integer NOT NULL)

CREATE TABLE sessionSettings (
id integer NOT NULL PRIMARY KEY AUTOINCREMENT,
sessionID integer NOT NULL,
theme integer NOT NULL,
enableScenery boolean NOT NULL,
turnBias real NOT NULL,
maxSpeed real NOT NULL,
autoAccelerate boolean NOT NULL,
maxForwardDOF real NOT NULL,
maxBackwardsDOF real NOT NULL,
autoSteer boolean NOT NULL,
maxLeftDOF real NOT NULL,
maxRightDOF real NOT NULL,
laps integer NOT NULL,
length integer NOT NULL,
notes text,
flipFrontBack boolean NOT NULL,
autoincrementDifficulty boolean NOT NULL,
autoincrementAfterValue real,
decrementBelowValue real,
enableAudio boolean NOT NULL)
```

12.2 Relationships



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