Development of an interactive rehabilitation game using the Nintendo® WiiFit™ Balance Board for people with neurological injury

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ABSTRACT

Visual biofeedback and force plate systems are often used for treatment of balance and mobility disorders following neurological injury. Conventional Physical Therapy techniques have been shown to improve balance, mobility and gait. The training program encourages patients to transfer weight onto the impaired limb in order to improve weight shift in standing and during gait. Researchers and therapists have been exploring the use of video game consoles such as the Nintendo® WiiFit™ as rehabilitation tools. Initial case studies have demonstrated that the use of video games has some promise for balance rehabilitation. However, initial usability studies and anecdotal evidence has indicated that the commercial games that are currently available are not necessarily suitable for the controlled, specific exercise required for therapy. Based on focus group data and observations with patients, a game has been developed to specifically target weight shift training using an open source game engine and the WiiFit balance board. The prototype underwent initial usability testing with a sample of four Physical Therapists and four patients with neurological injury or disease. Overall, feedback was positive and areas for improvement were identified. This preliminary research provides support for the development of a game that caters specifically to the key requirements of balance rehabilitation.

1. INTRODUCTION

Conventional Physical Therapy techniques have been shown to improve balance, mobility and gait following neurological injury. Visual biofeedback and force plate systems are used to assist treatment of balance and mobility disorders (Geiger et al., 2001; Walker et al., 2000; Yavuzer et al., 2006). The training programs encourage participants to shift weight onto the impaired limb in order to improve weight shift in standing and during gait. Visual feedback related to weight distribution and center-of-pressure positioning has been shown to be effective in increasing stance symmetry following stroke (Walker et al., 2000).

The use of the off-the-shelf video games as rehabilitation tools has gained much interest in the Physical Therapy arena over the past few years. However, limited published research exists on the feasibility and effectiveness of the use of this commercially available gaming system for rehabilitation. Researchers and therapists have been exploring the use of video game consoles like the Nintendo® WiiFit™ as rehabilitation tools. Initial case studies have demonstrated that the use of video games has some promise for balance rehabilitation. The published data presents case studies of patients who have survived stroke (Brown et al., 2009; Deutsch et al., 2009; Sugarman et al., 2009). These studies indicate that patients who used the Nintendo® WiiFit™ balance board and games demonstrated improvements in balance outcome measures. However more research is required with larger sample sizes and rigorous methodologies with comparison to standard treatment regimes.

Initial usability studies and anecdotal evidence has indicated that the commercial games that are currently available are not necessarily suitable for the controlled, targeted exercise required for therapy. Usability

studies with patients who had survived Stroke, Spinal Cord Injury and Traumatic Brain Injury, have found that some commercially available games are providing negative auditory and visual feedback to patients that are performing tasks effectively because the patient cannot move fast enough for the game play or cannot perform all of the required movements within the game (Lange et al., 2009). When playing the Nintendo® WiiFit™, some patients who had difficulty with weight shift attempted to perform the game based task using sudden jerky movements. Feedback provided to patients following the game tends to be negative or inappropriate for the patient's level of ability (Lange et al., 2009).

The objective of this research was to design, develop and assess the usability of an interactive game specifically focused on training weight shift in a controlled and customized manner. The game was designed to be customizable and used by therapists to train patients with a range of levels of ability, using the Nintendo® WiiFit™ balance board. The use of a video game for balance training has the potential to increase motivational factors, collect quantitative data from the training session and customize the level of difficulty to each patient's specific needs.

2. METHODS

2.1 System Development

The game prototype was developed using Panda 3D game engine and can be played on PC using the Nintendo® WiiFit™ balance board as the interaction device. Findings from previous usability testing with Nintendo® WiiFit™ games, focus groups and clinical observations contributed to the design of a game that can be controlled by the therapist for speed, placement of cues on the screen, and the type and amount of visual, auditory and after action feedback. The balance board was chosen as the interaction device due to the increasing popularity of the Nintendo® WiiFit™ in rehabilitation, the low cost of the device and the potential for the device to be easily accessible to clinics and patients.

The balance board contains multiple sensors located on the bottom corners of balance board to measure and calculate center of pressure changes. Within the prototype, when the player moves their body on the balance board, rather than being transmitted to the Nintendo® Wii™ console, the data from the sensors is transmitted to a computer using Blue Tooth (Figure 1). The data consists of seven kinds of information: the weight from each of the four corners of the board, the total weight, and the x and y coordinates.

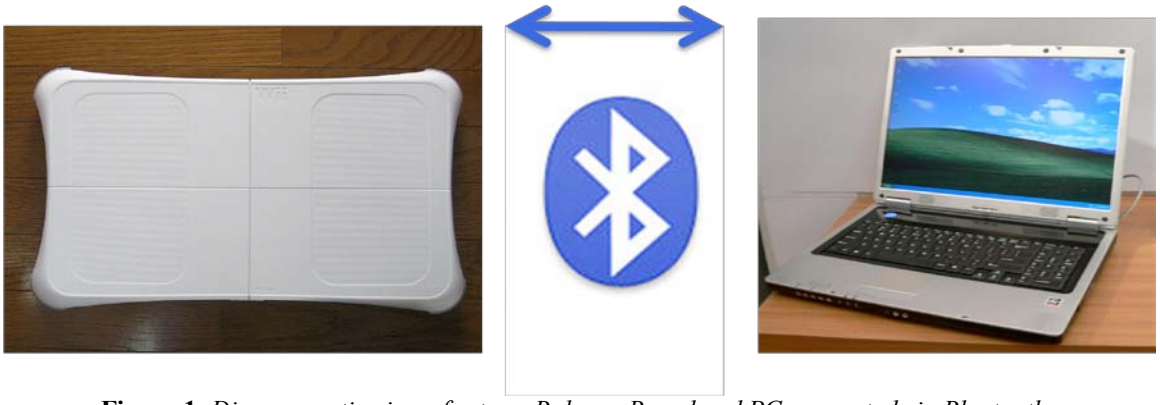

Figure 1. *Diagrammatic view of set up: Balance Board and PC connected via Bluetooth.*

The game prototype was developed using Panda3D. Panda 3D, developed by Disney and maintained by Carnegie Mellon University's Entertainment Technology Center, is a framework for rendering and game development using Python and C++ programs. Autodesk 3D Studio Max and Photoshop graphic tools were used to develop models and textures. 3D Studio Max is a comprehensive 3D modeling, rendering, and 3D animation software used by leaders in game development and film. OpenAL was used for audio effects. OpenAL is a cross-platform 3D audio API appropriate for use with gaming applications and many other types of audio applications.

Within the game, the player must navigate a balloon through a series of obstacles by shifting their weight on the balance board in the direction they want the balloon to move. These obstacles have been placed in such a way that the user has to shift weight from one leg to other in a controlled pattern. The ability to control the balloon within the anterior/posterior direction was initially disabled within the game. A user interface is

currently being developed to allow therapists to make changes to the game controls, in order to make the game more accessible for patients of different levels of ability. For example, the therapist will have the ability to slow the flow of obstacles or change the pattern of obstacle flow in order to control the therapy session.

The game has undergone a number of iterations prior to testing with therapists and patients. Figure 2 presents a screenshot of the initial prototype of the game in which basic graphics were used whilst the team focused on improving the data capture and integration of the balance board into the system.

Figure 2. *Screen shot of first prototype of the game. The player must navigate the balloon through a series of obstacles by shifting their weight on the balance board in the direction they want the balloon to move.*

Following integration of the balance board data into the system, improvements were made to the graphics and gameplay elements. Figure 3 provides screenshots of simple and moderate game levels in which the obstacles the user must guide the balloon past are located at predictable and evenly spaced intervals (simple) or more unpredictable and random intervals (moderate).

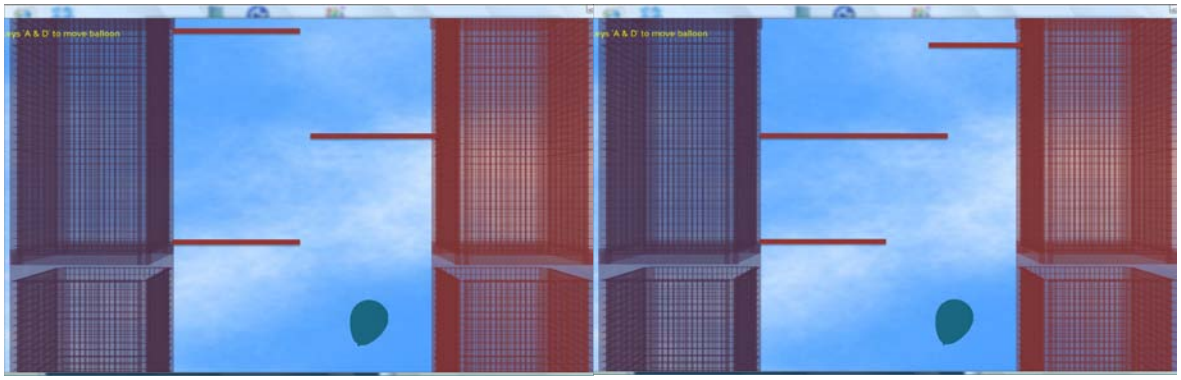

Figure 3. *Screenshot of second iteration of game with simple and moderate game levels.*

A more polished 3D version of the game was developed with realistic, professional graphics and music to provide a more 'game-like' experience (figure 3). Based on early user testing, the game was altered to include the collection of stars and the avoidance of other objects (rocks). The game has scoring for the number of objects you collect and the number of unwanted collisions with the rocks. The game has been designed so that different sounds are provided when the balloon connects with the stars and collides with the rocks. The balloon is not damaged if it collides with the rock, so as not to discourage patients whilst learning to play the game. However, in more challenging levels, the balloon will lose a small amount of size if it collides with a rock. This strategy aims to reduce the number of stop/start delays that occur during current commercial Nintendo® WiiFit™ games when the task is not achieved. Losing 'life' or failing the game as a result of limited ability to perform the task, therapist instruction or set-up delays can be frustrating and reduce patient confidence, motivation and compliance. The current prototype aims to improve upon these negative features, providing the patient with support, positive reinforcement and graded challenge levels.

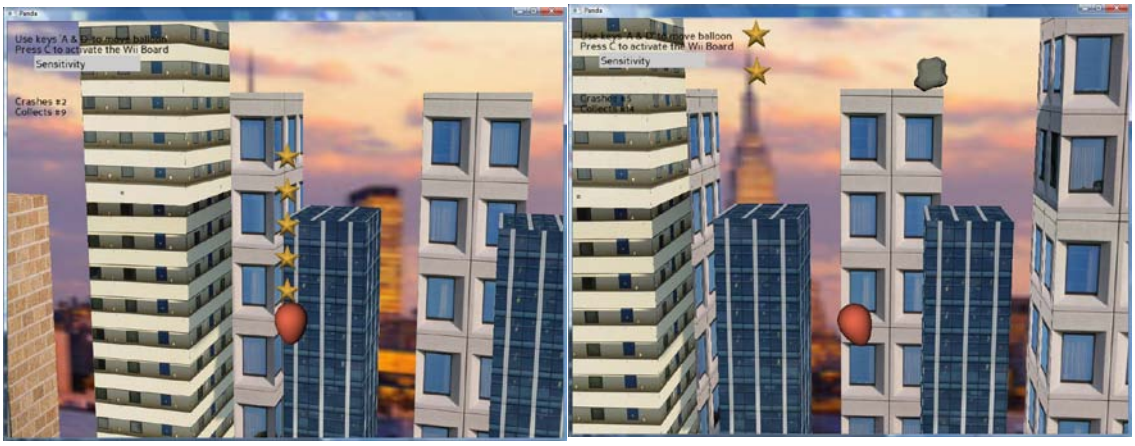

Figure 4. *Screenshot of third iteration of game with 3D graphics and objects.*

The system has undergone preliminary assessment within the research team to assess the features of the game prior to use with the intended patient population. Preliminary assessment with a sample of nine able-bodied participants aged 23 to 41 years provided ideas for scoring, timing and other game play activities that were incorporated into the current game prototype.

2.2 Initial Assessment of System

A sample of Physical Therapists and patients with neurological injury or disease were recruited from Precision Rehabilitation, a private outpatient neurological Physical Therapy clinic in Long Beach, CA. Therapists and participants with neurological injury were asked to play the game prototype within a safe clinical setting, with assistance if required. All participants played the 3D version of the game set at a standard difficulty level. All patients wore gait belts and were provided with the opportunity to use a frame if required. Participants were asked to comment on their experience through a semi-structured interview consisting of open-ended questions. The researchers also manually recorded observations of the interaction. When possible, if a patient's therapist was present during the testing, the therapist was also asked to comment on the interaction, system and game play. Both therapist and patient groups were asked to provide suggestions for improvements to the game play and system set-up.

3. RESULTS

3.1 Sample

To date, four Physical Therapists (two experienced clinicians and two novice 3rd year student clinicians) and four patients have been recruited. Two participants survived stroke at least one month prior to testing (one male and one female). Two males with a spinal cord injury, one was four months post injury and one was two years post injury and one female with ALS who was diagnosed 1.5 years ago were also recruited.

3.2 Patient Feedback

All patients were able to step up onto the balance board with assistance from the researchers. Two patients used a walker during the task. One patient had stand-by assist and three patients had light-to moderate assistance using the gait belt. All patients were able to play the game and achieve the game play tasks. Three patients reported enjoying playing the game. One patient reported that she did not enjoy the experience and the game was confusing. However this patient was able to score well within the game and complete all required gameplay without any obvious difficulties. All patients required a small learning period to adjust to the use of the balance board. Three patients reported that playing the game helped them to shift their weight more than they would during other exercises they do. Two patients had previously used the Nintendo® WiiFit™ balance board and commercial Nintendo® WiiFit™ games. These patients were asked how their experience with the prototype compared to the commercially available console games. One patient responded "*even though [the prototype game] was pretty challenging, it was easier to play than some of the other [Nintendo® WiiFit™] games that need you to have really good control and fast movements"*. The other patient responded "*I haven't played the other [Nintendo® WiiFit™] games since my injury but I'm pretty sure I wouldn't be as good at them as I was at this game*".

Some other comments made by patients about their experience are listed below:

"It took me a little bit to figure it out but after that it was fun"

"It gave me confidence to stand on one foot. I haven't done that in a while"

"It was hard work but I enjoyed it"

"It was a distraction. If you told me to shift my weight like that without playing a game, I would be really scared and I probably wouldn't do it but when it was in a game, I didn't really think about how scary it was. I had a goal and I just went for it"

"I had to really work hard but it was good"

"I worked harder than I would have in normal therapy and I could see myself doing it for longer if I played this rather than having to do one of the exercises I normally do in the bars"

"I would stand up more often if this game was here in the clinic all the time"

Researchers observed that patients took approximately four-seven weight shifts to adjust to the game. Patients made full weight shifts between right and left when required by the game. Maximum number of collisions with the rock objects was three and minimum number of star objects collected was 100, indicating that the patients were all successful in performing the required in-game tasks. Some difficulties were observed with maintenance of the patient's foot position within an ideal location on the balance board. One therapist suggested the use of a block between the patient's feet to reduce movement. This was trialed successfully with two of the patients, indicating the need for a more secure, yet flexible balance board set-up.

3.3 Therapist Feedback

All therapists were able to use the balance board device to interact with the game appropriately. Therapists commented that they enjoyed playing the game and they thought the game would be appropriate and useful for a number of their patients. The two therapists that worked with patients during the testing said they were impressed by the amount of focus and weight shift the patients had whilst playing the game. Both commented, without prompting, that they had not seen their patients transfer as much weight onto their impaired limb during other tasks. The therapists were enthusiastic about further use of a game like this with their patients in the future

Three therapists were asked to play two levels of difficulty of the 2D version of the game in addition to the 3D version of the game. Two therapists commented that they like the 2D version for patients because it was simpler and had a less distracting background. Therapists provided useful feedback and suggestions about how to improve gameplay in a way that would focus on specific therapy tasks.

Some comments from therapists include:

"This has great potential for our patients"

"I think [my patient] really enjoyed playing the game. She did really well too! She doesn't normally stand on her [impaired] leg"

"I think you could do a lot of different things with this, there are a lot of options for functional tasks to be incorporated and it would be great to have anterior/posterior movement as well"

"I like the 2D version better. The background is simpler and I think it would be better for some patients with cognitive impairments"

"I like that you can vary it like that, it's cool"

"It took a minute or so to get used to the sensitivity of the board…. But after I got used to it, it was fine"

"I feel like this will give some of my patients a sense of achievement during their therapy"

"It could help some of my patients to get the feel of weight transfer"

"I can see this being a very useful training tool"

Researchers observed that therapists took approximately two or three weight shifts to adjust to the game. Therapists did not need assistance to perform the task. Maximum number of collisions with the rock objects was 2 and minimum number of star objects collected was 140, indicating that the therapists were all

successful in performing the required in-game tasks.

3.4 Planned enhancements and improvements

Based upon the suggestions from the participants, further enhancements of the balance board set-up include the design of a platform and alterations in sensitivity of the pressure sensor measurement. Software improvements include enhanced clinician user-interface menu and alteration of the game play elements to provide more varied interaction.

4. CONCLUSIONS

A game was developed to specifically train weight shift and improve balance in patients using a Nintendo® WiiFit™ balance board. Initial assessment of the prototype with a sample of Physical Therapists and patients with neurological injury demonstrated that the use of this prototype has potential as a rehabilitation tool. Clinicians and patients provided valuable input and have identified a number of refinements and improvements to the system. Future directions in this research will be further usability testing followed by a larger feasibility trial to determine if the use of the game as a training tool improves balance outcomes.

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5. REFERENCES

J E Deutsch, D Robbins, J Morrison, P G Bowlby (2009), Wii-based compared to standard of care balance and mobility rehabilitation for two individuals post-stroke. *IEEE: Virtual Rehabilitation International Conference*. Haifa pp 117-120.

R A Geiger, J B Allen, J O'Keefe, R R Hicks (2001), Balance and Mobility Following Stroke: Effects of Physical Therapy Interventions With and Without Biofeedback/Forceplate Training. *Phys Ther*. 81(4). pp 995-1005.

B S Lange, S M Flynn, A A Rizzo (2009), Initial usability assessment of off-the-shelf video game consoles for clinical game-based motor rehabilitation. *Physical Therapy Reviews*.14 (5) pp 355-363.

H Sugarman, A Weisel-Eichler, A Burstin, R Brown (2009), Use of the Wii Fit system for the treatment of balance problems in the elderly: A feasibility study. *IEEE: Virtual Rehabilitation International Conference*. Haifa pp111-116.

C Walker, B J Brouwer, E G Culham (2000), Use of Visual Feedback in Retraining Balance Following Acute Stroke. *Phys Ther*. 80(9). pp 886-895.

G Yavuzer, F Eser, D Karakus, B Karaoglan, H J Stam (2006), The effects of balance training on gait late after stroke: a randomized controlled trial. *Clinical Rehabilitation*. 20(11). pp 960-969.