Development of an Interactive Game-Based Rehabilitation Tool for Dynamic Balance Training

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Conventional physical therapy techniques have been shown to improve balance, mobility, and gait following neurological injury. Treatment involves training patients to transfer weight onto the impaired limb to improve weight shift while standing and walking. Visual biofeedback and force plate systems are often used for treatment of balance and mobility disorders. Researchers have also been exploring the use of video game consoles such as the Nintendo Wii Fit as rehabilitation tools. Case studies have demonstrated that the use of video games may have promise for balance rehabilitation. However, initial usability studies and anecdotal evidence suggest that the current commercial games are not compatible with controlled, specific exercise required to meet therapy goals. 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 Nintendo Wii Fit Balance Board. The prototype underwent initial usability testing with a sample of clinicians and with persons with neurological injury. 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.
Key words: *balance training, game-based rehabilitation, video game, Wii Fit Balance Board*

Stroke incidence, new or recurrent, is approximately 800,000 every year.[1] This number is expected to rise as the population ages. The neurological impairments that can result from a stroke include hemiparesis, coordination difficulties, apraxia, and impairments in postural control.[2] All of these, especially impairments in postural control, can affect a person's balance and mobility in everyday activities. For community-dwelling adults with stroke, incidence of falls range from 23% to 50%.[3-5] Immediately following discharge from rehabilitation services, this rate is much higher.[6]

One of the main challenges in stroke rehabilitation is teaching weightbearing through the affected lower extremity to promote improved gait kinematics. This in turn can result in increased gait velocity, improved balance, reduced risk of falls, and greater confidence and function ambulating at home and in the community. Conventional physical therapy (PT) techniques have been shown to improve balance, mobility, and gait following neurological injury. Visual biofeedback and force plate systems are also used to assist treatment of balance and mobility disorders.[7-9] Visual feedback related to weight distribution and center-of-pressure positioning has been shown to be effective in increasing stance symmetry following stroke.[8]

Game-Based Rehabilitation

The use of off-the-shelf video games as rehabilitation tools has gained much interest in physical therapy over the past few years. Researchers and clinicians have been exploring the use of video game consoles like the Nintendo Wii Fit as rehabilitation tools. However, there is limited published research on the feasibility and effectiveness of the use of this commercially

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available gaming system for rehabilitation.[10-14] Initial case studies have demonstrated that the use of video games may have promise for balance rehabilitation. Deutsch and colleagues[12] compared a Nintendo Wii-based balance and mobility program with standard balance care. Although the Nintendo Wii-trained participant showed gains, these gains were not retained at follow-up. Sugarman and colleagues[13] presented a case study using the Nintendo Wii Fit as an additional intervention for balance training with small increases in balance and self-confidence. More research is needed with larger sample sizes and rigorous methodologies, including comparison to standard treatment regimes.

The aforementioned studies and anecdotal evidence suggest that currently available commercial games are not necessarily suitable for the controlled, targeted exercise required to reach therapeutic goals.[11,12] Usability studies with survivors of stroke, spinal cord injury, and traumatic brain injury have found that some commercially available games may provide negative auditory and visual feedback to individuals who are performing tasks effectively because they cannot move fast enough for the game play or cannot perform all of the required movements within the game.[11] For example, when playing the Nintendo Wii Fit, some individuals who had difficulty with weight shift attempted to perform the game task using sudden jerky movements. Many of the games are also inappropriate for balance tasks because they do not require direct control of their weight shift in the center of gravity of the body.[13] Feedback provided following the game tends to be negative or inappropriate for a given' level of ability.[11] The technology itself is also not sensitive enough to measure performance in all components of balance and often requires input from the treating therapist.[12]

Based on these issues, researchers are now developing games designed specifically for rehabilitation.[15-17] These systems, designed to target rehabilitation goals, use a conventional PC and the Nintendo Wii Fit Balance Board to carry out exercises that will reduce postural instability and improve balance and weight shift. These games have been developed using a user-centered design process, incorporating iterative input from key stakeholders (therapists, patient groups, and caregivers) throughout product development and refinement.

Game Design Process

Iterative design is a process-based design research methodology[18-20] in which designers create and test concepts in various basic forms prior to completing a full prototype (**Figure 1**). User-centered game design is an iterative process that begins with stakeholder interviews and observational studies of game play activities prior to the typical design activity of brainstorming and generating game ideas.[18] Interviews allow participants to talk about their experiences and provide more detailed, qualitative data, along with quantitative usability questionnaires. Observational studies are a form of playtesting that provide insight into the potential game play activities and identify the processes involved in these interactions. Soliciting key stakeholder input in the early stages of game design, before a software-based prototype is developed, is an effective method for defining and evaluating the user experience and driving the game design process. Upon completion of initial observational studies, key stakeholders, including game designers, clinicians, and patient groups, identify potential interaction activities and core game play components relevant to the specific therapeutic goal of the application.

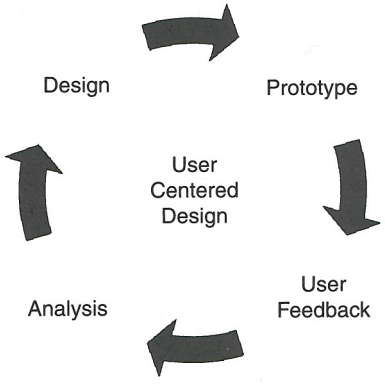

Figure 1. User-centered design cycle.

The next step in the process is brainstorming. Brainstorming for game development involves defining the problem.[20] Once the initial brainstorming is completed, the next session involves critically discussing and refining the ideas.[20] The process is repeated (brainstorming, expanding, and refining) until the team agrees upon the most appropriate idea. This idea can then be prototyped and further explored.

Rapid prototyping of game mechanics and core game play concepts can be performed using either physical props or software.[20] Regardless of the format, rapid prototyping provides the designers and the player with the ability to play the game in a simplified form to determine (1) whether the rules make sense and hold up during play, (2) whether the game mechanics work, (3) how scoring works, and (4) whether the game will be enjoyable to play.

Fullerton et al[20] suggest a range of levels of playtest participants. Designers should perform the initial playtests to determine whether the first prototype works the way they anticipated. Following the initial playtest and redesign stage, peers are suggested as the second level of playtest participants. Once the game is playable with a clearly defined set of rules and refined game play mechanics, the game should be playtested by participants from the target audience for the game.

During the playtests, the researchers follow a script to allow the playtester to play without receiving too much information about the game.[20] Playtesters are encouraged to talk aloud as they play. Following completion of the playtest, the playtesters are asked to complete a series of questionnaires, and the researchers ask a series of open-ended questions about specific aspects of the game. Both quantitative and qualitative measures are recorded during the playtests. Overall, the iterative design process involves cycles of design, prototyping, and playtesting to develop and evaluate the key components of play prior to beginning the actual software development. Once the playtesting and prototyping cycles are completed, the game can be developed in the intended format and evaluated in a larger trial to determine whether (1) the game is fun, (2) the graphics are appropriate and entertaining, (3) the game is engaging, and, perhaps most important, (4) the game performs the required therapy goals.

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 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 person's specific needs. The game was designed to be customizable and used by therapists to train patients with a range of ability levels, using the Nintendo Wii Fit Balance Board. Development of the game for this project followed the iterative process previously described and is currently at the level of playtesting with the intended user groups.

Methods

Stakeholder interviews

Informal interviews were performed with therapists, researchers, and key patient populations to explore the key development features of a computer-based game for balance exercises. All stakeholder groups supported the concept and provided specific needs/requirements, including the following:

- Motivating and fun games that encourages the accurate execution of a weight shift patterns
- Options to change the level and duration of weight shift for different patients
- Ability to record data from the interaction

Preliminary user testing

Following initial development of the game prototype, 8 people with neurological conditions participated in preliminary user testing and informal feedback about the game prototype. Each person played the game with assistance from a therapist at Precision Rehabilitation in Long Beach, California. After playing the game, the researchers asked each participant questions regarding enjoyment, ease of use, and therapeutic benefit of the game. Each participant was also encouraged to provide feedback about the technical elements of the game (ie, background, objects, game play). The comments and feedback from these informal discussions were compiled and reviewed by the

development team. Feedback was incorporated into the design where relevant, and appropriate changes were made to the game prototype.

Formal user testing

Participants

Four therapists and 4 persons with stroke participated in user testing. The 4 participants with stroke were male with an average age of 60 years. Each had varying degrees of hemiparesis that affected balance. Time since injury ranged from 4 months to 7 years. All attended Precision Rehabilitation in Long Beach, California, for outpatient physical and/or occupational therapy. All participants were over the age of 18 and could understand English at a 6th-grade reading level. All participants consented before beginning testing. The Institutional Review Board at the University of Southern California- University Park Campus approved this study.

Description of game

Findings from previous usability testing with Nintendo WiiFit games, focus groups, and clinical observations contributed to the design of a balance game prototype. This prototype was developed using the Panda 3D game engine. 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. The game can be played on a PC and uses the Nintendo Wii Fit Balance Board as the interaction device.

The balance board contains multiple sensors located on the bottom corners of the base to measure and calculate changes in center of pressure. In the prototype, when the player moves his or her body on the balance board, rather than being transmitted to the Nintendo Wii console, the data from the sensors are transmitted to a computer using Bluetooth. Seven data elements are collected: the weight from each of the 4 corners of the board, total weight, and the x and y coordinates.

Within the game, the player must move a balloon to avoid falling rocks and collect falling stars by shifting weight on the balance board in the direction he or she wants the balloon to move (**Figure 2**). These obstacles have been placed in such a way that the user has to shift weight from one leg to the other in a controlled pattern and maintain that weight shift for a period of time. Currently, the game has scoring for the number of objects collected 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

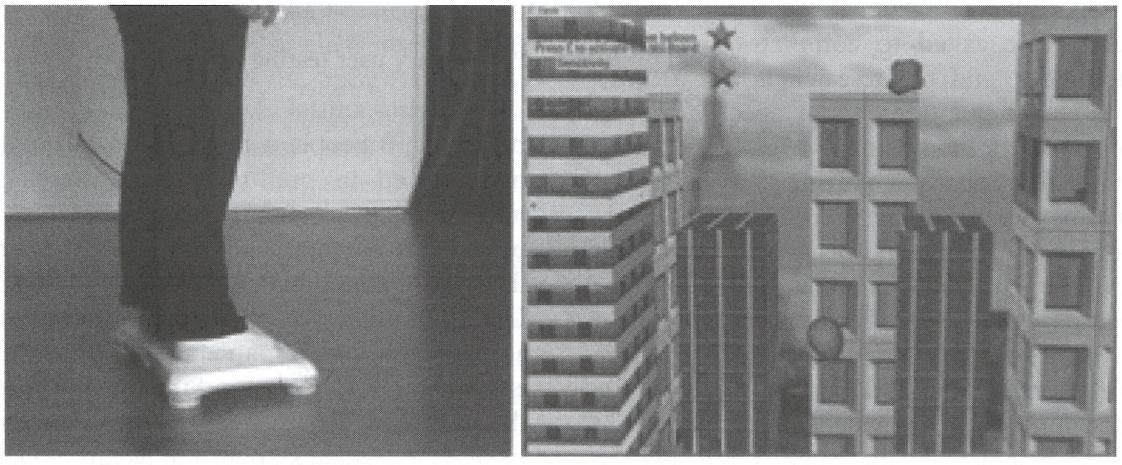

Figure 2. Screen shot of prototype of the game and Nintendo® Wii Fit™ Balance Board. The player must navigate the balloon through a series of obstacles (collecting stars and avoiding rocks) by shifting their weight on the balance board in the direction they want the balloon to move.

damaged if it collides with the rock, so as not to discourage players while they are learning to play the game. This strategy aims to reduce the number of stop/start delays that occur during current commercial Nintendo Wii Fit games when the task is not completed.

Data collection and analysis

After obtaining informed consent, the participant was instructed to step onto the platform surrounding the balance board and then onto the balance board. The treating therapist provided assistance if necessary. The rules of the game were explained to the participant, and he or she then played the game. Game play lasted between 4 and 10 minutes. The treating therapist provided any necessary physical or verbal cues to the participant. Observations of game play and participant-therapist interactions were recorded. After playing the game, the participant dismounted the balance board and surrounding platform. He or she then completed a questionnaire about his or her background playing video games and a usability questionnaire about the game. The usability questionnaire contained the Borg Scale of perceived exertion, and the participant was asked to rate his or her perceived level of exertion while playing the game. Additional questions were asked after the participant completed the usability questionnaire to elicit further information about the experience of playing the game and to identify potential improvements to the game. The treating therapist was also asked to complete a usability questionnaire and respond to open-ended questions about his or her experience with the game.

The data collected from the 2 questionnaires were loaded into an Excel spreadsheet and visually analyzed for trends. Additional comments were compiled and grouped according to themes that emerged.

Results

Feedback from participants

People with stroke felt that the game was more engaging but just as strenuous as typical physical or occupational therapy for balance training:

> "It was hard work but I enjoyed it."

> "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."

Many commented on how the game medium allowed them to do something they normally might not do in therapy:

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

> "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."

The clinicians saw the game as a useful training tool and commented on how it affected their 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 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."

Participants understood how to play the game and use the controller and reported experiencing little frustration while playing. Most participants felt that they could see themselves playing the game in the future and felt that they would benefit from using it in therapy (**Table 1**). Borg Scale ratings (scale of 6-20) ranged from 9 to 19, with an average of 15 (working hard).

Observations

Three out of 4 participants required hands-on assistance from their therapist. Some only needed assistance to get onto the platform and balance board. Others required further hands-on assistance while playing the game. Some people had difficulty understanding how to shift their weight fully onto one side, so the therapist would demonstrate, provide assistance, or a combination of both. Each therapist gauged the amount of assistance needed for the person with stroke to play the game. The therapists also provided verbal feedback and encouragement to everyone that played the game.

Table 1. Usability questionnaire rating scores

Question	Participant				Average response rating
	101	102	104	105	
I would like to use these games in therapy.	1	1	1	3	1.5
The game was more engaging than typical OT/PT exercises I have done before.	3	1	1	3	2
The game was more strenuous than typical OT/PT I have done before.	3	3	3	4	3.25
I could see myself playing this game in the future.	3	1	1	4	2.25
It was hard to understand the directions for playing the game.	2	5	5	4	4
I felt frustrated while playing the game.	5	5	5	3	4.5
I was motivated to keep playing the game.	1	1	1	4	1.75
It was easy to understand how to use the controller to play the game.	2	1	2	2	1.75
I feel as though I would benefit from playing these games in therapy.	2	1	1	3	1.75
Borg Scale of perceived exertion	19	13	19	9	15

Note: 1 = *strongly agree*; 2 = *agree*; 3 = *neutral*; 4 = *disagree*; 5= *strongly disagree*. OT = occupational therapy; PT = physical therapy.

Suggestions from participants

Based on feedback obtained during the preliminary user testing and formal user testing, there are several planned enhancements and improvements to the game and system. Suggestions for improvements identified by the people with stroke and clinicians were grouped into themes:

- *Game play goals:* Clearly outline goals of game at beginning and provide tutorial before starting game play.
- *Level design*: Change the background with different levels, and add the ability to change placement of objects to be collected to increase level of challenge in an individual basis.
- *Scoring*: Make the score more pronounced on the screen, provide a previous high score on the screen, and provide the option to set a goal for individual players.
- *Graphics/look and feel:* Provide a basic two-dimensional background with no buildings as an option for people who could find the background distracting, and provide an option to change background themes.
- *Audio*: Enhance the sounds related to collection of objects to provide audio feedback performance.
- *Device* (balance board): Provide the ability to change the sensitivity of the balance board for players with varying levels of ability to weight shift.

The suggestions within each of these themes were discussed by the development team, and changes have been prioritized and implemented into the game design document for further refinement of the game. Some of the improvements will combine suggestions across the themes. Following refinements, the testing process will be repeated.

Discussion

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. Through the user-centered design process, a game was created that was applicable to key populations and was user-tested with those populations. This differs from other studies that used off-the-shelf games and devices not necessarily appropriate for their key populations. Through the user-centered design process, participants were able to provide feedback at various stages of the design process. This method allowed the researchers to include refinements and changes to the game that would not have necessarily been identified or considered by the design team. For example, the participants made a variety of suggestions for background graphics and game objects. Seeing variability in weight shift abilities of the participants also helped the researchers map out difficulty settings for the levels in the game.

Limitations

There were several limitations to this study. This was a small sample size from one clinic. This makes it difficult to generalize findings to

the larger population of stroke survivors. Data collection is ongoing and will expand to other clinics following refinement to the prototype. The participants were willing to play the game during their normal physical therapy treatment and were willing to provide feedback. Not all people with stroke enjoy playing games. During the formal testing, the questionnaire limited the feedback that people provided. Many people did not expand past the questions, despite prompting from researchers using open-ended questions. Semi-structured interview questions will be added to the questionnaire (similar to the preliminary user testing format) in future data collection sessions.

Future directions

Further user testing similar to this study will be performed in an iterative fashion, continually improving the game and system. As this game is improved and progresses through the user-centered design cycle, it will be tested to evaluate internal validity, efficacy, and applicability to broader populations. To evaluate the developed game, it will be compared to existing therapy (ie, standard balance training using parallel bars available in most clinics) and available off-the-shelf games and systems (ie, the Nintendo Wii Fit balance games). The validity study will provide participants with 3 minutes on each intervention. Number and quality of weight shifts, patient and clinician perception of efficacy, level of enjoyment, and semi-structured interview questions will be analyzed between the 3 conditions. The user-centered design process can be taken advantage of to examine the external validity of the game as an intervention for broader populations with balance impairments. The existing game can be user-tested and brought to focus groups of people with balance impairments beyond stroke and feedback and suggestions implemented into the next iteration of the game. Efficacy will be assessed by comparing the game to standard therapy techniques and a Wii Fit off-the-shelf game within a randomized controlled trial.

Conclusions

This preliminary research provides support for the development of a game that caters specifically to the key requirements of balance rehabilitation. The game-based application has the potential to be used as a therapeutic tool within the clinic and home settings by a range of patient populations. The user-centered iterative game design process allows key stakeholders to participate in the design of the system, identifying core features to be incorporated into the game. Ideally, the result is a game that is fun to play, provides an appropriate level of challenge and appropriate feedback for a range of abilities, and provides clinicians with control over the game-based exercise tool.

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