Virtual reality rehabilitation – what do users with disabilities want?

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ABSTRACT

This paper will discuss preliminary findings of user preferences regarding video game and VR game-based motor rehabilitation systems within a physical therapy clinic for patients with SCI, TBI and amputation. The video game and VR systems chosen for this research were the Sony PlayStation® 2 EyeToy™, Nintendo® Wii™, and Novint® Falcon™ and an optical tracking system developed at the Institute for Creative Technologies at the University of Southern California. The overall goals of the current project were to 1) identify and define user preferences regarding the VR games and interactive systems; 2) develop new games, or manipulate the current USC-ICT games to address these user-defined characteristics that were most enjoyable and motivating to use; and 3) develop and pilot test a training protocol aimed to improve function in each of the three groups (TBI, SCI and amputation). The first goal of this research will be discussed in this paper.

1. INTRODUCTION

Individuals with Traumatic Brain Injury (TBI), Spinal Cord Injury (SCI), and amputation often experience impairments with balance and proprioception (Tyson and Selley 2006), sensation, cardiovascular fitness (Potempa, Lopez et al 1995), coordination and motor control (Duncan, Studenski et al 2003), and muscle strength (Duncan, Richards et al 1998). These impairments present obvious impediments to a functionally independent lifestyle, impacting mobility, performance of activities of daily living (ADL), and participation in leisure activities. Furthermore, an individual's sense of self-efficacy is hindered, often leading to an increasingly sedentary and isolated lifestyle (Riva 1998). Opportunities to participate in regular exercise are especially important for groups less physically active than the general population and more prone to secondary complications such as pain, fatigue and de-conditioning (Rimmer, Riley et al 2001).

One method of intervention currently receiving wide spread attention is the use of Video games and Virtual Reality (VR) systems for rehabilitation purposes. These systems demand focus and attention, can motivate the user to move, and provide the user with a sense of achievement, even if they cannot perform that task in the 'real world'. Current research indicates that motor function can be recovered or improved via a repetitive task-oriented motor training regimen in which an individual performs activities that target specific relevant movement, and is intensified in a hierarchical/progressive and optimal fashion based on patient progress and presents the client with a challenge (Winstein and Stewart 2006). Early research suggests that VR game-based technology can be used to improve motor skill rehabilitation of functional deficits including hand function (Boian, Sharma et al 2002; Chuang, Huang et al 2002; Adamovich, Merians et al 2004; Dvorkin, Shahar et al 2006) and walking (Fung, Malouin et al 2004; Fulk 2005; Baram and Miller 2006; Fung, Richards et al 2006). However, clinic and home-based systems need to be affordable and easy to deploy and maintain, while still providing the interactional fidelity required to produce the meaningful motor rehabilitation activity needed to foster transfer to the real world. Early research in the area of VR has used complicated and expensive systems to assist people to relearn how to move. These high-end laboratory-based systems do not meet cost and deployability requirements. A new area of research aims at assessing how off-the-shelf VR devices such as the Nintendo® Wii™ can be used in rehabilitation. While these games were not designed with rehabilitation in mind, they have the advantage that they are affordable, accessible and can be

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used within the home. The attitudes and opinions of people with disabilities who use these devices are not known. The overall goal of the current research is to employ user centered design process to develop VR games that improve sensorimotor function in individuals with disabilities and thus, as a first step, the research explored the opinions and attitudes, of individuals with disabilities, when using four different off the shelf, low-cost VR games and interfaces.

The goals of our current project were to 1) identify and define the characteristics of the games and 4 interactive systems (Sony PlayStation® 2 EyeToy™, Nintendo® Wii™, Novint® Falcon™, and the optical webcam tracking system) that were most enjoyable, user friendly, and motivating for individuals with TBI, SCI and amputation; 2) develop new games, or manipulate the current games to address these user-defined characteristics gathered during the first part of the research; 3) develop and start a training protocol that will improve functional ability in each of the three groups (TBI, SCI and amputation). This paper will present the findings from the focus group research.

2. METHOD

2.1 *Subjects*

A sample of convenience was selected from patients attending outpatient physical therapy at a local rehabilitation clinic. Participants were included if they 1) had sustained a catastrophic event (TBI, SCI or Amputation) more than one month prior to admission; 2) had no history of seizure; 3) were aged between 18 and 75 years old; 4) did not have serious uncontrolled medical complications; and 5) did not demonstrate pain that would limit their participation. All participants consented to voluntarily participate in this study. This study was approved by the University of Southern California Institutional Review Board.

2.2 *Virtual Reality systems and demonstrations*

During the focus group, participants were provided with demonstrations of the optical tracking system and standard games from the Sony PlayStation® 2 EyeToy™, Nintendo® Wii™, and Novint® Falcon™.

2.2.1 Sony PlayStation® 2 EyeToy™. The *Sony PlayStation® 2(PS2) EyeToy™ (Sony, 2004)* is a commercially available VR gaming system that uses a video capture interface to allow the user to interact directly with objects projected onto their own television screen. Hardware components for this system include a color digital camera device with USB interface (manufactured by Logitech, an OmniVision Video Device with an OmniVision sensor), a PS2, a DUALSHOCK 2 Analog Controller with pressure sensitivity, a powerful processor and graphics accelerator, an internal hard drive for data storage, and the EyeToy™: Play 2 disc. The total cost of the system is less than $200. The system uses motion and color-sensitive computer vision to process images taken by the camera. As the user moves his/her body, a USB connected camera digitizes and then superimposes the players' real-time likeness image on the television screen, with a graphic overlay of a virtual surrounding. Objects within the game environment move and react when contacted by the user's image (Figure 1.) creating an interactive experience between the two. The player is not required to hold a device and often uses his/her hand as the tool (racquet) to interact with the game. Sound and visual feedback indicate the success or failure of movement relative to the game task. The EyeToy™: Play 2 has 23 different games, each presenting similar movement challenges: accurate, target-based upper extremity motion, motor planning, dynamic sitting and standing balance, and eye-hand coordination. The movement tasks are multi-planar and multi-directional, with rotational and diagonal components, mimicking essential aspects of functional movement. Games can be played from a sitting or standing position. Most of the EyeToy™ games have three levels (easy, moderate, difficult) and cannot be manipulated to meet the needs of the user.

Figure 1. *The Sony PlayStation® 2 EyeToy™ (Sony, 2004), Table Tennis Game. (www.gamasutra.com and a248.e.akamai.net)*

2.2.2 Nintendo® Wii™. The *Nintendo® Wii™* uses a PowerPC based Broadway processor, has 88MB main memory and 512 MB built in NAND flash memory which can be expanded using SD card memory storage. The Wii™ uses a 12 cm Optical Disc and an 8cm Nintendo® Game Cube game disc. It has a 512 MB internal flash memory, secure digital card and a memory card. The Wii™ also contains an SD card that can be used to back up saved game data. The total cost for this system is approximately $400.00. To sense its position in 3D space, the "*Wii™* Remote" uses both accelerometers and infrared detection (via an array of LEDs) allowing for both gestures and button press to control the game. The *Wii™* currently has over 275 games to choose from with more games in development for release in the near future. The Wii™ system is different from the EyeToy™ in a number of ways. The user controls an avatar that appears in a virtual gaming environment on the television screen (Figure 2). This avatar can be made to appear in the likeness of the user and has been given the name "Wii™Me". Characteristics that the user can change on the avatar to make its likeness more realistic includes skin color, hair style, glasses, eyebrows shape and color, eye shape and color, clothing, and size. This "Wii™Me" is saved with the users name and can be used to play on all subsequent sessions. The avatar often appears in a ghost like version on the screen so that the user can see the objects or environment behind the avatar. In some of the games, the player is given the option of a "fly-over" to view the entire playing field. For example, in the Wii™ Golf game, before the player's avatar approaches the ball, the player is given a view of the entire hole so that they know how best to hit the ball. The player is given the option to select from a variety of golf clubs and to change his position and line of trajectory once the ball is hit. As the player swings the "Wii™mote" as a golf club, the angle and speed with which the player moves the "Wii™mote" will affect the distance and direction of the ball. The player is given feedback regarding direction and force once the swing is completed. Lastly, the player receives feedback via a vibration of the "Wii™mote". This vibration is not specific to any one game, but rather provides the user with feedback regarding contact with the target or ball. Most games within the Wii™ have a number of levels of difficulty built in. These levels cannot be manipulated or changed to meet the needs of the users.

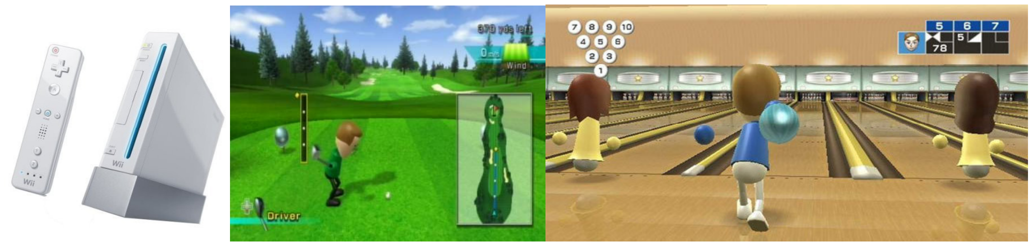

Figure 2. *The Nintendo® Wii™ Golf and Bowling game.*
(www.sfgate.com, www.frequencycast.co.uk/images, www.media.gwn.com/reviews)

2.2.3 Novint® Falcon™. In the real world, falcons prey on mice. Thus the developers of the *Novint® Falcon™* named this device the "Falcon" as they believe it will revolutionize and potentially replace the traditional computer mouse as a game controller. This device sells for just under $200.00. This type of controller revolutionizes 3D touch in that the *Falcon™* provides haptics (sensory feedback during gaming interaction). When using this device, the player feels weight, shape, texture, dimension and force of the object, allowing for more "natural" play. For example, if playing a ball catching game, the player feels the impact of the ball coming into contact with their hand. The device uses interchangeable grips that move in 3D and interact with objects on the screen. Once the controller comes into contact with the virtual object, the computer updates currents to the device's motor, resulting in a force applied to the handle that is felt by the user. The current in the handle is updated 1000 times per second. This device can be used in the place of a mouse with off-the-shelf computer games to enhance user feedback as well as 19 downloadable mini- games specifically developed by Novint®.

Figure 3. *The Novint Falcon (www.technabob.com).*

2.2.4 Optical tracking system. The low cost optical motion capture system employs off the shelf Logitech Web cameras that can track three, five and six degrees of freedom of movement from low cost LED's attached to the body or to relevant objects (i.e., handheld "jogging" weights). The system utilizes a combination of single camera+dual LED, dual camera+single LED, single camera+single LED that can be connected to any PC with Windows 2000/XP. This set-up costs less than $100. Seven games/tasks have been designed and include a reaching task, supination/pronation game, elbow flexion/extension, shoulder flexion/extension task). This system has been developed by computer engineers at the University of Southern California, Institute for Creative Technology to allow for a more user-centered game environment in which the game components can be easily manipulated and customized to an individual's abilities and needs. For example, during the "Tux Racer" game, the user must control a penguin as it skis down a mountain, avoiding trees and picking up "Herring" along the way. The "Tux Racer" is a free 3D game that is typically controlled using a standard mouse and/or arrow keys on the keyboard. Points are acquired by collecting Herring, avoiding trees, and by the speed in which the user completes the game. When the LEDs are connected to a player's shoulders, this game becomes a balance and motor control task. As the player leans to the left and right, the penguin moves to the left and right. As the player leans forward, the penguin speeds up, and slows down when the player leans backward. This game can be made more or less challenging by changing the range in which a person must lean to the left or right in order to make the Penguin move to the left or right and by making the player lean farther forward or back to change speeds.

Figure 4. *Tux Racer screen shot (www. gd.tuwien.ac.at/.vhost).*

2.3 Outcome Measures

The outcome measures used in this study included a Preferences Questionnaire (Figure 5) Usability Questionnaire (Figure 6), Likeability Questionnaire (Figure 7), and focus group questions.

2.4 Procedure

Following a demonstration the participants trialed the following seven games: EyeToy™: boxing and soccer, Wii™: golf and bowling, Novint™: baseball and target shooting, USC-ICT modified "TuxRacer" game. They completed questionnaires regarding their perception of each system's usability, appeal and enjoyment. In a focus group format, the participants were asked a number of questions. Sample questions from focus group include: 1) If you could have any game created just for you, what would it be? 2) Is it important to you to make an avatar that looks like you? 3) Should the avatar be disabled or be in a wheelchair? 4) Do you like playing using the first person view? 5) Do you feel like you had control over the game? 6) Did you feel you received enough feedback from the Wii, EyeToy, Falcon and ICT games? 7) How did you feel about the graphics, were they helpful, overwhelming, enhancing to the game or interfering with your ability to play the game? 8) Do you prefer graphics that are realistic or more "cartoonish"? 9) How did you feel about the auditory feedback and the music playing in the background of the games? 10) Are the games too simple, too complex, or just right? 11) What do you perceive as the barriers to using these games in rehabilitation? 12) How do you feel about the levels of difficulty within the games? 13) Were you bored playing the games? Participants were then given the opportunity to provide ideas for improvements and comment about what they found difficult, what they liked and what they thought would be a good addition to each of the systems and games. The focus groups were videotaped and the dialogue was transcribed.

1= Most Favorite 4= Least Favorite	Novent Falcon	EyeToy	Wii	ICT/USC
Overall preference	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Graphics	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Usability	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Likelihood of playing	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Ease of setup	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Color Scheme	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Characters	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Control	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Sound	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Interface device (hand control vs body movement)	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Level of enjoyment	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Level of engagement	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Ability to interact with environment	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Level of difficulty	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Similarlity to real life	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Responsiveness of device	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Accuracy of controlling/interface/interacting device	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
This device is most fatiguing to play	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4

Figure 5. *Preferences Questionnaire.*

		Strongly Disagree				**Strongly Agree**
1	The EyeToy has a distinct advantage because it projects the players image on the screen.	**1**	**2**	**3**	**4**	**5**
2	The sensory feedback from the Novent Falcon is helpful	**1**	**2**	**3**	**4**	**5**
3	I would like to use a pen/tablet to interact with the games	**1**	**2**	**3**	**4**	**5**
4	I would like to battle others when playing the games	**1**	**2**	**3**	**4**	**5**
5	I am extremely motivated to exercise.	**1**	**2**	**3**	**4**	**5**
6	I will be more motivated to exercise if I was playing this game	**1**	**2**	**3**	**4**	**5**
7	I would rather interact with a character that looks human	**1**	**2**	**3**	**4**	**5**
8	I would rather interact with an avatar	**1**	**2**	**3**	**4**	**5**
9	Because there are too many barriers to using this technology, I am not likely to use it for rehabilitation	**1**	**2**	**3**	**4**	**5**
10	The devices often did not permit me to move the way I intended to	**1**	**2**	**3**	**4**	**5**

Figure 6. *Likeability Questionnaire.*

	Strongly Disagree				Strongly Agre
I think I would like to use the device frequently	1	2	3	4	5
I found the device unncessairly complex	1	2	3	4	5
I thought the device was easy to use	1	2	3	4	5
I think I would need the support of a technical person to be able to use device	1	2	3	4	5
I found the various functions in the device were well integrated	1	2	3	4	5
I thought there was too much inconsistency in the device	1	2	3	4	5
I would imagine that most people would learn to use this device very quickly	1	2	3	4	5
I found the device very cumbersome to use	1	2	3	4	5
I felt very confident using the device	1	2	3	4	5
I needed to learn a lot of things before I could get going with the device	1	2	3	4	5

Figure 7. *System Usability Questionnaire.*

3. RESULTS

3.1 Participants

The study involved discussions from a focus group study consisting of nine participants with SCI (n = 4), TBI (n = 4) and Amputation (n = 1), four females, five males with a mean age of 55.89 ± 7.67 years. The participant demographics are listed in Table 1.

Table 1. *Participant Descriptive Statistics*

Subject Number	Gender	age (years)	Time Since Injury (months)	Diagnosis	Employed	Own Computer	Play Video Games
C-1	Male	65	6	CVA	No	Yes	No
C-2	Female	49	21	CVA	No	Yes	No
B-1	Female	69	25	Brain Tumor	No	Yes	No
C-2	Female	61	47	CVA	No	Yes	Yes
S-1	Male	53	120	SCI	No	Yes	Yes
S-2	Male	55	71	SCI	No	Yes	Yes
S-3	Male	50	12	SCI	No	Yes	Yes
S-4	Male	55	42	SCI	Yes	Yes	No
A-1	Female	46	11	Amputee	No	Yes	Yes
mean		55.89	39.44				
S.D.		7.67	36.71				

3.2 Preferences

The participants ranked the four VR systems from most favorite to least favorite with regard to each of the characteristics listed in the Preferences Questionnaire (Figure 5). The sums of the ranks were tallied and are presented in Table 2. In general, the EyeToy™ and Wii™ were preferred in terms of overall preference, graphics, usability, likelihood of playing, characters, control, sound, enjoyment, interactivity, similarity to real life, responsiveness to device, and accuracy. The USC-ICT developed game was preferred in terms of likelihood of playing, color scheme, control, and interface. The Novint™ Falcon was preferred in terms of ease of set-up, and engagement. The EyeToy™, Wii™ and Novint™ were all preferred in terms of level of difficulty and engagement. The games that were most fatiguing to play were the Wii™ and USC-ICT games.

Table 2. *EyeToy ™, W- Wii ™, N- Novint Falcon ™, I- USC-ICT developed games.*

	Rank1	Rank2	Rank3	Rank4
Overall preference	E	W	I	N
Graphics	E	W	N	I
Usability	W	E	N	I
Likelihood of playing	I/E		W	N
Ease of setup	W/N		E	I
Color Scheme	I	W	N	E
Characters	E	W	N	I
Control	E	W/I		N
Sound	E	W	I	N
Interface device (hand control vs body movement)	E/I		W	N
Level of enjoyment	E	W	I	N
Level of engagement	W/N		E	I
Ability to interact with environment	W	E	N	I
Level of difficulty	N	E/W		I
Similarlity to real life	E	W	N	I
Responsiveness of device	E	W	I	N
Accuracy of controlling/interface/interacting device	E	W	N	I
This device is most fatiguing to play	W	I	E	N

3.3 Likeability Questionnaire

The results from the Likeability Questionnaire indicated that the participants agreed that the haptics feedback from the Novint® Falcon™ was helpful. Participants responded that they were fairly motivated to exercise, and that they would be more motivated to exercise if playing these types of games. The participants were neutral on responses asking if they preferred characters that looked human or interacting with the games via an avatar. Lastly, participants did not feel there were too many barriers to using this type of technology and they were able to interact with the games as they intended.

3.4 Usability Questionnaire

The participants completed the Usability Questionnaire for each of the four VR systems demonstrated and trialed in this study. In general, there was no difference among the four devices in terms of usability Participants thought the devices were easy to use, well integrated, easy to learn, and they felt confident using the devices and would use each of them frequently. The participants did not feel that the devices were cumbersome to use or needed a lot of training before using them.

3.5 Focus Group Discussion Session

The participants took part in over two hours of group discussion regarding the four devices and a brainstorming session exploring potential future VR games for rehabilitation. The participants discussed a number of benefits derived from these devices. They reported not realizing how long they had been playing, and a sense of being distracted from their disability and from boring exercise regimes. Some reported enjoying, for the first time, the added dimension of receiving feedback and rewards while playing. Further comments were that the EyeToy™ was considered more interactive than the Wii™. Many felt that using the Novint™ Falcon restricted their movements more than the other games in which larger movements were encouraged. Each game system had its own unique attributes and uniqueness and was enjoyed for different reasons. Participants felt that having a somewhat unrealistic graphics background was helpful because it made the game seem more playful. For other games, participants felt that realistic graphics and an avatar that looked similar to themselves or a video captured image of themselves would be more beneficial, especially when the goal of the game was to create a very specific movement. The group consensus was that although the participants enjoyed creating avatars that looked similar to themselves the avatar need not look disabled nor move in the virtual world via a virtual wheelchair. The ability to move between first person view, fly-over view and third person view was helpful at different times within the game environment. The participants enjoyed the feedback provided from the games, especially with the EyeToy™ game in which the user saw a visual representation of them self on the screen. Although the EyeToy™ does not provide direct haptic feedback, the participants "felt" that they had made contact with objects in the game. The feedback from the handheld devices of the Wii™ and Falcon™ game were also helpful. However, some of the movements within the Wii™ and EyeToy™ games were difficult to control and participants were often unsure if they had made the correct movement. Realistic sound and auditory feedback were thought to be helpful. Auditory feedback that was linked to occurrences within the game would also be helpful. For example, the music tempo speeds up as the user moves faster through the environment or the volume increases as the user approaches the target.

4. CONCLUSIONS

In summary, users with disabilities have distinct opinions and preferences regarding VR games and their use in rehabilitation. Most importantly, these individuals expressed a great deal of enjoyment from using these games and a desire to use them during their rehabilitation process. They found the feedback in the form of visual feedback and haptics especially helpful. Participants also discussed how each game system had its unique set of attributes. Further research is required to assess the utility of off-the-shelf gaming technology and to adapt these games in a manner that is most helpful and enjoyable for individuals with disabilities. Despite the participants stating that they would use the games just because they were fun, rehabilitation specialists are obligated to develop games that are best suited to address the specific rehabilitation needs of the individual while remaining substantiated by rigorous theoretical bases. We have already begun manipulating our existing games based on the feedback collected in this study and testing these new games in a large scale study. These tools may be very helpful in encouraging individuals with disabilities to "play" with and against family and friends, thus promoting a healthier, more active and less isolating lifestyle.

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