Feasibility of Using the Sony PlayStation 2 Gaming Platform for an Individual Poststroke: A Case Report

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Abstract:
Rationale: Many Americans live with physical functional limitations stemming from stroke. These functional limitations can be reduced by task-specific training that is repetitive, motivating, and augmented with feedback. Virtual reality (VR) is reported to offer an engaging environment that is repetitive, safe, motivating, and gives task-specific feedback. The purpose of this case report was to explore the use of a low-cost VR device [Sony PlayStation 2 (PS2) EyeToy] for an individual in the chronic phase of stroke recovery.
Case: An individual two years poststroke with residual sensorimotor deficits completed 20 one-hour sessions using the PS2 EyeToy. The game's task requirements included target-based motion, dynamic balance, and motor planning. The feasibility of using the gaming platform was explored and a broad selection of outcomes was used to assess change in performance.
Outcomes: Device use was feasible. Clinically relevant improvements were found on the Dynamic Gait Index and *trends* toward improvement on the Fugl-Meyer Assesment, Berg Balance Scale, UE Functional Index, Motor Activity Log, and Beck Depression Inventory.
Conclusion: A low-cost VR system was easily used in the home. In the future it may be used to improve sensory/motor recovery following stroke as an adjunct to standard care physical therapy.

Key words: *virtual reality, rehabilitation, stroke*

(*JNPT* 2007;31: 180–189)

INTRODUCTION

Permanent neurological impairments and concomitant physical functional limitations occur in approximately 60%[1] of the 700,000 people in the United States experiencing a new or recurrent stroke each year.[2] Deficits for this population have been well documented in the areas of balance and proprioception,[3] strength,[4] motor control,[5] endurance, and aerobic capacity.[6] Strong evidence points to the benefits of rehabilitation and therapeutic exercise in all stages of stroke recovery,[4–7] yet rehabilitation hospital stays are of an increasingly shorter duration. This presents the need for alternative, long-term, and economically feasible treatment options.

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ISSN: 1557-0576/07/3104-0180
DOI: 10.1097/NPT.0b013e31815d00d5

Virtual reality (VR) is a developing technology that has historically been used for the training of motor tasks involving highly complex activities such as surgical techniques,[8] flight simulation,[9] and military exercises.[10] More recently, VR has been explored as a therapeutic tool to retrain faulty movement patterns and rehabilitation of function resulting from neural insult. While most current studies have used small sample sizes, promising trends have been established for improving hand function[11–13] and locomotor activity[14–18] in individuals with chronic stroke, controlling and coordinating volitional movement for children with cerebral palsy,[19] and decreasing akinesia for individuals with Parkinson's disease.[20] Furthermore, gains achieved through VR practice have been shown to carry over in real-world activity, sometimes resulting in spontaneous functional improvement in activities of daily living.[11–13,21]

Recent advances in the understanding of neural plasticity and motor function retraining suggest that greater quantity, duration, and intensity of practice are most effective in modifying neural (re)organization[22] and influencing motor learning.[23] Also, increasing rehabilitative treatment duration is associated with a reduction in death/deterioration following stroke.[24] Additionally, motor learning principles point to the value of augmented feedback regarding performance during the acquisition of a new motor skill. Research has further established the specific benefit of visual and auditory feedback in the retraining of motor function, including such tasks as increasing stance symmetry, recovering activities of daily living (ADL) abilities, and improving balance in chronic stroke patients.[25–28] In fact, visual cues have been shown to provide a more potent motivational context for improving performance than verbal cues.[26] As traditional physical rehabilitation is costly and not reimbursable long term, the development of novel interventions in which motor retraining can be performed without the constant guidance of a rehabilitative specialist is imperative. VR gaming using commonly available PC-based equipment is a self-directed activity not limited by the constraint of having a therapist present.[29] As such, it is capable of providing unrestricted frequency of treatment for an indefinite period of time in the individual's own home. Furthermore, in a VR system, augmented feedback occurs in the game environment, with visual and auditory cues informing the participant about their position in space and the success of their movement attempts. Moreover, the virtual environment (VE) provides an engaging and motivating framework for feedback,[30–32] allowing the participant to become immersed in the virtual world and to experience the emotional sense of "winning" in a particular game.[33] These attributes of VR training are important, as lack of motivation and adherence to exercise have been shown to be problematic in traditional treatment regimens, thus impacting therapeutic outcomes.[19,31,34–36]

Preliminary research in the area of VR has focused primarily on complex VR systems designed for specific therapeutic purposes, providing the participant with visual, sensory, and haptic feedback tailored to retrain a precise motor skill. What had not yet been explored is the therapeutic value of commonly available VR games not explicitly created for rehabilitation. Although less expensive and lower tech, these VR games do in fact share many tasks and behaviors similar to its higher cost predecessor, the IREX system.[15] While off-the-shelf gaming technology lacks specificity, it has the advantage of mass accessibility, broad affordability, and the potential for home use. The use of VR games played with Sony Eyetoy: Play 2 gaming software may provide an engaging environment to challenge and retrain motor activity. As the nature of the technology allows for unlimited repetition with ongoing feedback, training in the VE may lead to neural reorganization and a decrease in the deficits commonly found following stroke.

The primary purpose of this case report was to explore the feasibility of using a VR gaming device (Sony Eyetoy: Play 2 on a PlayStation 2) to improve function two years after stroke for an individual who has exhausted all traditional rehabilitative interventions. Given this participant's unique professional background as a retired professor of physical therapy, upon completion of the training program an in-depth interview was conducted to gather qualitative data regarding the participant's perceptions about this device and its application to physical therapy. Outcomes for impairment, activity, and participation, before and after using the VR gaming device at home, are included.

CASE DESCRIPTION

History

The participant, MRB, was a 76-year-old woman who sustained a right hemorrhagic stroke 17 months prior to the start of the study. Her past medical history was significant for low blood pressure, myofascial pain syndrome, fibromyalgia, and a hearing impediment for which she wore a hearing aid. Prior to her stroke, she led an active retirement lifestyle with no physical function or cognitive limitations. Before retirement, MRB worked as a physical therapist and a professor of physical therapy for many years.

On the day of the stroke, MRB was taken to the emergency room, where an MRI was used to diagnose her condition. She remained in the ICU for two days, entered acute care for three days, and then transferred to inpatient rehabilitation for five weeks. While in inpatient rehabilitation, she received physical, occupational, and speech therapy daily, with various adjuncts such as recreational and animal therapy. Upon leaving the hospital, MRB was ambulating on level surfaces using a quad cane and stand-by assistance. ADL could be performed independently, but often not at a functional speed; she required assistance with eating, grooming, and bathroom activities in order to complete them within a reasonable time frame. Cognitive deficits were also noted, including problems with memory and word-finding.

At the conclusion of inpatient rehabilitation, MRB began day therapy three times weekly for one month. During this period, she began to ambulate independently within the community. She also began to develop greater speed with ADL, but continued to require assistance with more complex fine motor tasks, such as buttoning, cutting food, and tying her shoes. Although MRB was able to communicate effectively, previously noted cognitive deficits remained (word-finding and memory difficulties), leading to a minor reduction in conversational speed.

Following completion of available treatment opportunities, MRB engaged in a daily self-directed program of exercise and activity aimed at maximizing both motor and cognitive potential. She made minor modifications to her home environment, including the addition of handrails in her bathroom and bedroom. Follow-up CAT and MRI imaging studies ruled out any additional cerebral vascular accidents (CVAs). She occasionally had low back pain with a rating of approximately 2 out of 10.

MRB indicated that her hobbies were reading, studying history, and traveling, all of which had become difficult following her stroke. Being a physical therapist, she engaged in exercises aimed at improving her gait and arm and leg strength such as cone stacking coordination exercises, playing ping-pong, and kicking a ball. She had not changed her exercise program in the recent past nor planned to change her exercise program during the course of this study. She had no experience with computer games, video games, or VR programs. She was interested in trialing the VR technology to further her rehabilitation.

MRB had the following characteristics necessary for the study and volunteered to participate. These characteristics included that the individual would (1) have had a previous stroke and completed available treatment options, (2) not currently be receiving physical therapy or be undergoing new treatment, such as surgery or a medication change, (3) not change their regular exercise regimen during the course of the study, and (4) be able to play VR games safely within their own home. The participant then signed an informed consent statement, in accordance with requirements of the Georgia State University Institutional Review Board.

Examination

MRB demonstrated normal passive range of motion in all extremities with the exception of left shoulder flexion, external rotation, and internal rotation, and left hip flexion, abduction, and internal rotation. She reported some pain in her left hip with all movements. She also had complete loss of proprioception in all joints on the left side except her shoulder. According to the Fugl-Meyer Assessment (FMA) of physical performance, she had marked tremor and pronounced dysmetria in her left hand and slight tremor and dysmetria in her left foot. Movement on her left side was slower compared with the right side. In summary, prior to beginning this study she had an 85% recovery according to the FMA With regard to her arm function, she reported moderate difficulty with housework, lifting groceries above her head, vacuuming, tying shoelaces, sleeping, or throwing a ball. She was unable to drive. Although MRB showed near normal functional reach distance, her balance was impaired in that she was unable to stand on one foot or in a tandem position. Despite walking fairly quickly [12.73 seconds on the Timed Up and Go (TUG) Test] and covering 1282 feet in six minutes, her gait showed mild impairments and mild deviations when asked to change speed, turn head horizontally, step over an obstacle, and walk up stairs. She had moderate difficulty when asked to look vertically while walking. With regard to mental function, MRB showed difficulty with counting backward from 100 by 7.

Tests and Measures

To assess the feasibility of using the device, the participant's perception relative to specific games was obtained through the use of daily logs. We performed an extensive interview after the one-month of training to assess feasibility with using this device. Specifically we asked questions regarding ease of use, training enjoyment, and adverse effects.

As potential benefits of VR were unknown, we selected a wide range of outcome measures in an effort to capture potential effects pertaining to motor and sensory function, balance, endurance, cognition, and emotional experience.[37] The measures were intended to address each component of the International Classification of Functioning, Disability, and Health model of disability: impairment, activity, and participation. The tests were also selected for their demonstrated validity and reliability for individuals poststroke. Testing was performed, in the standardized manner, prior to the onset of training (pretest), at the conclusion of 10 training sessions (midtest), at the conclusion of 20 training sessions (posttest), and six-months following the completion of training (six-month follow-up). The tests and measures before and after the intervention are presented in the outcomes section. All three authors participated in the testing.

Evaluation and Prognosis

In general, MRB had significant motor and sensory recovery poststroke; however, she had difficulty performing high-level coordination and balance tasks. From a motivation perspective, MRB's rehabilitation potential was excellent. However, due to her already high level of recovery, we were prepared for minimal change.

Intervention

The VR system used in this case was the Eyetoy: Play 2 (Sony, Park Ridge, New Jersey), a commercially available gaming system that uses a video capture interface to allow the user to interact directly with their own television screen. Components for this system include a color digital camera device with USB interface (an OmniVision OV519 Video Device with an OmniVision OV7648 sensor, manufactured by Logitech, Fremont, California), a PlayStation 2 (PS2) (model number SCPH-75001), a DUALSHOCK 2 Analog Controller with pressure sensitivity, 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, the camera presents a real-time likeness 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, creating an interactive experience between the two. Sound and visual feedback indicate the success or failure of movement relative to the game task.

The Eyetoy: Play 2 provides the player with 23 different game experiences, each presenting similar movement challenges: accurate, target-based upper extremity motion, motor planning, dynamic sitting and standing balance, and eye-hand coordination (Table 1). The movement tasks are multiplanar and multidirectional, with rotational and diagonal components, mimicking essential aspects of functional movement. Games can be played from a sitting or standing position. Six additional multiplayer games are available for use with up to four people.

MRB was provided with the system, which interfaced with her own television set via an AV cable. After the Sony Eyetoy was easily set up in her home, assistance was provided with lighting conditions and sound settings to allow for easy interaction with the screen. Setting up the system took less than one hour, and no modifications were made to the games. During the set-up in her home, a place that was safe and free from objects that may cause injury if she were to fall was chosen. On initiation of training, she was asked to play each of the Eyetoy games at least twice, after which game choices were at her discretion. As she was able to safely maintain standing balance while playing the Eyetoy, she chose to complete the activity from a standing position. The participant completed a total of 20 one-hour sessions of play over four and a half weeks.[38–40] The training sessions were completed in time intervals determined by the participant's fatigue level. For example, sometimes MRB played for 30 minutes before resting, while on other days she played for shorter times before requiring a break. The variability was due to training intensity, other activities performed that day, or general fatigue possibly due to myofascial pain or fibromyalgia. The research team did not supervise the training sessions; however, her companion monitored and encouraged her during the training sessions by being present in the room or home. Compliance was monitored via the use of daily play logs that listed games played, time of session, and comments regarding individual games, collected at the completion of 10 and 20 gaming sessions. The games played are summarized in Table 1. The research team contacted the participant weekly to answer questions and encourage her continued participation.

OUTCOMES

Feasibility of Use

After conducting an extensive interview and reviewing the daily logs, we discovered that this device was quite feasible as well as quite enjoyable to use. Since this participant uniquely understood the benefits of this research project, we queried her regarding her opinion of the device (Table 2). In general, she described the games as very motivating and

TABLE 1. Summary of Game Descriptions and Number of Times the Participant Played Each Game

Games Played	Description	# Times Played	Dynamic Balance	UE ROM	Speed	Cognition	Reaction Time	Target-Based
Air Guitar	The player uses her hands to strum along to music. Various symbols indicate movements ranging form single hits/picks, slides, strums, and windmills to rock along to some classic rock and roll riffs.	4	X		X	X	X	X
Bubblepop	The player attempts to pop all the bubbles as quickly as possible, leaving only the red bubbles. Bomb bubbles will detonate everything nearby, so player uses them wisely.	4	X	X	X	X	X	X
Colors	Player uses her upper extremities in all planes to color various templates as she chooses.	11	X	X				
Do It Yourself (DIY)	The player uses her arms to select the best techniques to finish a professional job, catch a runaway drill, chop wood, and shred trees while keeping other objects out of the shredder.	15	X		X	X		X
Drummin'	The player must move her hands to beat out rhythms using various timed beats in a specified pattern.	5	X		X	X	X	X
Goal Attack	The player attempts to prevent the computer from scoring any goals on her. Her body is used to block as many shots as possible. Other parts of the game include an agility drill, reaction test, and a fitness test.	4	X	X				X
Homerun	The player uses her hands to swing at pitches, run the bases, and try to score as many runs as possible with 10 baseballs. There are tools to increase the score such as a strike zone, mini-map of the infield, and a direction gauge.	5	X		X			X
Knockout	The player uses her arms to punch out the opponent in three rounds or less. A musical tune indicates the opportunity to launch a combo attack to focus on the opponent's weak spot. Other parts of this game include sparring, punching a heavy bag, and a speed bag.	16	X	X	X		X	X
Kung 2	The player uses her strength and agility to defeat all enemies in the way using various karate techniques.	2	X		X	X		X
Monkey Bars	The player swings her way across the monkey bars, grabbing as many bananas as possible while collecting various fruits for extra points and intermittently dodging opponents.	5	X	X		X		X
Mr. Chef	The player grabs and drags all the ingredients needed to complete the orders to assigned specifications followed by a speed competition against an opponent.	9	X	X	X	X	X	X
Pool	The player has to clear all of the balls from the pool table utilizing various angles of movement with her upper extremities under time constraints.	15	X	X				X
Secret Agent	The player is to sneak around collecting hidden items, solve puzzles, and move slowly so no one detects her movements as she breaks out of prison.	5	X		X			X
Solar System	The player navigates through the solar system by body movements.	2	X	X				X
Table Tennis	The player uses his arms as paddles to play against a number of incrementally more challenging opponents	6	X	X	X		X	X

Abbreviation: UE ROM, Upper Extremity Range of Motion

enjoyable to play. She also found some of the games to be too difficult or in need of modification for individuals with sensorimotor impairments. MRB commented on a number of possible benefits of using this technology. She suggested that individuals who are playing the games might exercise for longer periods of time without realizing how much time had passed. She enjoyed the competitive nature of the games. She indicated during her midtest session that she had set a goal of wanting to "knock down the wall before time ran out." She arrived for her posttest smiling and declaring, "I finally knocked down the whole wall before my time ran out–I finally did it yesterday!" Furthermore, she expressed enthusiasm for exercising at home. Shortly after her stroke, she noticed that her grandson was loosing interest in visiting her. During one of his visits, he observed her playing the games and asked if he could join her. Thereafter, he often asked to visit grandma again so that they could play together. Lastly, she found benefit in the convenience of playing the games

TABLE 2. Player's Comments

Game	Player's Comments
Air Guitar	"It takes a little time to figure it out, but after a couple of times, it gets easier."
Bubblepop	"It's fast and requires finesse with arm movement when trying not to pop the red bubbles."
Colors	"An interesting way to move without constraints on the type of movement or the speed of movement . . . can do trunk movements too."
Do It Yourself (DIY)	"It's a great game for a lot of various arm movements that is satisfying when you've succeeded in knocking down the wall."
Drummin'	"It's difficult to advance, but can get further with more repetitions."
Goal Attack	"It's good for weight shifts."
Homerun	"Hitting the ball is fun, but difficult to advance."
Knockout	"Challenging, but good game for stamina and accuracy."
Kung 2	"Good arm reactions and breaking the ice is fun."
Monkey Bars	"Difficult, but gets better with more repetitions."
Mr. Chef	"Good for cognitive, fast-paced decision making."
Pool	"The game requires difficult, varied arm movement in different planes."
Secret Agent	"Good for arm movements, but gets more difficult as the game advances."
Solar System	"Good for arm movements without the time constraints."
Table Tennis	"Good for two ways of hitting/arm movements, but difficult due to timing."

throughout the day, instead of having to exercise all at one time. She concluded by suggesting that while its widespread application may be limited, this device shows promise.

Tests and Measures

The following section describes the outcomes of the standardized assessments used in this study. The order of the tests were randomly selected and performed by the research team who were not blinded as to the intervention (Table 3). The following tests were chosen either because they are valid and reliable for individuals post troke and/or because they measured across the ICF continuum.

Fugl-Meyer Assessment

Based on Brunstrom's recovery patterns, the FMA is a valid and reliable[41–45] measure of recovery of sensorimotor function poststroke. The participant scored a total of 192/226 on the FMA during her pretest and a total of 214/226 on her posttest, demonstrating a 9.74% improvement following training. Scores for the individual components of the FMA were pretest: 94/100 motor, 11/12 balance, 10/24 sensory, 38/44 range of motion, and 39/44 pain and posttest: 96/100 motor, 10/12 balance, 21/24 sensory, 44/44 range of motion, and 43/44 pain. The largest change occurred in sensory function, specifically proprioception. Essentially she was unable to detect proprioception in her left side prior to beginning the study, and was able to detect it "flawlessly" after the one-month training period. Balance was the only component that did not show improvement over the course of training and improvement in other components was negligible. As an increase of 10 points has been theorized to represent clinically significant change,[41] an increase of 22 points represents meaningful improvement.

Upper Extremity Functional Index

This 20-item self-report questionnaire measures upper extremity task performance. MRB scored a 56/80 at her pretest and a 65/80 at her posttest on the Upper Extremity Functional Index (UEFI). The six-month follow-up showed a large improvement over the posttest, at a perfect 80/80. While a potentially promising result, the improvement indicated by this score is striking enough to be interpreted with caution. As this outcome is measured via self-report, the result is reliant

TABLE 3. Summary of Findings

Standardized Assessment (Total Score)	Improvement	Pretest	Midtest	Posttest	Six-Month
Fugl-Meyer Assessment % Recovery (100)	Increase	84.96%	87.00%	94.70%	98.00%
Upper Extremity Functional Index (80)	Increase	56	61	65	80
Beck Depression Inventory	Decrease	6	3	2	0
Berg Balance Scale (56)	Increase	51	53	54	54
Dynamic Gait Index (24)	Increase	16	18	21	20
Mini-Mental Status Exam (30)	Increase	24	26	29	26
Timed Up and Go (s.)	Decrease	12.73	10.75	11.68	9.62
Six-Minute Walk Test (ft)	Increase	1282	1250	1337	1187
Motor Activity Log-Quality of Movement (5)	Increase	3.50	3.92	4.70	5.00
Motor Activity Log-Actual Amount of Use (5)	Increase	5.00	4.26	5.00	5.00
Modified Ashworth Scale (0 = normal tone)	Decrease	2	0	1	0
Functional Reach Test (in)	Increase	11.33	10.25	11.50	12.00

on the accuracy of subjective recall and a consistent reading of test questions.[46]

Beck Depression Inventory

A minor decline in self-reported depressive symptoms was evident in this participant, although no scores (pretest, midtest, or posttest) were outside the normal range. She identified six items as originally problematic, dropping to two items by the posttest. Further decline was evident by the six-month follow-up, with a score of 0 at that time. Generally, a score of nine or greater indicates the presence of depression according to Beck Depression Inventory (BDI) criteria.[47–50]

Berg Balance Scale[51–53]

The Berg Balance Scale (BBS), a 14-item multitask balance test, showed consistent improvement over the pretest to posttest period. The participant scored an initial 51/54 and a final 54/54, a score that was maintained at the six-month follow-up. As only three points were deducted at the pretest and she eventually achieved a perfect score on this measure, a ceiling effect may have contributed to a lack of significant change for this individual.

Dynamic Gait Index

This eight-item tool assesses balance, postural control, mobility, and functional gait abilities. MRB initially scored a 16/24 on the Dynamic Gait Index (DGI).[54,55] By the posttest, she achieved a score of 21/24. As a score of 19 or below is a commonly accepted identification criteria for risk to fall, the change in scores represents a clinically significant result. At the six-month follow-up, she continued to demonstrate this reduction in fall risk, with a score of 20/24.

Mini-Mental State Exam

A screen for cognitive impairments, the Mini-Mental State Exam (MMSE) measures memory, language, and spatial ability.[56,57] The participant performed consistently better from the pretest to the posttest on the MMSE, with an initial score of 24/30 and a final score of 29/30. Although her score decreased at the six-month follow-up, it did not return to her pretraining level, but remained at the 26/30 midtest level. Generally, the cutoff for cognitive impairment in the post-CVA population is considered to be a score of 24/30,[42] and the participant remained above this level throughout.

Timed Up and Go[58,59]

As a functional test for mobility, MRB was timed at 12.73 seconds, 10.75 seconds, and 11.68 seconds on the TUG at the pretest, midtest, and posttest, respectively. Her fastest score (9.62 seconds) was actually achieved at the six-month follow-up. Although a change of 3.11 seconds is arguably a clinically important improvement on the TUG, the substantial variability of score through the length of the study does not indicate a consistent trend. All scores, however, were improved over her pretest time of 12.73 seconds and fall within the low end of normal range for the elderly population.

Six-Minute Walk Test

The distance MRB was able to ambulate during the Six-Minute Walk Test (6MWT) varied and did not demonstrate identifiable changes over time. Her pretest distance was 1282 feet, midtest distance was 1250 feet, and posttest distance was 1337 feet. Each distance was less than expected norms for women with a mean age of 62 , but this norm was established in the healthy elderly population and may not be relevant for an individual post-CVA.[60,61]

Motor Activity Log

The Motor Activity Log (MAL) is a 26-item interview that measures upper extremity functional poststroke. MRB scored a 5/5 per self-report on the Actual Amount of Use (MAL-AAU) portion of the MAL at the pretest, indicating that her affected extremity participated in all ADL.[62] The Quality of Movement (MAL-QOM), however, was rated a 3.5/5 at the pretest, a score that reveals a deficiency in the *quality* of motion. By the posttest, the QOM was rated a 4.7/5, signifying the self-perception that quality of motion had improved following training.

Modified Ashworth Scale

We used the Modified Ashworth Scale (MAS) to assess spasticity. The MAS revealed variable and inconclusive scoring: an initial score of 2, a 0 at midtest, a 1 at posttest, and a 0 at the six-month follow-up.[63] This participant generally experienced only mild and sporadic spasticity that did not significantly impact her life. This remained true in all stages prior to, during, and following training.

Functional Reach Test[64]

As an indication of postural responses, we used the Functional Reach Test (FRT). Reach distances did not improve over the testing periods, with a pretest measure of 11.33 inches and a posttest measure of 11.5 inches. All scores were within normal limits established for the participant's age group.

DISCUSSION

The outcomes of this study indicate that for this participant, VR rehabilitation using a commercially available device was feasible. There were no reports of increased pain or falls during the intervention phase. She was able to perform all of the training with relative ease. Despite her lack of computer/technology experience, after two to three days of practice using the device, she maneuvered through the various levels of the game choices. She explored different games and found games that she enjoyed playing more than others. MRB indicated her interest in purchasing a device to continue its use at her home. While we cannot rule out other causes for her gains in function during this one-month intervention, the VR gaming device positively impacted her function. She reported multiple attempts at performing specific tasks such as cutting her fingernails prior to participating in this study. After her one-month intervention, she reported that she could successfully cut her fingernails.

The participant in this is case demonstrated some improvements across the levels of impairment, activity, and participation in chronic stroke following daily play with the Sony Eyetoy. Improvements at the level of impairment measured by the FMA were mirrored by improvement in functional skill, as assessed by the DGI, UEFI, and MAL. This indicates that gains attained had real world application and that training completed in a VE may create functionally relevant change, even two years poststroke. MRB also showed an improvement in tests related to cognitive and emotional function, specifically the MMSE and BDI. Moreover, testing at the six-month follow-up indicates that improvements were maintained in the absence of *consistent* training (Table 3).

Measures on which the subject did *not* demonstrate change were the BBS, TUG, 6MWT, MAL-AAU, MAS, and FRT. For the most part, this lack of change may have been due to a ceiling effect; the participant was able to achieve perfect or near perfect scores on the BBS and MAL-AAU. Additionally, the MAS measured very little spasticity at all testing periods and the participant confirmed this was not a significant symptom in her life. Considering that most of the games require very little movement over ground, lack of improvement on the TUG and 6MWT may indicate that VR training may not specifically impact walking *speed*. The FRT remained relatively unchanged throughout the training, although other balance measures did show improvement. The FRT is a measure of balance as the center of gravity is maximally extended over the base of support. It may be that VR training has a greater impact on dynamic balance, such as the ability to balance while attending to multiple stimuli or while performing various movement tasks.

Perhaps the most striking change following training was evident in the sensory component of the FMA, where the participant demonstrated consistent gains in her score, from an initial 10/24 during the pretest to a final 21/24 at the posttest. The increase in score was primarily due to an increase in proprioceptive ability, an improvement at the level of impairment that has important functional implications. As discussed earlier, VR training with the Sony Eyetoy provides concurrent visual feedback regarding body position in space, as every movement a player performs is mirrored by their virtual counterpart. This mirroring occurs as the player engages in target-specific action, providing ongoing feedback about actual vs intended movement. An example of how this occurs is ping-pong, a game in which the player faces a virtual opponent with their hand functioning as the paddle. During this game, the player adjusts movements to hit the ball while viewing these adjustments in real time on the television screen. The attributes of the training may have contributed to the participant's increase in proprioception, as an awareness of body position is specifically encouraged. A return to full proprioceptive sense has great functional significance, as it plays a role in all movements; the participant in this study reported being able to walk over uneven surfaces to her mailbox for the first time after completing the training.

The outcome on the DGI is worth noting relative to injury prevention. The participant achieved a score of 21/24 by her posttest, an improvement over her initial 16/24 that placed her outside of the risk-to-fall category. People with stroke are commonly understood to be at increased risk for falling, with approximately 25% reporting recurrent falls.[65] Falling is associated with numerous complications and has been correlated with decreased mobility, decreased independence with ADL, and reduced arm function.[65] Loss of self-confidence secondary to recurrent falls can lead to self-imposed limitation to activity, causing further decline in strength, balance, and functional independence.[66] Given the significant value of a reduction in fall potential, we believe the participant's final score on the DGI represents important and noteworthy change. Furthermore, it should also be underscored that this change occurred in the chronic stages of stroke recovery, after the conventional course of post-CVA treatment had been completed.

As the Sony Eyetoy was not developed to retrain a specific motor skill in a particular disabled population, many outcome measures were chosen to explore change across a spectrum of possibilities. Each of the four testing sessions lasted approximately 2.5 hours and involved challenges to both motor and cognitive function. Fatigue during these sessions represents a confounding variable, with a possibility of later tests exhibiting a decline in function not indicative of true deficit. Some variability in scores where the participant initially showed improvement and then a decline during a particular test may be explained in this way. Specifically, the 6MWT showed an increase in distance in all test sessions except at the six-month follow-up. During this testing session, the 6MWT was the last test administered to the participant, who may have been fatigued and thus demonstrated a decrease in walking distance. Finally, it should be noted that the device itself, not necessarily the VE, might have contributed to a lack of improvements in these various tests. For example, the games are not played in the "first person" but rather are third person mediated. In other words, the person's image is projected on the screen instead of the screen being what the person would be seeing if a camera were attached to their forehead. Secondly, the games themselves are not modifiable. Therefore, some of the games may be too difficult to perform even at their lowest levels. In the future it would be beneficial to either develop the ability to modify these games or develop new games that address the specific needs of each individual.

It is unknown if regular training with the Sony Eyetoy affords equal or greater benefit than other types of independent exercise. The gains achieved may result from the commencement of a new daily exercise regimen and have occurred with any new form of training. However, as this individual was a trained physical therapist already performing a daily exercise routine prior to starting the study, this explanation is unlikely. Moreover, as a purpose of this case report was to explore the *motivational* aspects of a gaming-based exercise program, any improvement represents a meaningful result. Further study with a large sample size and control group could describe the relative benefit of Eyetoy VR training as compared to other self-directed forms of exercise, while simultaneously exploring secondary issues such as enjoyment and associated compliance.

Our participant represents a specific set of limitations following CVA and therefore captures the relevance of Sony Eyetoy VR training for these conditions. She was a fairly high-functioning former physical therapist who understood the fundamental importance of exercise and was motivated to exploit principles of motor control/learning and plasticity following her stroke. She had already completed traditional physical therapy and, prior to beginning this study, was engaged in daily activities to recover from her injury. Despite this unique participant and her professional knowledge, she demonstrated significant gains following VR exercise.

Further study is needed to examine the training outcomes for varied levels of disability following CVA, particularly for those with more severe restrictions. In a study exploring the benefits of a VR system designed to retrain hand function, Merians et al[11] found less improvement for individuals with more severe impairments. In a VR system that does not specifically encourage a particular function, individuals may be more inclined to resort to compensatory strategies to accomplish game tasks, resulting in the promotion of faulty movement patterns. Because cognitive reorganization occurs with repetitive practice, this is of particular concern with this population, as it carries the possibility of facilitating a pattern of trained disuse. In the Bobath approach to rehabilitation, this concern is addressed by limiting the progression of functional training until normal movement patterns are established.[67] Approaches with the more severely limited population may need to be modified to allow therapist-assisted training in conjunction with the VR technology in order to support optimum movement choices.

Compliance issues are common in physical therapy, leading to less than optimal outcomes. Identified barriers to compliance include a lack of interest, depression, and low outcomes expectation.[34] While traditional therapeutic activities can involve repetitive tasks that offer no emotional reward, VR creates an experience that is fundamentally engaging. In fact, following its release in 2003, the initial Eyetoy spent four consecutive weeks as the top selling game in the UK. Because movement is performed within the context of a game, it is perceived less as exercise and more as *play*. A player can experience an exhilarating feeling when a particular task is accomplished with visual and auditory feedback that applauds the action (a virtual player is knocked out or a ping-pong ball breaks through glass, for instance). The participant commented:

> If I were running a PT department, I'd want to have [a Sony Eyetoy] for people who don't like exercise, [who] don't want to keep doing something that they dislike, not understanding what it's doing for them. I just lose time. And I like to lose time . . . doing exercise. And it has such a wide variety . . . everybody likes playing games.

As the participant is a former physical therapist, this opinion is offered from an experienced perspective. For the individual that feels an emotional drive to win a game, there is an inherent motivation to participate in the activity and, perhaps, to creatively explore new movement choices.

VR is a highly adaptable technology that, in contrast with other more expensive VR or biofeedback technologies designed for use in the clinic or laboratory, can be easily set up in the individual's own environment. Additionally, the use of the Sony Eyetoy can be adjusted to accommodate a wide variety of stages in recovery, as it can be used with those who are ambulatory, those beginning to work on standing balance, or those who use a wheelchair as a primary means of mobility. The potential convenience of this system makes it appealing. Even during the early stages of stroke recovery, therapy is typically performed for three hours a day, resulting in long periods of time spent immobile within the confined space of a hospital room. VR systems may provide a way for general movement and exercise to be performed safely with minimal supervision in this context.

Individuals with residual deficits following a CVA have demonstrated improvement in function long after acute stages of stroke recovery.[68–70] Given that stroke survivors typically exhaust traditional options for physical therapy within approximately two to four months, available treatment may be insufficient to realize full potential for recovery. Given the implications for long-term improvement in quality of life, as well as a possible decline in costs associated with long-term stroke care, the development of rehabilitation opportunities in chronic stroke seems essential. Perhaps the best evidence that the participant in this case report found the Sony Eyetoy a relevant form of training is that she reported purchasing her own upon the completion of the study. She continues to play on a regular basis and has reported that it is a fun activity both she and her grandson participate in together.

SUMMARY

The improvements demonstrated by the participant in this case study present preliminary evidence for the effectiveness of low-cost VR sensory and motor retraining. Challenges to balance, proprioception, coordination, and motor planning with concurrent visual and auditory feedback may provide an environment conducive to sensorimotor recovery. As no adverse effects were noted during the gaming sessions, self-directed training in the home environment can be assumed to be relatively safe, even for the older adult. Furthermore, the training was found to be engaging and motivating for this individual, in a way that other forms of exercise were not. The objective of this research was not to look at replacing traditional physical therapy options, but to explore low-cost VR gaming as an adjunct to these options. Commonly available VR systems may have a role to play in a treatment gap, creating therapeutic alternatives that are effective, inexpensive, and result in a decrease in hospital expenses over a lifetime.

REFERENCES

1. Gresham GE, Fitzpatrick TE, Wolf PA, et al. Residual disability in survivors of stroke–the Framingham study. *N Engl J Med*. 1975;293: 954–956.
2. American Heart Association. Heart disease and stroke statistics-2006 update. *Circulation*. 2006;(113):e85–e151.

3. Tyson SF, Hanley M, Chillala J, et al. Balance disability after stroke. *Phys Ther*. 2006;86:30-38.
4. Duncan P, Richards L, Wallace D, et al. A randomized, controlled pilot study of a home-based exercise program for individuals with mild and moderate stroke. *Stroke*. 1998;29:2055–2060.
5. Duncan P, Studenski S, Richards L, et al. Randomized clinical trial of therapeutic exercise in subacute stroke. *Stroke*. 2003;34:2173–2180.
6. Potempa K, Lopez M, Braun LT, et al. Physiological outcomes of aerobic exercise training in hemiparetic stroke patients. *Stroke*. 1995; 26:101–105.
7. Dean CM, Shepherd RB. Task-related training improves performance of seated reaching tasks after stroke. A randomized controlled trial. *Stroke*. 1997;28:722–728.
8. McCloy R, Stone R. Science, medicine, and the future: virtual reality in surgery. *BMJ*. 2001;323:912–915.
9. Ungs TJ. Simulator induced syndrome: evidence for long-term aftereffects. *Aviat Space Environ Med*. 1989;60:252-255.
10. Rizzo A, Pair J, McNerney PJ, et al. Development of a VR therapy application for Iraq war military personnel with PTSD. *Stud Health Technol Inform*. 2005;111:407–413.
11. Merians AS, Jack D, Boian R, et al. Virtual reality-augmented rehabilitation for patients following stroke. *Phys Ther*. 2002;82:898–915.
12. Kuttuva M, Boian R, Merians A, et al. The Rutgers Arm, a rehabilitation system in virtual reality: a pilot study. *Cyberpsychol Behav*. 2006;9: 148–151.
13. Henderson A, Korner-Bitensky N, Levin M. Virtual reality in stroke rehabilitation: a systematic review of its effectiveness for upper limb motor recovery. *Top Stroke Rehabil*. 2007;14:52–61.
14. Jaffee DL, Brown DA, Pierson-Crey C, et al. Stepping over obstacles to improve walking in individuals with poststroke hemiplegia. *J Rehabil Res Dev*. 2004;41:283–292.
15. Kwon Y, Joong HK, Mi YL, et al. Recovery in chronic stroke: an experimenter-blind randomized study virtual reality-induced cortical reorganization and associated locomotor. *Stroke*. 2005;36:1166–1171.
16. Deutsch JE, Merians AS, Adamovich S, et al. Development and application of virtual reality technology to improve hand use and gait of individuals post-stroke. *Restor Neurol Neurosci*. 2004;22:371–386.
17. Deutsch JE, Paserchia C, Vecchione C, et al. Improved gait and elevation speed in individuals post-stroke after lower extremity training in virtual environments. *J Neurol Phys Ther*. 2004;28:185–186.
18. Fung J, Richards CL, Malouin F, et al. A treadmill and motion coupled virtual reality system for gait training post-stroke. *Cyberpsychol Behav*. 2006;9:157–162.
19. Bryanton C, Bosse J, Brien M, et al. Feasibility, motivation, and selective motor control: virtual reality compared to conventional home exercise in children with cerebral palsy. *Cyberpsychol Behav*. 2006;9: 123–128.
20. Ferrarin M, Brambilla M, Garavello L, et al. Microprocessor-controlled optical stimulating device to improve the gait of patients with Parkinson's disease. *Med Biol Eng Comput*. 2004;42:328–332.
21. Jack D, Boian R, Merians AS, et al. Virtual reality-enhanced stroke rehabilitation. *IEEE Trans Neural Syst Rehabil Eng*. 2001;9:308–318.
22. Krakauer JW. Motor learning: its relevance to stroke recovery and neurorehabilitation. *Curr Opin Neurol*. 2006;19:84–90.
23. Winstein CJ, Merians AS, Sullivan KJ. Motor learning after unilateral brain damage. *Neuropsychologia*. 1999;37:975–987.
24. Langhorne P, Wagenaar R, Partridge C. Physiotherapy after stroke: more is better? *Physiother Res Int*. 1996;1:75–88.
25. Shumway-Cook AA, Anson DD, Haller SS. Postural sway biofeedback: its effect on reestablishing stance stability in hemiplegic patients. *Arch Phys Med Rehabil*. 1988;69:395–400.
26. Sackey CCM, Lincoln NNB. Single blind randomized controlled trial of visual feedback after stroke: effects on stance symmetry and function. *Disabil Rehabil*. 1997;19:536–546.
27. Cheng PT, Wang CM, Chung CY, et al. Effects of visual feedback rhythmic weight-shift training on hemiplegic stroke patients. *Clin Rehabil*. 2004;18:747–753.
28. Engardt M, Knutsson E. Dynamic thigh muscle strength after auditory feedback training of body weight distribution in stroke patients. *Physiother Theory Pract*. 1994;10:103–112.
29. Rizzo AA, Wiederhold M, Buckwalter JG. Basic issues in the use of virtual environments for mental health applications. *Stud Health Technol Inform*. 1998;58:21–42.
30. Betker AL, Szturm T, Moussavi ZK, et al. Video game-based exercises for balance rehabilitation: a single-subject design. *Arch Phys Med Rehabil*. 2006;87:1141–1149.
31. Riva G. Virtual reality in paraplegia: a VR-enhanced orthopaedic appliance for walking and rehabilitation. *Stud Health Technol Inform*. 1998; 58:209–218.
32. Kizony R, Raz L, Katz N, et al. Video-capture virtual reality system for patients with paraplegic spinal cord injury. *J Rehabil Res Dev*. 2005;42: 595–608.
33. Stansfield S, Dennis C, Suma E. Emotional and performance attributes of a VR game: a study of children. *Stud Health Technol Inform*. 2005;111:515–518.
34. Forkan R, Pumper B, Smyth N, et al. Exercise adherence following physical therapy intervention in older adults with impaired balance. *Phys Ther*. 2006;86:401–410.
35. Siebens H, Aronow H, Edwards D, et al. A randomized controlled trial of exercise to improve outcomes of acute hospitalization in older adults. *J Am Geriatr Soc*. 2000;48:1545–1552.
36. Plonczynski DJ. Measurement of motivation for exercise. *Health Educ Res*. 2000;15:695–705.
37. Dobkin BH. Behavioral, temporal, and spatial targets for cellular transplants as adjuncts to rehabilitation for stroke. *Stroke*. 2007;38(2):832–839.
38. Jang SH, You SH, Hallett M, et al. Cortical reorganization and associated functional motor recovery after virtual reality in patients with chronic stroke: an experimenter-blind preliminary study. *Arch Phys Med Rehabil*. 2005;86(11):2218–2223.
39. Piron L, Tonin P, Picione F, Iaia V, Trivello E, Dam M. Virtual environment training therapy for arm motor rehabilitation. *Presence*. 2005;14(6):732–740.
40. Boian R, Sharma A, Han C, et al. Virtual reality-based post-stroke hand rehabilitation. *Stud Health Technol Inform*. 2002;85:64–70.
41. Gladstone DJ, Danells CJ, Black SE. The fugl-meyer assessment of motor recovery after stroke: a critical review of its measurement properties. *Neurorehabil Neural Repair*. 2002;16(3):232–240.
42. Malouin F, Pichard L, Bonneau C, et al. Evaluating motor recovery early after stroke: comparison of the Fugl-Meyer Assessment and the Motor Assessment Scale. *Arch Phys Med Rehabil*. 1994;75(11):1206–1212.
43. Arsenault AB, Dutil E, Lambert J, et al. An evaluation of the hemiplegic subject based on the Bobath approach. Part III. A validation study. *Scand J Rehabil Med*. 1988;20(1):13–16.
44. Duncan PW, Propst M, Nelson SG. Reliability of the Fugl-Meyer assessment of sensorimotor recovery following cerebrovascular accident. *Phys Ther*. 1983;63(10):1606–1610.
45. Fugl-Meyer AR. Post-stroke hemiplegia assessment of physical properties. *Scand J Rehabil Med Suppl*. 1980;7:85–93.
46. Razmjou H, Bean A, van Osnabrugge V, et al. Cross-sectional and longitudinal construct validity of two rotator cuff disease-specific outcome measures. *BMC Musculoskelet Disord*. 2006;7:26.
47. Groth-Marnat G, Schumaker JF. Hypnotizability, attitudes toward eating, and concern with body size in a female college population. *Am J Clin Hypn*. 1990;32(3):194–200.
48. Aben I, Verhey F, Lousberg R, et al. Validity of the beck depression inventory, hospital anxiety and depression scale, SCL-90, and hamilton depression rating scale as screening instruments for depression in stroke patients. *Psychosomatics*. 2002;43(5):386–393.
49. Gallagher D, Nies G, Thompson LW. Reliability of the Beck Depression Inventory with older adults. *J Consult Clin Psychol*. 1982;50(1):152–153.
50. Beck AT, Ward CH, Mendelson M, et al. An inventory for measuring depression. *Arch Gen Psychiatry*. 1961;4:561–571.
51. Berg KO, Wood-Dauphinee SL, Williams JI, et al. Measuring balance in the elderly: validation of an instrument. *Can J Public Health*. 1992;83 Suppl 2:S7–S11.
52. Shumway-Cook A. Predicting the probability for falls in community-dwelling older adults. *Phys Ther*. 1997;77(8):812.
53. Berg K. The Balance Scale: reliability assessment with elderly residents and patients with an acute stroke. *Scand J Rehabil Med*. 1995;27(1):27.
54. Hall CD, Schubert MC, Herdman SJ. Prediction of fall risk reduction as

measured by dynamic gait index in individuals with unilateral vestibular hypofunction. *Otol Neurotol*. 2004;25(5):746–751.
55. Whitney SL, Hudak MT, Marchetti GF. The dynamic gait index relates to self-reported fall history in individuals with vestibular dysfunction. *J Vestib Res*. 2000;10(2):99–105.
56. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res*. 1975;12(3):189–198.
57. Appelros P. Characteristics of Mini-Mental State Examination 1 year after stroke. *Acta Neurologica Scandinavica*. 2005;112(2):88–92.
58. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc*. 1991; 39(2):142–148.
59. Shumway-Cook A, Brauer S, Woollacott M. Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. *Phys Ther*. 2000;80(9):896–903.
60. Harada N, Chiu V, Damron-Rodriguez J, et al. Screening for balance and mobility impairment in elderly individuals living in residential care facilities. *Phys Ther*. 1995;75(6):462–469.
61. Enright PL, McBurnie MA, Bittner V, et al. The 6-min walk test: a quick measure of functional status in elderly adults. *Chest*. 2003;123:387–398.
62. Uswatte G, Taub E, Morris D, et al. Reliability and validity of the upper-extremity Motor Activity Log-14 for measuring real-world arm use. *Stroke*. 2005;36(11):2493–2496.
63. Gregson JM, Leathley M, Moore AP, et al. Reliability of the Tone Assessment Scale and the modified Ashworth scale as clinical tools for assessing poststroke spasticity. *Arch Phys Med Rehabil*. 1999;80(9): 1013–1016.
64. Duncan PW, Weiner DK, Chandler J, et al. Functional reach: a new clinical measure of balance. *J Gerontol*. 1990;45(6):M192–197.
65. Hyndman D, Asburn A, Stack E. Fall events among people with stroke living in the community: circumstances of falls and characteristics of fallers. *Arch Phys Med Rehabil*. 2002;83(2):165.
66. Whitney SL, Poole JL, Cass SP. A review of balance instruments for older adults. *Am J Occup Ther*. 1998;52(8):666–671.
67. Lennon SS, Baxter DD, Ashburn AA. Physiotherapy based on the Bobath concept in stroke rehabilitation: a survey within the UK. *Disabil Rehabil*. 2001;23(6):254–262.
68. Wolf SL, Winstein CJ, Miller JP, et al. Effect of constraint-induced movement therapy on upper extremity function 3 to 9 months after stroke: the EXCITE randomized clinical trial. *JAMA*. 2006;296(17): 2095–2104.
69. Wolf SL, Lecraw DE, Barton LA, et al. Forced use of hemiplegic upper extremities to reverse the effect of learned nonuse among chronic stroke and head-injured patients. *Exp Neurol*. 1989;104(2):125–132.
70. Kunkel A, Kopp B, Muller G, et al. Constraint-induced movement therapy for motor recovery in chronic stroke patients. *Arch Phys Med Rehabil*. 1999;80 (6):624–628.