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Developing Home-Based Virtual Reality Therapy Interventions

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Abstract

Objective: Stroke is one of the leading causes of serious long-term disability. However, home exercise programs given at rehabilitation often lack in motivational aspects. The purposes of this pilot study were (1) create individualized virtual reality (VR) games and (2) determine the effectiveness of VR games for improving movement in upper extremities in a 6-week home therapy intervention for persons with stroke.
Subjects and Methods: Participants were two individuals with upper extremity hemiparesis following a stroke. VR games were created using the Looking Glass programming language and modified based on personal interests, goals, and abilities. Participants were asked to play 1 hour each day for 6 weeks. Assessments measured upper extremity movement (range of motion and Action Research Arm Test [ARAT]) and performance in functional skills (Canadian Occupational Performance Measure [COPM] and Motor Activity Log [MAL]).
Results: Three VR games were created by a supervised occupational therapist student. The participants played approximately four to six times a week and performed over 100 repetitions of movements each day. Participants showed improvement in upper extremity movement and participation in functional tasks based on results from the COPM, ARAT, and MAL.
Conclusions: Further development in the programming environment is needed to be plausible in a rehabilitation setting. Suggestions include graded-level support and continuation of creating a natural programming language, which will increase the ability to use the program in a rehabilitation setting. However, the VR games were shown to be effective as a home therapy intervention for persons with stroke. VR has the potential to advance therapy services by creating a more motivating home-based therapy service.

Introduction

Stroke is one of the leading causes of serious long-term disability.[1] About 65% of the people in the United States who have survived a stroke live with minor to severe impairments, such as hemiparesis.[2] Although the benefits of rehabilitation have been shown to be effective, stroke patients are receiving less therapy and discharged home sooner (because of economic pressures on the U.S. healthcare system).[3] Lang et al.[4] showed current patients recovering from a stroke were conducting only 10–40 repetitions of a strengthening movement during a therapy session. However, animal models have suggested hundreds of repetitions are needed to improve functional arm movements.[4]

One creative solution to these issues is using virtual reality (VR). Benefits of VR include presenting a real-life yet safe environment to the patient and providing immediate feedback based on the client's responses. The use of VR has the possibility to increase the duration, frequency, and intensity of therapy to help retrain the patient's movements.[2]

For this study, a VR therapeutic intervention was created to provide massed practice, auditory and visual feedback, and a motivating user interface. A third-year doctoral occupational therapist (OT) student with supervision from an OT on staff with prior experience working with persons with stroke created the games. Prior to this study, the OT student performed a review of literature, observed OTs working in the clinical setting, and held focus groups with therapists and persons with stroke to gain a better understanding of the needs required. The two case studies will help to illustrate the plausibility of a rehabilitation therapist creating therapeutic games and the effectiveness of the VR games to improve function in the upper extremities in persons with stroke.

Subjects and Methods

Participants were recruited through faculty in the Program of Occupational Therapy at Washington University in St. Louis, MO. The criteria to be a participant was (1) having had an ischemic or hemorrhagic stroke and being at least 1 year

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post-cerebrovascular accident, (2) being between the ages of 40 and 80 years, (3) having upper extremity hemiparesis affecting the right or left arm, (4) reading and comprehending English at a sixth grade reading level, and (5) comprehending auditory and/or visual directions given through a computer medium. Participants were excluded from the project if they (1) could not give informed consent or (2) had a score of 2 or greater on the aphasia and neglect items on the National Institutes of Health Stroke Scale.

Case descriptions

Patient 1 was a 57-year-old woman who had had a stroke 10 years ago resulting in left hemiparesis. She was previously left hand dominant and independent in all her activities of daily living. Since her stroke, she stopped working at an international shipping company and worked as a dog walker. Her husband assisted her with cooking, cutting her meals, zipping zippers, and doing laundry. She enjoyed gardening and dogs and dreamed of riding a horse. Some of her goals included using her affected arm to independently shave under her arms, dressing herself, and gardening. She had minimally used a computer at her former workplace, with no previous experience playing computer games.

Patient 2 was a 48-year-old woman who had had a stroke 1.5 years ago, resulting in left hemiparesis. Before her stroke, she had worked as a live-in caregiver. She was right hand dominant and was independent in all her activities of daily living. Since her stroke, she had stopped working. Her family assisted with washing her laundry and cleaning the house. She only used her unaffected arm to cook, wash dishes, fold her laundry, and make the bed. The patient's goals included using her affected arm to independently bath, shop at the mall, fold and hang clothes, and play cards. She had had no previous experience playing computer games.

Measurements

The Canadian Occupational Performance Measure (COPM) was used to identify the participant's goals and priorities. The COPM is an individualized measure designed for use by OTs to detect changes in a client's self-perception of occupational performance over time.[5] The COPM helps to identify specific areas of concern from three domains (Self-care, Productivity, and Leisure). The COPM has a test–retest reliability of 0.89–0.88.

The Motor Activity Log (MAL) is a scripted, structured interview that was developed to measure the use of the impaired arm in persons with stroke.[6] MAL has a test–retest reliability of 0.91 and internal consistency of 0.81.[7] More activities were added to the standardized MAL for this study to gain a better understanding of the participant's perceived improvement.

The Action Research Arm Test (ARAT) assesses upper extremity function. The ARAT is a criterion-rated assessment of upper extremity activity limitations.[8] The ARAT includes 19 items divided into four subscales: Grasp, Grip, Pinch, and Gross Movement. The items within each subtest are ordered based on a 4 point ordinal scale ranging from 0 to 3, where 0 represents no movement possible and 3 represents normal performance of the task. A score of 57 indicates normal movement. The test has intrarater reliability and interrater reliability as well as validity.

A goniometer was used to measure the participant's current range of motion (ROM) for the shoulder, elbow, and wrist. The ROM information was also used in choosing an appropriate VR game and degree of difficulty suitable for the participant.

The number of movement repetitions and the amount of time played for each VR game were also recorded. A recorded repetition did not always mean a movement was completed, but that a substantial effort was made toward accomplishing that specific movement.

Intervention

Devices. The Wii™ (Nintendo® of America, Redmond, WA) remotes (Wiimotes) were used during the games to detect the participants' shoulder and arm motions. The Wiimote had an infrared camera sensor that tracked the movements on the arm conducted and a speaker to provide auditory feedback. The Bluetooth® (Bluetooth SIG, Kirkland, WA) on the Wiimote also allowed for a connection to a personal computer, providing the capability for customized games to be created.[9] These features allowed the games to be developed without using the Wii system itself. A Webcam and a colored tracking object (e.g., colored sock) were also used to detect and track the participants' shoulder and arm movements (Fig. 1).

VR games. The VR games were created by an OT student researcher in collaboration with the Department of Computer Science and Engineering at Washington University (Fig. 2). Games were created using the Looking Glass, a programming language that uses a drag and drop method, enabling people without computer science degrees to create games.[10] The Looking Glass is the successor to Storytelling Alice, which was created to encourage and enable middle school students to program three-dimensional animated stories.[11] This study was the first time the programming language was used by an OT student researcher to create games that would be implemented as a therapeutic intervention.

Before the games were created, the researcher interviewed each of the participants, asking about specific interests, hobbies, and dislikes. The information found from the interviews along with the results from the COPM was used to help create the initial games, including the setting, objects used, and the actions associated with the objects.

For the organization and recycling game, the participant controlled a virtual hand and placed food and non-food items

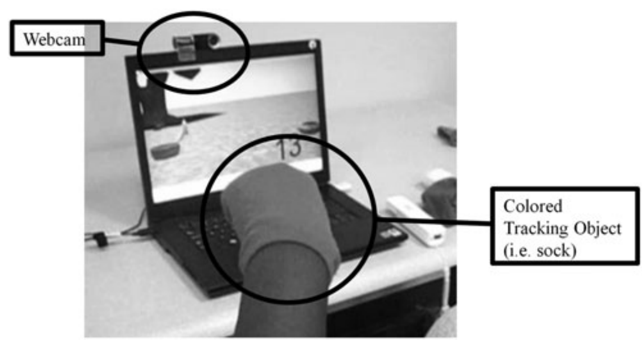

FIG. 1. General setup of a game using a Webcam and a colored sock to track arm movement.

FIG. 2. Examples of the games created for the participants: **(left)** the organization game, **(center)** the horse riding game, and **(right)** the bike riding game.

to its appropriate basket. Items were objects the participant expressed having interest in during the semistructured interviews. A point was given if the item was placed correctly. Auditory and visual feedback was provided when the participant placed the item either correctly or incorrectly. This game utilized the Webcam and a colored sock the participant wore on her hand to track her movement. A combination of movements, including shoulder and elbow flexion and extension and horizontal abduction, was required to complete the task.

In the horse riding game, the participant controlled when the horse jumped over various objects. A point was given if the horse was able to completely jump over the object and was deducted if not. Auditory and visual feedback was also given based on each jump. This game utilized the Wiimote, which was strapped on the participant's humerus to detect flexion and extension movements of the shoulder.

In the bike riding game, the participant controlled the movements of a virtual bike rider running over objects she disdained. A point was given for every object she was able to run over. Auditory feedback was given throughout the game. This game utilized the Wiimote, which the patient held in her hand to detect supination and pronation movements.

The helicopter flying game was created by the computer scientist and consisted of the participant controlling the elevation level of the helicopter while flying. Points were given if the helicopter was able to fly over a building. The difficulty level was increased automatically the longer the participant played the game. This game utilized the Wiimote, which was strapped on the participant's humerus to detect abduction and adduction movements on the shoulder.

Home therapy. Both participants participated in a 6-week home-based therapeutic intervention program. Each participant was given a laptop with the three games loaded on, Wiimotes, Webcam, and colored socks to track movements. The participant was asked to play each of the three games at home for 20 minutes, totaling 1 hour per day, for 7 days a week. A journal log was given to the participant to write down opinions about the games and any functional changes noted in daily activities. The participant met with the student researcher and computer scientist once a week to discuss these topics and to allow the researcher to modify the games based on her needs. The computer scientist assisted with technical support and modifying the code for the Looking Glass program to enable the OT student researcher to make changes on the games.

Results

Participant 1

Over the 6-week intervention, Patient 1 played on average 5–6 days a week. Combining all the arm movements together, she did approximately 430 repetitions of movements each day, totaling over 12,000 repetitions of movements during the intervention. She demonstrated increased range of motion, especially in shoulder flexion, abduction, and supination in her forearm, as shown in Table 1. She also improved her ARAT scores as shown in Figure 3. Overall, she had a 5 point change from improvements in the Pinch and Grasp subtests. On the COPM, she increased her perception for performance satisfaction in shaving under her arms and putting on a bra. Overall, a 1 point change was found in the Performance and Satisfaction scores.

Functional changes undetected from the standardized assessments were also found. Three weeks into the intervention, Patient 1 noted her left (affected) hand having a better grip while washing dishes. At post-intervention, she was able to wash under her arms, open and close latches in public restrooms, and hold soap in her hand. Improvements in bimanual tasks included zipping her own coat, cutting her own food, and assisting with laundry. She also noted improvements in her grip strength, which allowed her to complete tasks with better ease such as assisting with laundry, holding onto the leash when walking the dog, and opening bags and boxes of cereal.

Participant 2

By the end of the 6-week intervention, Patient 2 played on average 4 days a week. Combining all the arm movements together, she did approximately 100 repetitions of movements each day, totaling over 2,400 repetitions of movements during the intervention. Increased ROM for shoulder abduction, internal rotation, and external rotation was also noted by the end of the intervention as shown in Table 2. She

Table 1. Changes in Range of Motion Measurements for the First Participant

Upper extremity movement	*Baseline*	*Mid-intervention*	*Final*
Shoulder flexion	73°	100°	101°
Shoulder abduction	80°	75°	98°
Supination	30°	30°	44°

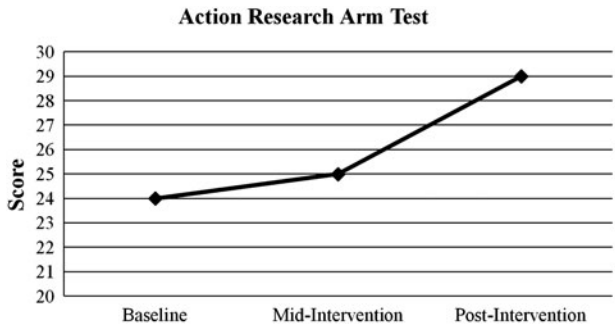

FIG. 3. Results from the Action Research Arm Test for the first participant indicating a 5 point change in upper extremity function.

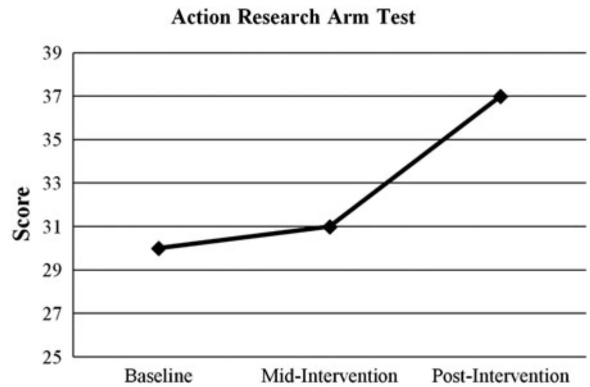

FIG. 4. Results from the Action Research Arm Test for the second participant indicating a 7 point change in upper extremity function.

improved her ARAT scores as shown in Figure 4. Overall she had a 7 point change, with improvements found especially in the Pinch subtest. According to the COPM, her perception of changes was found in her ability to hold and play cards as well as hanging her clothes. She showed a 1.6 point increase in her Performance score and a 1.8 point increase in her Satisfaction score.

The MAL, with modifications for this study, helped detect functional changes throughout the intervention. Patient 2 demonstrated improved use of her affected arm in wiping off the kitchen counter, picking up a cup by the handle, cutting food with a fork and knife, and cooking a meal. More functional changes were reported that were not detected with the MAL. She noted improvement in her grip strength, which allowed her to hold onto dishes when washing and onto skillets and pots while cooking and to grab clothes from the rack while clothes shopping. Other improvements in bimanual tasks included folding her clothes, tying her shoes, sweeping, and mopping the floors.

Discussion

The purpose of the project was to determine the effectiveness of individualized VR computer games for improving movement in upper extremities for persons with stroke. Without any programming experience, the OT student researcher was able to create individualized therapeutic games with help from the computer scientists for both participants in this study. Games were modified based on the participants' opinions and improvements in the arm. Background music was added, which provided more enjoyment in playing the games. Later, auditory feedback was included to notify the participant when a task was completed correctly or incorrectly. Visual positive reinforcement was also provided to encourage the participant to complete the game. Overall, these modifications allowed for variability, creating more interests in the games.

Table 2. Changes in Range of Motion Measurements for the Second Participant

Upper extremity movement	*Baseline*	*Mid-intervention*	*Final*
Shoulder			
Extension	33°	40°	45°
Abduction	84°	124°	133°
Internal rotation	18°	22°	45°
External rotation	43°	46°	65°
Wrist			
Flexion	10°	12°	40°
Extension	5°	10°	20°
Ulnar deviation	15°	15°	20°

Other studies have used gaming applications such as the Sony Playstation® 2 EyeToy® (Sony Computer Entertainment, Tokyo, Japan) and the Wii as a rehabilitation tool and have found improvements in upper and lower extremities.[12–16] However, none of these studies had games created by a therapist or were tested in the home setting. The games created by the OT student researcher were shown to be effective for both participants and functional improvements were seen. The games motivated both participants to complete hundreds of repetitions, which research has suggested are needed in order to evoke lasting motor changes.[4]

Previously, it was theorized motor recovery could only be found in the first 6 months after stroke, with only minor improvements afterward.[17] However, the first participant, 10 years post-stroke, and the second, 1.5 years post-stroke, showed functional improvements after the intervention. This study enhances the notion that changes can continue to occur 6 months post-stroke due to neuroplasticity.

A typical concern is if older adults can effectively use VR technology. Older adults tend to be less familiar with computers. The first participant had very minimal computer knowledge. During the beginning of the intervention, she had difficulty controlling the mouse and calibrating the movements before each game, which resulted in frustration. Simplifying the setup process resulted in less frustration and allowed the participant to enjoy playing the games. Functional changes observed by the participant along with the modifications made to the games motivated her to continue playing them throughout the intervention. By the end of the study, she felt more at ease in completing different tasks at home, recognizing her improved grip strength and range of motion in the arm. Similar improvements were shown in a study by Jack et al.,[2] who looked at three people with motor deficits and found even the oldest person at the age of 83 years was able to show positive effects from VR training. Our study continues the notion that VR rehabilitation can be beneficial to older adults as well.

Limitations

Some limitations included only having a small sample size of two. As such, statistical significance and overall generalization cannot currently be found until we have a larger sample. Testing our first participant, we were unable to track all the functional changes that occurred as a result of the intervention. Further development will be needed in choosing more appropriate assessments that will help quantify any functional changes.

Further development

Although the games were shown to be effective, further development can be made to improve the plausibility of the Looking Glass software in the rehabilitation setting. As the program is still in its pilot stage as a therapeutic intervention, the OT student researcher received some help to code certain functions from the computer scientists, which is not plausible for therapists in the clinic. Each game also took a few days to create the basic concept and hours every week to modify. In a rehabilitation setting, this amount of time spent would not possible.

Incorporating a more natural programming language may help to create the games more efficiently. Providing graded levels of support on the software will help accommodate for the therapists' proficiency level in computer skills. Therefore, a therapist with minimal computer skills can choose a game that is almost completed and add in details to help individualize it for the patient. However, another therapist may want to start completely from scratch and should be allowed opportunities to individualize the game from beginning to end.

Conclusions

This study reinforces the notion that changes can continue to occur 6 months post-stroke due to neuroplasticity. The functional improvements from the two participants suggest VR, as a home therapy intervention, has the ability to create a motivating environment that is individualized to patients, encouraging massed practice of repetitious movements. Further research still needs to be done for the Looking Glass software to be implemented in the rehabilitation setting. However, it is hoped this technology will help to further advance therapy services.

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Author Disclosure Statement

No competing financial interests exist.

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