CYBERPSYCHOLOGY & BEHAVIOR
Volume 9, Number 2, 2006

The Rutgers Arm, a Rehabilitation System in Virtual Reality: A Pilot Study

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ABSTRACT

Stroke is one of the leading causes of death and disability worldwide. Its prevalence calls for innovative rehabilitation methods. The Rutgers Arm is a novel upper extremity rehabilitation system consisting of a low-friction table, three-dimensional (3D) tracker, custom forearm support, PC workstation, library of Java 3D virtual reality (VR) exercises, clinical database module, and a tele-rehabilitation extension. The system was tested on a chronic stroke subject, under local and tele-rehabilitation conditions, over 5 weeks of training. Results show improvements in arm motor control and shoulder range of motion, corresponding to improved Fugl-Meyer test scores. Exercise duration, level of difficulty, and patient motivation were maintained under tele-rehabilitaion. A 1-week retention trial showed that gains were maintained.

INTRODUCTION

STROKE is the third leading cause of death and disability worldwide,[1] with over 750,000 Americans experiencing a stroke yearly. Physical therapy is generally stopped after 6–9 months, despite rehabilitation science evidence of the potential for improving motor function years after stroke.[2,3] Acute rehabilitation currently concentrates on the lower extremity, with less time spent on arm and hand activities. Therefore, 30–66% of stroke survivors will not regain use of their affected arm.[4]

Virtual reality (VR) addresses these needs through the intensity and duration of training it can provide, through improved motivation, objective performance measures, and the ability to monitor patients at a distance.[5] Several experimental VR rehabilitation systems exist for different limb segments affected by stroke. University of California Irvine developed a joystick-based system for wrist tele-rehabilitation.[6] Researchers at MIT used trackers in "teaching-by-example" simulations to remotely train a variety of functional arm movements in patients post-stroke.[7] Researchers in the United Kingdom developed the Gentle system that uses a combination of the Haptics Master robot and VR to train arm movements post-stroke.[8] This article describes the Rutgers Arm,[9] a system that trains shoulder movements through game-like VR exercises.

Experimental system

The Rutgers Arm (Fig. 1A) consists of a dual-processor PC, a tracker (Polhemus Fastrak[10]), a custom-designed low-friction table and armrest, Internet connection for tele-rehabilitation, and a

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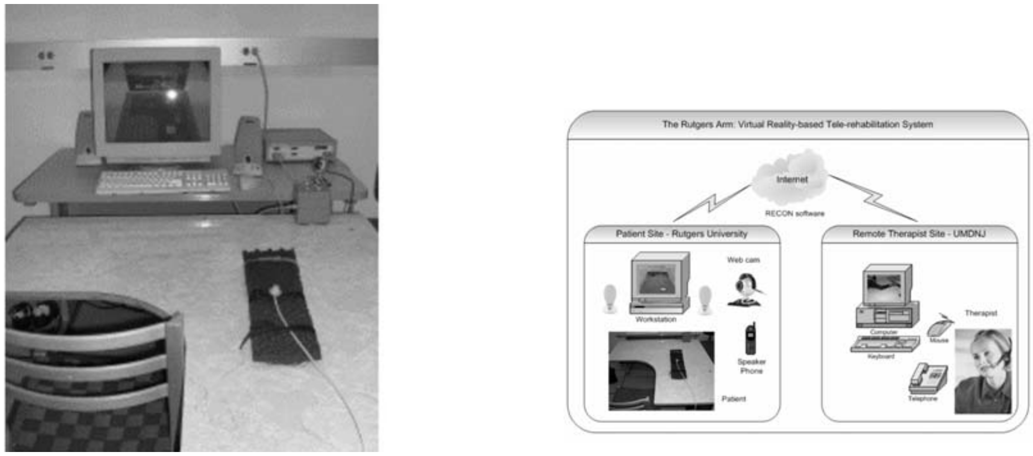

FIG. 1. The Rutgers Arm: system view (**A**) and tele-rehabilitation setup (**B**). © 2005 Rutgers University.

clinical database. The patient sits facing the computer, their arm on the Formica low-friction table supported by a custom armrest. A Posey[11] torso support attached to the patient's chair prevents compensatory trunk motions. A tracker receiver mounted near the patient's wrist measures the arm movements during therapy. The tele-rehabilitation system module (Fig. 1B) uses a similar setup as the local VR arm rehabilitation system, plus a web camera and speakerphone to allow remote patient monitoring. The ReCon[12] media client software is used to set up the connection between the patient's computer and the therapist's computer over the Internet.

At the start of a session, the patient's abduction/adduction (left-right) and flexion/extension (out-in) shoulder motion ranges are measured by the tracker and recorded in a data file. This baseline is used for mapping the real workspace to the virtual workspace and for positioning the objects in the VR scene.

Two Virtual Reality therapeutic games were created using Java3D.[13] The first, a pick-and-place exercise, uses a virtual environment consisting of a room and a proportional replica of the actual rehabilitation table (Fig. 2A). A ball and a square target are placed on the virtual table in different configurations (for lateral, in-out and diagonal shoulder motions). The virtual hand, mapped to the patient's wrist motion is moved along a specified trajectory, for a specified number of pick-and-place trials. The patient is told not to rush, and to follow a prescribed trajectory shown on the virtual table. When the virtual hand is in the proximity of the ball, a "pick-up" intelligent action is triggered, the ball then travels in the hand, and is released once the virtual hand is at the edge of the target box. Thus, this game trains precision

A B

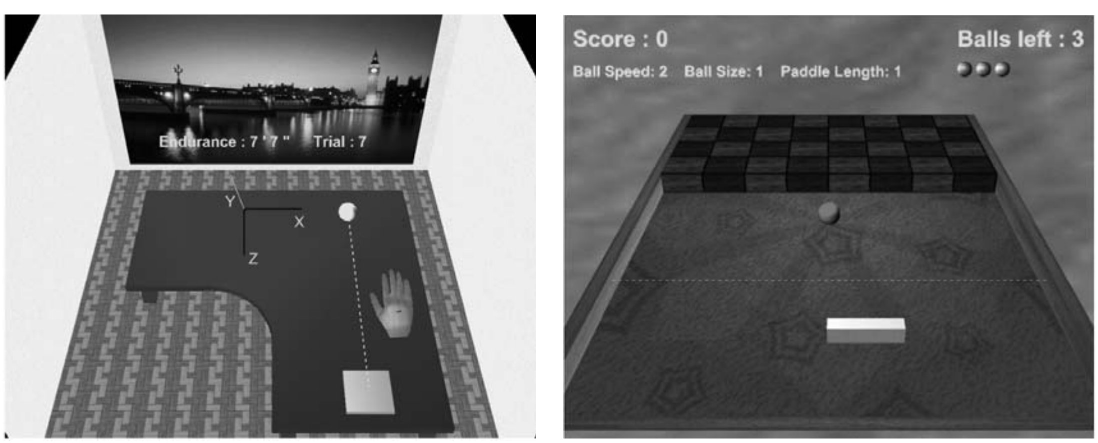

FIG. 2. Simulation exercises: **(A)** Pick-and-place game; **(B)** Breakout3D game. © 2005 Rutgers University.

shoulder motor control, emphasizing the need to follow the prescribed path. The simulation stores the time taken to complete the exercise, distance traveled by the wrist, and errors between the ideal path and the path taken by the patient. The patient receives continuous feedback regarding their hand path and auditory feedback is provided to make the game more engaging and motivating.

The goal of the second exercise is to improve hand-eye coordination and reaction time (Fig. 2B). It is an adaptation of the "Breakout" arcade game,[14] but was programmed from the ground up in our laboratory. The virtual environment consists of a ball, a paddle and a number of blocks placed on a game board. The task is to destroy all the blocks with four available balls, by using the paddle to hit the ball into the blocks. When the ball collides with a block, the block disappears from the table. Each ball destroys only one block for every bounce off the paddle. The difficulty level is set by changing the ball speeds and paddle length. Faster balls and smaller paddles correspond to more difficult games. The emphasis of this game is on speed of movement and coordination. The variables stored are peak wrist velocity, total distance of wrist movement and game completion time. The Euclidean peak velocity and game success rate (blocks destroyed vs. total available) are displayed as feedback to the patient upon game completion.

PILOT STUDY

A 56-year-old male, who had a right hemi-paresis secondary to a left middle cerebral artery infarct sustained 17 months prior to the study, was trained 3 days/week, for 12 sessions of local rehabilitation, followed by three sessions of tele-rehabilitation. There was a 1-week retention session (session 16). The subject showed limited return in his upper extremity, with active movement predominantly in the shoulder region. A Fugl-Meyer test[15] was conducted before and after the 12 sessions of local therapy.

The subject had limited shoulder flexion range at the beginning of the trials. As he underwent more VR therapy, he was able to move his wrist further out on the table surface with his performance continuing to improve during tele-rehabilitation. Total exercise time and total wrist movement per session were used as a measure of shoulder motion endurance (Table 1). The total exercise time went up 28%, and the total wrist translation motion in each session went up 90% by session 15. The subject had a 71% increase in peak Euclidian velocity of the wrist over the duration of therapy. The wrist paths became more consistent and overlapping indicating better shoulder flexion/extension motor control and coordination. During local rehabilitation Fugl-Meyer test scores had a 7 points increase and shoulder range improved 4 points

CONCLUSION

This initial study using the Rutgers Arm showed encouraging results. The system is currently being modified to increase its functionality. Exercise simulations were upgraded to support left-arm affected patients and the flat tabletop was redesigned, with an extra capability to tilt (pitch and roll) in controlled increments. New patient trials are planned.

ACKNOWLEDGMENTS

Work reported here was supported by Rutgers University and the University of Medicine and Dentistry of New Jersey. Leslie Soulen and Rich Szuminshy conducted the clinical trials. This article is based on a paper presented at the International Workshop on Virtual Rehabilitation 2005, Catalina Island, September 2005.

TABLE 1. ARM PERFORMANCE IMPROVEMENT FOR SESSIONS 2 (LOCAL), 12 (LOCAL), AND 15 (REMOTE)

Variable	*Session 2*	*Session 12*	*Session 15*	*Session 2 vs. 12*	*Session 2 vs. 15*
Total wrist displacement	3281 in	4572 in	6238 in	39% increase	90% increase
Average peak Euclidean velocity	17.1 in/sec	26.07 in/sec	29.24 in/sec	52% increase	71% increase
Fugl-Meyer test scores	UE Score 22 ROM 17/24	UE Score 29 ROM 21/24	—	32% increase, 24% increase	—

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