**Proceedings of Medicine Meets Virtual Reality 2002 Conference, IOS Press, pp. 64-70, Newport Beach CA, January 23-26 2002.**

# Virtual Reality-*Based* Post-Stroke Hand Rehabilitation

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**Abstract.**

A VR-based system using a CyberGlove and a Rutgers Master II-ND haptic glove was used to rehabilitate four post-stroke patients in the chronic phase. Each patient had to perform a variety of VR exercises to reduce impairments in their finger range of motion, speed, fractionation and strength. Patients exercised for about two hours per day, five days a week for three weeks. Results showed that three of the patients had gains in thumb range (50-140%) and finger speed (10-15%) over the three weeks trial. All four patients had significant improvement in finger fractionation (40-118%). Gains in finger strength were modest, due in part to an unexpected hardware malfunction. Two of the patients were measured against one-month post intervention and showed good retention. Evaluation using the Jebsen Test of Hand Function showed a reduction of 23-28% in time completion for two of the patients (the ones with the higher degrees of impairment). A prehension task was performed 9-40% faster for three of the patients after the intervention illustrating transfer of their improvement to a functional task.

## 1 Introduction

The American Stroke Association states that stroke is the third leading cause of death in the United States and a major cause for serious, long-term disabilities [1]. Statistics show that there are about four million stroke survivors living today, with 500,000 new cases being added each year. Impairments such as muscle weakness, loss of range of motion, decreased reaction times and disordered movement organization create deficits in motor control, which affect the patient’s independent living. Recent studies have showed that intensive and repetitive training may be necessary to modify neural organization [11,12,13,14] and recover functional motor skills [17,18]. Several authors have reported significant improvement in patients’ daily activities due to higher training intensities, even in the chronic phase of the disease.

The current health care system provides stroke rehabilitation in the acute care hospital setting, in the rehabilitation setting and in the outpatient setting. The frequency of training in the outpatient rehabilitation phase is usually once or twice a week. It is clear that the limited amount of therapy offered by the current system makes it difficult to provide the training intensity needed for neural reorganization and functional changes.

Research is currently focused on various approaches to provide better rehabilitation means for post-stroke patients. Virtual environments are a technology suitable for rehabilitation therapy due to their inherent ability of simulating real-life tasks. Besides helping to engage the patient in life-like activities, virtual environments provide the means to better measure and evaluate the patient's performance. Sensors can be attached to the patient's body to measure the motions, and the sensor readings can be transparently stored and evaluated by the system. Virtual environments can also improve the motivation of the patient toward the therapy by providing an engaging interface to the exercises.

Virtual environments have been used by Holden et al. [6] to develop a hand-reaching task for patients with chronic hemiplegia. Popescu et al. [16,15] have developed a library of VR exercises for hand rehabilitation in orthopedic patients. Virtual reality has been used for children with cerebral palsy to enhance spatial awareness and the operation of motorized wheelchairs [3,7]. A Stewart platform robot coupled to a virtual environment has been used to rehabilitate orthopedic and neurological patients with ankle problems [4,2].

Jack et al. [8,9] used VR exercises and traditional non-VR manual task practice in interventions on post-stroke patients. Lessons learned from our earlier study lead to the research reported here, in an attempt to see if VR exercise *alone* can improve post-stroke patients in the chronic phase.

## 2 Rehabilitation System

The rehabilitation system is distributed over three sites connected to each other through the Internet, as illustrated in Figure 1. The *rehabilitation site* is the location where the patient is undergoing upper extremity therapy. The system components deployed at this site are a PC workstation, a CyberGlove and a Rutgers Master II (RMII) haptic glove [5]. The two sensing gloves are integrated with VR exercises running on the PC host. The patient interacts with the system using the sensing gloves. Feedback is given on the computer screen. The *data storage site* is the location of the main server of the system. The server hosts an Oracle database, a monitoring server and a web site for access to the data. *Data access sites* do not have a fixed location, being computers with Internet access. Using a web browser, a therapist or physician can access the web portal and view the patient data remotely. The three sites of the system are presented in more detail in the next sections.

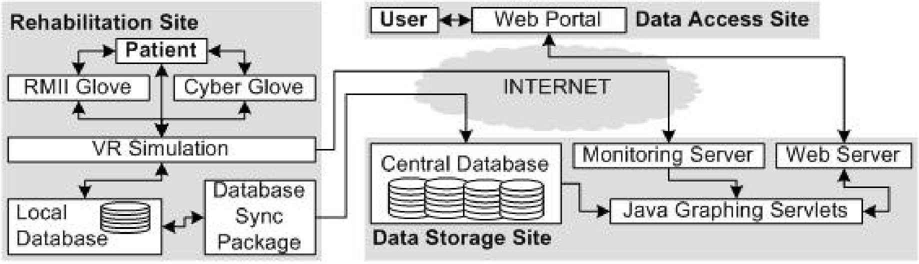


**Figure 1- Rehabilitation system architecture. © Rutgers University 2001.**

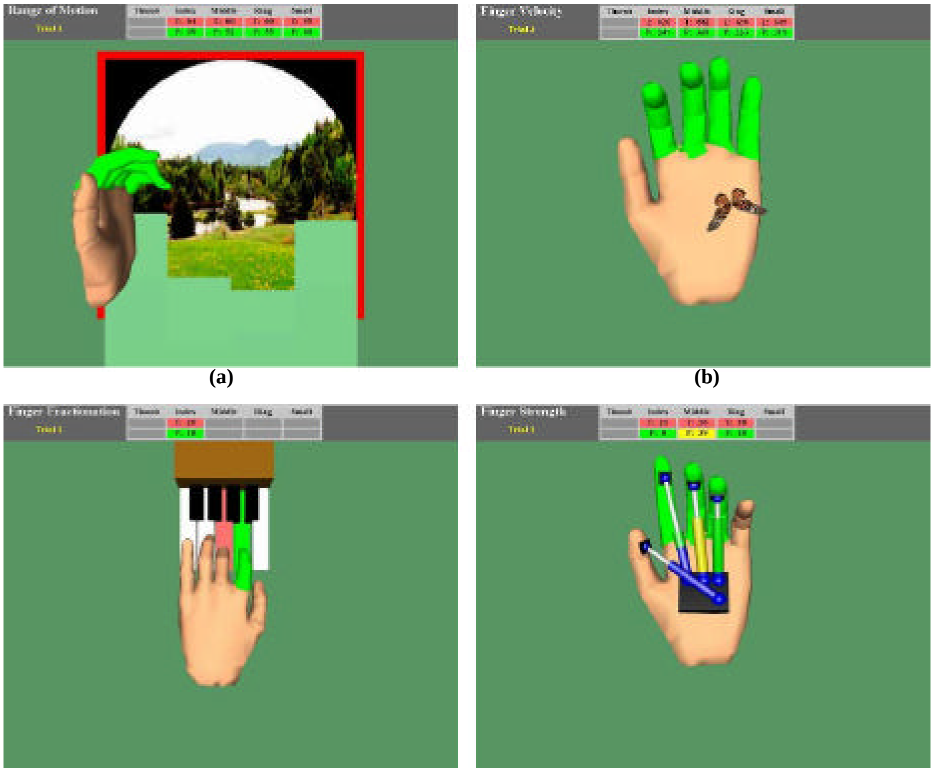
### *2.1 Rehabilitation Application*

The rehabilitation exercises target four major hand impairments: finger range of motion, finger speed of motion, degree of independence of (finger fractionation), and finger strength. Each corresponds to a specific VR simulation [8,9]. The first three exercises use the CyberGlove, while the strength exercise uses the RMII haptic glove.

All the rehab exercises ask the patient to close one or more fingers, starting from a fully open position. The beginning of the range, speed and fractionation exercises has a transparent hand overlapped on the virtual hand controlled by the patient. The finger angles of the transparent hand are set to the desired degree of extension, and patients are required to match the transparent hand before starting each exercise. The beginning of the strength exercise uses the RMII glove to apply forces to help the patient open the hand before switching to the target of the exercise.

The range of motion exercise is executed in two phases: one for the thumb and one for the fingers. The exercise provides performance feedback for each finger. As shown in Figure 2(a) each finger motion "cleans up" a portion of the image. The higher the range of motion, the larger the portion of the image is revealed.

The speed of motion exercise consists of a virtual butterfly flying in circles just above the virtual hand controlled by the patient (see Figure 2-b). The goal is to scare the butterfly away by closing the hand fast enough. If the speed performance does not exceed the target the butterfly continues flying above the hand. Since this design has no "start" signal, the patient is free to initiate the motion at any time (unlike an earlier version of this exercise that combined reaction time and speed of motion [8,9]).



(a) (b)

(c) (d)

**Figure 2 – VR exercises: (a) Range of motion exercise; (b) Finger velocity exercise; (c) Finger fractionation exercise; (d) Finger strength exercise. © Rutgers University 2001.**

The finger fractionation exercise has the patient play a virtual piano with one finger (Figure 2(c)). The patient has to flex the active finger and press the corresponding key while the other fingers (passive) must be kept extended. The performance is measured as the difference between the active finger flexion and the maximum finger flexion of the passive fingers.

The finger strength exercise (Figure 2(d)) measures the piston displacement that the patient can achieve against a constant force applied to the fingers. The VR simulation consists of a virtual model of the RMII glove attached to a patient-controlled virtual hand. The virtual pistons fill with color proportional to the displacement of the real ones.

The top portion of the screen provides performance feedback in a numerical format. This feature was added based on feedback from our earlier trials. Patients felt that numerical scores were a better indication of their progress. The exercises also contain a feedback bar displaying the name of the exercise, the trial number and the targets and performances for each of the fingers involved in the current exercise. The displayed performance (a letter P followed by a number) changes in real-time as the patient's hand moves.

### *2.2 Target Calculation*

The design of the rehabilitation procedure relies on a moving target approach. The exercises are executed in blocks, each block containing a number of trials. Each block is assigned an average target. The individual targets for each trial are chosen from a normal distribution around the assigned average target. The average block target is computed by first averaging the performances of the patient in the previous block. Then, the algorithm computes a new target by adding or subtracting a fraction to/from the current target. Thus, as the patient improves their performance they are pushed by higher target level to perform even better. The fraction change is positive if the current target was achieved and negative if it was not. The amount of target change is computed so that the day's trial success rate is kept close to 80%. This success rate was chosen to keep patients motivated.

### *2.3 Data Storage and Access*

The current version of our system stores the recorded data and reads the rehabilitation session configuration from an Oracle database. When the system uses directly the central database, the data storage site is updated in real-time with records from the rehabilitation site. If the network connection is unreliable (or slow), then the necessary data is replicated in a local database, as illustrated in Figure 1. The central database is then synchronized with the local database with a customizable frequency.

To provide the therapist with the possibility of monitoring the patient's activity we developed a client-server architecture that brings the data from the rehabilitation site to the data storage site in real-time. The server stores only the last record data. Due to the small size of the data packets and the lack of atomic transactions, the communication works even over a slow connection.

Data access is provided through a web portal implemented as a Java applet that accesses the data through Java servlets running on the data storage site. The therapist can access stored data, or monitor active patients, through the use of a web browser. The portal provides a tree structure for intuitive browsing of the data displayed in graphs such as performance histories (day, session, trial), linear regressions, or low-level sensor readings. The graphs are generated in PDF format to allow easy printing.

The real-time monitoring of the patient activity is done through a Java3D applet displaying a simplified virtual hand model. The virtual hand's finger angles are updated with the data retrieved from the monitoring server at the data storage site. The therapist can easily open multiple browser windows for different patients.

## 3 Patient Trials

The system described above has been tested on patients during a three-week pilot study in Summer 2001. Four post-stroke hemiplegic subjects, three male and one female, ages 58 to 72, participated in this study. These patients sustained a right hemisphere stroke (left hand affected) one to four years prior to the study.

One week prior to the study, all patients went through a baseline procedure to measure their performance for each of the four exercises. Subsequently the patients completed a one-week pilot to fine-tune the system followed by a three-week study. Each patient exercised daily (five days per week) for approximately two hours. A rehabilitation session consisted of four blocks of each exercise. A block contained ten trials except for the fractionation exercise, which contained 20 trials because it exercised individual fingers. After the first week, the number of exercise blocks in a day was increased to five. After the second week the number of strength blocks was increased to six. Two of the subjects participated in post-therapy retention tests at one week, two weeks and one month after the intervention.

To evaluate the transfer from our rehab exercises to real life functions, the subjects were asked to pick up and move objects of various sizes, shapes and weight. The patients' motions during these tasks were recorded using a CyberGlove and four electromagnetic trackers (Flock of Birds, Ascension Technology). In addition to computerized tests and exercises, the patients' performance was evaluated using clinical tests such as the Jebsen Test of Hand Function [10].

## 4 Results

Figure 3 shows the percentage change in the patients' performance on each of the four movement tasks over the three-week intervention. Three subjects had substantial improvement in range of motion for the thumb (50-140%), while their gains in finger range were more modest (20%). One patient had an 18% increase in thumb speed and three had between 10-15% speed increases for their fingers. All patients improved their finger fractionation substantially (40-118%). Only one subject showed substantial gain in finger strength, in part due to unexpected hardware problems during the trial. This subject had the lowest levels of isometric flexion force prior to the therapy.

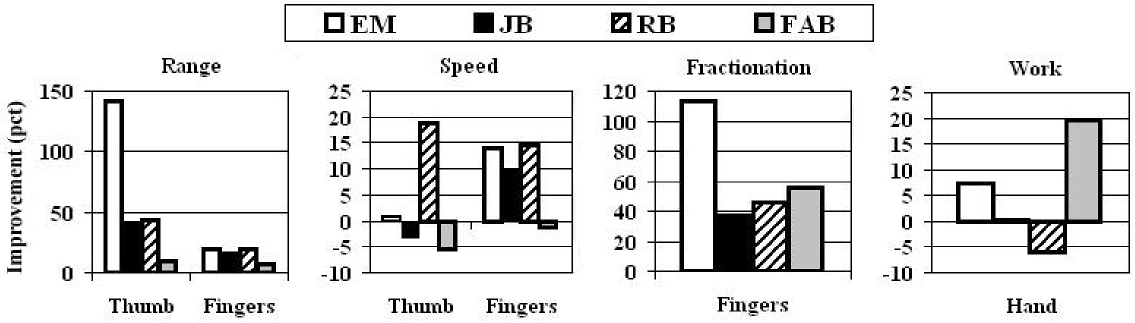


**Figure 3 - Percentage increase between the first and the last day for each of the four VR exercises.**
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Figure 4 shows the retention in the two patients that were measured, again for the four variables for which they trained. Their range and speed of motion either increased (patient RB) or decreased marginally (patient FAB) at one-month post intervention. Their finger strength increased significantly (about 80%) over the month following therapy, indicating they had reserve strength that was not challenged during the trials.

Figure 5 shows the results of the Jebsen evaluation, namely the total amount of time it took the patients to complete the seven component manual tasks. It can be seen that two of the patients (RB and EM) had a substantial reduction in the time from the measures taken prior to the intervention (23-28%, respectively). There was essentially no change in the Jebsen test for the other two patients (JB and FAB). Most of the gains occurred early in the intervention, with negative gains in the second half of the trials.

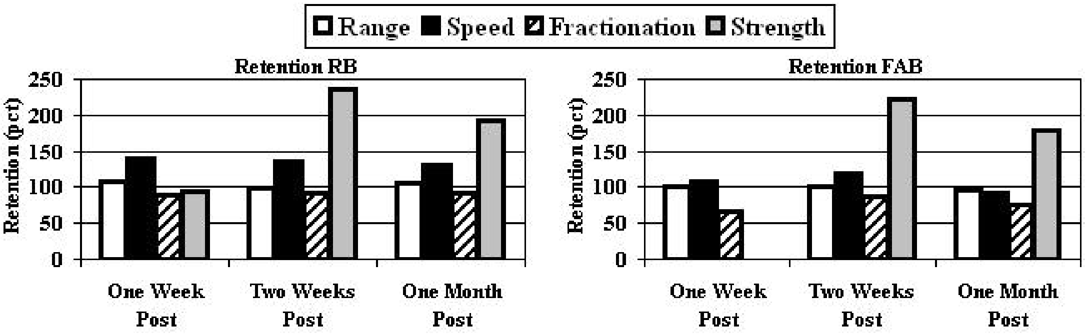

**Figure 4 - Percentage of retention. © Rutgers University 2001.**

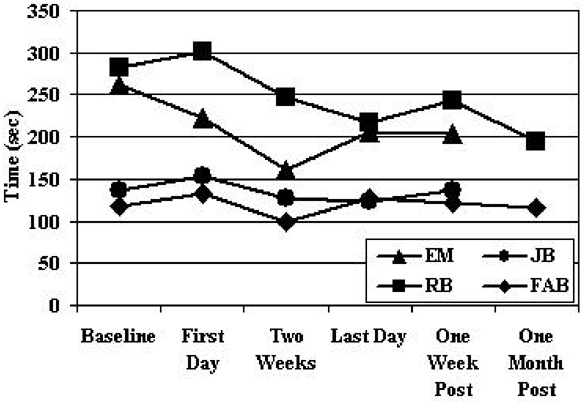

**Figure 5 - Jebsen test results on the affected hand (sum of completion times for seven manual tasks). © Rutgers University 2001.**

The transfer-of-training results for a reach-to-grasp task are shown in Figure 6. There was no training of this particular task during the trials. However, results indicate improvements in impairments appeared to transfer to this functional activity, as measured by the reduction in task movement time. Three of the patients had improvements of between 15% and 38% for a round object and between 9% and 40% for a square object. There was no change for subject RB for picking up a square object while the time to pick up a round object increased by about 11%.

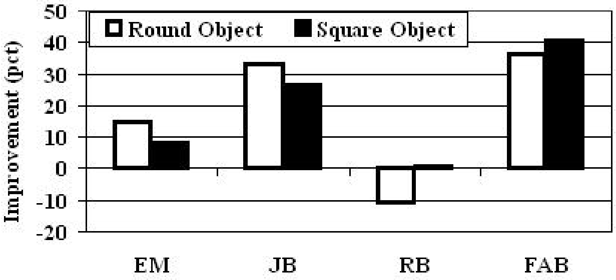

**Figure 6 - Percentage improvement between the first and last day for the transfer-of-training test. © Rutgers University 2001.**

## 5 Conclusions

The study described here was performed to determine whether VR *alone* could be used as a therapeutic intervention modality to improve the hand of chronic post-stroke patients. A CyberGlove was used to train finger range, speed and fractionation. A prototype RMII-ND glove was used to train finger strength. A library of VR simulations was created, using

WorldToolKit for graphics and an adaptive targeting algorithm developed for setting performance levels. Oracle databases were used to transparently store data locally and remotely, and to allow remote physicians/therapists to follow patient progress. Results of a three-week pilot on four patients showed various degrees of improvement in hand impairment following this unconventional therapeutic intervention. There was good retention in gains and a positive subjective evaluation of the system by the patients and therapist that participated. The patients with a higher degree of impairment showed gains in manual ability as measured by a reduction in the cumulative time (of 23-28%) to perform the seven subtasks of the Jebsen Test of Hand function. Three of the four patients participating in the study showed transfer to function for a pickup task with a reduction in the completion time of up to 40%.

## Acknowledgment

The research reported here was supported by an R&D Excellence Grant from the New Jersey Commission on Science and Technology. The authors wish to thank Karin Peterson and Anu Arora from the University of Medicine and Dentistry of New Jersey for their assistance in running the VR training trials.

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