Telerehabilitation Using the Rutgers Master II Glove Following Carpal Tunnel Release Surgery: Proof-of-Concept

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***Abstract*—Carpal tunnel syndrome is caused by the compression of the median nerve as it transits the carpal tunnel, with an incidence of about 1% of the population. If surgery is needed, the treatment involves decompression of the median nerve followed sometimes by musculoskeletal outpatient rehabilitation. This paper presents a proof-of-concept pilot clinical trial in which the Rutgers Masters II haptic glove was tested on five subjects, who were two weeks post-hand surgery. Subjects trained for 13 sessions, 30 min per session, three sessions per week, and had no conventional outpatient therapy. Computerized measures of performance showed group effects in hand mechanical energy (1200% for the virtual ball squeezing and DigiKey exercises and 600% for the power putty exercise). Improvement in their hand function was also observed (a 38% reduction in virtual pegboard errors, and 70% fewer virtual hand ball errors). Clinical strength measures showed increases in grip (by up to 150%) and key pinch (up to 46%) strength in three of the subjects, while two subjects had decreased strength following the study. However, all five subjects improved in their tip pinch strength of their affected hand (between 20%–267%). When asked whether they would recommend the virtual reality exercises to others, four subjects very strongly agreed and one strongly agreed that they would.**

***Index Terms*—Carpal tunnel, hand strength, Java 3-D, Rutgers Master II, telerehabilitation.**

I. INTRODUCTION

THE carpal tunnel is the narrow rigid passageway of ligaments and bones at the base of the hand by which finger flexor tendons are allowed to translate during grasp (see Fig. 1(a), [1]).

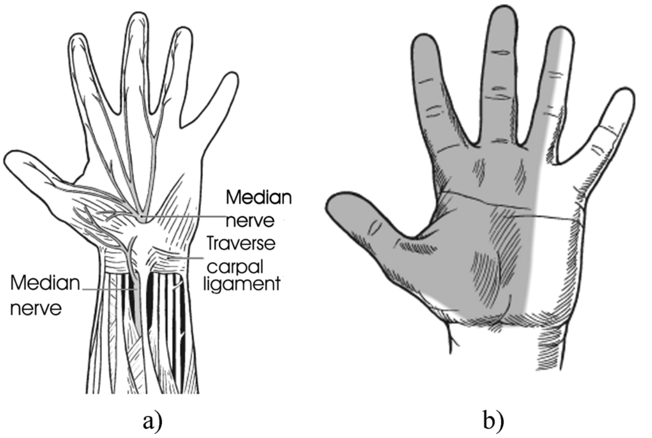

Fig. 1. Carpal tunnel syndrome. (a) Median nerve in the hand. (b) Numbness area of the palm [1].

The same passageway is shared by the median nerve, which controls sensations to the palm side of the thumb and fingers (except of the little finger), as well as impulses to some small muscles in the hand that allow the fingers and thumb to move [2]. The Carpal tunnel syndrome occurs when swelling causes the median nerve to become compressed within the carpal tunnel. The resulting symptoms are numbness and tingling of the thumb, index, middle, and ring fingers [see Fig. 1(b)]. The incidence of Carpal Tunnel syndrome is about 1% of the general population, being higher for professions where repetitive hand motions occur. Conventional treatment includes medication, splints to immobilize the wrist, or surgery to "decompress" the median nerve. Rehabilitation interventions postsurgery concentrate on regaining finger range-of-motion, grip strength, and relieving sensitivity in the surgical area. The aim is for the patient to be able to use their affected hand in activities of daily living and in their work, without experiencing the troublesome symptoms of numbness and tingling in their fingers. The improvement in hand strength is typically gauged by the patient's subjective responses and objectively, by measuring static grip strength and pinch strength using standardized instruments (handheld dynamometer and pinchmeter). A Semmens–Weinstein test [3] is used to gauge changes in sensation. Fine motor and functional task completion are also objective measures of improvement.

Virtual reality (VR) has many advantages to the current clinical practice, as well as some challenges for both technologists and therapists (see [4] for a review). The use of VR in

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physical therapy has focused mostly on the post-stroke population. Less effort has targeted patients with musculoskeletal deficits, whether from fractures, arthritis, or surgery (see [5] for a review). Kim *et al.* [6] developed a bicycle system for balance rehabilitation training in VR. They report that tests on 20 normal subjects showed that stimulus of continuous visual feedback by weight shifting was more effective than that of visual feedback in the postural balance control. VR also addresses the needs of subacute musculoskeletal training by providing virtual games designed to motivate and engage the patients in a period of intensive exercises. Sveistrup *et al.* [7] report on the use of the Interactive Rehabilitation Exercise System (IREX, OT, Canada) for the training of patients with chronic frozen shoulder. VR-based rehabilitation was provided in the form of soccer games aimed at eliciting shoulder flexion, abduction, and rotation. Two case studies showed about 20% improvement following six weeks of training (three sessions/week). Deutsch *et al.* [8] used the Rutgers Ankle robot and VR to train three patients with musculoskeletal impairments to their ankle. Patients sat in front of a PC and were asked to pilot a virtual airplane with their ankle, passing through hoops against the robot resistance. All three patients improved in various computerized measures (ankle torque, ankle control, or ankle range-of-motion).

Our group pioneered the use of VR in musculoskeletal rehabilitation for the upper extremity [9] in a precursor study to the research reported here. A patient post Carpal Tunnel release surgery trained at Stanford University (Stanford, CA) with remote monitoring from Rutgers University (Piscataway, NJ) [10]. The subject improved during a four-week outpatient training using an earlier version of the Rutgers Master glove. Subsequently, both hardware and software were refined and a series of five case studies were done in 2005 at Integris Healthcare (Oklahoma City, OK), again with remote monitoring from Rutgers University. Section II of this paper describes the experimental system used in these trials. The experimental protocol and data on the subjects participating in the study are given in Section III. Section IV describes the computerized, clinical and subjective evaluation outcomes, looking at group effects and subject-specific data. Section V concludes this paper.

II. EXPERIMENTAL SYSTEM

A. Hardware

The VR-rehabilitation system used in this study consists of a PC (Pentium III dual processor), a 3-D tracker (Polhemus Fastrak [11]), left-hand and right-hand Rutgers Master II gloves [12] [Fig. 2(a) and (b)] with their control box, a small and quiet compressor (50 dB) and a Cannon pan-tilt-zoom (PTZ) camera controlled over the Internet. The haptic gloves are used to measure in real time the thumb, index, middle, and ring fingertip positions versus the palm. Custom actuators resist flexion (up to 16 N) or assist extension to the neutral hand configuration. The extension assistance feature was not used in the study described here. Each actuator is controlled independently, such that some fingers may be resisted, while others are assisted. High-friction finger attachments for each piston, together with the Velcro used to position a palm plate for "grounding" the finger forces, obviate the need for a separate supporting glove. For all its advantages, the Rutgers Master II haptic glove has some limitations. The placement of the actuators in the palm makes it impossible to fully close the thumb and fingers. Furthermore, the feedback force is updated at a lower mechanical bandwidth (on the order of 10 Hz), compared to that of haptic interfaces using electrical actuators. Finally, there is no force feedback for adduction/abduction finger movements. The 3-D tracker is placed on the dorsum of the hand and is used to measure the patient's wrist movements 120 times/s. A remote therapist expert looks at the PTZ camera images through a web browser, communicates with the local therapist over the phone and both therapists have access to the patient treatment/history through a web portal.

B. VR Exercises

Five therapeutic games were created based on the advice provided by the clinician researchers at Stanford collaborating in this study. The simulations were programmed using WorldToolKit [13] running in the Windows 2000 operating system. The first three exercises ("ball squeezing," "power putty" and "DigiKey") train the hand impairments (finger strengthening). The other two simulations ("peg board" and "hand ball") are more complex and aim at improving the whole arm function (hand–eye coordination, active shoulder range-of-motion, precision placement of objects). As can be seen in Fig. 2(c)–(g), all exercises have a similar graphical user interface (GUI). This GUI mediates the therapist's input into the exercises and provides real-time performance feedback to both therapist and patient. At the bottom of the screen are graphical buttons to "start," "pause," or "quit" the exercise, as well as a hand icon indicating which hand (left or right) is being trained. Also at the bottom of the GUI is a "recalibrate" button, which allows the patient to recalibrate the glove in-between exercises, or as needed. Performance feedback is provided either graphically or numerically. For the finger impairment exercises, four bar graphs at the top left corner of the screen, visualize in real time, the level of individual finger forces. For all five exercises the bottom of the screen displays numerically the goal set by the therapist, and the patient's performance. If the patient completes the exercise in the allowed time, a congratulatory sound is displayed, otherwise the simulation slowly stops the exercise and exits automatically.

Virtual ball squeezing is designed to strengthen the patient's finger flexion movement, and consists of a virtual elastic ball that the patient grasps with a virtual hand. The goal is to "squeeze" the virtual ball a prescribed number of times, within a given time allotment. Thus, the frequency of resisted flexion movements is set implicitly by the time allotment. The same is true for the other exercises described below. The exercise difficulty varies with the ball stiffness (no resistance—level 0, soft, medium and hard-level 3). The color of the virtual ball changes to correspond with the difficulty level. The "finger forces" bar graph is initially a simple horizontal line for each finger. When the forces in a finger reach or exceed the force threshold set by the difficulty level, the bar will turn solid. Feedback forces are applied to all the fingers which make contact with the virtual ball, once the ball starts being deformed. The level of haptic feedback is proportional with the ball surface deformation as

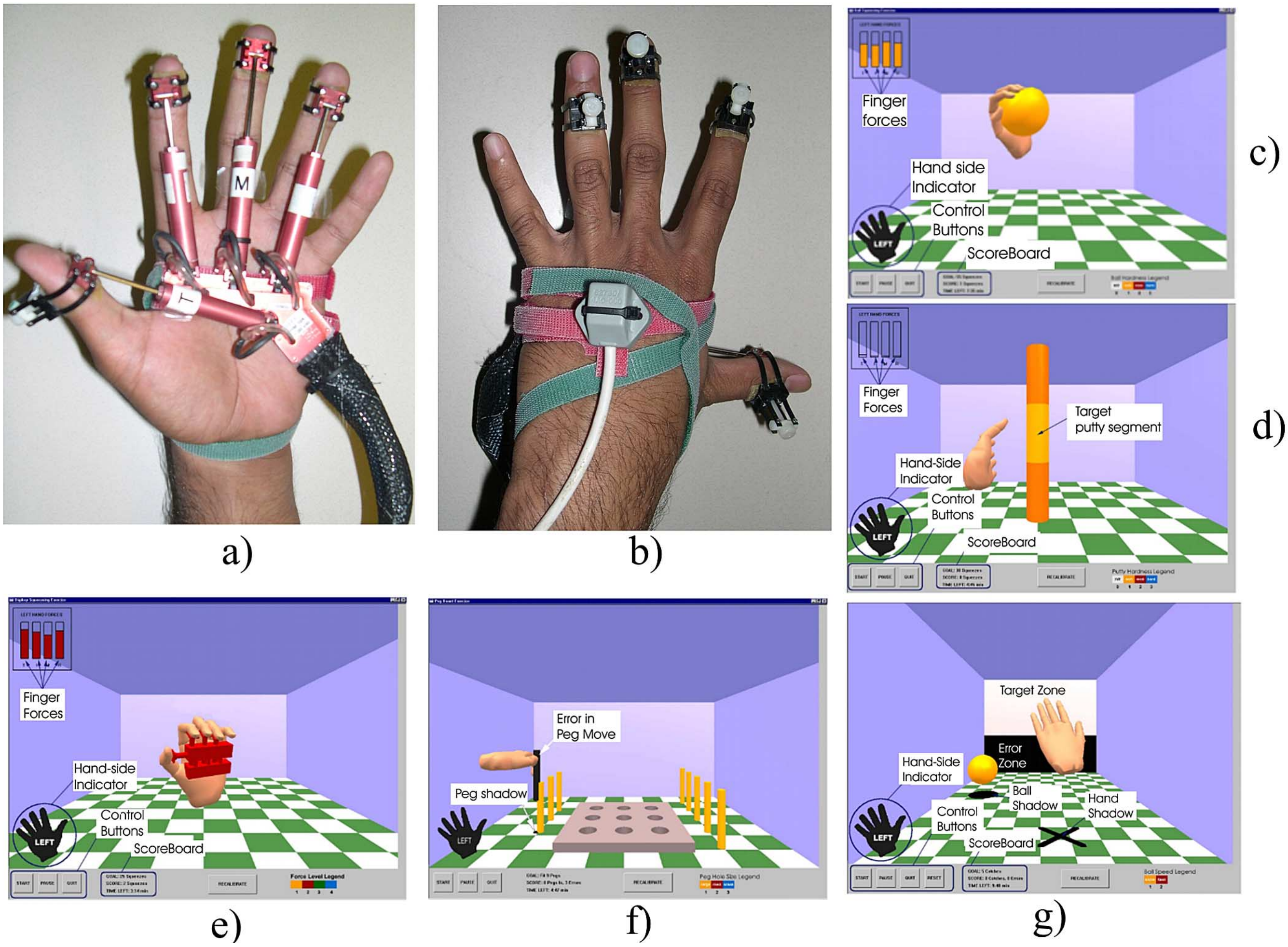


Fig. 2. VR system. (a) Rutgers Master II glove front view. (b) RMII back view. (c) Rubber ball squeezing. (d) Power putty. (e) DigiKey. (f) Peg board filling. (g) Handball exercise. Rutgers University.

well as its set compliance. A squeeze is recorded only when all four fingers are providing forces at or above the difficulty level set for the exercise. Thus, each finger has to travel a threshold distance before that squeeze is counted towards the required number of squeezes. The same approach is taken for the power putty and DigiKey exercises (described below).

Virtual power putty simulation exercises only the thumb and index finger, which plastically deform the power putty. In order to maximize finger excursion, the power putty is modeled as a sequence of individually deformable segments. After the target segment is squeezed, it translates out of the way, being replaced by a new non-deformed putty segment. Similar to the previous exercise, the patient is required to squeeze the virtual putty beyond a threshold determined be the putty's resistance for that difficulty level (0—no resistance to 3—hard-level).

The virtual DigiKey is modeled after the well-known DigiKey therapeutic device, which looks like a trumpet keyboard with springs. Due to the Rutgers Master II characteristics our simulation has a modified DigiKey to allow thumb training instead of fifth digit. There are five virtual DigiKeys, each with a different resistance level, corresponding to the color code legend at the bottom of the GUI. The patient is asked to squeeze and release the DigiKey repeatedly, to match the goal displayed on the screen.

The virtual pegboard is also modeled after a well-known therapeutic device used in patient evaluation and training of fine movements and hand–eye coordination. The simulation consists of nine pegs (cylinders) and a board with a nine-hole matrix, which the patient needs to fill, one peg at-a-time. The level of difficulty (1—"novice," 2—"medium," and 3—"expert") is set by the size of the holes, with tighter tolerances requiring higher skill. The goal of this exercise is to place a peg in each of the nine holes within the allowed amount of time. When a peg is placed above an unfilled hole, it will change color to green, and is released to fill the hole. The patient receives force feedback to his thumb and index, while the virtual hand holds the peg. An error is recorded if the patient drops the peg outside a hole, or when a grasped peg collides with another peg.

The virtual handball game asks patients to throw a virtual ball so it hits in the white target zone on a virtual wall [see Fig. 2(f)]. The ball will then bounce off the wall and needs to be caught by the patient before it hits the floor twice. The initial speed of the ball determines the level of difficulty (orange—"slow" ball, or red—"fast" ball). The GUI for this exercise has an additional button, to "reset" the ball to the initial position, bouncing in the center of the room. A reset will be recorded as an event to the database. An error occurs if the patient fails to throw the ball into the target zone, or when the ball bounces two or more times after hitting this zone, before being caught by the patient.

C. Clinical Database

While patients are exercising, the simulation transparently measures and stores several parameters in the clinical database. The data is stored first locally on the PC running the VR exercises. Subsequently, data are uploaded every night to the remote server running the Oracle graphing routine. The choice of nighttime data upload came from the need to maintain the real-time nature of the simulation exercises. The large amount of data would have slowed the simulation unacceptably, if database uploads were to happen during the training session. For the trials reported here, the PC was in Oklahoma City, OK, while the Oracle server ran on a PC at Rutgers University (approximately 2100 km away). Patient data from the exercises are stored at "low level" (detailing finger specific real-time movements, or forces) or "high level" (for averages of exercise completion time, number of grasps, mechanical work, number of errors). The mechanical energy is computed by multiplying the Rutgers Master II actuator's translation by their corresponding force and summing all such products per exercise type and session. A web-accessible password-protected database portal allows local or remote terapists to follow the patients' progress over time. For each subject and each exercise, it is possible to request variable-specific history graphs. The bottom axis plots the session dates, while the top horizontal axis shows the exercise difficulty for those sessions. It is thus easy to see how the subject progresses from level to level over time, without having to be next to the patient.

III. EXPERIMENTAL PROTOCOL

The five exercises described above form the basis of the musculoskeletal post surgical rehabilitation protocol for a five-week (13 sessions) training intervention. The difficulty level is progressing based on the type of exercises, their number of repetitions, as well as the difficulty level of each type of exercise. During the first two sessions, patients perform a fixed sequence of ball squeezing (no resistance-level 0, 20 grasps over 5 min), power putty (no resistance-level 0, 20 grasps over 5 min), DigiKey (level 1 resistance, 20 grasps over 5 min). Starting with Session 3, the sequence remains the same, but the difficulty is increased for ball squeezing (level 1—"soft," 30 grasps, 5 min), power putty (level 1—"soft," 30 grasps, 5 min), DigiKey (resistance level 2, 30 grasps, 5 min). In session 7, the peg board and hand ball games are added, resistance is increased to level 2 "medium" for the ball squeezing and power putty exercises, the DigiKey is producing level 3 forces, and the pegboard tolerances are tightened to level 2—"medium" in session 9. In session 12, the difficulty is increased further (ball squeezing, power putty are at level 3 forces, DigiKey at level 4 forces, and the pegboard is performed at the tightest tolerances—level 3 "expert").

The sequence of exercises is preprogrammed into the PC, such that each exercise will be started automatically, at the appropriate level of difficulty and in the correct order for the particular week of training. To allow a certain level of flexibility for a specific patient's impairment level and daily physical condition, a "Session Configuration" GUI is added. For each patient the GUI allows the therapist to deviate from the preset order by changing the default settings (completion time, number of squeezes, pegboard tolerance level, number of catches for the handball game). The same software allows the therapist to add/remove exercises from that session.

The protocol was submitted for review to the Institutional Review Board of Rutgers University and the Internal Review Committee of Integris Health and was approved. Subsequently, a collaborating orthopedic surgeon recruited eight subjects via direct referral. While this made recruiting less random than it could have been, using a single surgeon boosted the control on the pretraining surgical phase of the study. The admission criteria to the study were: 1) subjects needed to be post a first-time carpal tunnel release surgery; and 2) they had to have no other prior trauma, injuries, or surgeries to their affected wrist/hand. Each subject was instructed on the use of the Rutgers Master II glove and VR simulations. They subsequently signed the consent to participate in this study and underwent presurgical testing (hand dynamometer; pinchmeter and Semmes-Weinsten testing). The study began 13 days postsurgery if their wound had healed. Subjects started training within two days following the removal of their stitches. Of the recruited subjects, three withdrew from the study, two prior to starting the VR therapy, and one (Subject 1) because of time constraints. The remaining five subjects completed the study. Their age range was 39–67, with a mean of 59 years. Since one subject had a pacemaker, there was a safety concern with interference from the tracker magnetic fields. Engineers with both the tracker and the pace maker manufacturers were consulted and advised that there were no indications of such interference. That patient completed the study without incident. As mentioned before, the therapist had the option to customize the training should the subjects complain. Since there were no complaints, all patients performed the same sequence of exercises, under the supervision of a local therapist. The therapist had remote access to the clinical database at Rutgers, to better gauge patients' progress. Following completion of the study, subjects were again tested clinically using the same methods as the presurgical testing. They also had to fill subjective evaluation questionnaires rating the system.

IV. RESULTS AND DISCUSSION

A. Computerized Measures of Performance

Table I shows group averages for a subset of the computerized variables stored during the VR-based training. For the three exercises that trained at the impairment level (ball squeezing, power putty and DigiKey) the variables are trial completion time (in seconds) and mechanical energy (Joules) as a function of difficulty level. For the remaining two exercises (peg board and hand ball game), which trained function, the variables are trial completion time and number of errors as a function of difficulty level.

The computerized variables are tabulated for the group performance measured in the first session (1) (session 3 for ball squeezing and power putty; session 7 for the peg board and hand ball games) and the last session of training (session 13). A further caveat is the completion time of impairment-level trials, which is shown normalized for Session 13. This is due to the fact that the number of grasps changed from 20 (session 1) to 30

TABLE I
GROUP PERFORMANCE VARIABLES MEASURED BY THE COMPUTER
(* SESSION 3; ** SESSION 7)

Exercise	Group average (Session 1)			Group average (Session 13)		
Variable	**Time (sec)**	**Energy (J)**	**Difficulty**	**Time (sec)**	**Energy (J)**	**Difficulty**
Ball squeezing*	71	2	1	37 (-39%)	24 (1200%)	3
Power putty*	102	0.5	1	61 (-40%)	3 (600%)	3
DigiKey	54	1	1	39 (-28%)	12 (1200%)	4
Variable	**Time (sec)**	**Errors**	**Level**	**Time (sec)**	**Errors**	**Level**
Peg** Board	238	5.8	1	247 (4%)	3.6 (-38%)	3
Hand** ball	271	9.8	1	180 (-32%)	2.9 (-70%)	1

(sessions 7 and thereafter). It can be seen in Table I that the patients as a group were able to expand substantially more energy at the end of training and do so at a high level of resistance from the haptic glove. This was true for all impairment-level trials. Expended energy during the DigiKey exercises, for example, increased by 1200% for the subjects as a group, while the time to complete the trial decreased (−28%). Thus, the subjects' hand mechanical power improved too (their hand ability to expand energy in a given amount of time). The group took marginally longer to complete the functional training trials, but had a significant drop in errors (−38% for peg board and −70% for the hand ball game). This shows that the group improved in hand fine motor control and hand–eye coordination, despite an increase in the level of difficulty of the peg board game. The hand ball game, which started about midway through the therapy, was kept at a constant difficulty level, nevertheless the group showed substantial hand–eye coordination improvement. Note that such functional outcomes are not captured in clinical "static" strength measures detailed below, and represent a clear advantage of the VR system over conventional evaluation approaches.

While patients improved in their performance, this improvement was patient-specific, and in general did not reach a plateau during the study, as seen in Fig. 3. Patient-specific graphs show mechanical energy (work) increases for all patients without reaching a plateau. The completion time and error rate for the ball game exercise show decreases from the first session this exercise was introduced (7) to session 13. Interestingly, Subject 3 had no decrease in the ball game exercise time (due to his lack of prior training in real-life ball games and lack of computer skills). However the same subject had substantially less errors in the ball game exercise (a drop from 22 errors/session to 9 errors/session in that exercise). This substantial hand–eye coordination improvement is surely due in part to learning the handball game.

A further advantage (not described here due to lack of space) is the ability to gauge progress (in terms of strength, endurance, etc.) on a finger-specific level, and with high time granularity. In comparison to conventional postsurgical carpal tunnel release surgery, only one of these patients would have been referred to physical therapy for follow up treatment. According to the referring hand surgeon, Dr. S. O'Brian only about 10%–15% of his patients are referred to physical hand therapy.

B. Clinical Outcomes

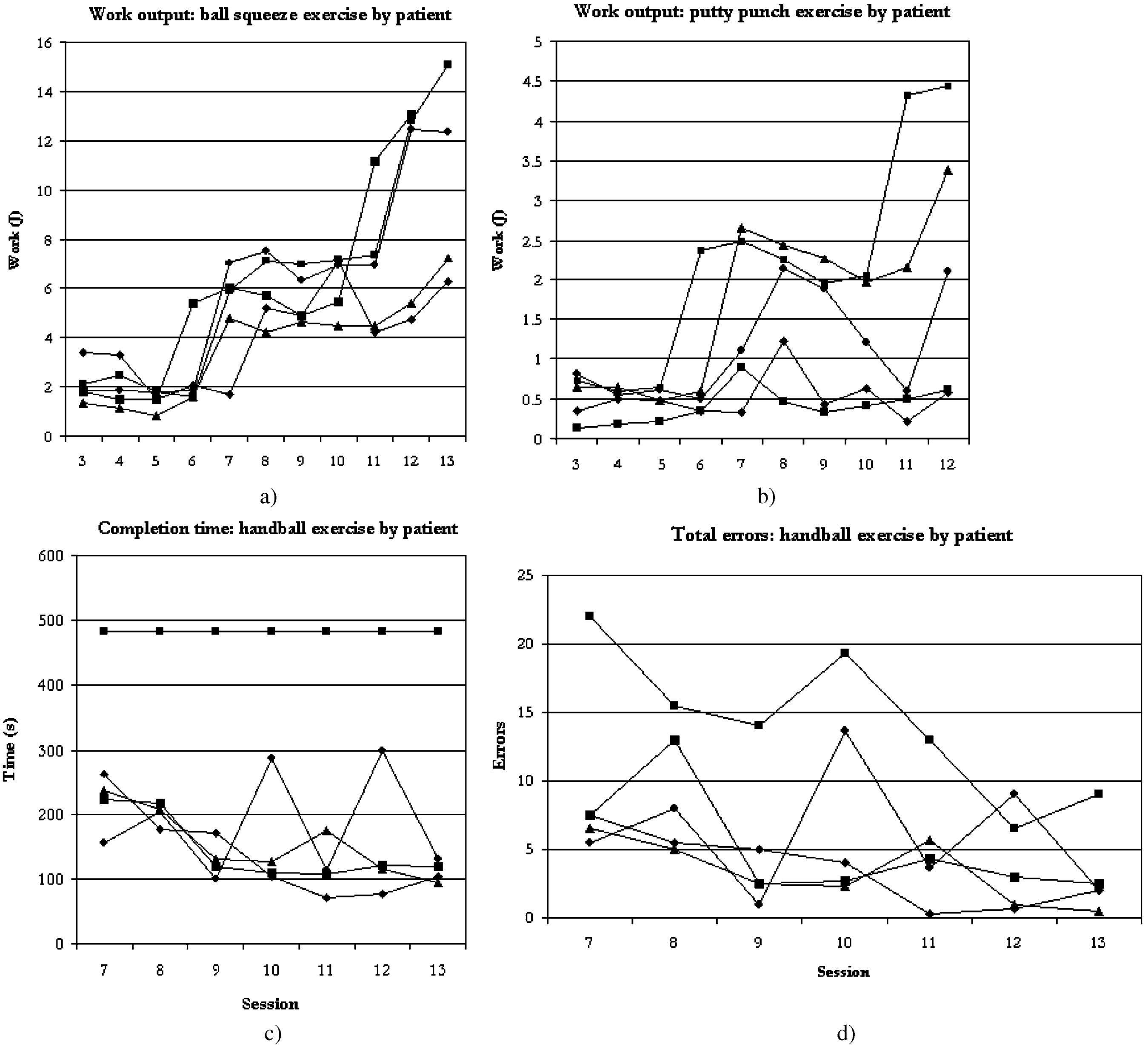
Table II presents the strength subset of the presurgery and post-VR therapy clinical measures. Data are shown for the affected hand, for grip and pinch strengths, as well as the subjects' percent increase/decrease in such strength, as measured by a dynamometer and pinchmeter. Data show substantially less clinical outcome uniformity among the group. Three of the subjects (60%) increased their grip (up to 150%), and key pinch strength (up to 46%). Subjects 3 and 8 (40% of the subjects) had a substantial reduction in their hand grip strength (up to −31%) and key pinch (up to −39%) during the study. The logical explanation is that Subject 3 was elderly and had not been performing any task with his involved hand until near the end of the study. Subject 8 was continuing to work, but admittedly neglecting to use her hand due to mild discomfort. Remarkably, all subjects improved in their tip pinch strength (between 20% and 267%).

C. Subjective Evaluation

The perceived exercise difficulty was rated by subjects on a five-step scale: no difficulty (1), mild difficulty (2), moderate difficulty (3), very difficult to perform (4), and unable to perform (5). The overall VR simulations were rated at a 1.6 difficulty, meaning that the subject group felt it had no-to-mild difficulty when performing the exercises. The subjects had no perceived difficulty doing the impairment-level training: ball squeezing (1) and power putty (1), DigiKey (1.6). As expected, the exercises training function were perceived as more difficult (hand ball—difficulty 2 and peg board—difficulty 2.4). One subject found the pegboard very difficult, and had to have support of the upper extremity and elbow at a proper height to complete the task. Another subject had no experience with video games, the internet, nor had any sports or ball playing experience in his lifetime. Thus, this subject had more difficulty with hand–eye coordination activities and quick movements that involved the entire upper extremity. Only one subject commented that the VR therapy had a shortcoming, namely the difficulty of the hand ball game to respond to the subject's speed of throw and retrieval.

The subjects were split in their subjective judgment of most and least beneficial exercises. Interestingly, the functional training exercises, which were perceived as more difficult, also received the most votes for being more beneficial (peg board—2 votes, handball game—1 vote). Other subjects perceived those same exercises as least beneficial (peg board—2 votes, handball game—1 vote).

The subjects were asked to rate their level of pain prior to training, after each session, and at the conclusion of the VR therapy study. The rating used a scale of 0 (no pain) to 10 (could not perform the exercise due to excessive pain). A couple of the subjects experienced some shoulder pain with all of the exercises. Two subjects reported having moderate pain prior to the start of therapy (one subject rated it at 2, one at 3). The perceived pain level went up during therapy with three subjects reporting the pain level at 2, one at 4 and one at 5. Following training, the pain level diminished (two subject had no pain, two reported it



a) b)

c) d)

Fig. 3. Patient-specific performance during the study. (a) Mechanical energy for the ball squeezing exercise. (b) mechanical energy for the power putty exercise. (c) Completion time for the handball exercise. (d) Total errors during handball exercise. Rutgers University.

TABLE II
SUBJECTS' STRENGTH FOR THE AFFECTED HAND PRE-THERAPY AND POST-THERAPY MEASURED WITH A DYNAMOMETER

Subject	Grip strength (lbf)		Key Pinch Strength (lbf)		Tip Pinch Strength (lbf)	
	Pre-surgery	Post-VR	Pre-surgery	Post-VR	Pre-surgery	Post-VR
2	37	69	13	16	10	12
Diff. (%)	32(86%)		3(23%)		2(20%)	
3	80	70	18	11	20	26
Diff. (%)	-10(-12%)		-7(-39%)		6(30%)	
4	10	25	3.5	4.5	1.5	5.5
Diff. (%)	15(150%)		1(28%)		4(267%)	
5	60	90	13	18	7	12
Diff. (%)	30(50%)		6(46%)		5(71%)	
8	65	45	18	13	11	15
Diff. (%)	-20(-31%)		-5(-28%)		4(36%)	

at level 2 and one at level 4). This mild-to-moderated pain did not prevent the subjects from completing their therapy.

When asked whether they would recommend the VR exercises to others, four subjects very strongly agreed and one strongly agreed that they would. Most subjects liked the training and were disappointed when it ended. Four subjects said that their children or grandchildren would love to have such a system. This shows a very positive overall rating from the subjects that completed the study.

In a *phone interview* conducted 19 months post study, all subjects reported that their presurgery symptoms were much improved. They reported improvements in their ability to get dressed (being able to close zippers and buttons), tool handling (without dropping the tools), cooking (without dropping the pans, being able to peel potatoes) and playing video games.

V. CONCLUSION

To the authors' knowledge, the system presented here is the first federally-funded telerehabilitation study (which started in 1997). It is also probably the only study so-far aimed at the use of virtual telerehabilitation for patients with Carpal Tunnel syndrome. While this proof-of-concept sample size was small this study provides an indication that postsurgery patients' hand strength improves with VR exercises (in the absence of conventional outpatient clinic therapy). Results also gave support to the hypothesis that repeated practice results in improved function (as measured by the computer). The subjective evaluation of the system by this small patient sample was positive, with good acceptance and perceived usefulness by the subjects. While in this study the therapist was colocated and assisted the patient, such acceptance bodes well for scenarios where the therapist will be remote.

This study also contributed potentially to ways of improving patient compliance with a prescribed training. It is hypothesized that patients will have a higher compliance in a telerehabilitation setting, compared to unsupervised training at home. Furthermore, the data collection and storage of hand kinematic and dynamic movements and accessibility to that data across the country represents a potential tool for epidemiologic studies. The technology reported here may be used in conjunction with telerehabilitation settings, where local therapist expertise or local clinics are lacking [14], and remote experts can then monitor such training.

While the patient population in this study suffered from Carpal Tunnel syndrome, the technology is applicable to other patient populations. The Rutgers Master II, for example, has been used by chronic poststroke individuals [15], [16]. While the VR exercises were different from those presented here, and a CyberGlove was also used, the same positive outcome was observed up to five years post stroke. The same remote access to clinical data was allowed and in some sessions patients exercised without a therapist present.

Newer generation of therapists, and patients, which have grown up with computers and video games will also be more accepting of the technology this study has tested. The technology described here is not intended to replace the therapist, or current rehabilitation methods. Virtual telerehabilitation is rather meant as a "force amplifier," empowering a therapist to do more, and with more patients. Thus, it is projected that telerehabilitation will gain wider clinical acceptance in the years to come. Indeed this authors believe that in the (not too distant future), virtual clinics will exist, allowing easy patient training regardless of physical distance or time zone. Furthermore, patient teams may become a way to compete with other patients in VR games, further enhancing their motivation to improve.

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