Virtual reality in stroke rehabilitation with the assistance of haptics and telemedicine

J Broeren[1, 2], M Georgsson[1], M Rydmark[1] and K Stibrant Sunnerhagen[2]

[1]Mednet, [2]Department of Rehabilitation Medicin, The Sahlgrenska Academy at Göteborgs University, Göteborg, Sweden

jurgen.broeren@mednet.gu.se, mattias.georgsson@mednet.gu.se, martin.rydmark@mednet.gu.se, stibrant.sunnerhagen@rehab.gu.se

[1] *www.mednet.gu.se,* [2] *wwwhost.gu.se/rehab/*

ABSTRACT

A 3D-computer game was used as a training utility to promote motor relearning on a telemedicine platform in a laboratory setting. The subject suffered from a left arm paresis. He was evaluated before and after treatment with a specific hand function task, a standardized grip force measure test and an upper extremity task. Grip force, endurance and the movement pattern of the upper extremity improved after the treatment. The telemedicine platform allows the professional to record and evaluate progress. The findings implicate that training with Virtual Reality and Haptics can promote motor rehabilitation.

1. INTRODUCTION

The impairment of the upper extremity is a prime obstacle in re-acquiring competence in managing every day activities. Stroke survivors (Feys et al, 1998) perceive the loss of upper extremity function as a major problem. Broeks et al (1999) assessed the long-term motor and functional recovery of arm function after strokes and concluded, as many before, that there is a need to develop active treatment methods for upper extremity function. After discharge from hospital units many patients with prior stroke are still in need of qualified rehabilitation. Yet, the alternatives given to patients after discharge from hospital units are limited in availability and vary locally/regionally (National Board of Health and Welfare, SWEDEN, 2001). Target oriented rehabilitation approaches and individually adapted training programs are essential in order to gain recovery. The recovery of the affected upper extremity is as in every other training situation dependent on regularity and intensity in training (Kwakkel et al, 1999), as well as on specificity. In order to stimulate the recovery, the training program must allow the individual to development and re-establish their motor system. Training programs should be made engaging in order to motivate the patient. Home rehabilitation might be an important complement that can produce results comparable to institutional rehabilitation (Duncan et al, 2001). In relation to the traditional approaches, new models must be developed for patients and health professionals. Providing rehabilitation in the home makes the role of telemedicine evident.

Virtual Reality (VR) technology is presently being explored as an assessment and training device for improving motor recovery after stroke (Holden et al, 1999, Burdea et al, 2001, Piron et al, 2001, Broeren et al, 2002). However, when performing tasks with the effected upper extremity in VR environments, which often means manipulating objects, the need for haptic force feedback becomes evident. In order for VR to better approximate reality for tasks, the senses of touch and kinaesthesia must be addressed.

The aim of this study is to make VR applications of existing occupational treatment methods and to develop a platform for home rehabilitation controlled telemedically where we emphasis on building a low-cost web-based video/audio telemedicine system.

2. MATERIAL AND METHODS

2.1 Design

A single-subject ABA research design was used (Zahn S, Ottenbacher KJ, 2001). Before the training, the subject was evaluated with a test battery (see below) followed by a 4-week training period (frequency: 3 times a week for 90 minutes each time). After the training period the subject was tested with the same test battery.

2.2 Subject

One male subject was included in this study, age 59 years. The time since stroke was 3 months. He had a first occurrence of a stroke, i.e. sudden occurrence of neurological deficits due to impaired blood flow in the brain due to either infarction or haemorrhage. In this case, the cause was an infarction, and the diagnosis was set by a clinical neurologist after examination and confirmed by CT-scan. He had a paresis in the upper left extremity (right hemisphere lesion) and normal spatial competence and body awareness. There were no limitations in understanding the information given

2.3 Haptic system and Telemedicine Platform

The computer hardware consists of an Intergraph Zx10 ViZual Workstation (2 x 750 MHz Pentium III with 512 Mb RAM and a WildCat 4110 graphic card, Windows 2000). Haptics are added using Reachin 3.0 from Reachin Technologies AB (Stockholm, Sweden). Reachin API is a programming environment allowing interactive manipulation of a 3D model using a haptic interface. Haptic force feedback is provided using the PHANToM™ haptic device (SensAble Technologies Inc., Woburg, MA, US). Stereoscopic visualization is accomplished using a standard CrystalEyes CE-2 setup (San Rafael, CA, US).

The Telemedicine platform is based on two standard computers, high performance web cameras (Philips Electronics N.V., Eindhoven, the Netherlands), the World Wide Web and low-cost Teleconference Application. The application uses protocols within the TCP/IP suite and enables the transfer of log files that show the patients results, and data concerning video/audio teleconference between the patient and the clinical personnel.

2.4 Training procedure

The subject was trained with a computer game (3D-bricks), which was originally developed by Reachin Technologies AB. At the start of the game, the subject grasps the PHANToM™ haptic device with his left hand. He obtains a view of a ball in a court filled with bricks. The game starts when the subject strikes the ball. The subject receives credit for the bricks knocked down. On the return, when the player missed the ball, the player collected minus points. The game was customized to operate at four levels of different speed. The effect of modifying the speed from 4-3-2-1 caused the program to speed up the velocity of the ball. The level of difficulty was changed after the subject had reached a given score of three consecutive games

2.5 Test procedures

Three tests were used to evaluate motor performance of the left upper extremity. It was evaluated in the following order: 1) Fine manual dexterity was measured by using the tasks of the Purdue pegboard. This test consists of manipulating small pins on a board as quickly as possible in a 30-second period. The score is the number of pins handled. 2) The dynamometer hand grip strength by Grippit™ (AB Detector, Gothenburg, Sweden) was recorded. Peak maximum grip force and the mean value of the 10-second sustained grip were measured. 3) A upper extremity test was developed. The subject had to move the PHANToM™ haptic device to different targets (generated positions) on the screen. The target placements (32) were apparently random to the patients, but actually set according to a pre-set kinematic scheme. The targets were numbered from 1-9, by starting with no 1 at the lower part of the right hand side of the computer screen, continuing with no. 2 and 3 to the left. The fourth target is placed above target no 1, no. 5 over no. 2, and so on. The motions of the left upper extremity were divided in different directions, i.e. sideways (left – right and right – left), up and down, diagonal (left – right) up and down. The x-, y- and z-coordinates for the haptic device and the targets were continuously sampled. Thereby, the kinematical pattern, time, speed, trajectory distance (actual passway of the upper extremity) and intertarget distance (geometric shortest distance between the targets) to complete the exercise were computed, constituting a measure by which the performance was evaluated.

3. RESULTS

Comparisons of pretreatment and post-treatment measures were used to indicate changes. Both the fine manual dexterity scores and the grip force changed for the subject after the intervention period (Table 1). The grip force improvement increased considerably, this change could elucidate the improvement in endurance while playing the virtual game. By the end of the intervention period, the subject progressed to game level 1 (most difficult).

Table 1. *Results of the Purdue pegboard and grip force.*

		Pre-treatment			Post-treatment
Time after stroke		1½ weeks	2½ weeks	11 weeks	15 weeks
Fine manual dexterity, No. of pins	left hand	impossible	impossible	6	8
	both hands	impossible	impossible	3	6
Grip force, N	mean	46	20	52	176
	peak	172	120	68	264

N = Newton

Figure 1 shows the kinematic pattern before and after the intervention. The subject shows an altered movement pattern after the intervention period. As seen in fig. 1 the subject improved in almost all direction, except for the Diagonal Up (R – L) direction. The enhanced motor pattern i.e. the shorter trajectory distance is due to the better precision to strike the targets. This is also verified by the improvement of the fine manual dexterity task. For exact measures see table 2. Morphologic changes of the movement pattern correspond to the improvement in (fig 2 and fig 3).

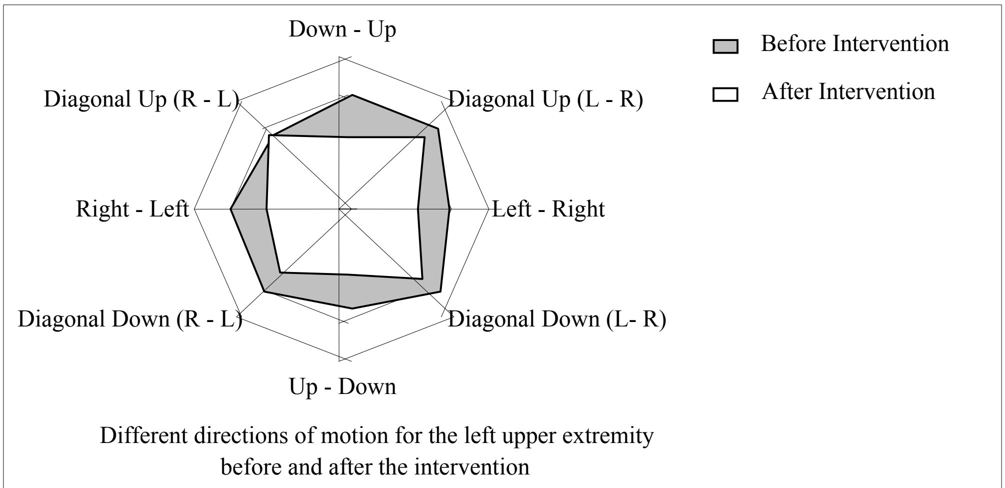

Figure 1. *Kinematic pattern (mean trajectory distance) before and after the intervention.*

Table 2. *Mean trajectory distance (m) for the directions of motion.*

	Before Intervention	After Intervention
Down – Up	0,3006	0,1869
Diagonal Up (L - R)	0,3004	0,2685
Left – Right	0,2369	0,1723
Diagonal Down (L- R)	0,3057	0,2611
Up – Down	0,2638	0,1732
Diagonal Down (R - L)	0,3043	0,2319
Right – Left	0,2993	0,2021
Diagonal Up (R - L)	0,2696	0,2702

The median inter-target time for the subject time to complete the tests improved (fig 2). The median times for trials 1B - 3B were 1.3, 1.1 and 1.2 sec before the intervention. After the intervention the time increased considerable into 0.92, 0.93 and 0.90 sec for the three trials (trial 1A -3A).

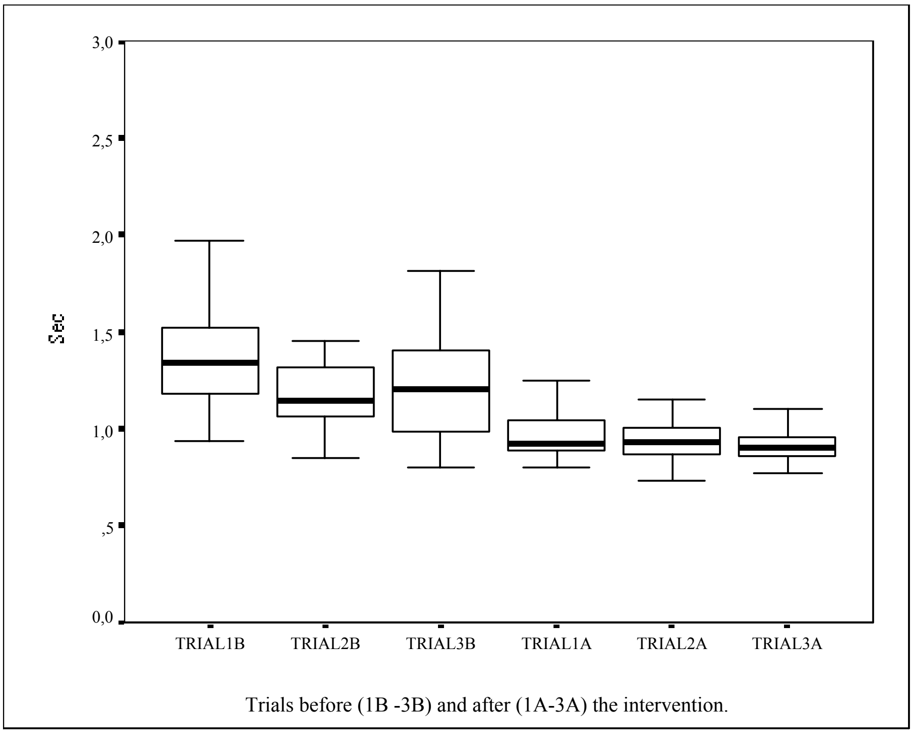

Figure 2. *Time (sec) to complete the exercise. Median values 10th, 25th, 75th and 90th percentiles.*

The velocity is the speed (m/s) along the trajectory of the haptic the device and is not calculated from the intertarget distance (fig 3). Even in speed there was an improvement. The median velocity before the intervention were for trials 1B – 3B; 0.16, 0.18 and 0.19 m/s. After the intervention the velocity was more or less equal, 0.31 m/s for trial 1A and 0.30 for trials 2A and 3A.

The subject had previous experience of communicating with computers and used it as a telephone for his long distance calls. The subjects spontaneous reaction about the telemedical communication were that the picture and the sound were well synchronized, the communication felt “close”, quick and of a good quality. He also stated that it’s more convenient; “you don’t have to travel into town, wait a couple of hours, make a quick exercise and then call the transportation service for older persons again and finally travel home again”.

4. DISCUSSION

The findings in this study implicate that virtual training of the effected upper extremity can promote motor rehabilitation. We investigated fine manual dexterity, grip force, motor patterns and velocity performed with affected upper extremity. A single subject research design was used. With a single subject design conclusions can be drawn of treatment effectiveness (Zahn S, Ottenbacher KJ, 2001). We observed that grip force, endurance and the motor pattern of the upper extremity increased after the treatment, which started 11 weeks after the stroke. The results imply that intensive training can reduce motor impairment and that it could optimize the stroke survivor’s motor skills. This is in line with the results of Copenhagen Stroke study (Nakayama H, Jörgensen HS, Raaschou HO, Olsen TS, 1994) where they show that the time course and degree of upper extremity function after a stroke with initial paresis basically occurred within the first 3 weeks and no further recovery of upper extremity function should not be expected after 11 weeks. For example, the subject’s velocity and time to complete the trials improved to a large extent, indicates that this might be an effective method to improve motor recovery. The kinematic motion pattern changed to some extent, with still difficulties in some direction, above all in the diagonal directions. The superfluous upper extremity movements along the trajectory to the target can be calculated. The quotation of the actual trajectory distance and the intertarget distance reflects the uncertainty of the upper extremity along the trajectory. This information can be the base for developing rehabilitation programs for upper extremity training.

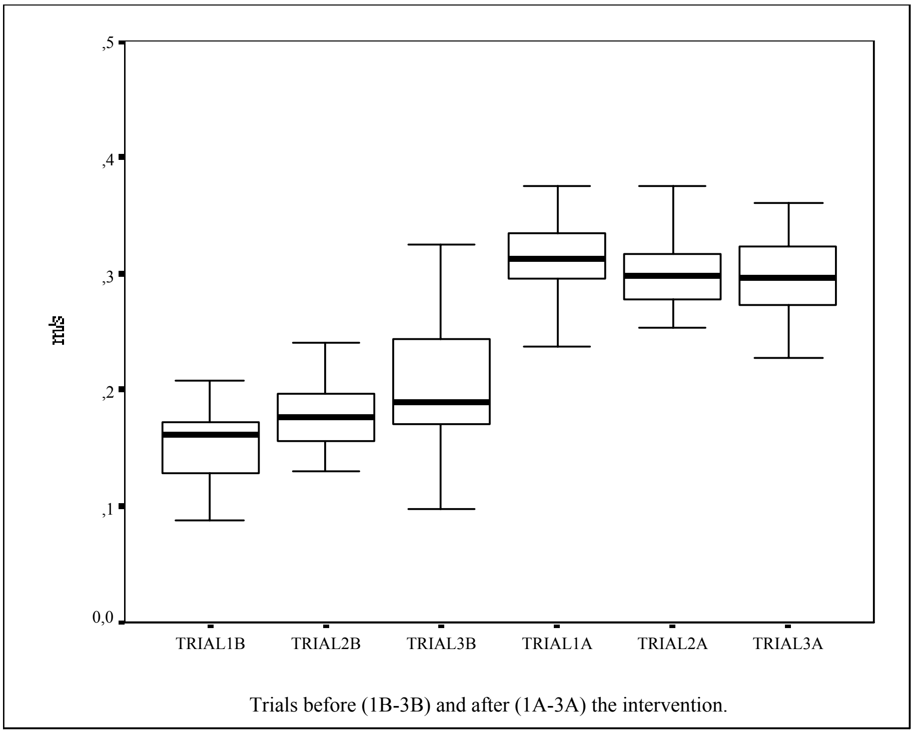

Figure 3. *Velocity (m/s) to complete the exercise. Median values 10th, 25th, 75th and 90th percentiles.*

The telemedicine application used was Microsoft NetMeeting 3.01. The main reasons why Microsoft NetMeeting were chosen was that it is a solid and fully tested software suite that provides an industry standard, good operating system residency, high performance and a smooth integration with other programmes at a low cost. The system was used as a personnel-patient communication tool before, after and even during the rehabilitation exercises, giving the patient the opportunity to e.g. show a hurting muscle group, his motor status and ask questions. In addition, the health professionals could for example instruct the patient, make a visual examination/status of the patient's motor capacity. The clinical advantage of using such a system is considerable. The trend is toward shorter hospital stays and fewer outpatients' visits. Today it is difficult to check a patient's progress once discharged from hospital. In order to reassure the patient's progress with their training programs new approaches must be adapted. The system probably demands, as today, good computer knowledge.

For an application like home care telemedicine, for people with neurological disorders, more development have to be done before this will be broadly accepted by patients and health care providers. Work need to be done in the following fields:

- Integration, interconnectivity (e.g. integration with electronic health record systems)
- Safety/privacy (e.g. on Internet)
- Standardization (e.g. in the field of home care telemedicine)

In conclusion: One subject with left hemiparesis improved his motor pattern, grip strength and manual dexterity. The results verify the efficacy of the treatment and justify further clinical trials. A larger trial is required to determine difference in improvement in motor abilities of the upper extremities in stroke survivors.

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