Investigating the use of force feedback joysticks for low cost robot-mediated therapy

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ABSTRACT

We are developing a low-cost robotic system– the Jerusalem Telerehabilitation System – using a force feedback joystick and a standard broadband internet connection. In this study, the system was found to be user-friendly by therapists, older and younger normal subjects, and a post-stroke subject. Kinematic analysis of the joystick movements showed differences between the older and younger normal subjects and between the post-stroke subject and older normal subjects. These preliminary data indicate that our low-cost and straightforward system has the potential to provide useful kinematic information to the therapist in the clinic, thereby improving patient care.

1. INTRODUCTION

Survivors of brain injury or stroke can improve movement ability with intensive, supervised training (Butefisch et al, 1995), and improvement with training may continue for a long time after injury (Forster and Young, 1996). However, economic pressures on health care systems and distance from rehabilitation centers prevent many patients from receiving the therapy they need. Robot-mediated therapy, which increases the time available for repetitive movement training, and telerehabilitation, the delivery of medical rehabilitation services at a distance via the internet, have the potential to address these problems (Rosen, 1999; Krebs et al, 2004; Fasoli et al, 2004).

In recent years, many researchers have investigated the use of computerized mechanical devices to automate movement therapy for neurological conditions (Krebs et al, 2004; Fasoli et al, 2004; Reinkensmeyer et al, 2002; Coote and Stokes, 2005; Broeren et al, 2004; Burdea et al, 2000; Jadhav and Krovi, 2004). Many of these devices utilize haptic interfaces. Robotic therapy has been found to significantly improve the movement ability of the affected upper limb in stroke patients (Fasoli et al, 2004; Coote and Stokes, 2005). In addition to providing a platform for intensive, repetitive movement therapy, the use of robots and other computerized mechanical devices also provides the opportunity for detailed kinematic analysis of patient movement. Kinematic analysis gives us information that we would not otherwise have. For example, Sugarman et al. (2002) demonstrated the presence of irregularities (segmentation) in the movement of the ostensibly unaffected hand in post-stroke subjects. Hwang et al (2005) had similar results showing segmentation of cursor trajectories. Quantitative information about movement (timing, joint angular and segmental paths, velocities and accelerations) can be used for diagnosis, evaluation and monitoring of patient progress (Liebermann et al, 2006), and would, therefore, be a useful tool for therapists in a clinical setting.

Despite the important information that can be derived from kinematic analysis, use of this type of analysis is not a routine part of treatment in most therapeutic settings. The reason is that most of the computerized systems that have been used for such analysis are complicated and expensive and, therefore, not suitable for ordinary clinic or home use. Moreover, in order to apply them for telerehabilitation use,

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special phone lines may be required (e.g. Piron et al, 2004). We have followed the lead of the inexpensive Java Therapy System described by Reinkensmeyer et al (2002) and are developing a low cost robotic system - The Jerusalem Telerehabilitation System (Sugarman et al, 2006) - for the treatment of stroke and traumatic brain damage. The system uses a commercially available force feedback joystick, which we have programmed to either assist or resist the patient's movements, an ordinary home PC, and an arm rest we designed and built ourselves. The arm rest is designed in such a way as to enable patients to move the joystick by means of relatively large movements of their shoulder and elbow joints. Use of the arm rest also eliminates the need to use a splint to help the patient grasp the joystick. A graphical representation of the client's movements is available via the "graph animator". The system monitors the status and progress of the patient, and various parameters of his movement abilities, such as movement time, as well as accuracy and trajectory, and prepares reports for the patient and the therapist.

The Jerusalem Telerehabilitation System can work in two modes, a stand alone mode and a cooperative mode. In the stand-alone mode, the patient works either in the rehabilitation clinic or independently at home; in either case, a file recording the exercise session will be stored locally and uploaded automatically to a central data base at the end of the session. In the cooperative mode, patient and therapist are online at the same time and the therapist can observe the patient's movements and can guide the patient's joystick if necessary. In the cooperative mode, the system will work via a standard broadband internet connection.

Compared to existing systems, our system will have the following advantages: 1) The system will be inexpensive and easy to use. 2) The system will have remote monitoring and guidance of the patient's joystick by the therapist in the clinic. 3) Our system will provide a detailed report of kinematic variables such as timing, path length, straightness of path, number of sub-movements and degree of segmentation (see Sugarman et al, 2002); this will give the therapist in the clinic a practical, easy to use tool for tracking patient status and progress. 4) Instead of using Java applets that download each time (as in the Java therapy system), in our system the game is downloaded once and then the client can use it at will without waiting each time; client programs and data from exercise sessions are stored locally on the client's computer and uploaded to a central server at a later date for monitoring by the therapist. 5) There will be a "smart" system which self-adapts to the patient's capabilities in real time by increasing or decreasing the difficulty of the exercise as needed, for instance by changing the size of the target. 6) Subjects who are unable to grasp the joystick will use the custom-made arm rest that will allow them to move the joystick by means of movements of their shoulder and elbow joints, instead of by the usual method of small wrist movements; this will allow even severely involved subjects to use the system. 7) We plan to develop a central, international database which, by gathering data on many patients over time, will provide the basis for "smart" therapy and will also facilitate coordinated multi-center research studies.

As a preliminary test of our system, we conducted a pilot usability trial with one subject after stroke as well as several normal subjects of two different age groups. We also asked two physical therapists to try out the system. The goal was to see if therapists and subjects were able to use the system, and to examine the nature of the data obtained from the trials. We were particularly interested in investigating whether a simple, low cost system based on an off-the-shelf joystick with a relatively low sampling rate of 50 Hz would provide useful kinematic information.

2. METHODS

2.1 The system

The Jerusalem Telerehabilitation System consists of a client system and a therapist system (Figure 1). Currently, both systems are located in the clinic, but our plans are to make the client system suitable for use at home, connecting to the clinic via a standard broadband connection. Each system consists of a standard PC computer, a custom made arm rest and a force-feedback joystick as the input device.

We use Java for the graphical user interface and for communication functions. The therapeutic exercise uses Open GL to enable 3D visuals and DirectX for the sound and the joystick. There is a communication module in C++ for communication between the client and the therapist. This communication allows the therapist to see the movement of the client's joystick and also to guide the client's joystick, both in real time.

2.2 The subjects

There was one subject, age 65, with left hemiparesis, 10 years after stroke. There were three normal subjects in the age range 20-30 (younger group) and three normal subjects in the age range 50-65 (older group). The subject after stroke used the system as a preliminary usability test only. This trial did not affect his usual rehabilitation therapy. In this paper, we are not reporting on using our system as a treatment option. Two physical therapists, specializing in neurological disorders, were trained to use the system.

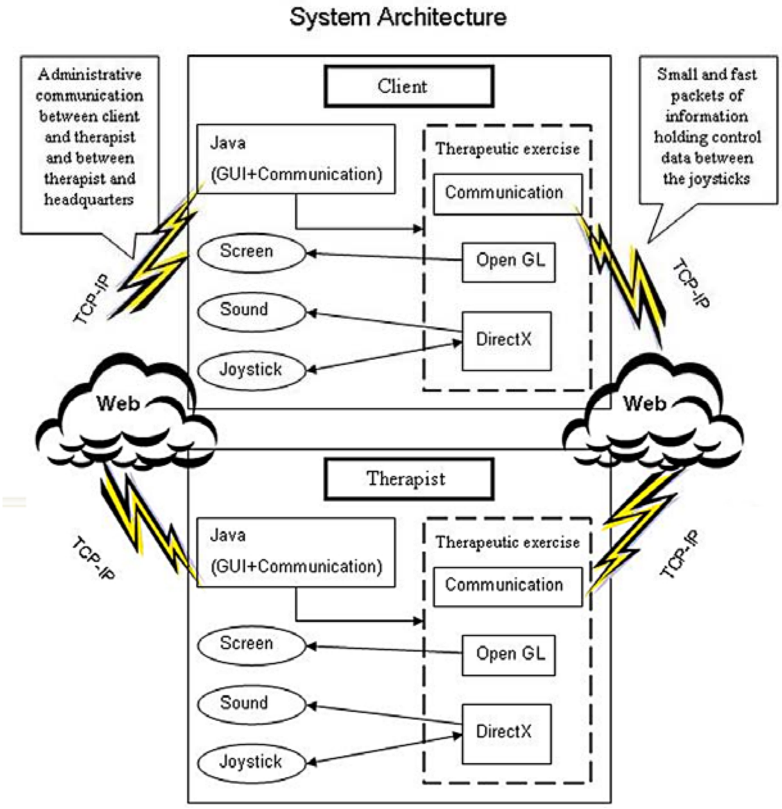


Fig 1. *Architecture of the JTR system. The client and the therapist each work with a PC and a joystick. They communicate with each other via the internet.*

2.3 The task

In the exercise that we tested, eight targets are arranged in a circle around the perimeter of the computer screen. (Figure 2) The subjects used the joystick to move the cursor to each of the 8 targets in turn, moving according to cue between opposite pairs of targets.

The motors in the force feedback joystick are programmed to either assist or resist patient movement. If the patients are unable to perform a movement, forces applied by the joystick will bring them very close to the target, and they then complete the movement on their own. If the patient is stronger, then the joystick is programmed to resist movement. The therapist can set the level of assistive or resistive force feedback as deemed appropriate for each patient. The maximum output of the joystick is approximately 5 newtons. In this study, subjects used the system both with and without force feedback. The kinematic analysis was done on those trials in which there were no forces applied to the joystick.

Each subject used the system for one session with three repetitions for each hand without force feedback. Afterwards, the subjects also tried out the various modes of force feedback – assistive and resistive at different strengths – and their reactions to the system were elicited.

2.4 Movement analysis

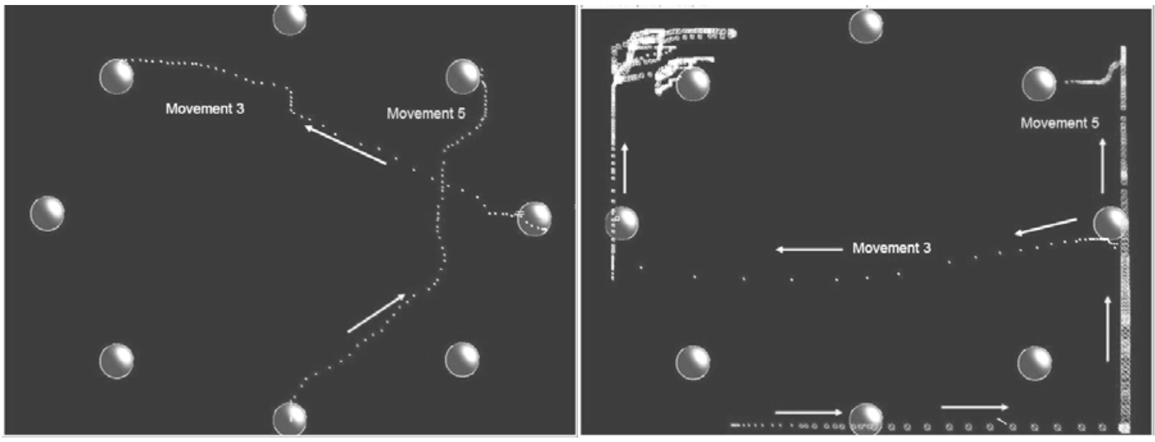
In each trial, the *x,y,* coordinates (in pixels) of the position of the joystick and the target position are sent by the joystick to the text file at a rate of 50 Hz. The forces applied to the joystick by the program are also sent to the text file at 50 Hz.

In this study, we examined the following kinematic parameters: movement time (average movement time between targets), and relative path length (the ratio of actual to ideal path length). In future studies, we plan to add other parameters such as analysis of the number of sub-movements in order to assess the degree of segmentation and thus the smoothness of the movements of brain damaged subjects.

3. RESULTS

3.1 Reactions of the subjects

Both normal subjects and the post-stroke subject reported that they enjoyed using the system. They were able to understand how to do the exercises and were able to concentrate on them. Subjects who were provided with feedback on the time it took them to complete the entire exercise (eight targets) said they enjoyed the competition aspect and tried to improve their time. The post-stroke subject asked when the system would be available for him to use at home. The two therapists who used the system found the program easy to learn and operate. Both initially expressed hesitation about using a computerized system; however, after a short (less than 1 hour) training session, both therapists were able to use the system independently. They had no difficulty remembering and using the various features of the program.



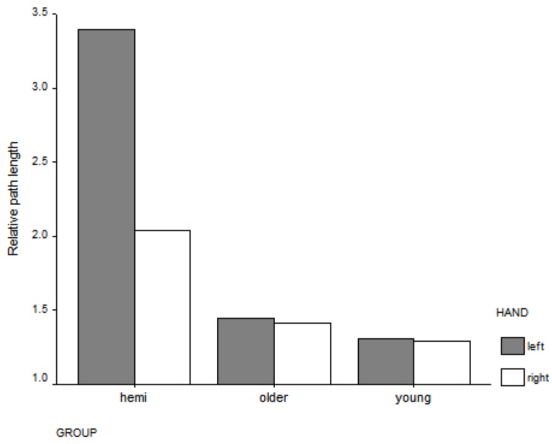
(a) *(b)*

Figure 2. *Screen shots from Graph Animator. The figure shows the eight targets arranged around the perimeter of the screen. These screen shots from the Graph Animator show movements 3 and 5 out of eight movements for a normal subject (a) and a post-stroke subject (b). Arrows indicate direction of movement. Distance between dots is proportional to the speed of the movement.*

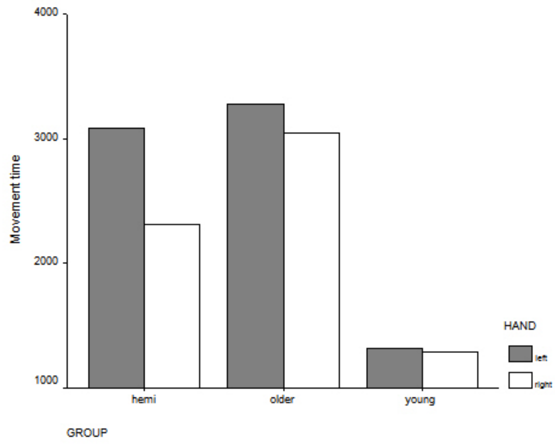
3.2 Kinematic analysis

Kinematic analysis showed differences between the movements of the older and younger subjects and also indicated abnormalities in the movements of the post-stroke subject. The average relative path length for the older normal group was 1.4 (ratio of actual to ideal path length) for both hands, compared to 1.3 for the younger normal group (Fig. 3A). In addition, the average time for the individual movements to each target was longer for the older subjects (Fig. 3B). The post-stroke subject demonstrated much greater relative path length (3.4 and 2.0 for more affected and less affected hands, respectively) as compared to the normal older group. However, the average time for individual movements of the post-stroke patient was similar to that of normal subjects in his age group.

Examining the data from the post-stroke subject, we were able to differentiate between two types of difficulties: moving towards the target and homing in on the target. Figure 2A shows a normal subject performing movements 3 and 5 of the exercise and Figure 2B shows a record of a left hemiparetic subject performing the same two movements with his affected hand without the assistance of the joystick forces. It can be clearly seen that the post-stroke subject was not able to perform oblique movements and instead progressed by moving around the perimeter of the screen. In addition, we can see it was much easier for him to "home in" on the target on the top right as compared with the target on the top left.



(a)



(b)

Fig. 3. *Kinematic parameters. A) The relative path lengths for the movement during the exercise was greater for the older normal subjects than for the younger group, and was much greater for the post-stroke subject. B) The average time for movement segments was greater for the older normal group than for the younger group; the average movement time for the post-stroke subject was similar to the older normal group.*

4. DISCUSSION

In this paper we have shown that the JTR system is capable of measuring differences in kinematic parameters such as movement time and relative path length. The trajectories of individual movements are recorded and can be analyzed for direction changes, difficulty in performing certain movements and the ability to home in on a particular target. This type of information − which movements and which directions are more difficult for each patient − will be useful to the therapist in customizing exercises for each patient. The system is simple and straightforward and was readily accepted both by therapists and the study subjects.

In recent years many studies have been done on kinematic abnormalities of movements following brain injury. Devices used include the Inmotion2 (commercial application of the MIT-Manus robot) (Rohrer et al, 2002), the Optotrak system (Michaelsen et al, 2006), the Elite 4 camera system (Van der Heide et al, 2005) and the Phantom (Broeren et al, 2002). Parameters evaluated included time, velocity, and relative path length (the degree of superfluous movements − trajectory/distance). These are all excellent systems; however, their high cost and the need for technical help in using them put them beyond the reach of the ordinary clinical setting. As far as we know, no low-cost easy to use systems are currently available. We would like to suggest that a possible spin-off of our simple, low-cost system would be to provide just this type of tool.

5. CONCLUSION

In conclusion, we found that this simple joystick paradigm can be used by patients and therapists and will give us useful kinematic information. The next step will be to do a wider clinical trial and develop more therapeutic exercises in preparation for distribution of the system in the homes of patients.

Acknowledgements. We are grateful to the Dorset Foundation for their generous funding of this project.

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