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Seminar Report on

Haptic Virtual Rehabilitation Exercises For Poststroke Diagnosis

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ABSTRACT

These days, stroke is perhaps the most continuous causes of extreme adult disability on the planet. Computer generated reality or virtual reality and haptic innovations have arisen as promising assistive devices for applicable diagnosis and rehabilitation intervention. The goal is to create and test a bunch of five virtual activities on top of a framework, which is intended for the diagnosis and rehabilitation of patients with hand hindrances. Task-situated activities dependent on well-established and familiar exercises are described, specifically the Jebsen Test of Hand Function and the Box and Block Test. These tests incorporate moving a cup, masterminding or arranging blocks, exploring a labyrinth, training with a hand weight such as a dumbbell, and getting a handle on a rubber ball. Moreover, key execution measures (metrics) are proposed for each activity to quantitatively assess and pass judgment on the performance of these exercises by stroke patients. The system aims at being used as a rehabilitation tool and for diagnosis to quantitatively measure and evaluate the patient's progress and level of recovery. The performance analysis of the exercises has shown the reliability and validation of the framework of haptic based exercises and its effectiveness as a diagnosis system to analyse the patients' data. Despite the limitations of state-of-the-art haptic devices, a huge set of interaction data can be captured and analysed to derive reference "golden" metrics for normal healthy subjects. Consequently, the patient's performance can be tested against the golden metrics, and thus, an objective decision about the patient's progress and level of recovery can be easily made. The assessment of these activities shows promising potential to define "golden" reference measurements for sound subjects, against which the exhibition and performance of a patient is looked at. The long-term objective is to develop a Decision Support System, whereby OTs at clinics can evaluate a patient's performance of exercises carried out at home and accordingly adapt tasks based on the patient's current capacity. This will be extremely beneficial for occupational therapists as it will help them assess the patient's progress.

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1. INTRODUCTION

Stroke is a primary cause of adult disability in the world nowadays and is anticipated to remain a leading problem in the years to come. In addition, stroke is the third leading cause of death in developing countries, and studies aim at curing of this neurological injury, particularly in such countries. According to the National Stroke Association, nearly 5 million people in the United States today have survived a stroke, and around 700,000 Americans have a new or repetitive stroke each year. The aging of the population and its negative impact on disabilities have led to an expected rise in the number of patients that will need rehabilitation in the coming years; as a consequence, available resources have unfortunately reduced.

According to Ottawa General Hospital, stroke patients are typically seen for one or two half-hour sessions per day, which is hardly enough time for a patient to recover, particularly when this is decreased to once or twice a week if the patient is seen as an outpatient. The reduction in the duration of rehabilitation and the lack of timely interventions could lead to permanent disabilities in certain cases of treatable or reversible conditions. On the other hand, the effectiveness of intensity and repetitive exercises also has a significant impact on the patients' recovery. In one of the first works, Langhorne and others studied the effects of changing levels of therapy intensity with approximately 600 patients. The results showed that a more intensive physical therapy leads to greater improvements.

Virtual reality (VR) technology is increasingly playing an important role in many areas. This technology allows users to interact with computer-simulated environments, and although it has traditionally been focused on game and entertainment applications, recently, it has been extended to other fields. In addition to VR systems that provide 3-D virtual environments within which the user can navigate, haptic devices enhance the level of user interactivity experienced in such environments and improve task performance.

Beyond the traditional therapies, the main advantages of VR-based rehabilitation or virtual rehabilitation are highlighted in repetition, feedback about performance, and motivation.

Repetition causes the decoupling of the patient's mind and reduces his/her motivation, so patients must be motivated. The use of game-based features into virtual environments is reported to enhance motivation during therapy. Moreover, auditory and performance feedback can help patients be motivated. Whereas virtual rehabilitation continues to develop, recent studies with stroke patients have proved how VR can positively contribute in the neural organization and recovery of functional motor skills.

Haptic, a term that was derived from the Greek verb "haptesthai," meaning "to touch," adds the sense of touch and force feedback in human–computer interaction. Haptic-based systems enable a user to manipulate objects in virtual environments in a natural and effective way and can provide information which cannot be completely described with visual or audio feedback, such as stiffness, texture, or weight of objects.

The reduction in the covered duration of therapy too has a negative impact on the patient's condition and on the recovery process. The duration of the rehabilitation therapy is important ,as is timeliness of treatment. Indeed, assessment and therapy have to occur early on, or else the same therapy duration will have diminished results. Timeliness and duration of rehabilitative therapy are problematic for those in remote rural locations or living in depressed urban areas. In such instances, generally there are no clinics in the vicinity of the patient's home. Avoiding travel to the clinic altogether would mean that adequate therapeutic intervention can be done at home, after an initial assessment at the clinic. However, therapists may not be able to travel to the patient's remote home or may be unwilling to do so.

Prototype systems that do provide forces for manual therapy have been developed by Hogan at MIT, Luecke at Iowa State University, Takeda and Tsutsul at Nagasaki Institute Applied Science, and, Rovetta at the Milano Politechnic Institute. All of these prototypes had certain advantages versus the clinical practice. For example, the MIT system showed faster upper limb motor rehabilitation for stroke patients who exercised with a robot. The Iowa State system allowed independent force control for each finger, while the Nagasaki system was extremely light and powerful through the use of pneumatic "muscle" actuators. However, all the systems mentioned above also had drawbacks, due mainly to their complexity (for example, the use of robot manipulators), making them difficult for use at home.

In occupational therapy, the aim is to help people with disabilities improve their ability to perform tasks in their daily living and working environments. By helping patients improve their basic motor functions and devising abilities to compensate for permanent losses of function, patients can achieve independence and a better quality of life. Due to the force feedback provided by haptic devices, haptic-virtual-based systems are well suited for simulating user interactions related to basic motor functions. In addition to the advantages of virtual rehabilitation, adding force feedback information within a virtual environment helps to objectively measure performance and to tailor performance-based exercises for each patient. This potential to assess the patient's performance, by measuring different parameters, which cannot be evaluated in traditional rehabilitation, can be of benefit to both patients and occupational therapists (OTs).

The results of testing five virtual hand exercises with ten healthy subjects from the University of Ottawa are presented. These virtual exercises have been designed based on well-established tests, which are frequently and commonly used by OTs for evaluating hand disability and recovery after training. In particular, the purpose of this test is to define key performance measures (metrics) for these virtual exercises to quantitatively assess a stroke patient's recovery. This will contribute as a further step toward the tele-rehabilitation and evaluation of the patient's progress over a long distance.

The results of testing five virtual hand exercises with ten healthy subjects from the University of Ottawa are shown. The virtual exercises described have been designed based on well-established tests, which are frequently and commonly used by OTs for evaluating hand disability and recovery after training.

The report has been structured as follows. In section titled related work , related work in the field of haptic virtual rehabilitation has been highlighted and how their work is different from others. Section titled system components mentions the framework and its software architecture. The five task-oriented exercises are described in section named exercise description. Performance evaluation section, elaborates the quantitative diagnosis analysis to evaluate the patient's state using the recorded haptic data. Finally, conclusion is provided based on the findings mentioned and suggests recommendations for future development.

2. RELATED WORK

In recent years, much research that involves VR and haptic devices has been addressed in medical rehabilitation and telerehabilitation. For instance, VR has been extensively used in the assessment and rehabilitation of brain injury disabilities, such as cognitive abilities [1] or motor rehabilitation [2]. These disabilities can be resulting from stroke, Parkinson's disease, acquired brain injury, muscular sclerosis, and/or paraplegia. In the area of psychological disorders, VR has also been applied as a treatment for overcoming agoraphobia, acrophobia, and fear of flying, as well as for obese patients [3].

In the case of haptic virtual rehabilitation for stroke patients, some research has been done on the rehabilitation of upper and lower extremities, such as the hand [4][5]-[10], arm [7], or ankle [11]. These haptic virtual systems help patients with upper or lower extremity weakness to relearn perceptual and physical daily activity actions. Furthermore, different studies on haptic virtual rehabilitation have shown its potential to continue to improve recovery after stroke [4][11].

VR head-mounted displays (HMDs) have been used to present visual cues overlapping the real visual scene during ambulation of patients with Parkinson's disease as a tool to facilitate a more normal gait pattern. VR training has been used for children with cerebral palsy to enhance spatial awareness and the operation of motorized wheelchairs. VR-based rehabilitation has also been investigated for orthopaedic patients following hand surgery or ankle accident. Robot training using a virtual environment has recently been shown to enhance stroke rehabilitation.

Motor function of the affected arm was improved following robot-assisted sensorimotor activity of that arm. Subjects assisted by the robot were able to relearn patterns of shoulder and elbow coordination in order to smoothly and efficiently move the handle of a robot to acquire targets. Often, the virtual exercises for hand rehabilitation consisted of a series of game-like tasks to address certain parameters of hand movement [12][4][5][6][13]. Moreover, one of these works has studied how VR training transferred to real-world activities by using the Jebsen Test of Hand Function (JTHF)[13] .

Unlike these exercises, the five selected exercises have been designed based on well- established and common exercises, such as the JTHF [13] and the Box and Block Test (BBT) [14].

The JTHF was developed by Jebsen and has been continuously used by OTs. This test consists of seven items and was designed to provide a test for evaluating disability and improvement after the training of hand performance used in tasks of daily living. Four of the five described exercises are based on the JTHF and have been collaboratively designed with OTs at Ottawa General Hospital.

These exercises are handling a cup, navigating a maze, squeezing a ball, and exercising with a dumbbell. In haptic virtual rehabilitation, some researchers have also designed a virtual Purdue pegboard exercise to evaluate the manual dexterity in stroke patients. However, this test may have a limited application in acute stroke patients. A simple and traditional test, such as the BBT, is also being used by OTs as a test of manual dexterity. The fifth exercise is “arranging blocks” and is based on this test.

To date, there exists little knowledge about the role of haptic virtual rehabilitation in the assessment of patients. A preliminary study was conducted with 13 patients suffering from various forms of neurological diseases and three healthy subjects was carried out for upper limb motion analysis[15]. The subjects were asked to navigate a virtual maze by moving a virtual ball attached to the haptic device, and when a collision between the ball and the wall occurred, they received collision force feedback. The results suggested that the proposed haptic virtual system was a potential tool for the objective assessment of upper limb movement deficits, for instance, tremor, movement control, and speed when navigating the maze.

In a later research, a simple task was tested for indicating the potential of haptic virtual environments as an assessment method. This task consisted of moving the haptic device from a position to nine other locations. The performance was evaluated by measuring the task completion time (TCT), speed, intertarget distance, and trajectory distance. The averaged measures obtained from seven healthy subjects were used as a reference to assess the results of three patients. In case of fingers and hand rehabilitation, four parameters of hand movement are exercised and measured, i.e., range of motion (i.e., finger flexion and extension), speed of motion, fractionation (i.e., a finger flexion while the others are kept open), and strength during a two-week test. In particular, they were focused on measuring motor parameters to show motor recovery during the therapy. However, if VR is planned to be used for remote diagnosis and treatment according to the results, the measured parameters must be consistent, compelling, and clinically meaningful.

3. SYSTEM ARCHITECTURE

To develop the five haptic-based exercises, the authors designed and implemented a framework that comprises three components, i.e., the sensory system, the simulation system, and the haptic/behavioural data repository (Figure. 1).

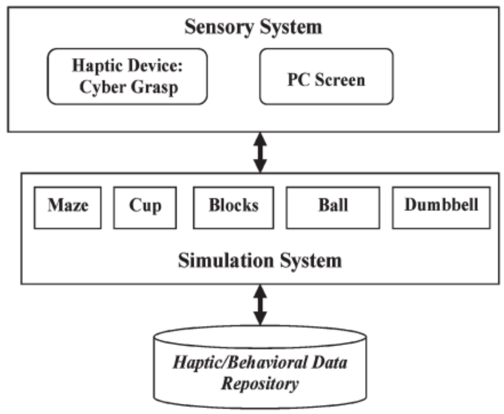

Figure 1: Framework For Haptic-Based Exercises

The haptic and visual interfaces are embedded within the sensory system. The haptic device used for all the exercises is the CyberGrasp system. This device consists of three pieces of hardware, i.e., the CyberGlove, the CyberGrasp, and the CyberForce armature. The CyberGlove is equipped with sensors to read palm position and the spatial coordinates of individual fingers to construct a realistic avatar of the hand in the virtual environment. The CyberGrasp provides force feedback to the fingers via actuators, whereas the CyberForce is a robotic armature that locates the position of the hand in space and simulates inertia.

The simulation system is responsible for simulating the complex calculations involved in the haptic rendering process loop, maintaining synchronization with graphic rendering and recording haptic behavioral data for further analysis. Likewise, loading and rendering the different exercises are managed by the simulation system.

The haptic/behavioral data repository acts as a collector for the data captured during each subject's exercise session. Data recorded throughout the exercises provide information about the position of the hand on the screen, the angles of the three phalanges, and, finally, a time stamping of the sampled data.

4. EXERCISE DESCRIPTION

The exercises have been designed to test certain abilities of an individual and include handling a cup, arranging blocks by colour, navigating a maze, squeezing a ball, and performing dumbbell training.

The rehabilitation exercises, supervised by OTs, involve applying task-oriented forces to the injured/disabled area to regain its strength and range of motion. On the other hand, it is critically important to help the stroke patient recover hand function abilities through not only easy-to-do but also diverse tasks. These exercises are diverse enough to support a combination of tasks that can be defined by OTs according to each patient's case (with the ability to change task parameters, such as weight, feedback forces, and object geometry).

VR rehabilitation exercises can be made to be engaging, such that the patient feels immersed in the simulated world. This is extremely important in terms of the patient motivation, which, in turn, is key to recovery. VR sensor technology can also be used to fully quantify any progress made by the patient, especially in terms of motor-control improvement. Although most neurologic recovery is attained by three months after the stroke, several studies investigating the outcome of treatment six months after the stroke have shown significant gains in dexterity, strength, and function. If VR-based rehabilitation of patients who experienced stroke years ago is proven successful, then treatment options become available past the traditional period of inpatient hospitalization and rehabilitation.

It has been shown, in normal subjects, that VR can be a beneficial environment for learning a motor task. One study used a VR system for table-tennis training, including virtual paddles for the teacher and the subject, as well as a virtual ball. Augmented feedback was used to indicate to the trainee the movement variables most relevant for successful performance of the task.

Results indicated that subjects who received the virtual environment training did better than subjects who received a comparable amount of training in a real environment. Another experiment comparing VR training and real-world training in a pick-and-place task showed improvement in both groups, but those trained in the real-world task did better. This is because the VR group used low-resolution HMDs and gloves with no force feedback.

4.1 Handling A Cup

This exercise involves handling a virtual cylindrical cup across the virtual space (Figure. 2).

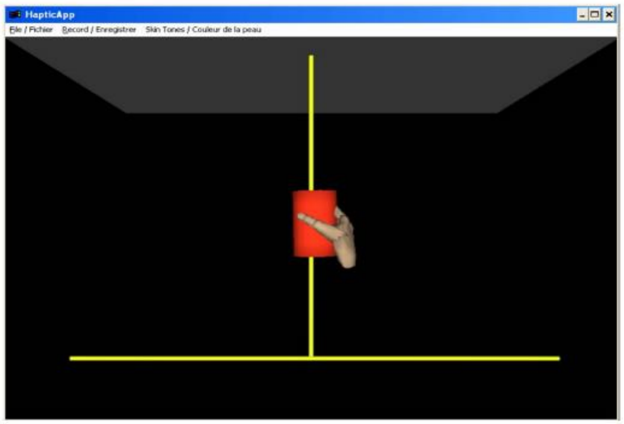

Figure 2: Handling A Cup

The subject has a view of a cylindrical cup and a virtual hand, which corresponds to his/her hand using the CyberGlove. The user can reach the cup and then grab it. A virtual touchable ceiling has also been added to the scene to limit the subject's hand movement.

4.2 Arranging Blocks

This is reportedly the most difficult exercise to perform. It involves four blocks with each face differently coloured (Figure. 3).

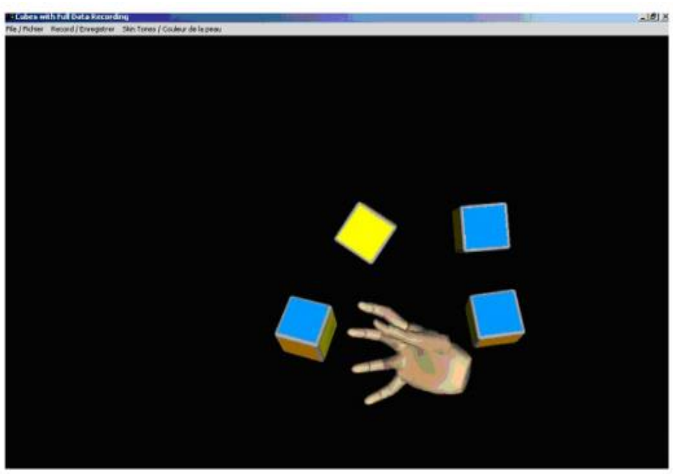

Figure 3: Arranging Blocks

The four blocks are randomly placed on the right so that the user can practice grasping objects and moving them to the left side. This exercise tests the subject's perception of patterns and also the dexterity and strength of the hand to grab, move, and arrange the blocks.

4.3 Navigating A Maze

As shown in Figure. 4, a subject sees a maze and a stick with a thin cylindrical-shaped handle.

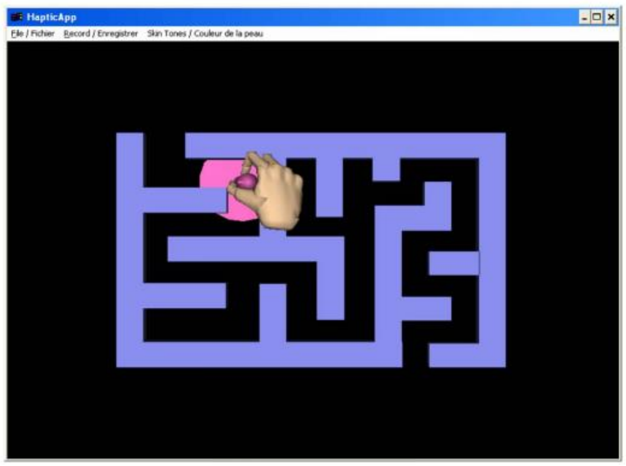

Figure 4: Navigating A Maze

Although there is the task of grabbing the stick, the main task here is to navigate the maze using the stick through the maze's paths to reach the end. The objective of this exercise is to improve the steadiness of the hand movement while performing a task, which also requires eye–hand coordination to avoid colliding with the walls. The size of the maze can be modified to make the exercise easier or more difficult.

4.4 Squeezing A Ball

As shown in Figure. 5, a spongy ball is placed at the center of a triangle so that the subject can easily locate it. The virtual squeezing ball consists of a virtual elastic ball that the patient grasps with a virtual hand, and is designed to strengthen the patient's finger flexion movement. The exercise difficulty is adapted by modifying the hardness of the ball (stiffness and elasticity). This is controlled by the OT by pressing a button.

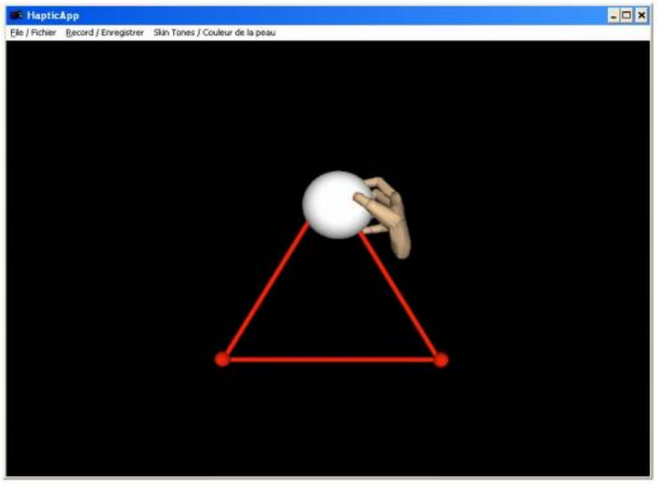

Figure 5: Squeezing A Ball

4.5 Dumbbell

The last exercise aims at fine and gross motor skills and strength. The user sees a weight dumbbell and grasps it in the horizontal direction with the palm oriented upward (as shown in Figure. 6). It helps in recovery of upper body push-pull muscles i.e., the shoulders, pectorals, and latissimus dorsi (a relatively thin muscle which covers almost all back muscles at the posterior trunk).

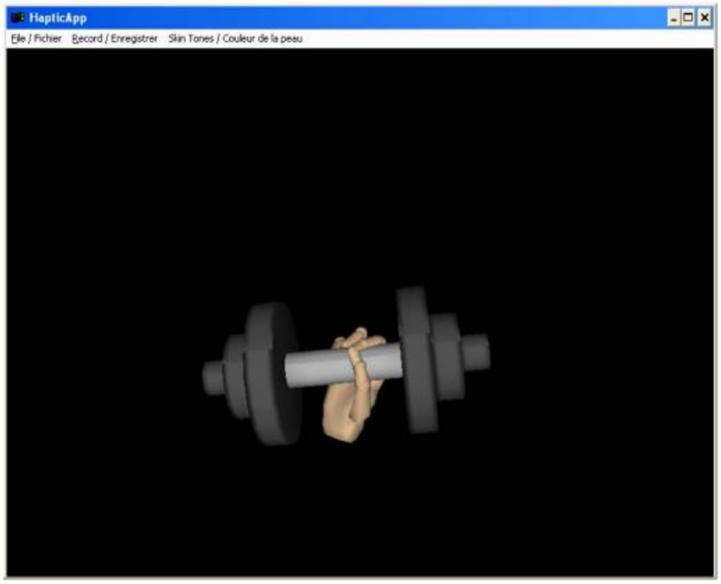

Figure 6: Working Out With A Dumbbell

5. PERFORMANCE EVALUATION

To prove the effectiveness of this haptic virtual system as a training and assessment tool for OTs, five hand exercise tasks are designed. In this section, the setup of the tasks is described, and how the captured data can be analysed and used to evaluate the progress of a stroke patient is also described. It is studied how “normal” is the demonstrated behaviour of each subject. Ten students (eight males and two females) had participated in the experimentation; each repeated the tasks three times over three days. Each trial session consisted of five task blocks, i.e., moving a cup, arranging blocks, navigating a maze, training with a dumbbell, and grasping a spongy ball.

The tasks were designed to examine and measure the spatial and temporal properties of the hand/finger movements. These parameters include the TCT, the range and speed of hand movement, the steadiness of hand movement, the grasping angles, the total energy consumed per every task, among other possibilities. These parameters are derived from the data captured by the CyberGrasp system using its supporting VirtualHand API. The captured data include timestamps, the 3-D coordinates of the subject’s palm, the five-finger joint angles (the distal, proximal, and metacarpal joints), and the number of collisions (in the “navigating a maze” task). These data were captured at a high rate of around 170 samples per second.

The first parameter observed was the TCT, which is the measure of time it took the subject to successfully complete the task. This parameter examines whether the subject can complete a specific task within a reasonable time interval. The TCTs for the ten subjects while performing the five exercises (three trials each) are listed in Table I. Subjects who never used the CyberGrasp before (three subjects), had a clearly high TCT in the case of the first trial of the cup exercise, which was the first exercise carried out. In general, TCTs tend to decrease or remain during the second and third trials. By performing a comprehensive usability study for a larger set of “normal” subjects, a reference TCT per exercise is estimated and used to test (jointly with other parameters) how close a patient is to full recovery.

Table 1: TCT For Ten Subjects Per Three Trials

	Trials	Task Completion Time (Seconds)				
		Cup	Blocks	Maze	Dumbbell	Ball
Subject 1	Trial 1	55.00	60.14	31.7	20.02	33.6
	Trial 2	54.64	64.25	42.2	32.37	43.8
	Trial 3	47.19	67.08	34.5	28.81	35.7
Subject 2	Trial 1	54.17	48.14	26.9	111.45	78.7
	Trial 2	49.34	47.56	26.5	26.90	45.1
	Trial 3	45.76	42.16	25.8	26.47	47.6
Subject 3	Trial 1	72.34	63.97	39.8	37.55	56.8
	Trial 2	56.78	116.02	39.1	26.44	43.5
	Trial 3	71.89	55.73	34.5	26.66	34.7
Subject 4	Trial 1	84.39	75.23	30.8	24.66	42.9
	Trial 2	53.42	68.37	27.4	22.87	34.8
	Trial 3	43.90	42.75	33.2	15. 90	26.1
Subject 5	Trial 1	57.55	51.03	44.4	153.22	21.1
	Trial 2	52.06	53.94	41.8	23.53	30.6
	Trial 3	40.06	38.94	33.2	20.70	26.4
Subject 6	Trial 1	49.33	101.58	41.6	15.22	32.4
	Trial 2	29.66	70.37	24.7	20.01	30.4
	Trial 3	45.64	39.12	23.3	14.30	46.4
Subject 7	Trial 1	104.7	84.08	30.7	30.60	50.9
	Trial 2	76.78	57.42	32.1	27.36	32.4
	Trial 3	69.55	93.81	43.8	26.56	32.6
Subject 8	Trial 1	49.52	23.86	17.7	16.73	28.0
	Trial 2	27.30	18.05	10.8	19.33	22.1
	Trial 3	24.23	18.06	9.64	21.70	23.3
Subject 9	Trial 1	85.72	59.25	39.5	25.47	36.5
	Trial 2	69.91	40.37	43.0	27.37	38.1
	Trial 3	57.26	59.72	37.7	32.58	31.4
Subject 10	Trial 1	90.14	127.58	74.5	30.31	60.0
	Trial 2	40.48	54.58	22.6	28.86	42.2
	Trial 3	40.80	61.70	18.0	39.33	28.8

5.1 Handling A Cup

As per the cup exercise, the task was to grasp the cup, lift it in a straight motion along a prescribed path, as shown on the screen (Figure. 2), and release it after five times of getting back to the start-up point. The subjects were asked to move their hands as steady as possible and to avoid moving their hands into or out of the screen. Each exercise was performed three times, setting the weight to the maximum that can be handled by the CyberGrasp cables (25 units). The objective of the exercise was to measure the ability of the user to follow a visual path and test the hand–eye synchronization. After completing the task, the XY plane trace of the subject hand movement (Figure 7) was plotted. The plot helped in examining the subject's eye–hand synchronization by comparing the prescribed path (the dotted path in Fig. 7) and the path followed by the subject.

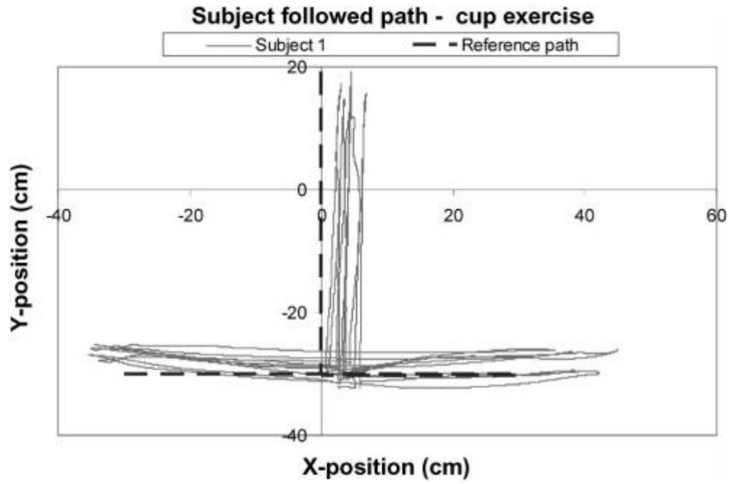

Figure 7: Position traces of the hand movement in the XY plane

5.2 Arranging Blocks

In the blocks exercise, the simulated task is to move the cubes, one by one, from the right side of the virtual space to the left one and then arrange the blocks to form one big block with its yellow face oriented out of the screen. The four blocks were randomly placed on the right so that the user could practice grasping objects and moving them to the left side. This exercise tests the subject's perception of patterns and also the dexterity and strength of the hand to grab, move, and arrange the blocks.

In addition to measuring the TCT for each subject, another important factor considered in this exercise is the compactness of the task completion. That is, the spatial workspace used by the subject to arrange the cubes.

This parameter was determined by finding out the minimum and maximum space coordinates reached by the subject and then computing the distance d between them. Geometrically, the subject movement was completely enclosed in a block with a diagonal equal to d.

The compactness factor acts as an indication of the effectiveness of hand movement toward completing a specific task. Table II shows the d factor computed for all the subjects during the three trials.

Table 2: COMPACTNESS FACTOR FOR THE CUBES EXERCISE

Subjects	Compactness of cubes exercise (cm)		
	Trial 1	Trial 2	Trial 3
Subject 1	28.55	36.23	30.00
Subject 2	36.355	39.69	37.30
Subject 3	25.985	46.42	42.74
Subject 4	31.50	41.91	29.70
Subject 5	61.16	72.78	38.43
Subject 6	37.31	42.60	34.16
Subject 7	53.30	39.80	34.90
Subject 8	36.18	45.70	38.35
Subject 9	35.28	36.14	56.82
Subject 10	35.75	29.92	30.38

5.3 Navigating A Maze

The task in this exercise was simply to navigate the maze. The subjects were asked to grab the stick and navigate the maze using the stick. This test was designed to test and examine the improvement of the steadiness of the hand movement while performing a task, which requires some concentration. Nonetheless, the challenge here is to complete the maze with the minimum number of collisions with the maze walls.

Plotting the captured position pattern in the same plane as the maze (XY plane in this case) shows the performed trajectory. The XY plane trajectory, as shown in Figure. 8, presents the movement quality. This plot helps therapists to subjectively evaluate the patient’s performance and whether she/he was able to complete the maze or if any wrong trajectory was followed.

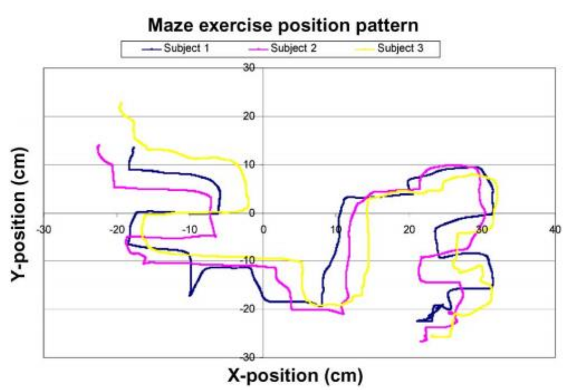

Figure 8: Position traces of the hand movement in the XY plane for three subjects.

The steadiness of the hand movement (tremor) was evaluated by conducting a frequency-domain analysis. High frequency components contain the tremor information and reflect the ability of the patient to control the haptic device tip during movement. The fast Fourier transform (FFT) has been used to compute the frequency components of the captured position pattern. For a normal subject, the spectrum comprises low-frequency components, whereas for a patient with unstable hand movement, the high-frequency components should be significant. Figure. 9 represents the frequency-domain analysis for three normal subjects, where the absence of high frequency components indicates a “normal” hand movement. A usability analysis could be performed to find an average frequency spectrum for normal subjects that could eventually be used to quantitatively evaluate the patient’s hand steadiness.

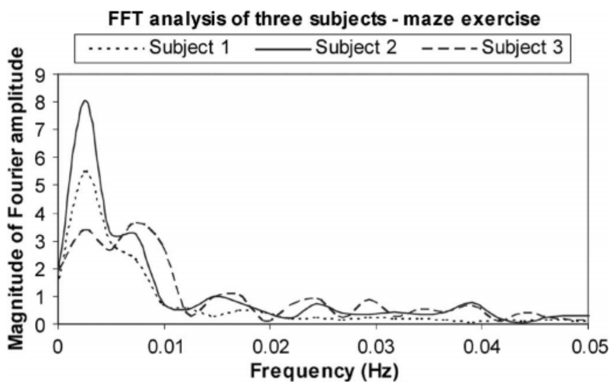

Figure 9: Frequency spectrum for three subjects (maze exercise).

5.4 Dumbbell

The subject was initially asked to grasp the dumbbell and maintain his/her hand in the horizontal direction with his/her palm oriented upward. Then, the subject was instructed to slowly lift his/her forearm until it becomes vertically oriented, and then slowly return to the starting position during ten times. The purpose of this exercise was to help in the recovery of the upper-body push–pull muscles.

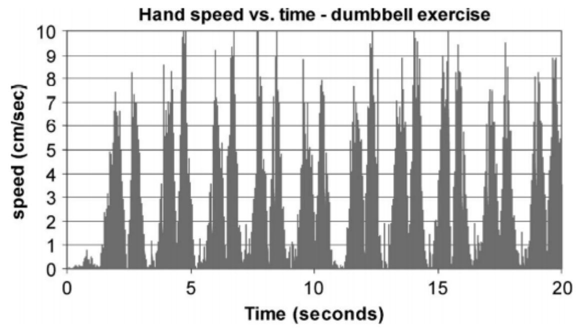

Figure 10: Speed of hand as a function of time for a subject.

To examine the movement of the subject’s hand, the speed of hand movement during the exercise was measured. As shown in Figure. 10, the speed distribution reflects the steadiness of the hand movement. It is mentioned that, a therapist could use such a curve to evaluate whether a subject was able to perform the ten times exercise with the same level of activeness, which leads to a better understanding of the patient’s specific impairment. By comparing the speed of hand distribution curve of a patient with a reference one, therapists could get an insight into the patient’s behaviour, which, thus, leads to a better diagnosis.

Another important parameter considered, was the total mechanical work performed when moving the hand against the dumbbell. Figure. 11 shows the kinetic energy while performing the task as function of time.

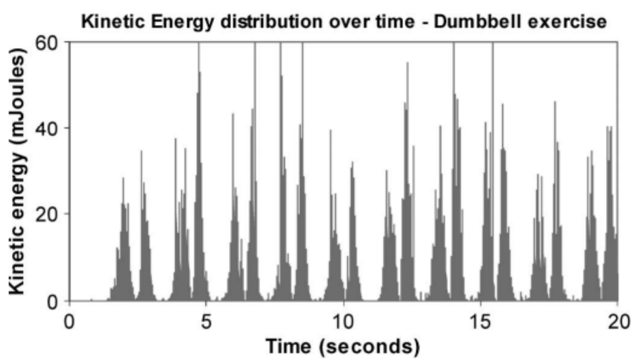

Figure 11: Kinetic energy distribution over time for a subject

The total energy could be computed by adding all the components drawn in Figure. 10 and this parameter is important to quantize the effort a patient puts in an exercise, and helps in examining and diagnosing the patient’s motor system.

5.5 Squeezing A Ball

The task is to grasp the ball and perform 20 uniform grips. The stiffness of the ball remained unchanged through all the trials (at 1 N/kg). This exercise aims at quantizing the griping behaviour for normal humans (the range of finger movement) and examines the finger extension capabilities. Therefore, the subjects were instructed to straighten their fingers and make a "complete" grip of the ball.

First, the grasping angle variations over time (speed) was examined. The grasping angle was defined as follows. Compute the total grasping angle per every finger as the summation of the three angles (metacarpal, proximal, and distal joint angles) and then calculate the average grasping angle for the five fingers. The grasping angle variation over time, for one subject, is shown in Figure. 12.

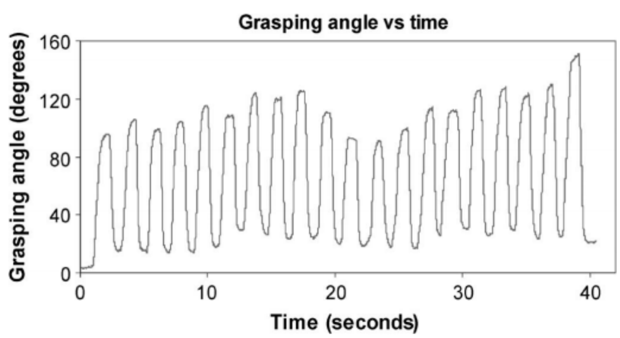

Figure 12: Grasping angle distribution over time for a subject

This plot could be used to detect specific finger deficits that might impede the finger movement and thus the proper grasping. Plot the grasping angle per finger to examine the behaviour of individual fingers. The range of finger movement (grip) for normal hand could be computed from the same diagram as the difference between the minimum and maximum grasping angle and could be used to evaluate the patient's performance. Another indication of finger behaviour is the measure of the finger speed over time, or finger acceleration, during a grip activity. Accordingly this plot can demonstrate any abnormal timings, sudden stops, hesitations, or abrupt changes in finger movements before, during, and after squeezing the spongy ball.

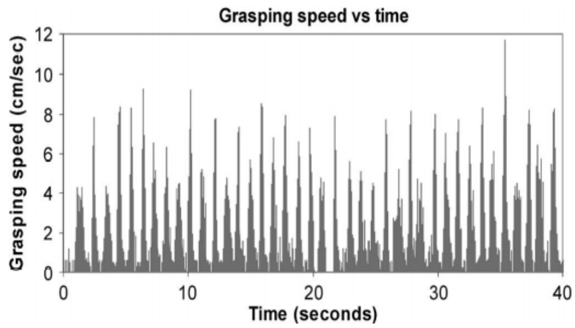

Figure 13: Grasping speed versus time for a subject.

For instance, Figure. 13 shows the grasping speed distribution as a function of time for one subject. It is observed that a sudden change in the finger movement happened during the 18th grip (around 36 s). After conducting the five tasks with ten subjects for three trials (altogether 30 trials per task), they derived preliminary normative values that characterize "normal" human hand behaviour.

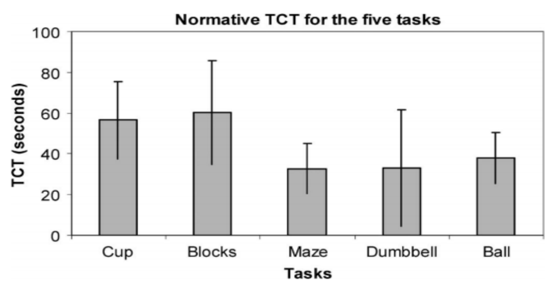

Figure 14: TCT for the five tasks (mean and standard deviation)

Figure. 14 shows the mean and standard deviation of the TCT for the five tasks. Table III lists three vital properties of the hand and finger function, i.e., kinetic energy, grasping angle, and grasping speed. These data, along with the TCT, position traces, and FFT analysis, could be potentials to be used as normative data to assess the patient's performance.

Table 3: Excerpt Of Normative Hand Function Parameters

	Exercise	Average	Standard Deviation
Kinetic energy (mJoules)	Dumbbell	41.32	21.40
Grasping angle (degrees)	Ball	131.51	21.65
Grasping speed (degrees/sec)	Ball	3.00	0.86

6. RESULTS

6.1 Analysis

The performance analysis of the exercises has shown the reliability and validation of the framework and its effectiveness as a diagnosis system to analyse the patients' data. The VR system was evaluated on three stroke patients in an intensive therapy program. Typically, three or four sessions of the four training exercises detailed were run three times for three days a week. Objective measurements revealed that each patient showed improvement on most of the hand parameters over the course of the training.

6.2 Comparison

In comparison to these five exercises another proposition has been made wherein researchers suggests a novel adaptive haptic-based serious game for post stroke rehabilitation. Real-time patients emotions monitoring based on the Electroencephalogram (EEG) is used as an additional game control. EEG is a non-invasive technique recording the electrical potential over the scalp which is produced by the activities of brain cortex, and reflects the state of the brain. A subject-dependent algorithm recognizing negative and positive emotions from EEG is integrated. The EEG-enabled haptic-based serious game could help to promote rehabilitation of the patients with motor deficits after stroke. Such games could be used by the patients for post stroke rehabilitation even at home convenience without a nurse presence.

6.3 Inference

A set of 5 exercises were derived from Jebsen Test of Hand Function (JTHF) and the Block and Box Test (BBT) . These exercises have been implemented using a VR environment and its effects have been observed from the subjects. The tests have shown significant improvement in the overall rehabilitation of the post stroke victims. Other VR instruments such as EEG could also be used to provide a more serious rehabilitation for post stroke patients.

7. CONCLUSION

The authors have designed and developed a haptic virtual rehabilitation system with five virtual daily life exercises for stroke rehabilitation. The system aims at being used as a rehabilitation tool and for diagnosis to quantitatively measure and evaluate the patient's progress and level of recovery. It was observed that the overall TCT score for patients assigned to navigate the maze was the lowest while that to arrange the blocks was the highest. This implies that with the help of VR stroke patients were able to regain normal function of their hand at a faster rate.

Recently, many research efforts have been put to overcome the current limitations of the haptic hardware technologies for rehabilitation applications. These include reducing the price of the hardware to make affordable for home use, minimizing the setup and calibration times, and providing a more transparent and stable performance of force rendering.

The long-term objective is to develop a Decision Support System, whereby OTs at clinics can evaluate a patient's performance of exercises carried out at home and accordingly adapt tasks based on the patient's current capacity and select exercises appropriately. VR technology thus has the potential to impact traditional rehabilitation techniques. A PC-based VR system for rehabilitating hand function in stroke patients developed was found instrumental in their recovery and could revolutionize the way such patients are treated and thus provide some help in their recovery.

In addition, further research could be done to get clinically meaningful, consistent, and reliable normative data also the topic could be expanded to accommodate more exercises as and when the VR technology develops. A database could be developed to provide easy access for data retrieval and analysis. A left-handed glove is under development to support patients with left-handed deficits. Also, other haptic devices for applying force feedback to the elbow and shoulder are under consideration.

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