3D-Cybertherapy and Immersive Learning Environments for Hand Stroke Patients' Daily Living Activities

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***Abstract*—This paper introduces the development of CyberTherapy System (CTS) based on needs analysis (interview and observation), a single subject experimental design and digital standardized cognitive assessment (DSCA) data. Restoring hand strokes patients' and independent lifestyle is the main objective of the CTS. The study began with an investigation of the problems faced by hand stroke patients during their conventional therapy sessions followed by designing and developing of CTS. A population of 115 hand-stroke patients with cardiovascular accident (CVA) who had undergone medical treatment in the ward and registered as outpatients at a general hospital in the Southern Malaysia, Occupational Therapy Unit and their therapists were the subjects of this study. The results of the investigation become the basis for the development of CTS. This new developed system is aimed at improving the functioning recovery of hand-stroke patients' by stimulating their cognitive ability, motor re-learning and coordination. The design and development of CTS were guided by therapists, neurologist and principles of motor re-learning to help and stimulate patients' cognitive ability and establish their motor functions. The environments of the system are related with daily living activities (DLA) such as hobbies and daily life routines. Digital cognitive assessment was embedded in the CTS to measure and obtain information on stroke patients' cognitive status before and after treatment. The completed CTS was pilot tested through a single-subject ABA experimental design over a longer period of 12 weeks and every hand-stroke patients were exposed to the varying levels of the flex-extend fingers range of motion. Results showed stroke patients' finger extension increased from the baseline to end of treatment. The stroke patients' cognitive scores attained the scores of DSCA < 24 further indicating that they are cognitively intact. Presumably, higher cognitive test scores considered CTS elements to be successful in stimulating to stroke patients' cognitive ability and forced their finger movement.**

Keywords-Hand stroke rehabilitation; Cybertherapy system (CTS); Virtual Reality Technology; Immersive 3D environments; motor re-learning theory;Digital standard cognitive assessment (DSCA); Technological Learning tool & innovation

I. INTRODUCTION& BACKGROUND

By definition, stroke is the loss of half of an individual's capacity (hemiplegia) to do normal activities or the state of being fully paralyzed. Stroke usually results in damage of brain cells and consequently leads to cognitive impairment [3]. The patients can be temporarily or permanently paralyzed throughout their lifetime if not treated immediately [7]. The hand is the most common body part affected by stroke. It plays an important role in implementing the daily activities of human life, which is used to hold, pinch, grasp, throw, and many other activities. Therefore, without the ability to function well can seriously affect the psychological aspects of the patient in a negative manner and the victims will develop serious difficulties in other aspects in performing their daily activities. The ensuing change in lifestyle due to stroke attack can be devastating. The patient may suddenly need assistance, just to eat, groom, dress, bathe, study, or do daily activities. Due to this fact, there is a desperate need to develop specialized teaching methods and effective rehabilitation tool to re-learn skills that are lost due to stroke affected by brain injury among the patients. Furthermore, a stroke may cause more serious long-term disabilities than any other diseases if not treated immediately. Hence, an intervention should be introduced to enable them to become more independent in their day-to-day activities.

II. PROBLEM FORMULATION

Several recent studies have provided remedial systems that focused on using healthy hand fingers to stimulate impaired hand fingers [1] [2]. Few devices were developed to assist the stoke patients to flex and extend each digit of the impaired hand based on the flexion/extension movement of the healthy hand fingers [1]. Stroke patients with impaired hand use reported improved ability to grasp and release objects after the therapy sessions using the Hand-Wrist Assisting Robotic Device which used real objects and guided by the neurological principle of motor learning [2]. Most studies mentioned above focused on functional recovery and fitness improvement rather than improving stroke patients' cognition. Restructuring and re-activating cognitive function of stroke patients is the main focus in order to force any movement or establish motor function. Regardless of what caused the stroke, it is possible to recover many of the cognitive skills.

Nevertheless, studies related to the implementation of effective methods and cognitive recoveries of stroke patients are still minimally investigated in Malaysia [6]. This study concentrates on improving, stimulating and activating stroke patients' cognitive ability using immersive virtual reality and 3D environment elements. Maintaining the Integrity of the Specifications

III. Problem Solution

Thus, this study and invention are important in the treatment of hand stroke patients, especially in re-learning their self-care skills. The development of the intervention may be used as an alternative approach during therapy session in hospitals or at patients' own home. Furthermore, the CTS developed in this research, can act as a therapist to assist patients at any time, providing daily living activities (DLA), easy access and low-involvement (engagement).

Earlier studies found that the use of computers with the combination of high tech equipment will help to educate stroke patients to go through hand rehabilitation effectively and efficiently [16]. In this study, virtual reality technology was used as a simulation whose criteria are interactivity, repetitive, fun, engaging and functional diversity which likely to provide a significant contribution to the learning situation for stroke patients at different levels of severity.

The use of virtual reality technology and approach is highly potent, especially in rehabilitation [13]. Low self-esteem and lack of confidence have also become the barriers between stroke patients and their social life. The feeling of insecurity, especially in self-care skills inhibit them to socialize with their peers. Hence, an intervention should be introduced to enable them to become more independent in their day to day activities. The use of the intervention in therapy reduces difficulty, particularly in delivering information from the therapist to the stroke patient whilst providing a safe and controllable environment. The feeling of presence and immersion in a real simulation allows therapists to provide an immediate feedback while maintaining the excitement and efficiency of the treatment.

IV. Methodology

A. Research Design

- The patients' needs were assessed using a qualitative approach through interview and observation [4] during the conventional therapy session.
- Single-subject ABA experimental design was employed to evaluate the effectiveness of the intervention for duration of 12 weeks and every hand-stroke patients were exposed to the varying levels of the independent variable (flex-extend fingers range of motion). Participants underwent two test sessions separated by at least 6-week washout period. Each session consisted of roughly an hour CTS evaluation before and after a 30-min tracking session using the Digital Standardized Cognitive Assessment (DSCA).
- DSCA was used to test stroke patients' cognitive ability. In repeated pretest-posttest design, patients' cognitive status measures were taken immediately before and after the treatment session. Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

B. Participants Recruitment

Data were obtained on patients that were referred and admitted to general hospitals in the Southern Region of Malaysia at Occupational therapist unit from January 2011 to December 2011 with various neurological cases (brain injuries) and primary diagnosis of ischemic stroke. Ethical consent was obtained from the Occupational Therapist (OT), Rehabilitation Unit, Malaysian Hospitals' Ethical Committee and Ministry of Health Malaysia. The research population of 370 patients are classified as having a minimal disability (CVA) and registered for the first time. They consisted of a total of 267 patients with moderate to severe disability (TBI), and 103 patients with Right-hemisphere CVA. The research samples for the first phase of this study was determined following the stratified random sampling, consisting of 115 patients with the specific inclusions were selected (Table 1).

TABLE I. THE RESEARCH SAMPLE

MONTH	L CVA	R CVA	CVA
	Bil pesakit	Bil pesakit	Bil pesakit
1	3	5	11
2	1	3	1
3	6	3	8
4	2	5	3
5	1	3	3
6	4	1	2
7	2	5	2
8	1	4	4
9	2	2	2
10	3	5	2
11	4	2	2
12	4	2	2
TOTAL	33	40	42

a.L-CVA(Left cerebrovascular accident)=weakness on right side of the body (left brain hemisphere)
b.R-CVA(Right cerebrovascular accident)=weakness on the left side of the body(right brain hemisphere)
c. CVA - Patients who did not indicate whether right or left brain injury/weakness was unknown
* Repeated cases are not included (The number of patients who first time register only)

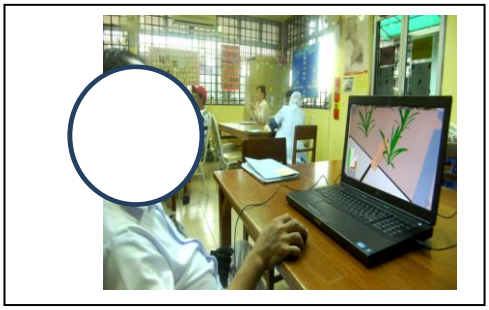
C. Testing Procedure

The CTS and wireless 5DT dataglove (which can be used to manipulate 3D objects and environments) were introduced to the research participants. The interface of the CTS and a dataglove provided the patients with the immerse feeling and enjoyment in the hand exercises. These were designed in a

manner that the patients can control the intensity of stimulation, which was set on CTS based on Bloom's Taxonomy level from easy to difficult level, the subjects used the CTS to perform active repetitive hand opening exercises 2 hours a day at home and functional tasks for 1½ hour twice a week at the rehabilitation centre for 12 weeks.

D. Intervention: The Development of the System: The Reaching Task

For the purpose of this study, reaching task was designed particularly for stroke patients who suffer from "motion deficits in the upper extremity". Based on the need analysis results, the interface of the reaching task was carefully designed so as to meet the patients' special needs. This system necessitates the users to open and close their affected hand on various finger flexion and finger extension movements to produce a functional ability and increased patients' range of motion and return to normal state. This finger/hand exercises are associated with their cognitive stimulation to force some movement.



Picture 1. 3D Immersive cyber therapy set

The CTS act as a virtual tutor or educator for the stroke patients. It is an interactive system that provides real-life feeling that triggers meaningful learning and develops favourable outcomes. The illustration of the system welcoming the users in a friendly and untreated manner can be seen in the Figures 1, 2 and 3 below.

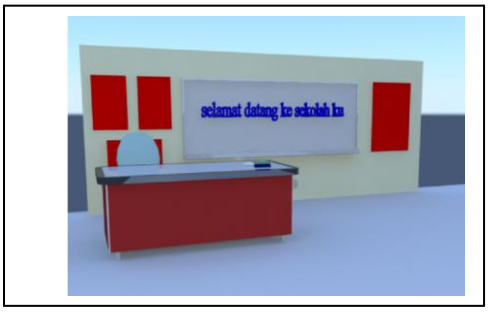


Figure 1. Welcome interface 1-Classroom environment

In Figure 1, the "Welcome Interface 1", the patients were exposed to classroom environment that were designed and developed based on the needs of stroke patients. Some of the patients in this study were retired teachers following the stroke attack with hopes and desires to return to their former profession. Therefore, the research provided them with intrinsic motivation or inner strength to stimulate and boost their cognitive and motor re-learning skills during the process of rehabilitation.

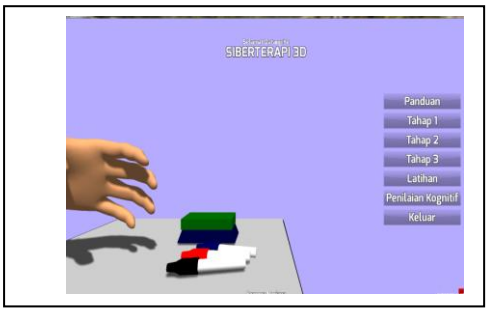


Figure1a: Task

Figure 1a: Functional task levels were arranged based on cognitive learning theory. For the first time user, he/she has to do the activities in a step-by-step mode (from level 1, 2 and 3) to accomplish the reaching task

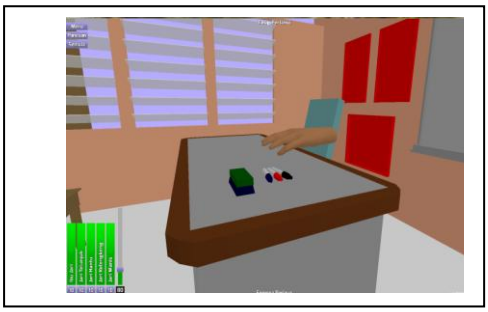


Figure 1b: Level 1 Task

Level 1: The patient should spread/extent their fingers at a range of 20 degrees. The level of bend fingers is 80 degrees curve. 20 degrees means the differences of finger opening space to hold an object. The default setting for the reaching task is at: Range of motion setting of 20^o. Maximum extension angle = 0^o/depends on patients' condition or various levels of hand impairment (for example, some patient finger initial extension at 20^o). Maximum finger flexion = 110^o. Thumb flexion = 80^o

Figure 1c: Grabbing Task

Grabbing task: In this task patients were stimulated to grab the virtual object on the screen. The diameter of the white board

pen is 5cm so it takes the patient to bend their fingers 80^{o} curve.

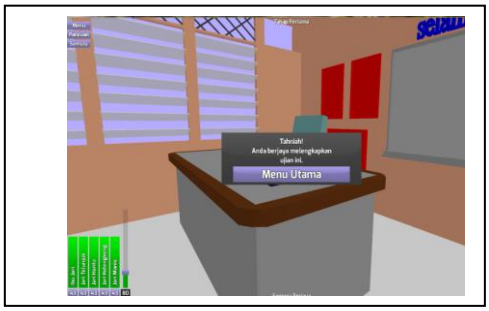


Figure 1d: End Task For Level 1

When the reading reaches 80 degrees, the patient must grasp the object (pen) for 5 seconds and a tag will pop-out when they have surpassed this level.

Within the 3D spatial space, the users are required to reach particular virtual objects in order to provide rooms for them to employ their hands excessively. Inability in doing everyday task among stroke survivors causes them to become more dependent on the caretakers. Thus, in this treatment with 3D CyberTherapythefocus was on enhancing their fine motor skills and self-care skills whilst maintaining the involvement of entertaining and leisure activities. Users are exposed and encouraged to become independent and; thus, allowing them to minimize their disability and increase their independence, especially in their daily activities. The tasks are illustrated in the Figure 2 below:

Figure 2. Kitchen environment

After they completed the excessive practice of simple reaching tasks, the patients were presented with more difficult tasks; which are still within the real-life contexts. Basically, the tasks were developed based on the hobbies or life tasks which require lots of hands and finger movement exercises in reaching specific objects. For example, the patients are required to grab, touch and if possible pull out weeds in the backyard as demonstrated in the Figure 3 below:

Figure 3. Backyard environment

V. RESULTS & DISCUSSIONS

E. The Investigation of the Stroke Patients' Needs

A survey was carried out to investigate the problems occurring among stroke patients in a hospital in Southern Malaysia who were attending rehabilitation therapy sessions. One hundred and fifteen (115) stroke patients with cardiovascular accident (CVA) and their therapists were interviewed. The interview sessions seek to identify the patient needs and formed the basis in the design and development of a new system which aimed at improving the stroke patients' cognitive aspect and also the hand rehabilitation. Both patients and therapists represent the core voices of the population who provide invaluable data for the study.

A total of six core categories of problems/needs emerged from the interviews and observations, namely physical, psychological, social, infrastructure, time recovery and geographical location. This phase of there search focused largely on overcoming the physical problems encountered by patients with disability after stroke, which covered all the mobility and reducing the difficulty in carrying out the daily life activities. A decrease in the number of hand functions after a stroke causes many hand stroke survivors to be incapacitated in their Activities of Daily Living (ADL) such as hygiene care, dressing, mobilization and sensory problems. Therefore, these limitations decrease their quality of life [7]. The hand stroke survivor also experiences sensory problems depending on which part of the brain has been affected. They usually have problems to respond to touch, pain and change in temperature [20], causing discomfort and uneasiness. For example, the participants said;

Participant 1 : I can't brush my teeth after I wake up in the morning… I need to wait for my husband to help me…

Participant 2: I want to drink, but how… I can't hold the glass…

Participant 3 : I like to sew beads….but now..I can't do it anymore due to stroke attack...

F. DSCA Result

The CTS (the intervention) main objective is to improve finger movement or range of motion by stimulating the stroke patients' cognitive functioning.The research employed DSCA a sa general screening indicator of intellectual decline or cognitive stability among stroke patients from the baseline to the end of the experimental session. Therapy session using CTS was introduced to 27 participants where cognitive ability was measured by an index score at pre-test and post-test phases. The cognitive ability index ratio is a measure ranging from 0 to 30. A DSCA score of 24 and below for cognitive disturbed screening indicates that the patient is cognitively impaired, DSCA score 24-30 on the other hand suggests the patient is cognitively intact [15]. In this study the DSCA was able to adequately screen for cognitive condition before and after the intervention of CTS. The Scores were tested and analyzed by using a paired sample t-test. The level of significance selected is at the probability value of p = 0.05 (two tailed) for accepting or rejecting the null hypothesis.

Results: The *t* value of -4.364 fall within the critical region defined by the critical value of 2.056 (df=26, p < 0.05), and the p-value of 0.000 is lower than α of 0.05. Therefore the H_o is rejected and H_1 is accepted. Thus, there is significant difference of means by -1.74 between pre-test and post-test. The post-test average score of cognitive ability (mean = 26.7407, SD =4.69527) is statistically greater than the pre-test average score of cognitive ability (mean = 25.00, SD = 5.16460). The results of t-test indicate that the patients' cognitive ability state before and after being stable condition, it can also be concluded that most of the stroke patients(especially patients with R-CVA) were cognitively intact.

G. Measuring the Effectiveness of the Developed System – Single Subject Experimental Design

At the evaluation phase, the stroke patients were required to use the wireless cyber 5DT data glove in order to perform the tasks designed by the system. The glove applies the concept of visibility as it becomes the mapping between the determined tasks and actual actions [12]. The system offers feedbacks to respond accordingly to the patients' actions, which make it appears to be real and interactive. The results of every access that the patients made were recorded in a database and can be assessed online. This enabled the patients to monitor their own progress thereby motivating them to keep on using the system and consequently improve their confidence.

In evaluating the system effectiveness, the technique used was the tracking data method in which involves pre-test and post-test. This kind of evaluation deals with the data generated in the computer whenever the patients' access the system. The time series data will indicate how much the patients have improved in cognitive and hand rehabilitation aspects within the particular time duration. Observations were done for both tests as to support the data from the computer system. The researcher's field notes were used as evidences in validating the findings from the tracking data. At this stage, the objective is more to assess the feasibility of CTS in improving stroke patients' fingers range of motion by stimulating their cognitive functioning. The observation was done on only three samples that have completed this experiment. Their characteristics are shown in Table 2.

TABLE II CHARACTERISTICS OF RANDOMLY SELECTED PARTICIPANTS

Participant	Age(years)	Gender	Time Post stroke	Dominant hand
PT 1	61	M	1 year	R-CVA
PT 2	69	F	3 years	R-CVA
PT 3	70	F	8 months	R-CVA

Figure 4 and 5 show the percentage of change in the patients' finger movements over the 12-week intervention. All the three subjects showed improvement as recorded by the therapist. The substantial improvement is in range of motion of the thumb and fingers.

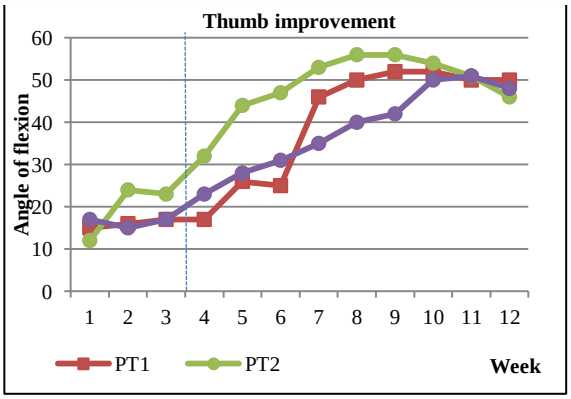


Figure 4. Thumb performance

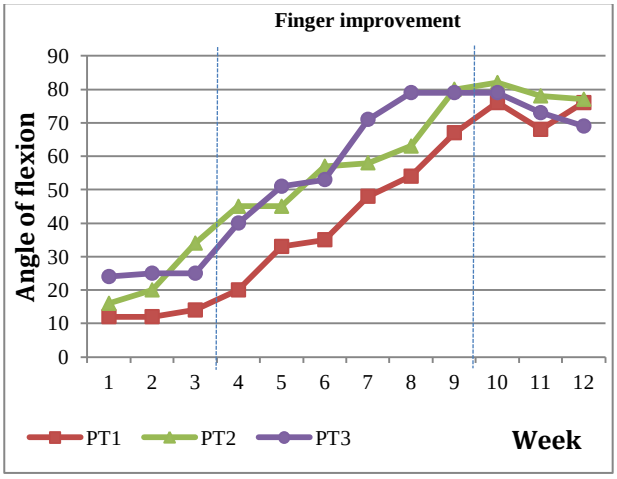


Figure 5. Finger performance

All the participants show improvement throughout the treatment session. Results showed that there were significant differences in the angle of thumb flexion. PT1 exhibited 55% increase in flexion where the maximum value of flexion for PT1, PT2 showed 65% improvement and PT3 flexion increased by 49%. Follow-up session took place after the initial treatment was introduced. Figure 4 shows that there was still an enhancement by weekly treatment and participants still have energy to continue and showed finger extension movement throughout the treatment. The increased range of motion for PT1 is about (73%), PT 2 (67%) and PT 3 (52%). The improvements generally declined at 3 months time.

VI. CONCLUSION

The data collected through three different sources clearly show that the CTS should be developed according to the needs of stroke patients, their age, their culture and their interests. All of the criteria mentioned above, encourage them to carry out the therapy and training and finally restore a paralyzed hand. In addition, the CTS should also be suitable with the patient's cognitive abilities. The results confirmed that the CTS did make available positive motivation. It is proven by the patients' progress/performance of each of their finger movement. This is in line with DSCA results obtained from this study that clearly show that patients with R-CVA do not suffer cognitive impairment compared with patients who experience L-CVA. These results are consistent with a study [15] which states that stroke subjects with left hemispheric involvement were more likely to be cognitively impaired than those with right-sided lesions.

Therefore, the results suggest that the use of CTS and a wireless 5DT dataglove is effective in improving the conditions of hand stroke patients, meriting further investigation of the intervention. The use of virtual reality as one of the newest technology and approaches is highly potential, especially in rehabilitation [21].The use of CTS in Malaysia is still new as most of health care providers rely on the conventional method (particularly therapeutic exercises) in providing services for their patients. This research has proven that CTS and immersive environments increases attention span and prevents boredom during a therapy session among stroke patients.The new intervention developed in this study will be very useful for health care, rehabilitation centres or hospitals in treating and building independence of stroke survivors in doing everyday tasks.

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