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Evaluation of the TheraDrive System for Robot/Computer Assisted Motivating Rehabilitation After Stroke

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Abstract— **This paper presents experimental data evaluating the merits of using a fun and engaging therapy protocol over a less engaging one in the context of a low-cost robot/computer motivating rehabilitation system for stroke rehabilitation called TheraDrive. The preliminary results suggest that there is a small advantage of the engaging therapy over the rote therapy in reducing motor impairment, improving ADL function, and improving stability. The more engaging protocol has an advantage in maintaining engagement and interest in therapy.**

I. Introduction

Stroke is the leading cause of disability and affects about 5.4 million individuals today (AHA). Presently, there is a need for effective and cost-sensitive rehabilitation strategies that provide functional recovery, even after the patient has left the clinic and returned home. Evidence supports that enriched environments [1], highly functional and task-oriented environments [2-3], and highly motivating environments [4] that increase task engagement are important for motor re-learning and recovery. Robotic-assisted therapy devices for upper arm therapy after stroke utilize automated therapeutic exercises that range from rote to functional goal-directed reaching tasks. Our method involves capitalizing on robotic technologies to automate the therapy, thereby providing an objective assessment of functional recovery as well as applying repeatable force-feedback to the impaired arm to offer graded therapy and constant challenge to the patient.

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The goal of this study is to evaluate the usability and potential of our custom-designed, home-based, robot/computer-assisted motivating rehabilitation (R/CAMR) system, called TheraDrive [5]. Our specific aim involves assessing the effect of unilateral steering tasks on impaired arm function as defined by clinical and biomechanical scales. These steering tasks are embedded in more or less game-like and functionally relevant to driving. We will determine if the more engaging (fun and interesting) and functionally relevant therapy leads to more enjoyment (determined by a previously validated motivation assessment tool) and higher efforts (determined by a self-assessed scale). Motivation will be determined using enjoyment and perceived value and effort subscales of the previously mentioned motivation tool.

II. Methods

A. Experimental Setup and Data Collection

Experimental Hardware: The main components of the TheraDrive system are a pair of modified, commercial force-feedback steering wheels, commercial gaming software as well as customized software called UniTherapy. Other peripheral devices such as a Microsoft Sidewinder Joystick are also being mounted on the system during the assessment sessions. The system can be utilized in several training modes, which are unilateral steering utilizing the Logitech force-feedback wheel in front or side drive [5,6] and bilateral steering utilizing the two steering wheels mounted in the bus-drive mode. All modes are available for training and assessment activities. During sessions, subjects are seated within the frame while the wheel is moved to the front, or either side, of the frame depending on which is the affected side. A flexible wheel mount allows for angular adjustment between 0° and 90°. The frame is adjustable from 22'' to 27'' giving the devices vertical adjustment. The width of the platform, currently 36'', can accommodate a wheelchair. TheraDrive can be used with or without an autonomous mobile robot that can move about the perimeter (fig. 1b). The robot can monitor arm and torso movements and provide visual feedback on activities [6].

The software employed for the operation of the TheraDrive system consists of several commercial driving programs and a custom designed software program, Unitherapy [5]. The

Unitherapy software was developed by the neuro-rehabilitation labs of Dr. Jack Winters at Marquette University and is the data collection and assessment software that is in operation throughout all of the tasks. We use force-feedback to create different levels of assistance or resistance on the wheel during therapy, depending on the functional level of our subjects. The level of resistance is increased as needed to maintain challenge during tracking. Conversely the assist level is decreased as the therapy progresses. Position and force data were collected at 33Hz for all tasks.

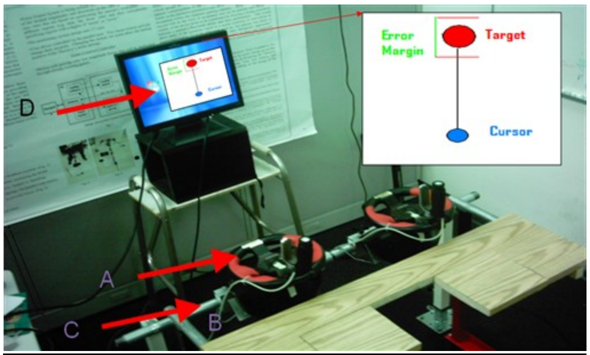

Figure 1: TheraDrive system setup in BiTheradrive mode: **a)** Commercially available Logitech Wheels **b)** Wooden arm rest resting on side metal frame **c)** Height adjustable front metal bar **d)** Graphical display of the unidirectional tracking task.

Procedure: Data were collected from 10 stroke affected subjects that were asked to complete a training paradigm composed of 24 individual 1-hour therapy sessions consisting of 9 kinematic evaluations. Informed consent was obtained from all subjects and the Institutional Review Board of the Clement J Zablocki VA and Marquette University approved all experimental procedures. Table 1 lists motor control scores using the Fugl-Meyer [7] motor assessment and their ADL Function scores using the Rancho Los Amigos Functional Test for the Upper Extremity [8].

TABLE I
SUBJECT PROFILES

Subject	Age	Impaired Hand	UE-FM	UE-FT	Group
1	60	R	21	5	Fun
2	54	R	55	4	Fun
3	57	R	55	6	Rote
4	49	L	27	3	Fun
5	55	R	36	5	Fun
6	50	L	23	3	Rote
7	54	R	32	3	Rote
8	59	L	16	3	Rote
9	59	L	59	3	Fun
10	56	L	53	6	Rote

Table 1: Age, identification of impaired arm, Fugl-Meyer score for the impaired arm and Functional Test score for the impaired hand. Average FM score was 39.6 for the Fun Group and 35.8 for the Rote Group. Average FT score was 4 for the Fun Group and 4.2 for the Rote Group.

Subjects underwent two initial clinical evaluations where a certified physiatrist, who examined them to qualify them for the study, evaluated them. Once found suitable for the study, a trained, certified occupational therapist performed clinical evaluations including assessing motor impairment levels and ADL function in the impaired arm, left neglect, grasp and grip strength. Subjects were asked to complete a set of assessment tracking tasks, in random order, using both one and two handed wheel configurations as well as different device in conditions with and without forces applied. Tasks such as sine tracking, circle tracking and target-acquisition were employed. A special V-grip handle was used while tracking data was collected from each trial. Video data and feedback about system performance were collected. Initial motivation was assessed. For safety, pain and exertion levels were monitored during each session and subjects were asked to discontinue trial execution if they consistently report excessive discomfort or pain outside a pre-determined threshold level. These sessions were then repeated after the intervention and at 1-month follow-up.

Intervention: Ten subjects were randomized into one of two groups (Fun driving (n=5) or Rote tracking (n=5)) and asked to return for therapy using the TheraDrive system. Therapy sessions typically lasted an hour on average and spanned 6-8 weeks for 24 sessions in all. During each session, subjects in the fun-driving group were asked to pick 2-3 driving games (e.g., TrackMania, Millipede, Need for Speed etc.) that they then completed with the impaired arm. Subjects in the rote-tracking group selected from a list of tracking tasks (e.g., pseudo-sine tracking). All subjects completed 20 minutes each of unilateral steering with the impaired arm in the 'front drive', 'bus drive' and 'side drive' orientations. These wheel orientations were randomized. Pain and exertion levels were monitored similar to the assessment. Only position tracking data were collected during the therapy sessions.

Outcome measures: The *primary clinical measures* employed to aid in the evaluation of the TheraDrive system's efficacy were the Fugl-Meyer (FM) (Scale 0-66), and the Rancho Los Amigos Functional test (FT) (0-7 Levels). The *secondary clinical measures* were the manual muscle test for weakness (0-5 scale) [9], the Ashworth test for spasticity (0-4 scale) [10], Grip Strength [3] as well as pain levels. These measures were collected pre, post and at follow-up. *Biomechanical primary measures* for motor impairment and functional ability encompass the kinematic metrics derived from position data collected during steering activities during the assessments. Examples of these are mean square error (accuracy) and percentage time on target (stability) [5,6]. The *primary measure* for motivation is the intrinsic motivation scale. Each patient was given a 25 questions to evaluate their motivation [15]. The patients were to rate their experience with the ongoing study in the range of one to seven, one being not true at all, four being somewhat true and seven being very true. Biomechanical and Psychological measures were collected every 4th session. Motivation Survey was conducted after each 4th session to assess the interest, usefulness, importance, and tension subscales of the study.

B. Overview of Data Analysis

Our hypothesis was that the more fun, functional robot/computer-assisted therapy will lead to more reduction in motor impairment and more increases in ADL function (as indicated by clinical scores and supplemented by kinematic variables) in the upper extremity than the less-engaging and functional rote therapy. We anticipated that the fun driving group would have significantly higher changes in overall motor function as well as significantly lower reduction in impairment. These changes will be related to higher levels of enjoyment and perceived effort and value.

The spasticity data were averaged for the muscle groups: Shoulder Adductors, Pronators, Elbow Flexors, Elbow Extensors, Wrist Flexors, Finger Flexors. The Manual Muscle Test data were averaged for the muscle groups: Shoulder Abductors, Finger Extensors, Elbow Flexors, Wrist Flexors and Finger Flexors.

Kinematic outcome measures such as Percentage Time on Target (PTT) that quantifies steadiness in tracking [9] and Root Mean Square Error (RMS) that quantify accuracy in tracking [9] have been established in previous literature as having a direct correlation to the clinical outcome measures. These measures are determined for the 2 (groups) x 2 (1 pre and 1 post-assessment) so as to supplement the clinical outcome measures and to quantify the impact of the unilateral steering tasks on impaired arm function.

The data collected from the motivation survey was categorized into seven subscales including interest/enjoyment and value/usefulness. Mean and standard deviation of the each subscale were calculated.

III. Results

Table II shows the results of pre and post assessment of the subjects in the fun and rote therapy groups for clinical measures (FM, FT, Ashworth, MMT), kinematic measures (PTT, RMS for sinusoid and circle tracking task) and motivational subscales for value/usefulness and enjoyment. The clinical scales evaluated motor impairment, ADL function, spasticity, and muscle weakness respectively. Percent time on target evaluated stability/steadiness in tracking and root mean square evaluated accuracy.

Clinical Scores: Figure 2 shows the pre and post clinical scores. The Fun group registered a greater increase in FM and FT scores as compared to the Rote group. The average FT for the Rote group showed no change with the intervention. This group registered a greater decrease in Ashworth Score (spasticity measure) compared to the Fun group even though both groups started at nearly identical baseline average values. Baseline average MMT for Rote group was lower than Fun group. Both groups demonstrated nearly identical changes in MMT due to the intervention.

Kinematic Scores: Figure 3 shows the kinematic scores. Although Percentage Time on Target (PTT) is greater for baseline for Fun group both groups show slight increases in stability (PTT) for our representative tasks (Circle and Sine tracking). Trend lines would suggest that Rote group registered a higher gain in stability for the Circle tracking task while the Fun group had a slightly higher gain for the Sine task. The Fun group shows no change in average Root Mean Square error from pre to post for the Sine tracking and Circle tracking tasks. The Rote group average decreased for both tasks. Baseline averages for Rote group were significantly higher for both tasks. For the current subject population, average values for change in accuracy from the Rote group seem to outweigh the changes for the Fun group.

TABLE II

Metric	Fun Pre	Fun Post	Rote Pre	Rote Post
Value/Useful	6.7(0.3)	6.85(0.1)	6.1(0.42)	6.7(0.24)
Interest/Enjoy	6.47(0.45)	6.83(0.1)	5.65(0.5)	5.67(0.43)
FM	39.6(7.5)	45(7.4)	35.8(7.8)	37.8(8.2)
FT	4(0.45)	5.2(0.6)	4.2(0.7)	4.2(0.7)
Ashworth	8.6(3.4)	7.8(3.1)	8(2.6)	6.2(2.1)
MMT	21(8.65)	22(2.47)	17.6(3.7)	18.2(3.7)
PTT-Sine	40.7(5.3)	47.1(4.1)	26.8(2.1)	31.5(3.6)
RMS-Sine	17.5(2.9)	17.3(4.6)	30.85(3.1)	28(5.56)
PTT-Circle	46.7(5.9)	48.5(13)	26.8(5.3)	41.9(7)
RMS-Circle	19.1(3.2)	18.97(7)	45.1(9.9)	33.9(8.4)

Table 2: Average, raw scores for the various metrics, before and after the intervention, for the two groups. Standard errors are provided in parentheses.

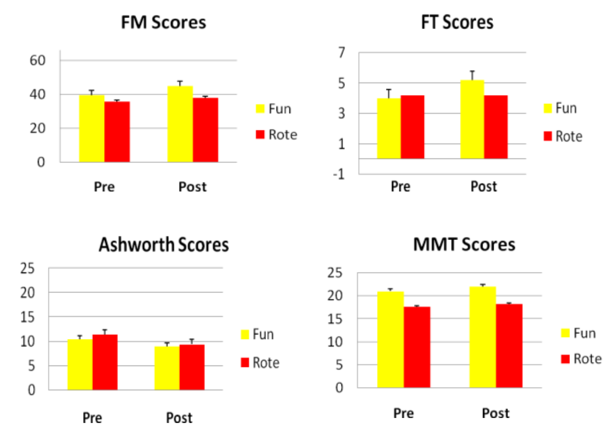

Figure 2: Changes in Primary (Fugl-Meyer and Functional Test) and secondary (Ashworth and Manual Muscle Test) Clinical scores from the ten stroke affected individuals (with standard error bars).

Motivation Analysis: The Fun group showed a greater change in Interest/Enjoyment versus Rote group although baseline average values for Fun group were greater than that for Rote group. The Rote group showed a greater change in Value/Usefulness versus Fun group while baseline average values for Rote group were lower than that for Fun group.

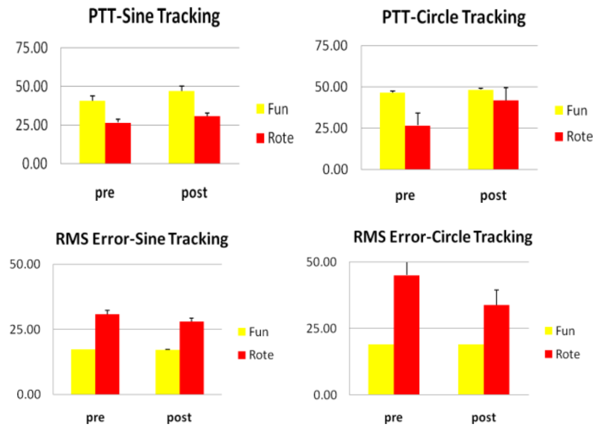

Figure 3: Raw scores for primary kinematic (Percentage Time on Target –PTT and Root Mean Square Error –RMS) variables from the ten stroke affected individuals from pre-intervention to post-intervention (standard error bars)

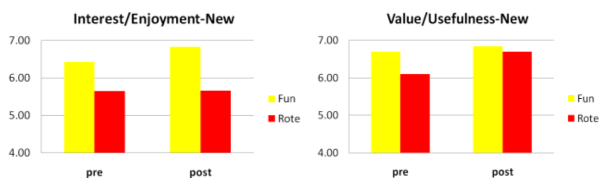

Figure 4: Change in motivation sub-scores for the Interest/Enjoyment and Value/Usefulness categories from the ten stroke affected individuals.

IV. Conclusions and Discussion

This paper presents results from evaluating the merits of a fun and engaging therapy protocol over a less engaging one in the context of a low-cost robot/computer motivating rehabilitation system for stroke rehabilitation called TheraDrive. The preliminary results suggest that there is a small advantage of the engaging therapy over the rote therapy in reducing motor impairment, improving ADL function, and improving stability. For the 10 subjects that participated in the study, a preliminary investigation of the kinematic data suggests that both groups registered slight changes stability and accuracy. The Fun group demonstrated a larger change in PTT for the Sine task while the Rote group showed a larger change for the Circle task. This difference could have been explained because the rote group practiced tasks similar to the tracking tasks used in assessment. Clinical parameters indicate that the Fun group shows a greater average reduction in motor impairment (FM) and a greater increase in ADL function (FT) from pre to post-intervention. The Fun group started with slightly lower motor impairment compared to the Rote group as indicated by the FM scores, but was relatively comparable in ADL function These differences were not significant. The fun group tended to perform slightly better as a result. This could have been explained by a training effect. The fun group experienced a larger variety of tracking tasks and postures than the rote group.

The preliminary results suggest that there is a large advantage in maintaining engagement and interest in therapy. Motivation scores for the Fun group, pre-session, are higher than the Rote group. A saturation effect (closer to full scale) might explain the smaller change in perceived value/usefulness sub-scale for Fun group post intervention. As expected the Fun group outscored the Rote group in changes on the interest/enjoyment scale indicating a higher level of engagement during the intervention. Changes in clinical parameters seem to correlate well with the motivation scores from our subject population that validates the choice of these clinical metrics as one part of the effort to establish the effectiveness of the TheraDrive system as a CAMR device that may eventually be used in the home-environment.

V. Future Direction

We will continue to collect data information from stroke-affected individuals and will analyze the data for statistically significant trends observed within the two groups. We will also determine whether any changes observed can be sustained one month post-intervention to determine the carryover function for the therapy. Finally, we will perform a case study involving two subjects using the TheraDrive in their home environment and compare differences in the time course of task engagement between supervised therapy (in the clinic) and under-supervised therapy (in the home).

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