Robot/Computer Assisted Motivating Rehabilitation: A Strategy for Robot Therapy After Stroke for the Clinic, Home and the Community

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Abstract—There is a need for effective stroke rehabilitation systems that are affordable and can be used in under-supervised/unsupervised environments whether in the clinic, the home or in the community. This paper discusses the challenge of developing such systems and presents briefly two studies that examine how issues such as engagement and compliance affect the long-term effectiveness of these systems. We discuss the studies in the context of a Robot/Computer Motivating Rehabilitation device, TheraDrive.

1 Introduction

There is a need to improve the effectiveness of robot-assisted therapy strategies in unsupervised and under-supervised environments. We define unsupervised and under-supervised environments as those characterized by no or a few clinical experts to supervise therapy activities. Patients in these environments may be non-compliant in that they may under perform or not perform prescribed therapeutic activities, they may lack motivation and/or even may engage in compensatory behaviors such as using excessive trunk movements to complete tasks [1-2]. Developing robot-assisted therapy devices for this arena means developing devices that are therapeutic and safe as well as able to engage and motivate the user and elicit compliance with prescribed exercises. Evidence from animal and human studies support the need for engaging robot therapy systems. These studies indicate that enriched environments [3], highly functional and task-oriented environments [4,5] and highly motivating environments [6] that increase task engagement are important for motor re-learning. Moreover, those environments that require subjects to maintain attention and stay engaged during the learning of new motor skills or the re-learning of forgotten skills are important for inducing cerebral plasticity after neurological impairments [7,8].

Computer-Assisted Motivating Rehabilitation (CAMR), a concept first introduced by Bach-Y-Rita and colleagues, promotes the development of inexpensive device solutions for the home/clinic that can deliver motivating, effective stroke rehabilitation through game-based tasks or activities that are not monotonous [6]. They developed a one-degree of freedom device called the “Palanca” that enabled stroke survivors to use their impaired arm to play an electronic pong game. Patients were motivated and able to maintained high levels of interest throughout the game and therapy. Despite the simplicity of the system, patients had reduced motor impairment in the affected upper limb and increased function on activities of daily living (ADLs).

Other rehabilitation devices have utilized aspects of the CAMR principle and have successfully embedded affordable robot/mechatronic systems into games or game-like tasks. Driver's Simulation Environment for Arm Therapy (SEAT) is a low-cost, therapy system developed for stroke therapy in the home which utilized a driving-game simulator environment controlled by a novel split-steering wheel outfitted with force sensors capable of measuring forces on the wheel by the impaired and less-impaired limbs [10]. The control system developed used the force information from each limb to devise a control strategy that encouraged impaired arm use and discouraged compensatory use of the less-impaired arm in bilateral steering tasks related to the game [9]. TheraJoy and JavaTherapy are two joystick-based systems targeting home rehabilitation for stroke survivors [10,11]. The systems utilized commercial or customized force-feedback joysticks along with custom software for interacting with commercial or custom games for therapy and assessment of the impaired limb. TheraJoy and JavaTherapy were well accepted and tolerated by the stroke survivors and were able to accurately assess motor performance and improve it (in the case of JavaTherapy) after intervention. Colombo and colleagues also introduced two affordable robot systems (a 1-dof wrist robot and 2-dof shoulder/elbow robot system) for stroke rehabilitation therapy. These systems coupled the robot movements to custom computer-based tracking tasks [12]. They demonstrated that not only were the robots effective but that new quantitative metrics can assess compliance and motivation during therapy. Affordable bilateral systems such as the Bilateral Arm Trainer [13] have also been developed for home therapy.

Taken together these devices further demonstrate the potential of affordable robot/computer assisted therapy involving gaming devices and tasks to be effective in assessment of motor impairment and in the treatment of motor impairments in the clinic [7-13]. Despite this, there is still a need to better investigate how motivation, engagement and compliance affect the magnitude and extent of functional recovery when these robot therapy systems are used in the home. Our studies in this arena focus on investigating
engagement and compliance within the context of TheraDrive, one of the devices in the suite of devices developed by Johnson and colleagues for Robot/Computer Assisted Motivating Rehabilitation [14]. The Robot/Computer Motivating Rehabilitation strategy advocates therapeutic exercise mediated by custom or commercial joysticks, steering wheels systems, and small robot devices. The devices are apart of an integrated suite of low-cost robotic/computer-assistive technologies driven by a novel software framework, UniTherapy[15]. The UniTherapy software becomes the “glue” permitting therapists to design protocols utilizing commercial games and/or simply custom tracking tasks in combination with any of the devices. This paper briefly reports on two studies. Study 1 examines the level of engagement, specifically defined as the level of play and its affect on the magnitude of recovery of function. Study 2 examines how monitoring compensatory activities and providing encouragement during unsupervised exercise may affect patients’ compliance and desire to continue to engage in a task. The studies took place either at the Clement Zablocki VA Medical Center or at Marquette University in Milwaukee, Wisconsin. Informed consent was obtained from all subjects and all experimental procedures were approved by the Institutional Review Board of the Clement Zablocki VA and Marquette University.

2 TheraDrive

The TheraDrive system uses game therapy to motivate stroke survivors to functionally use their impaired limb for sustained periods of time (fig. 1). The current system consists of commercial force-feedback wheels from Logitech, several hardware support platforms for the wheel, and several software support platforms for collecting and evaluating data. Other peripheral devices such as a Microsoft Sidewinder Joystick are used on the system. 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° - 90°). The frame is adjustable from 22” to 27” giving the wheel a good amount of vertical adjustment. The width of the platform, currently 36”, can accommodate a wheelchair. Four types of tasks can be performed on the system: unilateral steering with the wheel mounted in front, on the side, or parallel to the horizontal plane termed as ‘bus driver’ mode and bilateral steering with the wheel mounted on both sides (both in bus driver mode). All four modes are available for training and assessment activities. The TheraDrive system 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 [16].

Figure 1: TheraDrive in front and bilateral drive modes. A mobile robot system maybe used with the TheraDrive.

The TheraDrive software consists of several commercial driving programs and Unitherapy. The driving programs are played with the steering wheel mounted on the hardware described above in the various unilateral modes described above. 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 will increase as needed to maintain challenge during tracking. Conversely, the assist level will decrease as the therapy progresses. Position and force information are collected at 33Hz.

3 Study 1: Level of Play and Functional Recovery

The goal of the study was to examine the effects of training stroke patients in more or less enriched environments on clinical outcomes such as arm motor impairment levels and on ADL function. We hypothesized that training in the TheraDrive environment using games (commercial) (FUN exercise condition) will improve clinical outcomes more so than training in the TheraDrive environment using custom tracking task (ROTE exercise condition). The mobile robot was not used. Data was collected from 7 stroke affected subjects that were asked to complete a training paradigm. Table 2 summarizes the subjects. The primary clinical measures employed to aid in the evaluation of the TheraDrive system’s efficacy were the Fugl-Meyer (FM) (Scale 0-66) which assesses motor impairment level [17], and the Rancho Los Amigos Functional Hand evaluation (FT) (0-7 Levels) which assesses ADL function [18].
Improved clinical outcomes were quantified in terms of reduced motor impairment and increased ADL Function.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Impaired Hand</th>
<th>UE-FM (0-66) Pre-Therapy</th>
<th>UE-FT (0-7) Pre-Therapy</th>
<th>Therapy Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>R</td>
<td>21</td>
<td>5</td>
<td>Fun</td>
</tr>
<tr>
<td>2</td>
<td>54</td>
<td>R</td>
<td>55</td>
<td>4</td>
<td>Fun</td>
</tr>
<tr>
<td>3</td>
<td>57</td>
<td>R</td>
<td>55</td>
<td>6</td>
<td>Rote</td>
</tr>
<tr>
<td>4</td>
<td>49</td>
<td>L</td>
<td>27</td>
<td>3</td>
<td>Fun</td>
</tr>
<tr>
<td>5</td>
<td>55</td>
<td>R</td>
<td>36</td>
<td>5</td>
<td>Fun</td>
</tr>
<tr>
<td>6</td>
<td>50</td>
<td>L</td>
<td>23</td>
<td>3</td>
<td>Rote</td>
</tr>
<tr>
<td>7</td>
<td>54</td>
<td>R</td>
<td>32</td>
<td>3</td>
<td>Rote</td>
</tr>
</tbody>
</table>

Table 1: Summary of subjects in study 1

A certified physiatrist and an occupational therapist evaluated the impaired arm of all subjects before and after therapy. Subjects then completed a set of assessment tracking tasks in random order using both the one- and two-handed wheel configurations as well as different devices such as the joystick. They performed the tracking tasks in conditions with and without forces applied to the wheel and joystick. They completed three trials each of pseudo-random sine tracking, circle tracking and target-acquisition tasks [18]. A special V-grip handle was used to enable uniform gripping on the wheel. Intrinsic motivation and user experience were assessed before and after therapy [19]. The primary measure of interest/enjoyment subscale is the self-report measure of intrinsic motivation. Value and perceived effort subscales were calculated. Subjects were randomized into the FUN or ROTE therapy groups. Therapy sessions were about an hour on average and spanned 6-8 weeks for 24 sessions. During each session, subjects in the FUN 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 group self-selected from a list of tracking tasks (e.g., pseudo-sine tracking); they completed 20 minutes of unilateral steering with the impaired arm in the ‘front drive’, ‘bus drive’ and ‘side drive’ orientations in randomized order.

Figure 2 and Table II summarize the clinical results. We evaluated the trends in change scores for motor impairment as measured by the Fugl-Meyer and ADL function as measured by the Functional Hand Evaluation (FT) for the two groups. Both groups improved and experienced reduction in motor impairment. There was a clear trend favoring the group that performed training using the fun therapy tasks. The group participating in the fun therapy also experienced significant ADL improvement. Both groups also experienced decreased spasticity and improved muscle strength especially in the shoulder elbow region with no clear trend favoring one group over the other. The subjects participating in the fun therapy considered the therapy sessions more enjoyable and valuable than the rote group from the onset and maintained this enjoyment throughout the therapy. The rote group did consider the therapy experience more valuable by the end of the therapy.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Fun</th>
<th>Pre</th>
<th>Post</th>
<th>∆</th>
<th>Rote</th>
<th>Pre</th>
<th>Post</th>
<th>∆</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value/Usefulness</td>
<td>6.63(0.38)</td>
<td>6.81(0.12)</td>
<td>0.18</td>
<td>5.50(0.63)</td>
<td>6.50(0.38)</td>
<td>1</td>
<td></td>
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</tr>
<tr>
<td>Interest/Enjoyment</td>
<td>6.33(0.56)</td>
<td>6.83(0.1)</td>
<td>0.5</td>
<td>5.56(0.68)</td>
<td>5.67(0.19)</td>
<td>0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FM</td>
<td>34.8(7.4)</td>
<td>41(8.1)</td>
<td>6.25(1.8)</td>
<td>36.67(9.53)</td>
<td>39.67(9.94)</td>
<td>3(0.58)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FT</td>
<td>4.25(0.48)</td>
<td>5(0.71)</td>
<td>0.75(0.48)</td>
<td>4(1)</td>
<td>4(1)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results support the idea that these affordable systems are able to drive recovery. The FUN level of
play seem to cause a higher engagement in therapy which may result in subjects paying more attention to the task, engaging in a higher problem solving and using the impaired arm during the therapy session.

4 Study 2: Level of Monitoring and Compliance

The goal of the study was to examine the potential of a mobile robot system to improve TheraDrive effectiveness in the home by ability to motivate the patient to exercise and reduce non-compliance by discouraging compensatory behaviors. The main approach was to design a safe, user-friendly and cost-effective mobile robot capable of observing and monitoring stroke affected arm and torso movement during each session. The robot was designed to behave and respond in the form of encouragements and reminders to the movements sensed from impaired arm and trunk. Apart from that, the robot was to collect video data to keep track of progress during the duration of the study, facilitate the tele-rehabilitation environment. The prototype for TheraBot was developed using a low-cost mobile robot base from iRobot (www.iRobot.com) [16]. Data was collected from 5 subjects (4 healthy: ages 19-25, 2 male and 2 female and 1 stroke: female, age 54).

A modified version of the TheraDrive system was used. Subjects were trained on the set-up for 15-30 minutes or as long as it took to be comfortable. Subjects took a 10 to 60 minute break (and then completed the assessment tasks. To confirm and validate the stability and accuracy of the execution of robot’s behavior, we instructed subjects to do stop moving the arm for 5s, keep moving for more than 15s and tilt forward (≥30°). Reminder and encouragement behavior of the robot was collected as they completed the session. In these sessions the robot was designed to give an encouraging feedback when arm movement was sensed above a threshold for 15s or more, and elicited a warning cue as a reminder when the arm movement was not detected for 5s or when the trunk sensors were triggered due to forward trunk movement by the subjects. Overall, steering position data, arm orientation data and tilt data, and robot response data were collected. Steering position data was collected via Unitherapy. The TheraBot system was able to accurately execute the behaviors at any given time if the condition met the given threshold point. Figure 3 show an example of how the robot responded with a reminder cue when the subject stopped moving the arm and how it provided encouragement as needed. Overall, execution of robot behavior by monitoring the arm and trunk movement was accurate and stable across subjects. Three of 5 subjects enjoyed the presence of the robot and felt that the robot provided adequate encouragement during the session. Two subjects preferred to work unsupervised without the robot and felt that robot can act as a distraction during the session. The motivation survey showed that all subject, especially the stroke survivor, valued the combined TheraDrive/TheraBot system and thought it was interesting and enjoyable. The study suggested that if subjects were tempted to engage in behaviors where they did not move their arm during the therapy session or moved their trunk excessively a robot monitor could be valuable and positively perceived. It is important consider the frequency of the encouragement cues and the reminder cues in order to minimize frustration that may occur during exercise. These results echo results from Mataric and colleagues who in applying socially assistive robots to rehabilitation demonstrated that an autonomous robot helper sensorized to monitor subjects’ movements and provide positive feedback [20]. Our very low-cost mobile robot system was able to monitor and act as an embodiment of the therapist in an under-supervised stroke rehabilitation. We anticipate that a long-term intervention with the TheraDrive system may improve clinical outcomes.

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Figure 3: Representation of robot response during circle tracking for encouragement and arm movement

6 References


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