Robot-Assisted Arm Training in Physical and Virtual Environments: A Case Study of Long-term Chronic Stroke

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***Abstract*—Robot-assisted training (RT) is a novel technique with promising results for stroke rehabilitation. However, benefits of RT on individuals with long-term chronic stroke have not been well studied. For this case study, we developed an arm-based RT protocol for reaching practice in physical and virtual environments and tracked the outcomes in an individual with a long-term chronic stroke (20+ years) over 10 half-hour sessions. We analyzed the performance of the reaching movement with kinematic measures and the arm motor function using the Fugl-Meyer Assessment-Upper Extremity scale (FMA-UE). The results showed significant improvements in the subject's reaching performance accompanied by a small increase in FMA-UE score from 18 to 21. The improvements were also transferred into real life activities, as reported by the subject. This case study shows that even in long-term chronic stroke, improvements in motor function are still possible with RT, while the underlying mechanisms of motor learning capacity or neuroplastic changes need to be further investigated.**

Keywords— Stroke Rehabilitation; Robotics; Virtual Reality; Upper Extremity

I. Introduction

Regaining upper extremity motor function is one of the main goals of stroke rehabilitation. The main objective of this case study was to investigate whether an individual with a long-standing chronic stroke can benefit from Robot-assisted training/therapy (RT) and improve the upper extremity function even after long-term disuse. The secondary objective was to investigate whether the subject would perform differently in a physical environment (PE) than a virtual environment (VE) during RT sessions.

II. Methods

A. *Subject Case Description and Setting*

The subject was a 48 year old female who had an ischemic stroke in 1994 (20+ years ago). The stroke manifested hypo density of left anterior middle cerebral artery regions and left frontal lobe. This resulted in right hemiparesis. At the time of participation in this study, her score of the arm section of the Chedoke-McMaster stroke assessment was 3 with spasticity in the right elbow and wrist flexors. Her score on the Upper Extremity section of the Fugl-Meyer Assessment (FMA-UE) was 18. She did not have any hemispatial neglect, visual problem, upper limb surgery, or any pain interfering with the arm function. Despite being right-handed before the stroke, she had learnt to carry out most daily activities with only the left upper limb after the stroke. During the time of study, the subject did not participate in any other therapy or research study. A local research ethics committee approved this research study and the subject provided her informed consent.

B. *Instrumentation*

In this study, we used the HapticMaster (MOOG Inc. FCS) robotic arm (Fig. 1) [1]. We programmed this robotic arm to create a virtual tunnel (radius: 4 cm) between the starting position and the targets of interest, and to provide gravity support by not letting the subject's forearm fall. In addition, we programmed the robot to assist the subject when needed to complete the reaching task. The robot arm moved at a fixed update rate of 2.5 kHz and the force application and measurement and the position measurement had a precision of 0.01 N and 0.012 mm, respectively.

C. *Procedures*

The training consisted of reaching to six targets in both PE and VE in ten sessions over the course of a month. The subject was seated on a chair, either in front of a vertical board when

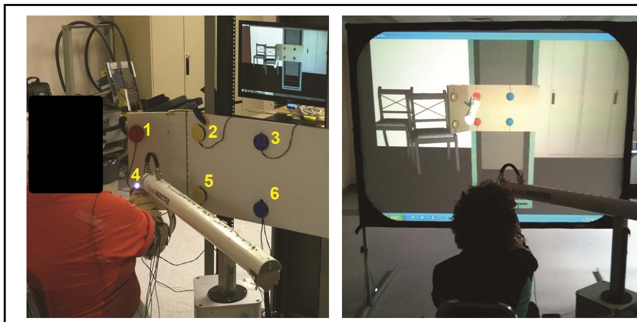

Fig. 1: A. The Physical Environment (with LED of target 4 being on) and B. The Virtual Environment

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performing in PE (Fig. 1A)., or a screen when performing in VE (Fig. 1B). The VE was created by projecting images at 120 Hz to a projection screen, providing a 3D perspective view of the experimental scene. VE was calibrated to have the same metrics as for PE.

In each session, the subject was instructed to move at a comfortable speed and to reach and press the target buttons while not producing any compensatory trunk movements during the experiment. During each of the ten sessions, there were 5 reaching trials to each button, for a total of 30 trials in each environment, summing up to 60 trials per session. In each reaching trial, when the subject could not go further on her own, she asked for help and the robot arm provided physical assistance to help complete the movement. When the subject reached the target button, the percentage of the movement distance that the subject could complete without assistance from the robot was displayed as feedback.

D. Outcome Measures and Data Analysis

The FMA-UE was measured at the first session prior to the start of the experiment and at the last session following the completion of the experiment. To analyze the movement, we extracted several kinematic metrics from the trajectory data of each session and focused on the portion of movement solely done by the subject, without assistance from the robot. The kinematic metrics were: 1) movement completion; 2) mean speed over the path line (i.e. trajectory); 3) straightness (ratio of the straight line over the path line); and 4) jerkiness (number of zero crossings in the acceleration profile over the path line).

III. Results

The subject attended all the ten sessions and did not report any pain, fatigue, or adverse effects during the training. We observed evident changes in movement completion by the subject; At the first session, the subject had difficulty in completing the reaching task towards targets 1, 2, 3, and 6 and needed the robot's assistance to complete the task. In the last session, she independently reached to all the targets. In targets 1, 2, 3, and 6, there was an increase in the movement jerkiness until the subject reached the plateau. Following that, the jerkiness value started to decrease in the following sessions. The mean speed over the 10 sessions did not vary much. However, the straightness measure did vary a lot within each session and across the sessions with a trend in targets 1, 2, 3 and 6 showing increase of straightness toward the last sessions of RT. We did not find any meaningful differences between the two environments in terms of kinematics measures. The FMA-UE improved by 3 points, from 18 prior to the experiment to 21 at the end of last session. At the sixth session, the subject reported that while she had not been able to push the elevator button in the last 20 years following her stroke, she has become able to do it; we checked this with her on the last session and she said she has become very comfortable in doing it.

IV. Discussion

This study clearly demonstrates that even in long-term chronic stroke cases, RT can be used as an effective tool for regaining some upper extremity motor function. The subject in this study had been dealing with stroke consequences in the last 20+ years and still benefited from RT. The improvements seen during the reaching practice was transferred to real life activities. RT can greatly benefit the stroke patients in chronic stages even with no/little residual movements. The robot arm assisted the subject in two ways: by providing anti-gravity force in form of preventing the arm from falling and by assisting the subject to complete the reaching as soon as she asked for it. Therefore, the subject never reported any fatigue or pain during the practice sessions.

While improvements in kinematic measures were evident and measurable, the FMA-UE only improved by 3 points, which was below the minimal detectable change (MDC) of 5.2 [2] and/or minimal clinically important difference (MCID) of 7 [3]. A recent study, however, has shown that the MCID can be accepted at 4 [4]. As we only focused on training the arm, not the wrist and hand, we did not expect a major improvement. The tests in FMA-UE do not differentiate between the two aspects of movement: strength and motor control [5]. Therefore, it might not be a clear representative of the improvements by the subject achieved with RT.

We did not find any noticeable and/or meaningful differences in terms of the movement variables (speed, straightness, and jerkiness) between the two environments. This can be explained by a study on healthy subjects comparing reaching tasks in real vs virtual environment in presence/absence of visual/haptic feedback [6] in which the results showed that the subjects' performance were similar in both environments when the subjects had visuo-haptic feedback in VE. In our study, besides the presence of visual feedback in VE, the robot arm provided haptic feedback at the endpoint for the subject by stopping her when the virtual button was reached. Also, both PE and VE shared the same haptic feedback in terms of forearm attachment to the robot arm.

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