Task-Oriented Robot-Assisted Stroke Therapy of Paretic Limb Improves Control in a Unilateral and Bilateral Functional Drink Task: A Case Study

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Abstract—**The purpose of this paper is to evaluate the functional, temporal and spatial effect of a unilateral task-oriented, robot-assisted training on unilateral and bilateral task performance of a drinking task using a real object. Two chronic stroke survivors experienced task-oriented robot assisted therapy, in which the paretic arm was trained using reaching and grasping tasks over 4 weeks. Both subjects experienced improvement in motor control as measured by Fugl-Meyer. The paretic arm was evaluated using movement smoothness (MS) and time to completion (TCT) measures before and after therapy. From the results, we found that the unilateral robot-assisted training improved paretic arm control in the unilateral and the bilateral drink task. However, the influence of the non-paretic movement on the temporal and spatial paretic arm control was evident both pre and post therapy suggesting inter-limb coupling aids in the transfer of unilateral improvements in motor control to improvements in bilateral motor control.**

I. INTRODUCTION

Stroke is a leading cause of adult disability [1-2]. Upper-limb dysfunction in stroke is characterized by paresis, loss of manual dexterity, and movement abnormalities that may impact considerably on the performance of Activities of Daily Living (ADLs) [3]. Arm recovery after stroke is typically poor, with 20% to 80% of patients showing incomplete functional recovery depending on the initial impairment [3]. Several principles have been proposed for better treatment outcomes in stroke patients, including high-intensity, task-specific activities, high repetition, and active patient participation in treatment activities [4-5]. The best technique for training the paretic arm is still unclear.

Robots can play a role in training the paretic limb to recover from severe neurological dysfunction [6-8]. They can administer high-intensity, repetitive functional and also motivational physical motor therapies. Robot-mediated therapies improve motor control and motor performance of paretic arm in acute and chronic stroke survivors [6-8]. It is still not clear which robot-based strategies are best to maximize functional recovery of the upper limbs for simple and complex ADLs that require the use of the paretic limb alone or with the non-paretic arm. There are several studies suggesting unilateral training of the paretic limb is sufficient for relearning both bilateral and unilateral ADL tasks and the use of the non-paretic arm may be detrimental to motor re-learning [5, 10, 18]. In contrast, other studies suggest that bilateral training is important for more generalizable learning and the presence of the non-paretic arm maybe beneficial in assisting the paretic arm to learn [9, 11-12].

Robot-assisted therapy environments typically engage in unilateral training of the paretic limb. A few such as MIME and B-IMANU-TRACK have allowed for practice of mirrored or symmetric bilateral training. It is not always clear how unilateral training of the paretic limb influence its bilateral task performance. The literature show that the paretic arm improves after robot-assisted therapy in general, however not many have quantified the effect on paretic arm control in a bilateral movement in general and specific to a real ADL activity. The goal of this paper was to examine the bilateral versus unilateral paretic limb performance on a functional drinking task before and after robot-assisted therapy where patients practiced reaching and grasping tasks [13-14]. The paper evaluates upper arm movements of two stroke patients who have gone through ADL robotic training with improvements in motor control. We hypothesized that unilateral task-oriented robotics therapy would improve unilateral paretic arm movement and there would be some carry over improvements in bilateral arm control. We describe temporal and spatial trends seen in paretic arm use pre and post therapy when moving by itself or with the non-paretic arm.

II. METHODS

A. Subjects

Two chronic stroke subjects (S1, S2) participated in this case study (Ages 48 and 71, respectively). They suffered a cortical stroke in the right motor area and were both moderate functioning. Both experienced improvements in motor control as measured by the Upper Extremity Fugl-Meyer Score (UE-FM: S1:5 and S2:9). Initial UE-FM were 43 and 48 respectively [15]. The details are given in table 1. All subjects gave informed consent.

TABLE I. DETIALS OF THE STROKE SUBJECTS

Subject	S1	S2
Age	48	71
Gender	M	F
Paretic Side	L	L
Therapy	RT	RT
Pre-FM score	43	48
Post-FM score	47	56

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B. Procedures

Task-Oriented Robot-Assisted Therapy [13,14]: The ADLER robot-assisted therapy environment was used to administer therapy 3 times per week for 4 weeks (12 sessions). The gimbal at the end of the robot was attached to the paretic arm of the subject for assisting with the movements. Each session involved 1 hour of therapy where subjects completed reaching and grasping tasks in 4 modules; modules were organized around the head: games, selfcare tasks, grasping, and 2-D and 3-D reaching (Fig 1). Fig. 1 shows ADLER.

Unilateral and Bilateral Assessment: The patients were assessed using clinical and biomechanical measures pre and post therapy. The bilateral assessment robots (BiAS) [15] were used to measure their paretic and non-paretic arm movements in several functional tasks (Fig. 1b). We report here on unilateral drink and bilateral drink task. The drink task can be broken down into 4 events: 1) reach from rest to grasp cup, 2) lift cup to mouth, 3) return and release cup, and 4) return arm to rest position; rest position was palm facing down (Fig. 2) [8,13-14]. The cup was placed at a position 25 cm away from the end of table. The start and end positions are marked with green and red dots respectively. Fig. 2 shows an example of position and velocity profile for a normal person completing the task.

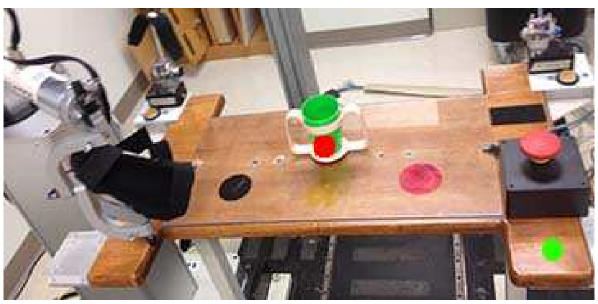

Figure 1. Robot-assisted therapy environment and BiAS testing set-up.

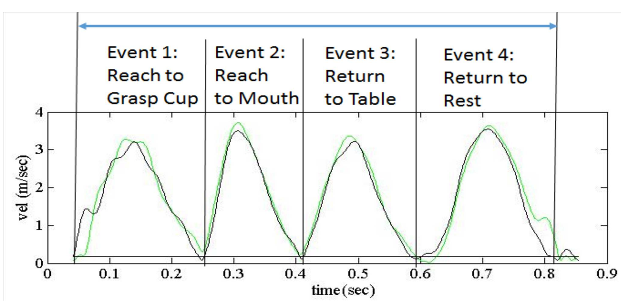

Figure 2. Example velocity plot of the functional drink task with events shown of a normal subject.

C. Data Analysis

The paretic and non-paretic arm movements of two stroke subjects were evaluated for the overall movement and for movement within the 4 events. We quantified the temporal and spatial quality of the movements using time to completion metric (TCT) and the smoothness metric (MS), respectively [15-16]. Start and stop was determined when the velocity dropped consistently below 5% of maximum velocity so as to reduce the noise in the data where the BiAS continued reading in values even after the movement stopped for the tasks. TCT was defined as the time it took each arm to complete the overall task (TCT) or the event (TCT_n) where n varies from 1 to 4. Movement smoothness is measured as the mean speed divided by the peak speed [16]. A custom Matlab program is used to calculate these metrics overall and within the four events for unilateral and bilateral drink pre and post ADL robot therapy. Two trials were done each pre and post therapy for measurements.

In the next sections we describe the trends observed and discuss paretic arm movements and whether unilateral task-oriented robotics therapy improved both unilateral and bilateral paretic arm movement. The influence of the non-paretic arm on the paretic arm is also discussed.

III. RESULTS

Fig. 3 and 4 shows the representative kinematic results pre and post for unilateral and bilateral tasks.

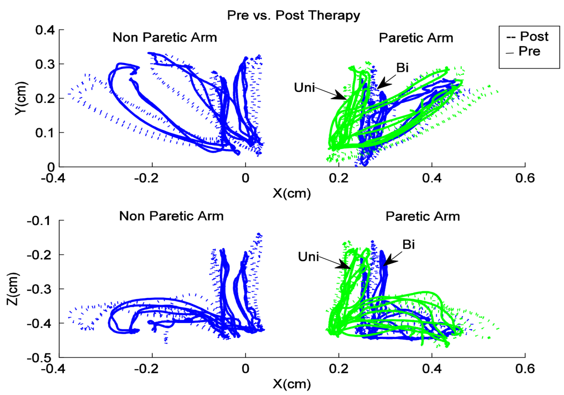

Figure 3. Bilateral and Unilateral wrist position pre and post therapy

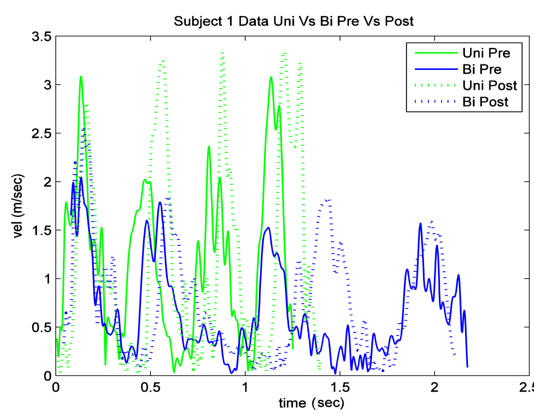

Figure 4. Unilateral and Bilateral drink pre and post therapy

Fig. 3 shows the position results for subject S1 and S2 in pre and post for unilateral and bilateral drink task. The top plot shows the X-Y plane which is the plane of the table. The bottom plot shows the X-Z plane which is the plane of torso. The cup was located at about X=0 cm. Subjects completed more of the task post versus pre. For example, in X-Z plane, the post trajectories reflect that the cup was lifted higher.

Fig. 4 shows the corresponding velocity profiles. These suggest that in the bilateral task subjects took longer. In the bilateral task subjects typically completed more of event 2 and 3 better resulting in longer task times. In addition, the stroke survivors tended to be less smooth in the execution of the movement than a normal subject.

A. *Overall Functional Task Results.*

Fig. 5 show the MS results for the paretic arm and non-paretic arm. Table 2 summarizes the TCT and MS measures across the entire task. Table 2 shows that TCT increases in post therapy compared to that of pre therapy movements. The TCT for the impaired arm while doing the bilateral ADL is close to that of the non-impaired arm. TCT increased as a result of therapy most likely due to the fact that the subject could do more of the task. From these results, it's clear that the smoothness decreased with therapy indicating improvement in control and the precision of the subject increased. The smoothness decreases with the use of the non-paretic arm as can be found from Fig. 5. So the use of paretic arm helps the subject's movements smoother.

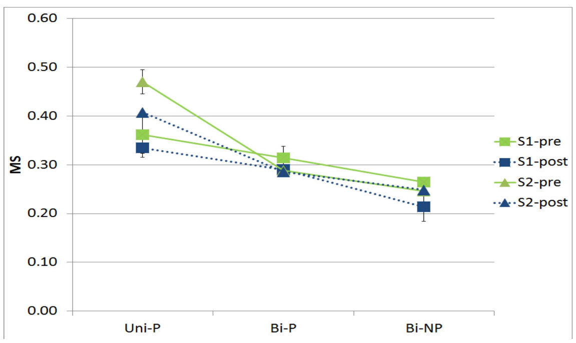

Figure 5. Overall MS for Unilateral and Bilateral Pre vs Post.

TABLE II. TCT AND MS DATA FOR OVERALL EVENT

	PRE		
TCT (s)	**Uni-P**	**Bi-P**	**Bi-NP**
S1	1.19	2.13	2.08
S2	0.94	1.77	1.73
Mean	1.07	1.95	1.91
	POST		
S1	1.37	2.07	2.07
S2	1.32	2.06	1.99
Mean	1.54	2.21	2.15

B. *Event Results*

Fig. 6 show TCT results for the paretic arm in unilateral and bilateral for events. Fig. 7 shows the TCT events by percentage of time it took to complete them. Fig. 8 show MS results for paretic arm. Table 2 summarizes the TCT and MS measures across the events.

Fig. 7 shows that overall the events took longer for completion post therapy for both bilateral and unilateral tasks. The TCT was longer for post therapy events as compared to pre therapy events for all except event 4 (return to rest) in the bilateral task. The figure indicates that subjects spent most of the time in events 2 and 3 (where the cup is grasped, transported and released). Figs. 6 and 7 indicate that although the TCT post therapy was greater than pre therapy, the % of time spent in an event was essentially stable, pre v post and uni versus bi.

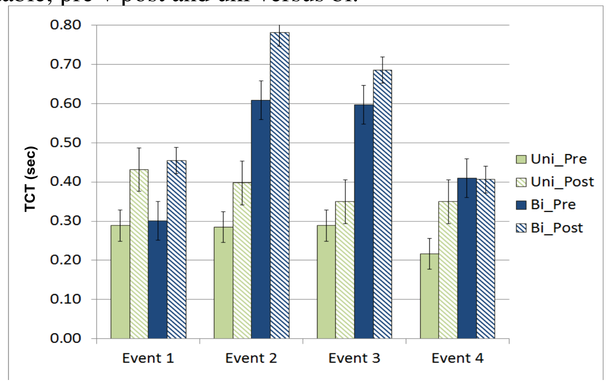

Figure 6. TCT across events for unilateral and bilateral drinking task

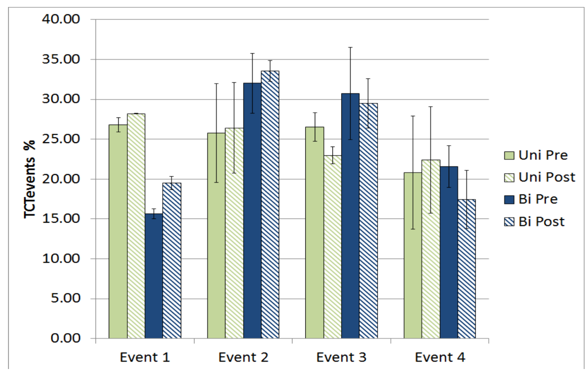

Figure 7. Percentage of TCT for each event for unilateral and bilateral drinking task

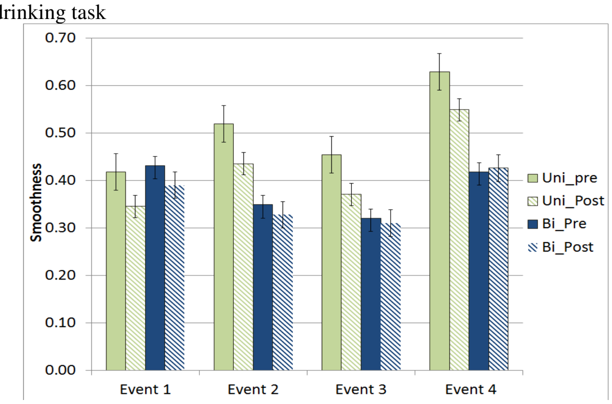

Figure 8. MS across events for unilateral and bilateral drinking task

Event 1 showed a distinct difference between % time the paretic arm spent in reaching to the cup when it move alone (uni) and when it moved with the non-paretic arm (bi).Here it suggest that when the paretic arm was able to complete the reaching tasks best. From Fig. 8, we can see the smoothness decreased for all the events for pre versus post therapy. The smoothness decreased when the subject was doing bilateral ADLs as compared to unilateral ADLs too.

IV. DISCUSSION AND CONCLUSION

Does improvement in motor control as a result of robot-assisted training of the paretic arm lead to improvements in the control of the paretic limb in tasks where both hands are used? Robot-assisted therapy (RAT) [8] is task-specific in that training should be targeted to the activity one wants to improve [5]. Suggesting that if the goal is to improve paretic arm control during a bilateral task, then the training should be a bilateral robot-assisted training [10]. Some studies show improvements of the paretic limb after either bilateral robot therapy or unilateral robot therapy [5]. We evaluated the functional, temporal and spatial effect of a unilateral task-oriented, robot-assisted training on unilateral and bilateral task performance of a drinking task using a real object. We found that the paretic arm movement was smoother post therapy and when the non-paretic arm was used along with the paretic arm. This observation is supported by previous studies and suggests that the paretic limb benefits from the inter-limb coupling between limbs [10-12]. The time to complete the task typically increased post therapy in both unilateral drink and bilateral drink. This may appear to not support previous literature that typically show decrease in movement time post therapy [15]. Published results were typically based on reaching over a fixed distance. The functional task tested was not as constrained since as subjects improve they are able to accomplish more of the functional task. Therefore, we suggest that the reason for the increased in time post therapy overall and across events is mainly due to the fact that the subjects were able to complete more of the functional task. The significant increase TCT in Event 2 and 3 suggest that both subjects had difficulty in grasping and releasing of objects. But the smoothness decreased with therapy and in bilateral tasks for both Event 2 and Event 3 indicating improvement in control and the precision of the subjects for moving out of plane events.

From our case study results, we found that the unilateral robot-assisted training improved paretic arm control in unilateral and the bilateral drink task. In the case of smoothness, this is clearly evident. The MS decreased across all the events and TCT was also affected. Unfortunately, the use of the non-paretic limb also affected TCT and MS, especially MS and the influence of the non-paretic movement on the temporal and spatial paretic arm control was evident both pre and post therapy; this suggests an inter-limb coupling aids in the transfer of unilateral improvements in motor control to the bilateral improvements in motor control [10-11]. So, is it important to have a bilateral RAT in addition to unilateral RAT? This is still not clear. Summers et. al. suggest that individuals receiving bilateral training showed improvements in the time to complete the test movement with the impaired limb while little change was observed in impaired limb movement time in individuals engaging in unilateral training[10]. Future work is to collect additional data and to explore training bilateral versus unilateral using a bilateral robot-assisted therapy environment called bi-ADLER [17].

V. Acknowledgment

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