Mixed Reality Rehabilitation for Stroke Survivors Promotes Generalized Motor Improvements

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Abstract— **This paper presents results from a clinical study of stroke survivors using an adaptive, mixed-reality rehabilitation (AMRR) system for reach and grasp therapy. The AMRR therapy provides audio and visual feedback on the therapy task, based on detailed motion capture, that places the movement in an abstract, artistic context. This type of environment promotes the generalizability of movement strategies, which is shown through kinematic improvements on an untrained reaching task and higher clinical scale scores, in addition to kinematic improvements in the trained task.**

I. Introduction

MILLIONS of people in the US live with chronic upper extremity movement disabilities as a result of stroke [1]. Research has been done to restore functional ability to these people through various innovative techniques. One of these techniques, mixed reality rehabilitation, integrates traditional rehabilitation and motor learning theories with state of the art motion capture and sensing technologies, smart physical objects, and interactive computer graphics and sound design. This type of rehabilitation transforms the stroke survivor's movements and interactions with the environment during a task-based therapy exercise into informative, motivating virtual feedback. This allows users to experience their movement in a unique and engaging way, while receiving useful information about how to correct their movement to achieve task completion or improve their body function. One advantage, as compared to traditional repetitive task-based therapy, is the potential to encourage and facilitate the user to create and maintain a generalizable motor plan [2]. Another advantage is that the system can track each individual's progress and can then be adapted to customize the difficulty, task, duration and feedback of each session, providing challenging therapy without causing frustration [3,4]

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Seven stroke survivors completed therapy using the adaptive mixed reality rehabilitation (AMRR) system for reaching and grasping developed in our lab [5]. The experimental results demonstrate that most of participants improved their kinematic results while performing both the trained and untrained tasks. Most participants also showed an increase in their standard clinical scale results. This indicates that our AMRR system has the potential to promote a generalizable motor plan.

II. Methods

A. Adaptive Mixed Reality Rehabilitation

Our AMRR system provides real time audio and visual feedback representative of goal accomplishment (e.g. reaching the target), activity performance (e.g. efficient trajectory), and body function (e.g. excessive compensatory trunk flexion) during a reach and grasp task. Visual feedback is used to convey the spatial information about the end-effector (e.g. the size and orientation of the picture on the screen is related to the location and orientation of the hand). Audio feedback is used to help time the movement (e.g. the velocity of the hand controls the rhythm of the music) and to provide audio indicators of undesired movement strategies (e.g. compensatory strategies cause undesirable, disruptive sounds). A description of the system and its underlying principles can be found in [5].

The system uses kinematic information, computed from motion capture data from the affected hand, arm and torso, to evaluate the quality of the movement and to drive the feedback. The therapist can focus the treatment on pertinent aspects of recovery based on the evaluation, but the nature of the feedback places each movement component in the context of the full action. This results in the stroke survivor experiencing integrated improvement and being able to produce a generalizable motor plan. A photo of a stroke survivor being trained in the system is shown in Figure 1.

B. Experimental Setup

The present study is a subset of a larger study, in collaboration with Banner Baywood Medical Center in Mesa, AZ, comparing the AMRR system therapy with traditional reaching therapy. Comparisons between the AMRR therapy group and the control group will be

Figure 1. AMRR System. As the stroke survivor performs a reach, her movements are mapped to the image on the screen (e.g. the picture comes into focus when the reach is complete) and sounds playing from the speakers. The movements are measured by data from markers on her hand, arm and body, collected by OptiTrack cameras (two shown above the screen). The therapist is present to aid in understanding the feedback and to provide additional instruction.

presented in forthcoming publications. To date, seven stroke survivors have been recruited to participate in AMRR therapy. All subjects were right-handed before the stroke and had resultant right-sided upper-extremity hemiparesis. Table 1 shows the age, months post-stroke, gender and clinically determined impairment level for each subject. Each subject received AMRR therapy three times a week for one month and was evaluated within three days before therapy (pre-test) and within three days following therapy (post-test). These evaluation sessions involved reaching and grasping tasks to four different cone targets (same targets used during training), untrained reaching to touch tasks using the START system [6] and standard clinical scales. The START task involves reaches to lighted buttons that are spaced to provide a range of functional reaching positions and require a greater range of motion than the trained task. The clinical scales include: the Wolf Motor Function Tests (WMFT), which measures quality (using a functional activity score – FAS) and time to completion of arm movements and functional tasks; the Fugl-Meyer (FM), which measures a variety of aspects of the upper limb; the Motor Activity Log (MAL), which measures self-reported amount of use (AOU) and quality of movement (QOM) of the affected arm during activities of daily living; and the Stroke Impact Scale (SIS), a self-reported scale of recovery following a stroke.

TABLE 1. DEMOGRAPHIC AND STROKE INFORMATION FOR EACH SUBJECT

Sub	Age	Months post-stroke	Gender	Impairment
1	72	11	Male	Severe
2	60	16	Female	Mild-to-Moderate
3	55	22	Male	Moderate-to-Severe
4	66	6	Male	Moderate
5	74	7	Male	Mild-to-Moderate
6	83	6	Male	Moderate-to-Severe
7	71	14	Male	Mild-to-Moderate

C. *Data Collection and Analysis*

During the reaching assessments, kinematic data from each subject was recorded using the OptiTrack system from 14 retroreflective markers on their torso and right hand and arm. The raw data was transformed into a reduced movement representation of 33 kinematic features, chosen for their appearance in reaching rehabilitation literature [5] and through experience working with clinicians.

Composite kinematic impairment measure (KIM) scores were averaged across the four targets (trained task) as an overall measure of improvement on the trained task. The KIM is a kinematic-based evaluation that incorporates results from all 33 kinematic features and uses unimpaired data as a reference [7]. The composite KIM is examined here in the context of the clinical scale results. Individual kinematic parameters of the untrained START reaches are compared to those of the trained task to evaluate if specific movement aspects improved in tandem across the two types of tasks. Relationships between significant (measured by the Wilcoxon rank sum test) improvements in each kinematic parameter in the trained and untrained tasks are drawn.

III. RESULTS

A. *Trained and Untrained Task Kinematics*

Results are evaluated over all buttons and cone locations. Many kinematic parameters improved in both the trained and untrained task. Figure 2 shows the reach time duration, vertical trajectory error, torso flexion and elbow-shoulder joint correlation as examples. These results are shown as mean values with standard deviation bars. Changes were significant (*) at an $\alpha = .05$. Similar changes were seen in the untrained task as the trained task in 50% of the parameters over all subjects. S2 is not shown due to missing kinematic data during the untrained task.

B. *Trained Reaching Task Overall Kinematics and Clinical Scale Results*

Clinical scale results are presented as a percent change from the pre-test score to the post-test score. The percent change of each scale and the composite KIM are presented for each participant in Figure 3, with a ‡ indicating a change in the positive direction. The four clinical scales are also

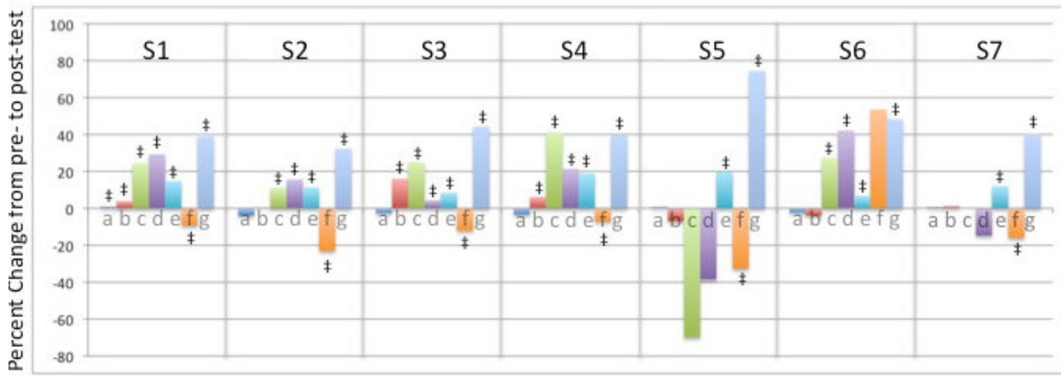

Figure 3. Scale results for each subject as a percent change from pre- to post-test. (a) FM total, (b) MAL AOU, (c) MAL QOM, (d) SIS, (e) WMFT FAS, (f) WMFT time to task completion, (g) composite KIM. A ‡ indicates the change is in a positive direction for that scale.

evaluated as a group. The average change for the total FM score was a decrease of 1.3%. The average change for the MAL Amount of Use (AOU) was an improvement of 8.5% and the average change for the MAL Quality of Movement (QOM) was an improvement of 8.5%. The average change in the SIS score was an improvement of 2.5%. The average change the functional activity score (FAS) of the WMFT was an increase of 13.1% and the average change for the total time to task completion of the WMFT was a decrease of 6.6%. The average composite KIM improvement was 45.4%.

IV. Discussion

The results of these seven stroke survivors suggest that AMRR therapy can both promote improvements in the task that was trained during therapy, and generalized improvements in an untrained reaching task and clinical scale scores. However, the results in Figures 2 & 3 show that the generalizations were not consistent across all subjects. For example, S5 had the greatest improvement in his WMFT functional activity score, decreased his WMFT time to task completion by almost 1/3 and had the greatest improvement of his composite KIM (75%) during evaluation of the reaching task. However, those substantial improvements did not transfer to his reported arm use or recovery scores. We speculate that this subject may have not internalized the positive progress he made, and only focused on the negative feedback he was receiving. Another possibility is that this subject was using different personal criteria for evaluating his recovery in the pre-test versus the post-test. His case illustrates the need to both objectively assess and train the participants' movements, as well as providing illustrations of progress and encouraging the use strategies learned during therapy in daily activities, to encourage recovery both in and out of the clinic.

There were also some inconsistencies across the kinematic results in the trained and untrained tasks. Some subjects, such as S1 and S3, showed very strong generalized kinematic improvements (Figure 2), whereas others, such as S4 did not. Current research includes investigating the underlying reasons for the inconsistencies, such as physiological or psychological factors, and improving the system to address those reasons.

V. Conclusion

The adaptive, mixed-reality rehabilitation (AMRR) system employs audio and visual feedback, smart sensing objects and detailed motion capture to create an enriched therapy environment. This system provides a platform for therapist to track the participant's performance and adapt the system to customize the therapy. Clinical study results show that training with the AMRR system promotes generalizable movement strategies, shown through kinematic improvements on an untrained task and increased standard clinical scale scores, in addition to kinematic improvements during the trained task.

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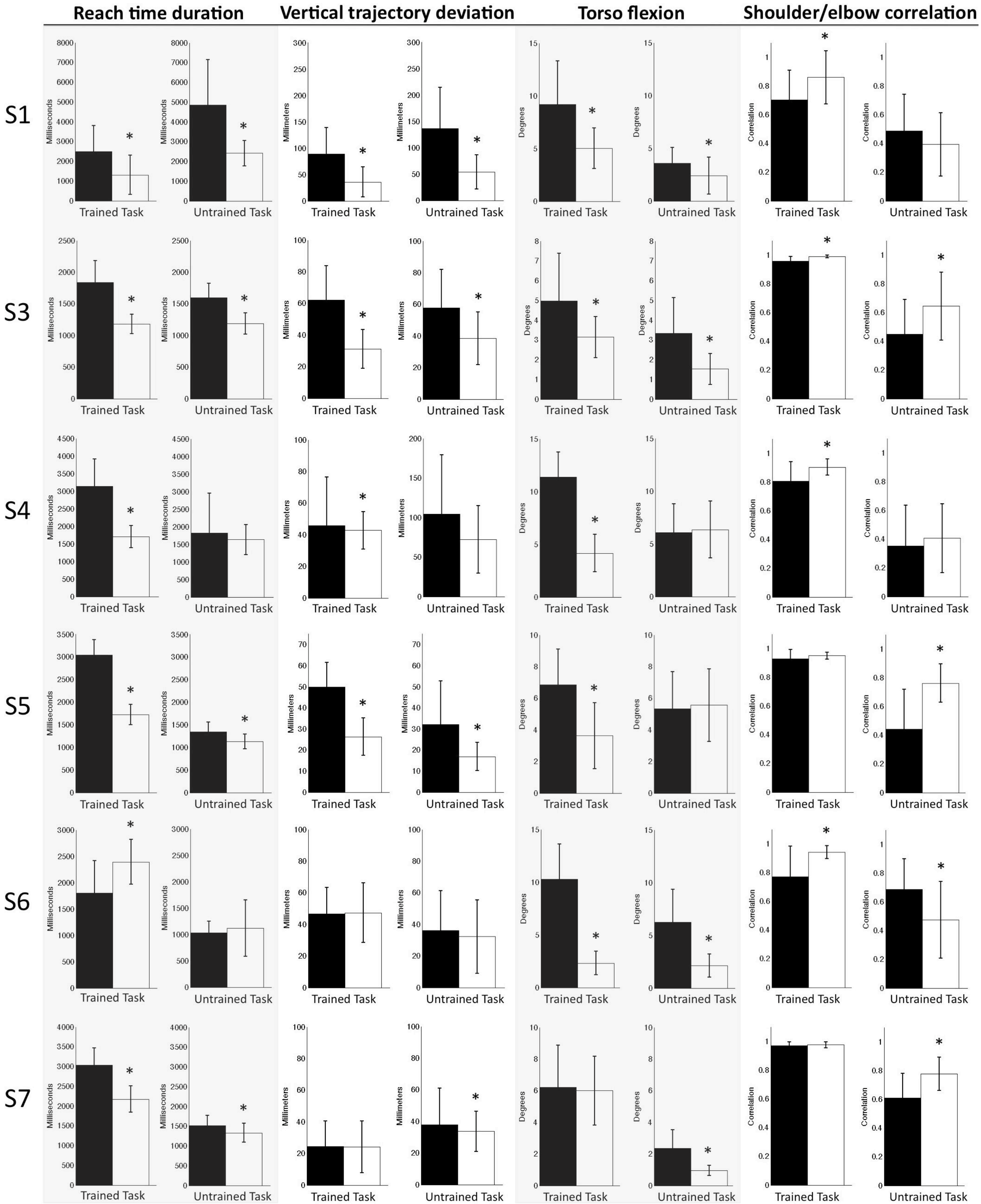

Figure 2. Kinematic results for Subjects 1, 3, 4, 5, 6, and 7 (Subject 2 not shown due to missing data) for the Trained and Untrained Tasks. Black bar shows the pre-test results and the white bar shows the post-test results. A * indicates an improvement at significance level at α = .05.