

Selection of Robotic Therapy Algorithms for the Upper Extremity in Chronic Stroke: Insights from MIME and ARM Guide Results

Leonard E. Kahn, M.S.^{1,2}, Peter S. Lum, Ph.D.^{3,4}, David J. Reinkensmeyer, Ph.D.^{1,5}

¹*Sensory Motor Performance Program, Rehabilitation Institute of Chicago, Chicago, IL, USA*

²*Department of Biomedical Engineering, Northwestern University, Evanston, IL, USA*

³*Hunter Holmes McGuire Dept. of Veterans Affairs Medical Center, Richmond, VA, USA*

⁴*Biomedical Engineering, Virginia Commonwealth University, Richmond, VA, USA*

⁵*Department of Mechanical & Aerospace Engineering, University of California, Irvine, CA, USA*

1. Introduction and Background

Recent efforts using robotic devices to provide movement therapy following neurologic injury have revealed insights into recovery of arm movement after stroke. The first robotic therapy study was conducted with MIT-MANUS and confirmed that robots could be used as effective tools to aid in rehabilitation of movement deficits by increasing the amount of therapy delivered to acute stroke patients [1, 2]. Subsequent studies with MIME and the ARM Guide aimed at comparing robotic therapy in chronic stroke patients to matched amounts of non-robotic therapy in order to shed insight into the modes of therapy that maximize the recovery of arm movement [3, 4]. This paper briefly compares some of the results from the MIME and ARM Guide studies, and based on this comparison, suggests a form of robotic therapy that could potentially improve functional recovery over previous robotic and conventional methods.

Quantifying the differences between robotic and conventional therapies for the chronic hemiparetic patient has been the driving motivation behind both the MIME and ARM Guide projects. The MIME [3, 5] system consists of a six degrees-of-freedom (DOF) robot manipulator (Puma 560) that provides three active therapy modes: (a) an active-assisted mode in which the subject tries to follow along with movement imposed by the robot (b) an active-constrained mode in which the robot only allows movement when the limb forces are appropriately directed towards the target, and (c) a bimanual mode in which the device moves the more affected limb in mirror-images of movements made by the less affected limb sampled through a position digitizer. Both conventional (N = 14) and robot-assisted (N = 13) therapy groups improved significantly on clinical scales of functional movement ability after two months of treatment consisting of three one-hour sessions per week [3]. When compared to conventional treatment, however, robot-assisted therapy resulted in larger gains in strength and larger increases in reach extent (Fig. 1).

The ARM Guide [4, 6] is a singly-actuated, four DOF robotic device that consists of a hand piece attached to an orientable linear track and actuated by a DC servo motor. An active-assisted therapy mode, similar to that in the MIME study, was used to train chronic stroke subjects. This was compared to a matched amount of therapy in which a control group freely reached to seven targets placed throughout their workspace, unattached to any device. Again, both the robot-assisted (N = 10) and free reaching groups (N = 9) improved significantly on a clinical scale of functional movement ability. However, neither those subjects who participated in non-robotic therapy nor those who used active assistance from the ARM Guide improved their reaching extent, measured similarly to the MIME study [4] (Fig. 1).

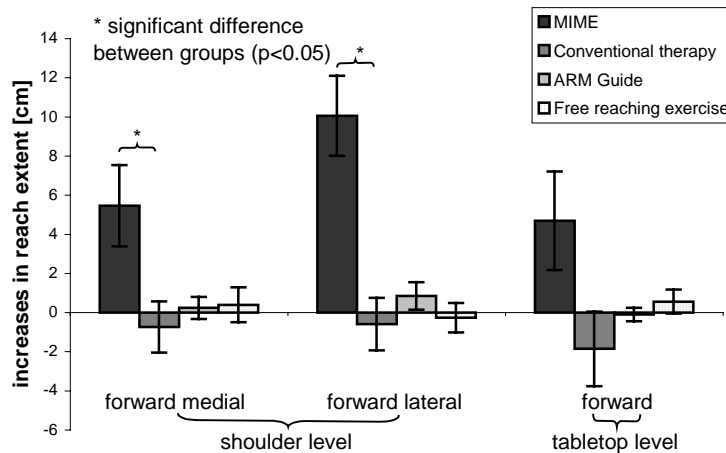


Figure 1. Free reaching extent improvement from the MIME and ARM Guide studies.

2. Possible Explanations for the Observed Differences

To gain insight into the relatively greater recovery of reach extent by the MIME subjects, we considered three potential sources of differences between the two therapy programs: therapy intensity, kinematics of practiced movements, and therapy modes. Participants in robotic therapy with MIME experienced 24 50-minute sessions over eight weeks, compared with 24 45-minute sessions over eight weeks for ARM Guide subjects. We believe that this dissimilarity in time was too small to cause the difference between highly significant improvements with MIME and the complete absence of these improvements with the ARM Guide.

Another possible explanation is that the movements practiced with MIME were different. In particular, the MIME device has six DOF, while the ARM Guide constrains movement to two DOF. However, the kinematics of the whole limb in movements practiced with MIME varied only slightly from the movements practiced with the ARM Guide. This, coupled with the fact that both devices supported the limb against gravity leads us to believe that the larger kinematic repertoire of MIME was not the primary reason for the greater strengthening or range increases.

Lastly, two modes of active therapy were included in the MIME study but not the ARM Guide study. The training of bimanual mirror movements may have provided a unique stimulus for recovery of bilateral or ipsilesional neuromotor pathways. However, the task during the assessment of reach extent was unilateral reaching and therefore was more likely affected by the unilateral exercises. In active-constrained mode, a force sensor measured the direction of force generated by the subject's hand at the interface between the hand and the robot. If the force vector had a component in the desired direction (i.e. toward the target), then the robot moved in that direction with a velocity proportional to force. If the force was misdirected, however, the robot stopped moving toward the target, and a programmed impedance allowed the robot to deflect slightly in the direction of the force, providing visual feedback of the misdirection. This mode of training forced subjects to not only activate muscles to move the limb, but activate muscle groups in appropriate combinations dependent on the desired target and the limb configuration.

3. A Hypothesis and Future Direction

We hypothesize that the active-constrained mode accounts for the difference between the two studies because it is an efficient way to relearn the sensory motor transformations that are required for reaching. Essentially, the robot halted the subjects' movements when incorrect muscle activation patterns were sensed, forcing subjects to learn how to generate the correct pattern at each troublesome workspace position. Generating the correct pattern required lifting the arm against gravity, which likely helped strengthen the arm. If the subjects reassembled the learned patterns into a correct sequence, they were rewarded with a smooth, uninterrupted movement to the target. The active-assist mode used exclusively with the ARM Guide helped the subjects move through their full passive range of motion, but did not afford an opportunity for the subjects to systematically decompose and correct incorrect muscle activations. It also did not penalize subjects for allowing the device to support the arm as they moved.

To test this hypothesis, a new study has begun with the ARM Guide in which a form of the active-constrained method will be employed. The outcomes from chronic stroke patients participating in this form of robotic therapy will again be compared to a group participating in repetitive free reaching. It is anticipated that the robotic therapy group will exhibit significant improvements in reach extent similar to those in the MIME study and absent in the free reaching and conventional therapy groups. If so, then the study will provide evidence that robots can contribute novel, effective therapy algorithms that would be difficult if not impossible for a therapist to implement otherwise.

Acknowledgements

Research supported in part by NIDRR Field-Initiated Grant H133G80052 (Reinkensmeyer), a Whitaker Foundation Biomedical Engineering Research Grant (Reinkensmeyer), a NIH NICHD Institutional NRSA training grant (Rymer), and the Department of Veterans Affairs Merit Review Grant B2056RA (Burgar).

References

1. Aisen, M.L., H.I. Krebs, N. Hogan, et al., "The effect of robot-assisted therapy and rehabilitative training on motor recovery following stroke". *Archives of Neurology*, 1997. **54**(4): p. 443-6.
2. Krebs, H.I., N. Hogan, M.L. Aisen, et al., "Robot-aided neurorehabilitation". *IEEE Trans. Rehab. Eng.*, 1998. **6**(1): p. 75-87.
3. Lum, P.S., C.G. Burgar, P.C. Shor, et al., "Robot-assisted movement training compared with conventional therapy techniques for the rehabilitation of upper-limb motor function after stroke". *Archives of Physical Medicine & Rehabilitation*, 2002. **83**(7): p. 952-9.
4. Kahn, L.E., M.L. Averbuch, W.Z. Rymer, et al. "Effect of robot-assisted exercise on functional reaching in chronic hemiparesis". in *23rd Annual International Conference of the IEEE-EMBS*. 2001. Istanbul, Turkey.
5. Burgar, C.G., P.S. Lum, P.C. Shor, et al., "Development of robots for rehabilitation therapy: The Palo Alto VA/Stanford experience". *Journal of Rehabilitation Research and Development*, 2000. **37**(6): p. 663-673.
6. Reinkensmeyer, D.J., C.D. Takahashi, W.K. Timoszyk, et al., "Design of robot assistance for arm movement therapy following stroke". *Advanced Robotics*, 2000. **14**(7): p. 625-637.