Adaptive Mixed Reality Rehabilitation (AMRR) : Extending interactive upper extremity stroke rehabilitation from the clinic to the home

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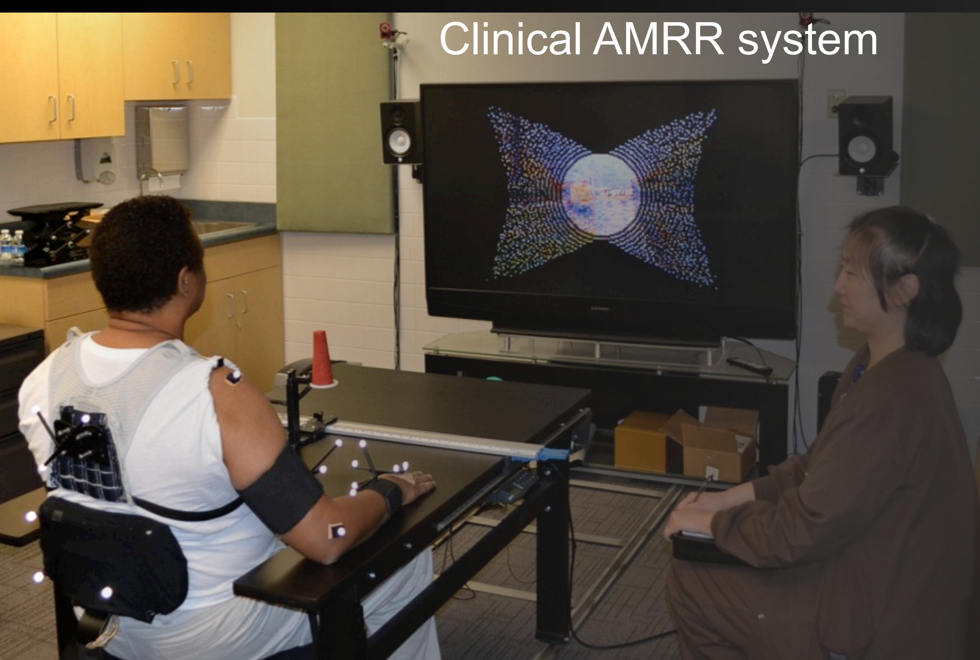
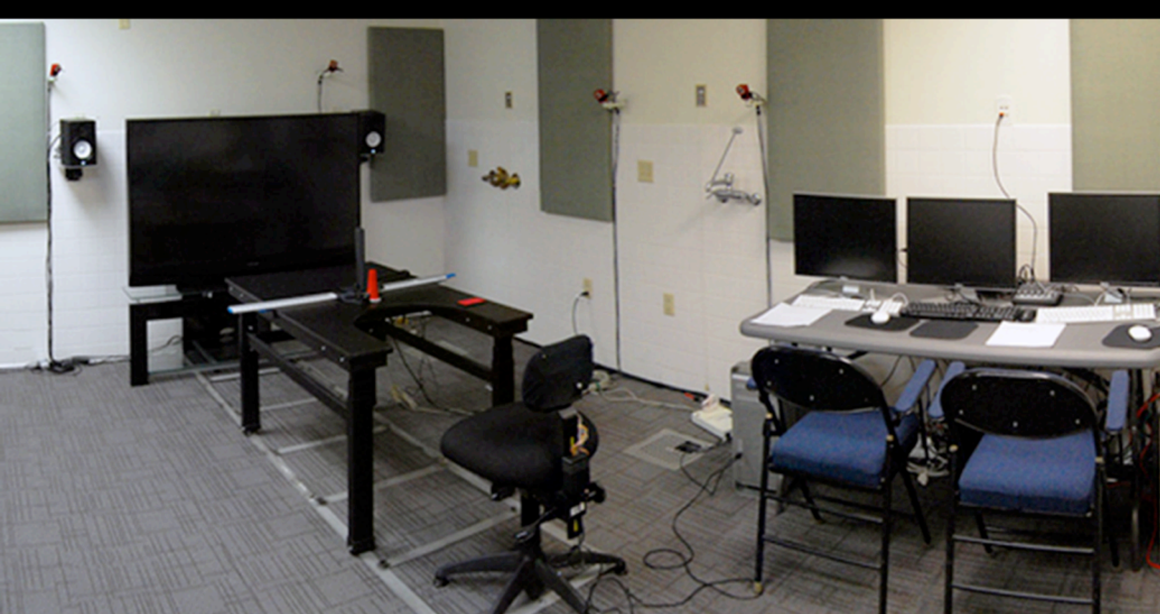


REDUCING THE IMPACT OF STROKE – Stroke is a leading cause of long-term adult disability in the United States. Effective rehabilitation techniques require a long therapy process that is often repetitive, tedious, and uncomfortable, as they can encourage reversal of learned non-use and/or compensatory strategies developed by the stroke survivor. Additional challenges associated with current rehabilitation techniques include insufficient intensity and high cost of maintaining the duration of therapy. Furthermore, health insurance provides a limited amount of support for rehabilitation beyond the initial stages of recovery, which may limit the full potential of recovery for each individual stroke survivor. Home-based rehabilitation provides a low-cost alternative to extensive clinical therapy, while facilitating the stroke survivor's independence, to become the driving force behind his or her recovery.

MIXED REALITY REHABILITATION SYSTEMS – Mixed reality systems provide clinicians with multimedia and computational tools to create an engaging and customized rehabilitation experience for each stroke survivor. Motion capture technology provides accurate assessment of the stroke survivor's movement performance, and can also be used to generate detailed feedback to the stroke survivor for self-assessment. A mixed reality environment combines virtual and physical elements to provide visual, audio, and tangible feedback on the user's performance. The Adaptive Mixed Reality Stroke Rehabilitation (AMRR) system was developed for highly monitored and extensive training of various reaching tasks within a clinical setting. The assessment, adaptation, and feedback frameworks used within the clinical AMRR system are currently being applied to the development of a home-based therapy system for long term use by stroke survivors following clinical rehabilitation. Here we focus on identifying key challenges that arise in designing a home rehabilitation experience and explain how we approach these challenges within our system.

System Sensing and Hardware



In the clinical system, 11 OptiTrack motion capture cameras track 14 reflective markers worn by the participant on the back, shoulder, and arm.

44 key kinematic features are extracted from the participant's movement as he performs a reaching task, for computational evaluation of his movement performance.

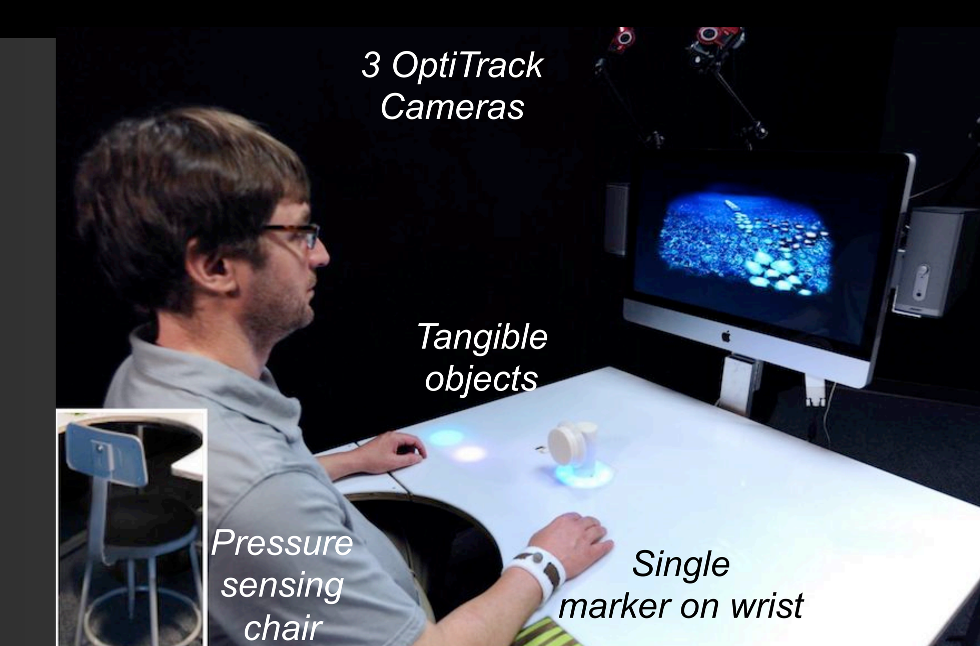
Multiple computers are utilized for computational analysis of movement and feedback generation, while a large LCD display and speakers present the feedback for the participant.

- *Reduce the cost of sensing*
- *Reduce any complication of marker setup*
- *Facilitate integration into the home*

The home system includes an iMac computer for all computation, feedback generation and display, and 3 OptiTrack cameras that track a single infrared reflective marker worn on the participant's wristband.

Pressure sensitive tangible objects and a chair sensor system provide low cost embedded sensing solutions. The tangible objects measure hand manipulation and the chair measures coarse torso orientation.

Kinematic features that are tracked are greatly reduced from the clinical system and focus primarily on hand movement over time and space.



Task and Feedback Environments

As the participant reaches towards the grasping target, her hand's movement pushes the particles back to assemble the image on the screen. Inaccurate reaching will stretch the image in the direction of spatial error. Her hand speed simultaneously controls the rhythm of a musical phrase, which is used to assist the participant in timing her reaching movements.

Continuous detailed feedback is provided during an individual reach.

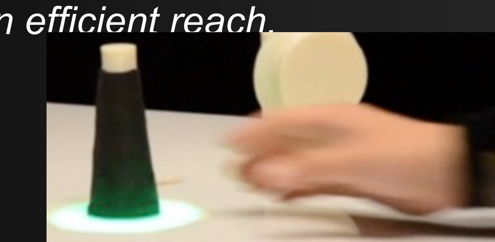
Visual feedback communicates spatial accuracy of the hand, while the audio feedback communicates aspects of timing.

Unique audio indicators also can be introduced to communicate if the participant is extending her elbow (orchestral sound), or using excessive shoulder of torso movements (discordant sounds).

- *Decrease reliance on detailed real-time feedback to encourage self-assessment*
- *Support more complex tasks*
- *Provide a multi-level structure for multiple months of use*

The home system provides a narrative-based, multilayered feedback environment that communicates end point performance over space and time, hand manipulation of the object during a task, and coarse torso movements.

***Level 1**: Real-time visual feedback on trajectory error is provided as colored light embedded within base of the object, followed by a detailed summary (in the shape of the rock path) on the screen. This example demonstrates an efficient reach.*



As in the clinical system, the hand's speed controls the rhythm of a musical phrase generated by the participant's movement.

***Level 2**: Summary feedback provided after a set of reaches*

***Level 3**: Summary feedback in the form of a short animation provided after the completion of a complex functional task*

System Adaptation and Therapy Progression

The therapist (left), participant (center) and media expert (right).

A participant receives 1 hour of AMRR therapy, 3 times a week for 1 month, for a total of 12 therapy training sessions.

Based on direct observation and the system's computational assessment on movement performance, the clinician and media expert may adapt the task type or difficulty as needed to better suit the needs of the participant.

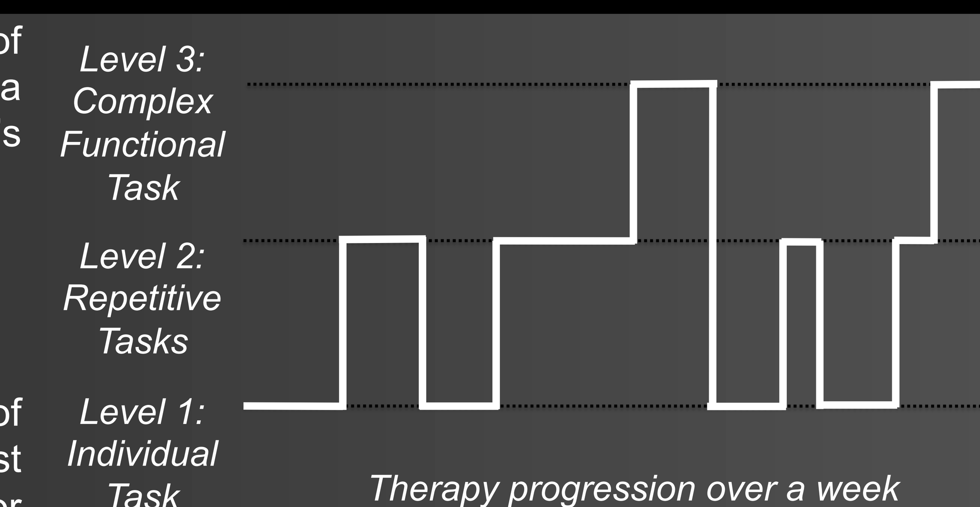
Any aspect of the digital feedback may be turned on or off for reaching tasks to physical targets. The table allows various target objects to be mounted and adjusted in location.

- *Require less supervision time by therapist*
- *Integrate more complex tasks into therapy*
- *Connect patient learning across therapy tasks*

The home system provides a framework to run one week's worth of therapy sessions, such that the therapist only needs to review data on a weekly basis and make adjustments to a subsequent week's therapy sessions. The therapist provides two inputs:

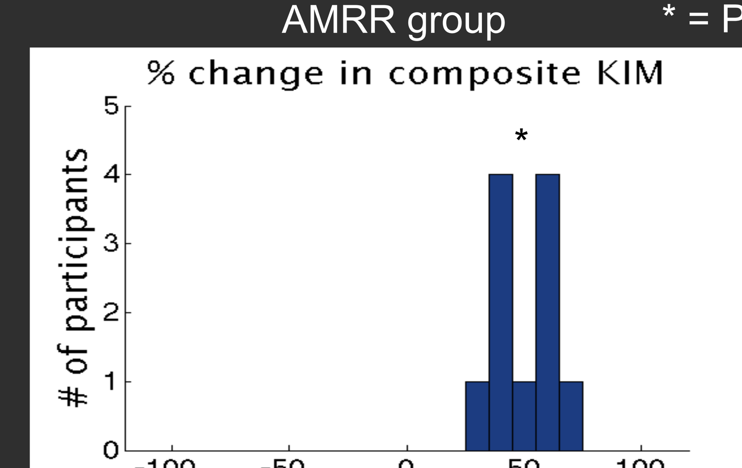
(1) a profile prioritizing rankings of a patient's movement attributes
(2) a relative dosage of time to spend on each movement attribute

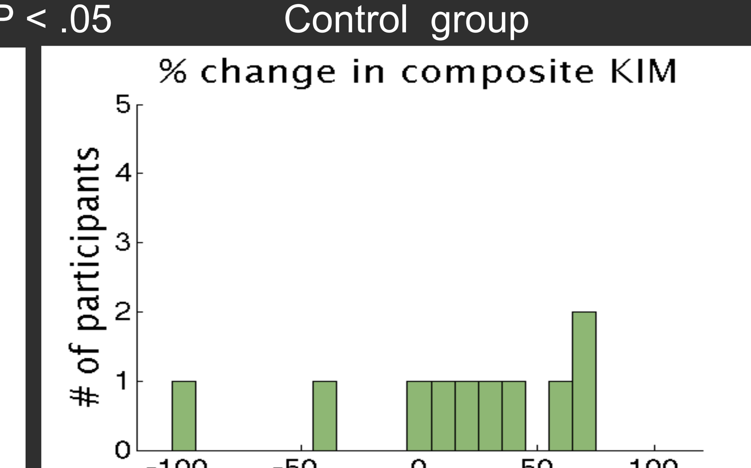
The resulting sequence provides a progression through each level of the task and feedback environments. The multi-layered, reductionist feedback design is utilized to continually connect the individual motor elements focused on in the lowest level with more aggregate movement quality focused on in the highest level.



Our group has recently completed a study that compares mixed reality therapy with traditional clinical therapy. A summary of preliminary results are shown (right) comparing changes in composite Kinematic Impairment Measure (KIM) before versus after one month of therapy for a group experiencing AMRR therapy versus the control experiencing traditional therapy. The KIM was developed by our group to map raw measurements of movement features to a normalized assessment scale based on movement performance data collected from both unimpaired participants and from stroke survivors possessing a wide range of impairment. A composite KIM score provides an overall performance measure across all kinematic parameters measured during reach and grasp movements. The AMRR group significantly improved their composite KIM, while the control group had no significant change in composite KIM. Also, control participants were scattered between extremes of a 100% worsening and a 70% improvement in composite KIM, demonstrating more variability than the AMRR group, which saw at least 30% improvement.

AMRR group * = P < .05 Control group





The home system will provide the opportunity to evaluate if continued training at home using a mixed reality system can sustain or build upon improvements achieved in clinical therapy.

In fall 2012, a multi-site study will provide the home system for multiple stroke survivors in their homes to use for several months. Continued development is underway to further reduce sensing costs by using the Microsoft Kinect camera and wearable, portable sensing solutions.

Mixed Reality Rehabilitation Team Members who have contributed to this work:
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