

# **A System for Sensory Motor Rehabilitation of the Upper Limb with Virtual Reality, Exoskeleton Robot, and Real Objects**

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Technology assisted therapy has the potential to transform rehabilitation options available, and to dramatically increase the reach of today's healthcare system. Yet challenges persist in rendering translational application designs that optimize the full potential of technology and create value for the patient and the therapist. In a step towards optimizing value of technologies for practical applications to support very weak patients who might otherwise be unable to participate in traditional therapies, an integrated sensory motor training station was designed and developed. Inspired by recent neuroscientific research findings the goal of the design was to provide concurrent first person perspective immersive action observation of both virtual and real elements for motor and sensory experience; the system incorporates a virtual limb proxy that can be personalized and actuated by the robot and that is accompanied by exercise practice in peripersonal space for a plasticity promoting experience for the hand and arm. The station uses virtual reality and real objects for visual sensory experience, real objects also provide tactile sensory experience, and an exoskeleton upper limb robot provides assistance to patients. For many patients, successful movement and movement intensity required in rehabilitation is not achievable without the robot assistance. The multi-sensory features of the system promote a top-down strategy for training the upper limb (hand and arm) complementing the robot training; the system is ideally targeted for weak patients and those with tactile or proprioception sensory loss who are known to benefit from multi-sensory experiences. The system offers opportunities to provide the nervous system with realistic and modulated sensory experiences during exercise at multiple levels of difficulty based upon the principle that sensory observation and practice improve outcome of rehabilitation more than either one independently. In addition, certain visual experiences provided by the system might reduce interference effects of exercise with robots.

A number of injuries and conditions affect sensory motor skills, for example, stroke, spinal cord injury, cerebral palsy, peripheral nerve conditions, etc. The population and extent of sensory and motor injuries is heterogeneous inspiring sensory motor rehabilitation that is easily personalized and that can provide intensity in a variety of task oriented exercises for patients with a wide range of skills, deficits, and interests. Stroke represents a serious disabling condition for people around the world affecting 1.7 million in Europe and the United States. Persons suffering hemiparesis of stroke (85%), and loss of body sensations (50%) experience a cascade of events affecting use of their upper limb and quality of life. Upper limb therapy to address reduced body sensations, improve coordination, and ability to manipulate objects is needed; evidence demonstrates that therapy improvements may be achieved in acute, sub-

acute, and chronic stages. Improvements that affect quality of life result when the hand and arm function improves.

The training station incorporates computers, projectors, multimedia displays, semi-transparent mirrors, and various lighting sources to present, conceal, or modulate visual and auditory sensory stimulus and feedback during exercise which is concurrently assisted by the ARMin robot with the human in the loop. Advantageously, visual sensory stimulation may be displayed on the semi-transparent mirror in a first person perspective (within peripersonal space) in the position where objects will be manipulated for realistic interaction during technology assisted exercise. The system provides views of the proxy virtual limb, virtual targets, and real objects for a fully integrated blended reality. The current applications focus upon reaching to touch objects incorporating hand and arm exercises.

Using the system, movement intention, motor assistance, and sensory experience are synchronized and modulated to achieve the needs of the individual person in terms of level of difficulty, or multi-sensory experience to achieve a unique blended reality environment suitable for intensive repetitive task-oriented exercise necessary for cortical reorganization. Practice conditions may be easily titrated adapting difficulty of tasks as skills change and offering just as much technology assistance as needed. One important value of the employed technology is to provide measurements during exercise since clinical measures are provided less frequently, do not readily identify the specific intervention that might be effective in an individual, and do not account for incremental changes in performance. Measures taken during training using this system also provide information about dose achieved during the session and may be tracked across sessions providing important information to the patient and the therapist. Measures also provide information to personalize training to better meet the individual needs of the patient in a simplified manner.

In a recent experiment with control subjects, seeing and touching the real objects improved performance over pointing to virtual objects in an arm location task demonstrating value in the additional sensory experience resulting from the presence of the real object. Subjects were asked to view and point to virtual or to view and touch real objects and then to locate their hidden arm. The ARMin seven degree of freedom upper limb exoskeleton robot was used to measure subject compliance with arm movement in the active condition, and to move the subjects' arm in the passive movement condition using position control. The see and touch real objects condition improved performance of arm location regardless of the robot condition.

Feasibility of use of this system and method with patients is under investigation. Several exercises have been developed wherein the patients may view and reach to virtual targets or view and reach to and touch real targets with and without the active assistance of the robot, while the robot and virtual reality system monitor performance. The exercises optimize multi-sensory experiences and the support or measurements of the robot. The subjects who are patients with motor and sensory loss perform the arm and object location exercises.

Implications for rehabilitation are that the system with virtual reality, real objects, and robot support may provide a practical means to integrate important multi-sensory experiences directly related to the exercise task into a technology assisted therapy environment, to extend reach of therapies to very weak patients, to provide a simplified means of personalizing therapy, and to increase exercise intensity required for cortical reorganization.