

Recent Research Advances in Upper-extremity Rehabilitation

Furui Wang*

Abbott Laboratories, Princeton, USA

Upper extremity impairment is a prevalent outcome for a variety of neuromuscular disorders, such as stroke. According to the American Stroke Association, each year about 795,000 Americans experience a new or recurrent stroke; i.e., every 40 seconds in the United States, someone suffers a stroke [1]. 60-75% of these patients will live beyond one year after the incidence, resulting in an estimated stroke population of 7 million in the USA alone [1-3]. Upper-extremity function is acutely impaired in a large majority of those diagnosed with stroke [4-7]. Furthermore, acute hemiparesis presages chronic hemiparesis in over 40% of individuals [5,6] suffering from stroke. Chronic deficits are prevalent in the distal upper extremities, especially with regard to arm and hand motor function. Intensive physical therapies help patients regain useful functions of upper extremities, help with activities of daily living, and make them more independent.

Clinical results have indicated that movement assisted therapy can have a significant beneficial impact on a large segment of the population affected by stroke. In recent years, new techniques adopting a task-oriented approach have been developed to encourage active training of the affected limb, which assume that control of movement is organized around goal-directed functional tasks [8,9]. "Shaping" is one of the task oriented behavioral training techniques employed in Constraint-Induced Movement (CI) therapy [8-10], which has the effect of placing optimal adaptive task practice procedures into a systematic, standardized and quantified format. The availability of such training techniques, however, is limited by the amount of costly therapist's time they involve, and the ability of the therapist to provide controlled, quantifiable and repeatable assistance to complex arm and hand motion.

Consequently, robot assisted rehabilitation could be used to automate labor-intensive training technique, to provide programmable levels of assistance to the patients, to quantitatively monitor and adapt to the patient's progress during rehabilitation, in a more cost-efficient manner. Robot-assisted physical rehabilitation has been an active research area in recent years to assist, enhance and quantify rehabilitation. The robot-assisted therapies provide autonomous training where patients are engaged in repeated and intense practice of goal directed tasks leading to improvements in motor function. Robotic rehabilitation devices and systems are being developed to automate therapy for the arm, wrist and hand following stroke. The MIT-Manus (Massachusetts Institute of Technology Manus) [11,12], Assisted Rehabilitation and Measurement (ARM) Guide [13,14], Mirror Image Movement Enabler (MIME) [15-17] and GENTLE/s [18] are developed to facilitate the arm movement of stroke patients. Robotic devices designed for wrist rehabilitation has been reported in [19-21]. A number of devices have been developed expressly for or applied to hand rehabilitation. These include both commercial products, such as CyberGrasp (Immersion Corporation, San Jose, CA) [22], the Hand Mentor (Kinetic Muscles Inc., Tempe, AZ) [23], and the Amadeo Hand System (Tyromotion GmbH, Graz, Austria) [24]. Experimental devices include Rutgers Master II-ND [25], HWARD [26] and HandCARE [27] among others [28-31].

The promising results of the above mentioned rehabilitation robotic systems indicate that the robots could be used as effective rehabilitation tools. However, the question regarding the best use of these robotic

systems for rehabilitation remains. The extent to which rehabilitation robots should assist, resist, or otherwise alter movement of the user is still unclear. This is a key area where progress needs to be made for rehabilitation robotics.

Those with the most success to date tend to focus on intense and repetitive practice of the affected limb with cognitive processing as a means for motor program reorganization, during which patients not only make repetitive movement but also pay attention to tracking accuracy. However, the patients may not be able to track the desired motion because of their impairments during the task execution. Thus, robotic assistance is provided to help the patients complete the task in different manners. Several strategies have been developed, including passive [32,33], active-assistance [13,14,19,32-35], active-constrained [33], counterpoise control [36], resistive [35], error-amplifying [36-39], and bimanual modes [33,40,41]. The primary strategies tested so far is active assistance [13,14,19,32-35], a clinical term that refers to exercises in which the patient attempts a movement (active) and in which a therapist manually helps complete the movement if the patient is unable (assistance) [42]. It has been suggested that in robot-assisted rehabilitation, assisting every movement of a patient is not as beneficial compared to assistance as needed [43]. Performance-based therapies have showed better results in improving patients' impairment scores than conventional therapies [13,14,44]. Meanwhile, research has demonstrated that movement tracking training that requires cognitive processing achieved greater gains in performance than that of movement training that did not require cognitive processing [45]. Many models and artificial learning systems such as neural networks suggest that error drives sensorimotor learning of a person, so that one can learn adaptation more quickly if the error is augmented to a certain degree [46]. Such error-driven learning processes are believed to be central to adaptation and the acquisition of skill in human movement [44,47]. It has been shown that visual error augmentation can improve the rate and extent of motor learning in healthy participants [38] and elicit functional improvements in patients with chronic stroke and traumatic brain injury [39]. Incorporating visual feedback and visual error augmentation strategy with active robotic assistance has the potential to improve the efficiency in robot-assisted rehabilitation training [48].

In recent years, advanced robotic systems are developed aiming for the upper-extremities rehabilitation, including upper-limb, wrist and hand. Rehabilitation strategies are investigated to make the best use of these robotic systems. Rehabilitation robotics has become an

*Corresponding author: Furui Wang, Systems Engineer, Abbott Laboratories, Princeton, USA, E-mail: furui.wang@gmail.com

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important topic in robotics research. With the continuous progress in rehabilitation robotics research, it is reasonable to believe that robot-assisted rehabilitation systems will greatly improve the efficiency and reduces the cost of rehabilitation, and benefit patients with motor disabilities.

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