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Reprogramming the mind

Rehab Technology for Stroke Survivors

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Stroke is one of the main causes of long-term and permanent motor disabilities, where many patients are unable to integrate affected limbs into everyday-life activities, resulting with a need for rehab long-term intervention. Thus, stroke survivors are putting a large physical, emotional and economic burden on individuals, family and society, and present practical challenges for health care therapy.

After stroke, the rehabilitative process relies on three main foundations: Reliable and valid diagnosis; accurate evaluation of recovery or adaptation; and prolonged training. The rehabilitative process depends on the effective evaluation of sensory motor deficit, precise assessment of treatment effects, and extended treatment for continuous recovery during the chronic stage.

There are a variety of rehabilitation methods and techniques for post-stroke patients, some of which have been in use for decades, such as: Neurodevelopmental treatment (NDT)/ Bobath, Brunnstorm, Proprioceptive neuromuscular facilitation (PNF), functional electrical stimulation, mirror-therapy, mental training, cognitive behavioral therapy (CBT) and constraint-induced movement therapy. The above assessment's 'resources' to evaluate sensory-motor impairment after stroke, intended to address aspects such as active and passive movement, joint range of motion, muscle tone and muscle strength, synergistic execution such as speed, accuracy and rhythmus of movements, reaching and grasping capabilities, object manipulation, balance, coordination. etc

Despite these techniques, it is still difficult to rehabilitate motor control in general, and specifically hand and fingers motor control. The motor learning/adaptation component is unclear in the functional improvement achieved by using these methods, as compared to use of compensating movements in order to perform a functional task. Other disadvantages of the above treatment methods are lack of monitoring of the patient’s movements during the treatment, as well as protracted 'interesting' treatments that increased compliance over a long treatment period. In summary, the above treatment methods and procedures are commonly applied by specialized health care professionals, yet often yield inconsistency, incomplete and variability in assessment and treatment outcomes. In other words, these traditional well-acceptable assessments are first unable to capture the entire spectrum of the 'true' and valid function of the patients and consequently providing inferior treatment results. Although progress in patients is observable during physical and occupational therapy sessions, nevertheless task completion not always reflects recovery, as patients often adopt different movement patterns as a function compensation, and such movement performance is not always noticed and recorded. In addition, essential assents such as technological devices are needed for effective and successful rehabilitation are often constrained by limited resources.

Recently, more researchers reported and more clinicians found and recommended that in order to acquire the most optimal outcomes after stroke one must consist of an iterative process involving objective/technological devices for assessments and beneficial training.

Upper extremity impairment due to stroke cause many difficulties in managing and handling daily life activities. Robot technology with a particular focus on the upper extremity functions has the potential to objectively assess, treat and monitor patients inside and outside medical environments, enabling the individual to receive a user-friendly device and effective rehabilitation therapies. Therefore, nowadays it is more appealing to consider using robotic devices (e.g. sensors) and machines for rehab of stroke survivors. Robotic devices/machines are highly accurate, can reduce evaluation times and provide objective, quantifiable data on the patients' capabilities, reducing diagnostic errors, providing additional information extracted during the execution of multiple tasks (e.g., muscle activity), measuring progress automatically, and allowing choosing the best choice for a greater personalized therapy. Furthermore, interactive robotic devices can be sustained for very long periods, thus allowing repetitive practices and letting patients to work more extensively and comprehensively towards recovery.

Movement patterns after a stroke

Lateral lesion of upper limb deficits are common in people after stroke, remain present in a large number of patients, also in the chronic phase after stroke, and require rehabilitation strategies to address the upper limb deficits. The chronic phase starts six months post stroke and is typically characterized by the start of a plateau phase in patients in which no further significant improvement is observed. Nevertheless, patients can still improve in functional ability in the chronic phase after stroke, due to exercise-dependent plasticity.

Normal muscle synergy after stroke is impaired and usually described as 'abnormal/not stereotypical' movement pattern, which does not allow the patient to perform any other stereotypical movement patterns such as walking and writing. Furthermore, 'abnormal movement pattern' does not permit the muscles to work in synchrony and harmony relative to each other thus harming kinematic features of well-controlled movement. As a result, disorganized and ineffective movement is created, which in turn impairs functional ability.

Abnormal movement pattern typically appears together with spasticity, and those develop during the chronic stage after the stroke. The resulting movement is lacking harmony between the flexors and extensors muscles a well as between proximal and distal muscle groups. This is how the cerebral cortex, brain stem and spinal cord control levels of freedom of movement. Examples of this can be seen between shoulder extension and movements of the wrist, and between elevation of the shoulder and movements and control in the wrist and fingers. The consequence of such dependency address that recovery of the shoulder should lead to better hand and fingers control.

Technological devices and robotics used in stroke patients

Recent development of technology devices has grown rapidly and has been utilized in academia, industry and in clinical setting aim towards achieving a reliable, valid, objective and unobtrusive method of studying and training human movement, as well as to monitoring rehab progress and for outcomes recording. Technological resources have developed remarkably in recent years, with smarter and greater sophistication of electro-mechanical-ergonomic components. Generally, the robotic devices can be divided into two main categories: those for the upper limb and those for the lower limb. This technology has made robotics available for rehabilitation from initial evaluation through intervention. Robotic and wearable sensory devices are the most frequently used in the study of human motion, and can deliver personalized rehab program, high-dosage, and high-intensity training with special emphasis on monitoring of upper limbs in stroke patients. Thus robot-assisted therapy, accelerometers, potentiometers, and surface electromyography (sEMG) are frequently used.

Therapeutic robots Vs assistive robots

Assistive robots are for compensation purposes, whereas therapeutic robots provide task-specific training. Therapeutic robotic devices used for motor training by applying mechanical forces through either facilitating or resisting the desired movement. These robots provide direct control of individual joints, which can minimize abnormal movement.

The upper limb robotic systems can be classified in two main categories and designed for certain purposes: According to the joint segment of the upper limb (Shoulder, Elbow, Wrist and Hand); According to the control strategy (Passive movement, Active-assist, Active, Resistive, and Error enhancement).

Error-enhancement approach

The functional and structural changes that take place in the brain cortex and brain stem during acquisition of a new and old motor skill highlight the need to find a rehabilitation method based on known motor learning/relearning principles that include:

- **01** Massed practice;
- **02** Task-specific for the required daily task;
- **03** Variability of practice;
- **04** Practice of increasing difficulty

Rehabilitation of hand and finger movements using a robot with the technique of error enhancement is an innovative rehabilitation method which seeks to bring better movement, eliciting greater accuracy and range of motion during reaching as well as increased stability and smoothness when performing reaching tasks.

deXtreme™ robotic device is a CE & FDA marked rehabilitation device that offers this error-enhancement approach during three-dimensional movements. The deXtreme™ measures the hand movements during a movement exercise, during which it calculates the movement error and enhances it proportionally to its magnitude. The principle of enhancing the error, instead of correcting it, based on the assumption that a movement error is essential for creating neuroplasticity and acquiring movement skill. Therefore, magnifying the error may enable better motor learning. In addition, this method allows intensive training, including a large number of repetitions in a short time span, an essential factor in motor learning.

Error enhancement can be explained as follows: unexpected external perturbation forces acting upon the upper limb during a reaching movement will cause the upper limb to deflect from the reaching pathway and these results in errors. If we allow for repetitive reaching performance with the same systematic perturbation forces, then we notice a decrease in errors. The motor learning component responsible for this error reduction is an internal model update, in other words the preplanned motor program is continuously updated during the reaching movements. In healthy participants, error augmentation force fields have been shown to increase the accuracy of reaching movements.

Many studies that have investigated forward reaching movements of the upper limb after stroke merely focusing on movements in the horizontal plane whereas functional reaching movements are nearly always conducted three-dimensionally. deXtreme™ is able to apply this technique during three-dimensional movements, resulting with a significantly increased intervention outcomes.

How Error enhancement works?

Error enhancement rehabilitation is based on motor learning principles, adaptive capacity of the central nervous system (i.e., cortex, brain stem and spinal cord), and biomechanical properties, yet it differs from other rehabilitation methods that make use of movement facilitation or use passive techniques as part of the rehabilitation. According to this mechanism, exposing the patient to an ongoing stimulus (in this case, a force field) will cause a temporary change in the motor pattern that was in place before exposure to that stimulus – a change in the movement pattern. An additional explanation of how this mechanism leads to improved learning as a result of practice with this method is that the nervous system which suffered injury as a result of a stroke, for example, does not respond or does not learn when the motor task is performed with small movement errors. Therefore, magnifying the movement errors should improve learning via a greater exposure of the sensory system to the error that occurred.

Internal model as a neural motor learning mechanism

We believe that there are neural mechanisms representing incoming and outgoing information which grant humans the ability to control objects, including one's own body, and enable us to use objects skilfully while anticipating what is about to happen. These mechanisms are called internal models. The central nervous system (CNS) uses two types of internal models: inverse internal model and forward internal model. In the context of outstretching the hand, a forward model enables transmission of an efferent copy of the motor command for the purposes of executing the trajectory of the hand movement. In other words, for moving an object, this model enables prediction of how the object will move as a result of the person's acting upon it. An inverse model, in contrast, converts the anticipation of a certain hand movement into a motor command, while comprehending how the movement should be done. That is, assuming that the object will move to a specific desired location, what manipulation is required in order to bring it to there. For example: in the case of controlling a computer mouse, one can say that the anticipation of where the cursor will move as a result of moving the mouse is a forward model; in contrast, assuming that the cursor will reach a specific point, and then determining which movement of the mouse is required, is an inverse model.

Creating an internal model requires practice with many repetitions in order to cause the brain to perform adaptation, despite impairment of the blood aspect, and perform assimilation of this ability. The brain's ability to change neural connections in CNS and change function of brain regions are known as 'neuroplasticity' or functional reorganization. This ability has influenced theories and applied approaches in neurological motor rehabilitation. Learning that incorporates many repetitions, such as that applied in rehabilitation by error enhancement, creates an internal model in the brain, which is a motor schema created as a result of the practice. Practice in this method enables the patient to correct the movement trajectory during its performance (forward model) and also after its performance (reverse model). When the patient reaches the desired performance, and after many repetitions, it may be that a permanent internal model is created, indicating assimilation of the action into motor memory.

Adjusting the treatment's difficulty level to the patient's level by changing the parameters for error enhancement enables even patients with moderate to severe motor impairment, including those with minimal active movement of the shoulder and elbow, to practice at the same intensity as stroke patients with mild impairment. In addition, unlike normal active rehabilitation with many repetitions in which the patient performs the tasks without any monitoring of the quality of the movement, and without any physical intervention in performance of the movement, in error enhancement, every movement is monitored by the robotic system. Thus the system reacts during performance of the motor task, and intervenes in the forces operating on the limb.

Why to use technological devices?

Post stroke patients need constant and intensive rehabilitation, often requiring one-on-one interaction with the physical and/or occupational therapist. Unfortunately, lack of human resources and budget restrictions do not permit this thorough rehabilitation. Therefore, there is a need for new technologies improving the efficacy and effectiveness of stroke rehabilitation. The available scientific literature with accumulated clinical reports suggest that the most effective rehabilitative interventions are those providing a valid and reliable assessment, on-going monitoring and recording changes, a tailored-based training program able to offer intensive, task-specific, friendly-user and multisensory stimulation.

01 Conventional assessment is vulnerable to biases derived from measurement errors.

02 Some assessment tools objected to ceiling effects.

03 Frequently, compensatory strategies adopted by patients while performing different tasks interfere with optimal recovery.

04 Offering structured and monitored program which is individual-based.

05 Offering fun activities to stimulate patients and increase motivation.

06 Avoiding unnecessary and redundant repetitions and activities.

07 Allowing prolonged training.

08 deXtreme™ Error-enhancement robotic device offers three-dimensional movements, better able to changeover to a normal muscular synergy resulting in a meaningful functional improvement.