A REVIEW REGARDING NEUROREHABILITATION TECHNOLOGIES FOR HAND MOTOR FUNCTIONS

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Abstract: The paper deals with a short review regarding neurorehabilitation technologies for regaining human hand mobility functions after a cerebrovascular accident or stroke. The aim of this paper is to form a general understanding of the current technologies used in the field of neurorehabilitation and highlight key characteristics, advantages and disadvantages. Technologies that are studies include robot exoskeletons, electro stimulation, brain computer interfaces (BCI), EEG and limb mounted sensors. After a presenting a summary of current existing technologies, a brief conclusion proposing the future direction of this study is proposed.
Keywords: Neurorehabilitation, neuroplasticity, exoskeleton, EMG, BCI.

1. Introduction

The scope of this paper is to review current high-tech technologies that are used in the field of neurorehabilitation therapy for people that have hand mobility impairment after suffering from a stroke. The technologies reviewed focus on new and modern methods of therapy.

It is estimated that the life of more than 79500 people is affected every year by stroke in the United States[1]. Damage to the cerebrum cortex can often result in damage to neural pathways responsible for motor control of limbs, causing partial or full immobility in some areas of the body due to the disconnect of the damaged neural pathways.

Losing motor control due to brain damage substantially alters the quality of life of stroke victims [2]. The most often met disability is the loss of fine control in the hand of patients. Even though hand movements require little energy and effort, due to their finesse and precision, require complex neuronal activity in the brain. The impairment of movement is caused by damage to the neural pathways.

To be able to regain motor functions, people who have suffered stroke need to participate in a rehabilitation program, in order to rebuild the neural connections between the brain and the affected parts of the neuromuscular system. Rebuilding the neural pathways required for motor control is obtained through the brains capability of neuroplasticity, meaning damaged neural connections can be recreated in other parts of the brain using methods of physical therapy and exercise with the limbs that remained without mobility [3].

Rehabilitation exercises were traditionally executed with the help of physical therapists, and require a substantial amount of effort and time from the medical staff. This and a constant lack of human resources resulted in the need for adaptation of existing advanced technology, integrating these technologies into the medical procedures for neuromuscular rehabilitation. This resulted in lowering the volume of the work required of the medical experts while at the same time increasing the number of treatable patients and also creating more efficient methods and exercises to regain full mobility.

2. Classifications of Motor Function Neurorehabilitation

There are a number of technologies that exist at an experimental level [4]–[8] and some that have made their way to the marketable stage and can be purchased by medical and research institutions.

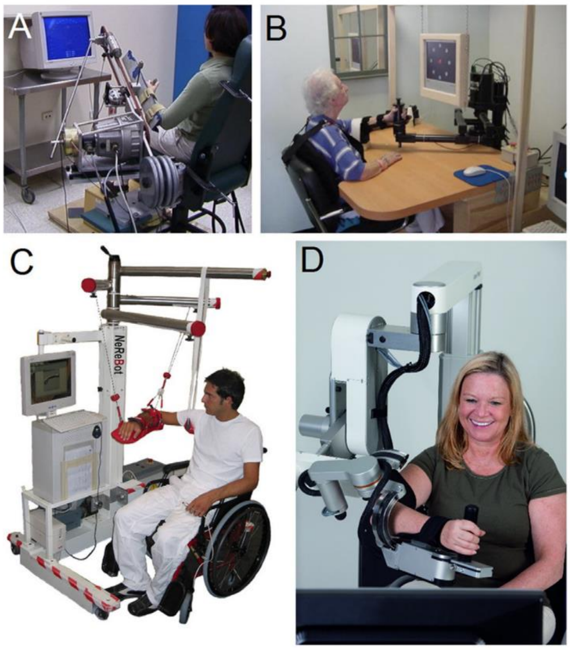

Fig. 1. Examples of rehabilitation devices for upper limb rehabilitation. (A) ARM Guide; (B) InMotion ARM; (C) NeReBot; (D) ArmeoPower (Maciejasz et al., 2014); licensee BioMed Central Ltd [12]

Some existing projects implement one or multiple technologies such as movement of the human hand via robotic exoskeleton in combination with EEG sensor placed on the hand for providing feedback [9], [10]. In this section of the paper technologies are classified depending on their key elements. While there is not yet any standard protocol for assessing technical and clinical outcomes in the case of neuromuscular rehabilitation, there are several studies that compares multiple rehabilitation technologies and draws conclusions from them [11].

2.1. Robotic Exoskeleton Assistance

Robotic exoskeletons were created with the aim of assisting and augmenting humans or animals. They attach around an individual and contain actuators that deliver mechanical power to aid movement.[13]

For the objective of neuromuscular rehabilitation, robotic exoskeletons are used as therapeutic devices that resist, perturb or assist the users attempted movements to provide motor practice and exercise.

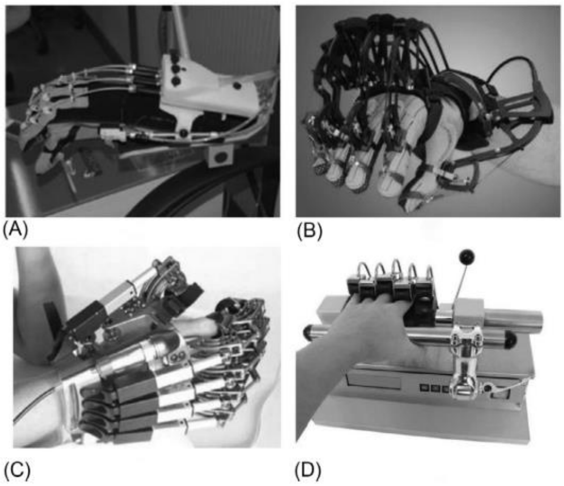

Fig. 2. Exoskeleton examples: (A) Gloreha (B) CyberGrasp (C) Hand of Hope (D) Reha-Digit [12]

Robotic exoskeletons were the first technological elements that were used for aiding physical therapists in the execution of rehabilitation exercises and even now is the most used technology. A great advantage of exoskeletons is that they can be easily combined with other fields of technology to enhance and improve the neuromuscular rehabilitation process.

2.2. EEG Feedback

Neural activity in the brain has the effect of causing variations in electric fields over the surface of the skull. These electric fields are generated by millions of neurons neighboring each other and can be quantified using electroencephalography.

Electroencephalography requires the placing of electrodes around different scalp regions of a patient's cerebrum.

These electrodes can then measure and record the electrical neural impulses emitted by the brain. The frequency of brain wave recordings via EEG reflect a corresponding brain activity in the cerebrum cortex.

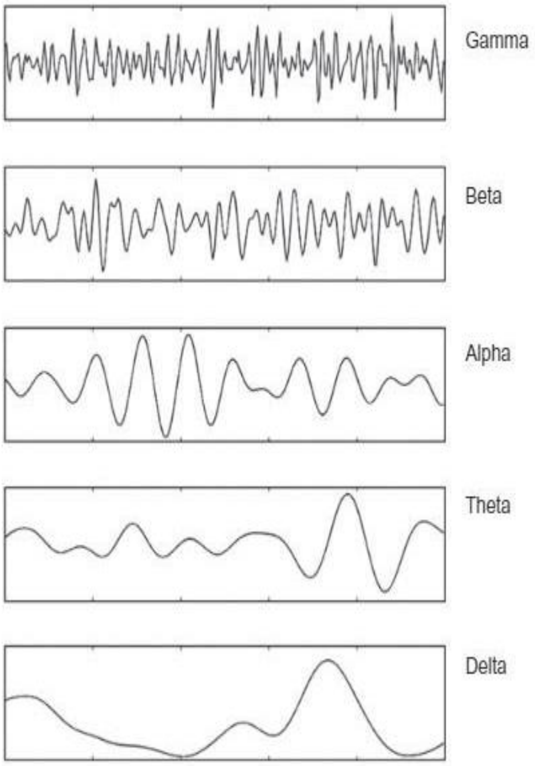

Fig. 3. EEG signal wavelengths [14]

The signals recorded by EEG electrodes have a very small amplitude of 10-100 µV, in the frequency range of 1-100Hz. Only large clusters of active neurons are able to generate recordable electrical potentials that the electrodes can measure through the scalp.

Table 1. EEG signals [14]

EEG signal	**Frequency (Hz)**	**Location**	**Activity**
Delta	<04	Frontal, parietal, occipital lobe	Deep sleep adult, in babies
Theta	04 – 07	Parietal and temporal lobe	Drowsiness in adult, young children
Alpha	08 – 12	Parietal and occipital lobe	Eye close, relaxation
Mu	08 – 13	Sensorimotor cortex	Sensorimotor movement
Beta	13 – 25	Frontal and parietal lobe	Awaken, conscious person, focus
Gamma	>25 (max. 100)	Whole brain	Cognitive activity

This technology is a preferred noninvasive neurodiagnostic tool that provides information about the changes occurring in the cerebrum cortex during the recovery process after stroke, detects abnormal brain waves and pairs well with a robotic exoskeleton for improved neuromuscular rehabilitation when used in a system of BCI.

2.3. Electromyography (EMG) Feedback

Electromyography is technique that is used to measure electrical signals coming from the skeletal muscle groups once muscle activation is triggered. The nerve cells that are called motor neurons are responsible for stimulating these muscle groups using electric signals, and cause the muscles to contract or relax.

EMG is used to diagnose neurological and neuromuscular problems, and many neurorehabilitation systems integrate this technology thanks to its motion determination capability, using EMG pattern recognition methods. [15]

2.4. BCI Feedback

Brain-Computer interface is a technology that records brain activity by measuring the electrical signals in the cerebrum cortex, quantifies the recorded signals and attributes them to external actions that a subject can perform.

A BCI system consists of two primary components:

- The technology that measures the brain images/signals (EEG, Electrocorticography(ECoG), Computed Tomography (CT), Magnetic Resonance Imaging(MRI)) [16].
- A central unit that receives the recorded brain activity and processes the input from which it extracts the intentions and actions that are to be executed by a subject or device.

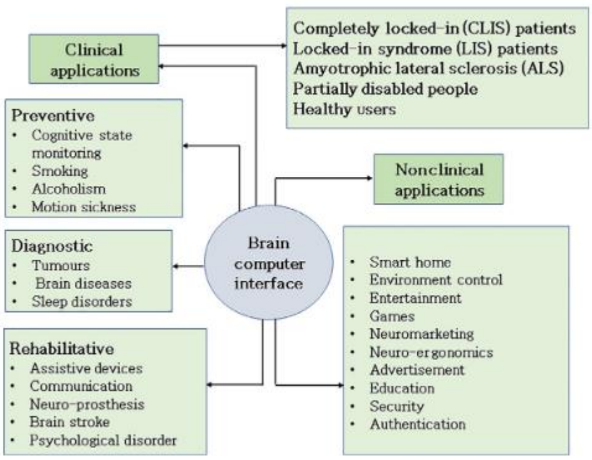

Fig. 4. Brain-Computer Interface application [14]

A BCI system with the above components can be used for several applications such as prosthesis control, locomotion, device control, movement control or neuro rehabilitation.

For neuro rehabilitation the BCI system offers the best solution to extract movement intention of a patient and use this information for rehabilitation in the form of reinforced visual learning, meaning the action that the brain wishes to carry out is shown on a screen, or by pairing with a robotic actuator / exoskeleton to achieve an efficient physical therapy, combining brain signals with mechanical output.

2.5. Electro Stimulation

Electro stimulation is a physical therapy technology that is used to achieve muscle contraction and strengthen areas where mobility has been partially or fully lost or muscle tissue has been damaged. It can be used for treating simple muscle injuries, but is also useful for treating patients that require neuromuscular rehabilitation. Following a stroke, control over some areas of the body is lost and muscle inactivity in these areas can result in muscle atrophy[17], [18]. To avoid this, regular activation of muscle tissues in areas with no control is required, which can be achieved through physical therapy or by electro stimulation [19]–[21].

Using electrical stimulation can also help patients to achieve faster neuroplasticity (creation of new neural pathways) to regain full individual control over areas that lost mobility due to damaged neural pathways.

2.6. Mixed technologies

2.6.1. BRAVO Exoskeleton with MI-BCI

This system uses an exoskeleton that features shoulder, elbow and wrist assistance, as well as adaptive kinematics for the hand. The rehabilitation scenario consists of five phases: preparation of movement, reaching, grasping, bringing back and and releasing an object. The system is driven using a patient’s intentional control through a self-paced asynchronous Motor Imagery based Brain Computer Interface [22].

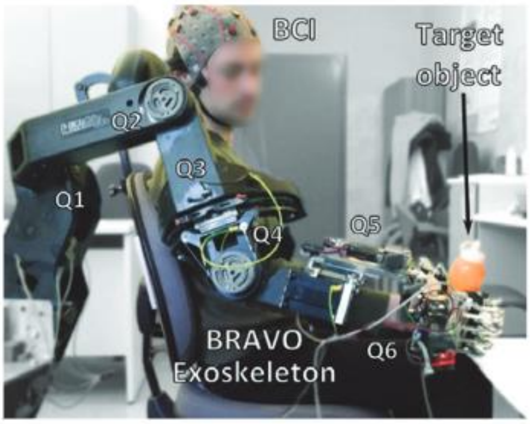

Fig. 5. Bravo Exoskeleton [22]

2.6.2. Gloreha (Glove Rehabilitation Hand) with EEG, EMG and Kinematic Signals

This setup allows the execution of all the combinations of fingers joints flexo-extension. EMG signals are recorded using a multi-channel signal amplifier, EEG signals are recorded using a Sam32 amplifier, while the kinematic signals are measured using a electrogoniometer, that is placed on the index finger of the patient. [23]

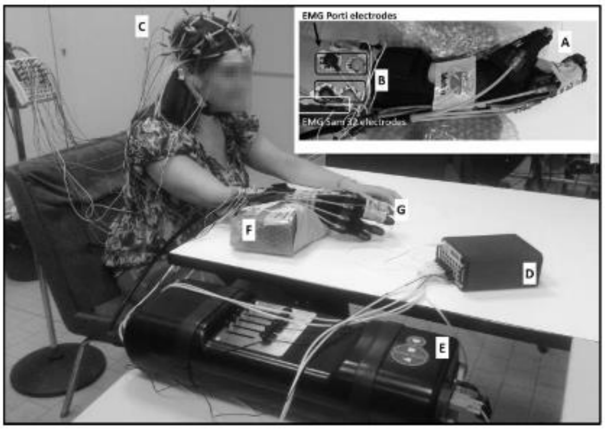

Fig. 6. Gloreha (Glove Rehabilitation Hand) setup [23]

2.6.3. EEG-EMG based Hybrid Brain-Computer Interface

This project fuses EEG brain signals with EMG muscle activation signals to control a rehabilitation exoskeleton. Compared to a simple EEG based system which can suffer from low spatial resolution, the fused signal processing proves more capable to generate accurate feedback for the BCI [24].

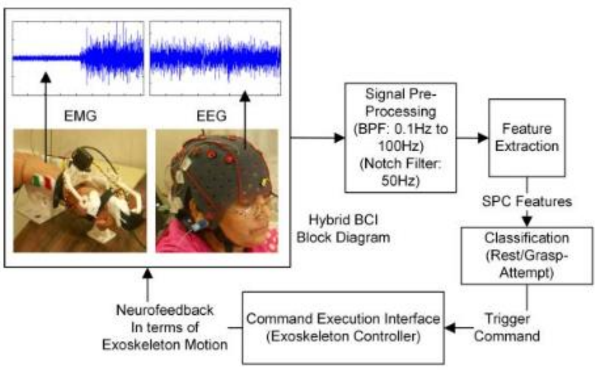

Fig. 7. Hybrid Brain-Computer Interface Block Diagram [24]

3. Conclusion

There are many technologies that can be applied for rehabilitation of hand motor functions, but probably the most obvious and used technology to date is the use of a robotic exoskeleton. Even though there are methods that do not require a mechanical actuator and use only brain and neural signals to try and initiate a kind of reinforced learning, such technologies are only in an experimental state, and most rehabilitation is still being done with the use of physical therapy exercises, thus making the robotic exoskeleton the primary and most useful technology in this domain. A great benefit of this technology is how it is compatible with almost every other instance of technology presented in this review, making it a great base technology for a neuro rehabilitation project, which looks to extend its capabilities by using other innovative and experimental technologies, such as brain-computer interfaces, EMG signals or electrical stimulation.

To conclude, this review finds that physical therapy by the use of robotic exoskeletons is probably the best base for any neuro rehabilitation system. The study was done to have an in depth understanding of rehabilitation technologies in order to develop a new hand rehabilitation application.

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