

Brain-Computer Machine-based Rehabilitation Procedure Efficiency For Post-Stroke

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Abstract. Stroke still remains one of the major cause of disability. The post-stroke impact one may experience is multifaceted, from motor, cognitive, and emotional influences, reducing one's quality of life. Past treatments developed in the past had strict requirements, therefore limiting treatment enrollments. Recent research on brain-machine interface-based therapy for post-stroke motor rehabilitation showed promising outcomes. Moreover, these BMIs have been modified to consist of different signal acquisition and device outputs, to be centered around post-stroke cognitive and emotional influences. BMI based system relays on the mechanisms of neuroplasticity, and the present essay attempted to explore the efficiency of different BMI systems in maximizing neuroplasticities in order to restore motor and cognitive impairments. Moreover, the essay also explored the regulatory efficiency in combating post-stroke related depressive issues. As conclusion, BMI shows promising results in promoting motor and cognitive rehabilitation, also showing encouraging prospect in mood regulation. However, evidence focusing on the transferability and endurance of these observed effects is still largely lacking.

Keywords: Brain Machine Interface, Stroke Rehabilitation, Neuroplasticity

1. Introduction

Stroke, results from hemorrhagic and ischemic injuries to the brain; disrupts the dynamic activities of cortical and subcortical networks making it the world's third leading cause of morbidity [1]. Such abrupt changes in one's quality of life impose long-term psychological and economical pressure on the individual, the individual's family, and even the healthcare system [2]. Consequently, developing rehabilitation programs targeting restoring patients' quality of life effectively is essential for the patient, the patient's family, and even the public sector [2]. Although, advances in current rehabilitation choices have led to significant reduction in the mortality rate. Still, many stroke survivors become disabled each year [3].

Traditional rehabilitation programs for stroke, focus mainly on the bottom-up approach [3]. For instance, constraint-induced therapy (CIT) relays on limb modulation to cause changes in previously disrupted neural circuits [3]. However, for patients suffering from paralysis, physical movement may often be challenging, therefore leading many stroke survivors unable to enroll in such rehabilitation programs. As result, such a limit puts the effectiveness of these traditional bottom-up programs in doubt [3], while signaling the need for more advanced rehabilitation programs.

The recent shift in rehabilitation focus lead to the development of programs based on top-down approaches, which center around neural circuit re-structure to restore damaged abilities. The mechanism behind these approaches is neuroplasticity [2]. The concept suggests that learning is essential for the restoration of disrupted neural circuits, as it promotes the forming of new synapses and strengthen the connection of current occurring synapses, which leading to restoration of disrupted brain regions [2]. Consequentially, the key to the development of rehabilitation programs remains to construct protocols that optimize neuroplasticity, which in turn leads to long-term recovery. Stroke motor recovery mainly relays on neuroplasticity to create readjustments in damaged circuits to association with a particular function. To maximize such readjustment, the chances of coincident activation in connections of networks should also be aggrandized [2]. In that, Brain's machine interface as a system that both decodes brain activity and activates circuits to reinforce synaptic connections is viewed as promising by many recent researchers [2]. As the role of BMI in stroke

recovery became more and more prominent, it is essential to evaluate BMI's effectiveness systematically.

Therefore, the present essay aims to explore the efficiency of non-invasive BCI in facilitating motor, cognitive and emotional rehabilitation.

2. Related Study

2.1. Brain Computer/ Machine Interface

Recent advancements in neural recordings and measurements facilitated the development of neurofeedback. It's the visual and auditory representation of measured brain activity. The integration of neurofeedback into rehabilitation programs led to the construction of Brain-machine interface-based treatments.

Brain-machine interface or BMI enables user to interact with their surrounding environment directly, without any muscle involvements. In that, BMI quantifies one's mental state or intention into physiological measures, then convert these measurements into control signals to direct an external device [2]. For instance, in a BMI-based stroke motor rehabilitation program, patients were usually first instructed to self-regulate brain signals (e.g. EEG) by using various techniques (e.g. motor imagery), then this pattern is converted to a control signal and delivered to a computer or machine (e.g. robotic limbs) for the reproduction of the intended motor activity, which allows a direct control connection between patient's brain and the output. The focus of BMI systems in stroke rehabilitation expands beyond motor rehabilitation and has been developed and modified to consist of different signal acquisition and device output methods to center around different rehabilitation purposes [3].

2.2. Signal recording in BMI

A BMI relays on the recorded signal to extract one's intention. The recording methods of BMI can be categorized as invasive and non-invasive in nature. Invasive methods rely on implants to gain better spatial and temporal data. In contrast, non-invasive methods are safer and collect electrophysiological and hemodynamic signals depending on the specific recording form (e.g. electroencephalography (EEG); magnetoencephalography (MEG)).

2.3. Outputs in BMI

The output devices act upon the converted brain signals extracted by signal recording methods. The form and design of these outputs vary to fit the need of rehabilitation programs, the present essay will focus on robotic devices, orthotics and functional electrical stimulation (FES).

2.3.1 Robotics & Orthosis

The goal for these two output devices is based on replacement. Orthotic provides extra support to the body during dynamic movements. Robotic outputs act as a replacement for limbs to allow the generation of motion, without actual body involvement.

2.3.2 Functional electrical stimulation (FES)

FES induces artificial muscle contractions through electrical impulses. The previous study has shown such artificial induced contraction can facilitate artificial neuroplasticity and therefore leads to neural reorganization [4].

3. Rehabilitation efficacy

3.1. Motor function rehabilitation

As suggested above, motor rehabilitation is the main target for intervention programs. While for individuals who suffer from post-stroke motor dysfunction, traditional interventions usually fall into

1) direct stimulation (e.g. transcranial direct current stimulation); 2) peripheral limbs. Such categorization provides the basis for the innovation of BCI-based treatments. In the present essay, BCIs that incorporate robotics, orthosis, and virtual reality, as output methods; and EEG and MEG as signal recording methods, will be examined.

3.1.1 Upper limbs

The initial focus of BMI-based stroke rehabilitation was on the upper limbs' motor control, as it's being shown to be the most effective method to improve one's quality of life. Individuals targeted by this initial scheme were people who suffered from severe motor defects and who does not meet the minimum motor requirement to be enrolled in a traditional rehabilitation program, such as constraint-induced movement therapy. Following such, the integration of the concepts: motor imagery (MI) and BMI, led to the development of MI-based BMI. Specifically, it's been suggested that real movement and MI share similar recruitments of neuronal circuits, involving areas such primary motor cortex. Following such, explored the effect of robotic EEG-MI-BMI for hand and wrist motor rehabilitation in stroke survivors [5]. As result, improvements in upper limbs control abilities were reported, demonstrating promising effect. Interestingly, such effect in motor rehabilitation facilitated by the MI-robotics BCI program is also found to be constant in studies based on different external output devices, such as MI-FES-BMI. In Daly et al. (2009) [6], the patient was trained for 9 sessions and was reported to experience an increase in index finger control. The promising effect of BCI-based motor intervention can also be detected in studies based on different signal acquisition methods, such as MEG. Broetz et al. (2010) [7], combined EEG and MEG-based BMIs with physical therapy. Through using orthosis as external feedback, the study demonstrated significant motor improvement in participants.

3.1.2 Lower Limbs

The prominent effects of BMI-based intervention on the upper limbs are suggested to be transferable to lower limbs as well. Using FES-BMI as treatment, Chung et al. (2020) [8] found a significant improvement in lower limb strength, which results in an observable increase in standing and walking control abilities. Ren et al. (2020) [9] took a step further by integrating FES MI-BMI with VR in creating a ball-kicking game to assist stimulate muscle contraction in lower limbs, as a result, healthy participants' performance in ball-kicking action improve significantly. However, it's unclear whether the outcome is transferable to post-stroke individuals.

3.1.3 Perspective of motor rehabilitation

Current evidence has suggested that BMI-based training programs, especially MI-BMI have a significant short-term effect on post-stroke individual's motor function. However, there are limited systematic studies available that compare the transferability of such effects in the long term. Moreover, it's still unclear which specific combination of BMI-based training programs is the most effective.

3.1.4 Neural basis for BMI based motor rehabilitation programs

It's suggested that BMI-based rehabilitation follows the principle of learning and Hebbian plasticity. In the primal stage of learning, a sensory stimulus is involved to stimulate planning and responses. Feedback will also be facilitated based on the made response. In an MI-BMI training program, participants use such mechanisms to enhance SMR desynchronization and motor imagery control, which leads to cortical plasticity and cortical reorganization, specifically in motor-related brain areas, promoting motor function recovery in post-stroke individuals. Such hypothesis is explored by Costa et al. (2004) [10], the study showed the 6 post-stroke individuals who participated in the MI-BMI-based program had higher connectivity in motor-related brain areas, thus demonstrating evidence for brain plasticity.

3.2. Cognition rehabilitation

Individuals who suffer from stroke may also experience cognitive impairment. Such deficit is multinational, ranging from attention, information processing, memory, and speech production [3].

However, current treatment plans even including BMI-based interventions require minimum cognitive abilities that allow individuals to understand and respond to rehabilitation according to instructions. Moreover, a certain attentional level is required for the individual to participate in training schemes. Therefore, current rehabilitation programs are not feasible for individuals suffering from severe cognitive impairment. Even though studies focusing on specific BMI-based cognitive training for stroke patients are still limited [3]. However, BMI is shown to be effective in improving cognitive functions in other neurodegenerative disorders. For instance, in improving attention in the individual with attention-related hyperactivity disorder (ADHD) [11], where EEG-based neurofeedback interventions reduced inattentive symptoms in ADHD children [11].

For studies focusing solely on stroke patients, similar neurofeedback-based BMI was implemented. In [11], the experimenter focused on improving the alpha activity which is suggested to be linked with motor and cognitive skills, as result the study showed promising prospect in motor and speech rehabilitation. Moreover, within the limited studies focusing on stroke cognitive rehabilitation, BMI is also found to be useful in treating memory deficits in patients [3]. However, more empirical data are needed to assess the efficiency of these treatment.

In conclusion, BMI-based neurofeedback intervention is suggested to be effective in providing immediate cognitive improvements, however, the transferability and endurance of these observed effects are still unknown due to lack of evidence.

3.2.1 Underlying mechanism

Similar to the neural biases for movement, the neuro-mechanism for cognition also relays on the concept of neuroplasticity, which is induced by neurofeedback training. Specifically, neuroplasticity is the basis for learning which leads to changes in neural properties, and therefore possibly the repair and restoration of damaged brain regions.

3.3. Emotion regulation

As suggested by [12], disability is also accompanied by the development of depressive episodes, where such symptoms can worsen one's cognitive impairments. Importantly, these episodes not only interrupt one's quality of life but can also impact one's rehabilitation progress [12].

The most prominent feature of depression is a lack of motivation [13], where one's intended desire conflicts with their actual action. Because of the closed-loop nature of BMIs, researchers highlighted the opportunity to develop emotion regulatory BMI. Emotion-related BMI focus on regulating brain state rather than external devices.

Consequently, recent research has focused on exploring the relationship between mood and BMI-related mechanisms. For instance, this work has integrated music therapy with BMI, which lead to promising prospect in emotion regulation [14]. These recent studies have all been associated with the stimulation of the amygdala [14]. However, due to the structure of the amygdala, its impact on EEG activity is largely unknown, still, such initial findings provide a ground for the development of future BMI-based emotion regulation programs.

Although, evidence from the field of emotion regulation in stroke patients is still lacking. However, current research based on other fields highlights a promising prospect.

4. Conclusion

The present paper attempted to review the efficacy of BMI-based rehabilitation programs targeting motor, cognitive and emotional domains. BMI-based rehabilitation programs focusing on motor function have shown to be most widely addressed. Showing a significant result in improving the patient's upper limb and lower limb motor control. Similarly, BMI programs focusing on cognitive abilities, for instance, attention and memory also demonstrated promising outcomes. However, studies in the domain of emotion regulation appear to be limited, but still, demonstrate an encouraging prospect for future research. Moreover, as demonstrated by neuroimaging evidence, the underlying mechanisms underlying these significant outcomes are the result of restorative neuroplasticity or the

Hebbian's rule. Such functional recovery is observed across the motor and cognitive domains. While emotion appears to influence such relationships, the specific underlying mechanism is still unknown.

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