Rehabilitation of Chronic Stroke Using Neurofeedback, Functional Electrical Stimulation and Cerebrospinal Direct Current Stimulation

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ABSTRACT

This work presents the application of a rehabilitation protocol using a novel Non-Invasive Brain Stimulation (NIBS) technique, called cerebrospinal Direct Current Stimulation (csDCS), together with the use of a Brain-Computer Interface (BCI) based on Motor Imagery (MI) with Neurofeedback (NFB), and applying Functional Electrical Stimulation (FES) plus the use of a pedal exerciser. This protocol uses the concept of Alternating Treatment Design (ATD), in which a chronic post-stroke subject is submitted to these techniques to recover his left hand and leg movements. The rehabilitation progress was verified through metrics, such as Fugl Meyer Assessment (FMA), Functional Independence Measure (FIM), Ashworth Scale, Muscle Strength Grading (MSG), and surface Electromyography (sEMG). Results from these metrics include a 41% gain in hand function recovery, a 5% gain in performance in motor and cognitive/social domains, and a 50% improvement in both wrist extensor muscle strength and finger extensor muscle strength. There was a 17% gain of Maximum Voluntary Contraction (MVC) for the tibialis anterior muscle of the patient's left leg. There was a worsening in some values of EMG, due to the participant having received application of botulinum toxin in his hand.

STUDY DESIGN

This study is based on the concept of ATD, which is a single-case research design study that typically involves a single subject that acts as both the control and the treatment group, i.e., the subject is considered as his own control in sham phase.

MATERIALS AND METHODS

RPC value is generated, which is translated to the screen as on-line feedback, the success rate in recognizing his MI, thus motivating him

EEG signals were processed using a 1-s window, and Relative Power Changes (RPC) were calculated in μ and β bands, using a Laplacian filter around C3 and C4

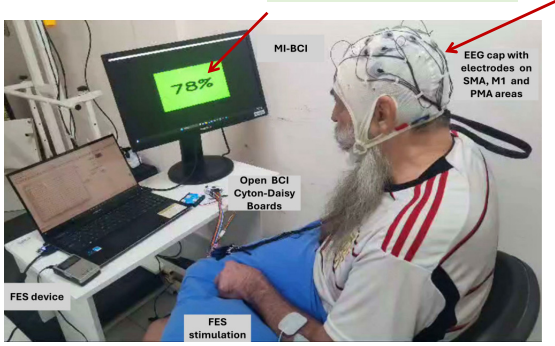


Fig. 1. Neurofeedback provided to the subject, according to his performance in generating MI values.

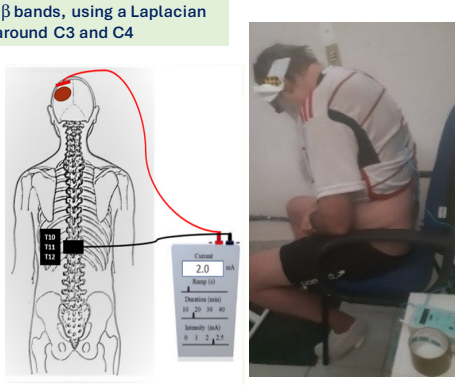


Fig. 2. Application of cerebrospinal Direct Current Stimulation (csDCS).

These EEG channels were selected because the signals recorded from these channels show a tight relationship to activity of the most relevant sensorimotor areas. In our protocol, scalp-electrode impedances are maintained below 20 kΩ, which is suitable to have a good quality of the EEG signals, in addition to accelerating the participant preparation time.

NEUROFEEDBACK (NFB)

NFB was implemented to provide the subject with his success rate related to the MI recognition in both calibration and online stages while he imagined performing limb movements.

Online stage

- Classification model
- Calibration stage (with the subject in rest)
- MI detection using the EEG dataset as input

Second stage

A new split is performed to obtain new training and validation datasets

Dataset: 20% for testing, 80% for training

1-s sliding window (50% overlap) is applied to segment the data for processing

Butterworth zero-phase band-pass filter (7 to 30 Hz) is used to isolate the μ and β bands

Final Stage

FEATURE EXTRACTION	CLASSIFICATION
Riemannian Geometry (RG)	Linear Discriminant Analysis (LDA)

A mean ACC of 0.72 was achieved, while recognizing MI and resting classes

EXPERIMENTS

In this protocol the participant was worn with the EEG cap and instructed to imagine his paretic arm movement. Thus, once the BCI was able to recognize his MI, the NFB calculation was performed. A FES device (Balego EMS Digital Neuromuscular) was used to target the flexor muscles of the fingers and wrist, and the extensor muscles, simultaneously.

After that, the leg protocol started (Fig. 2), in which csDCS was applied for 20 min (five days a week, for two weeks, with current intensity of 2 mA, and fade-in and fade-out periods of 30 s each), using a DC-Stimulator Plus, NeuroConn. In this technique one electrode (anode) is located on the M1 region of the affected hemisphere, and the other electrode (cathode) is located on the spinous process of the thoracic vertebra over T11 (T10-T12) by palpation. During the cerebrospinal stimulation the subject watched a video, and was instructed to imagine himself pedaling, in addition to pedaling a pedal exerciser (Mini Exercise Bike, from Himaly).

RESULTS

Results of this study show a 41% gain of the left-hand function, a 5% gain in performance in motor and cognitive/social domains, and a 50% improvement in both wrist extensor and finger extensor muscle strength. Regarding the lower limb, there was a 17% gain of Maximum Voluntary Contraction (MVC) for the left tibialis anterior muscle.

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