SHORT REPORT

Emotiv EPOC+ fed electrical muscle stimulation system; an inexpensive brain-computer interface for rehabilitation of neuro-muscular disorders

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Abstract

Advancements in the Neuro-rehabilitation across Pakistan is warranted to effectively and efficiently deal with the disease burden of neurological conditions. Being a developing country, an in-expensive treatment approach is required to culminate the rise in the disease occurrence in Pakistan. Brain-Computer Interfaces (BCIs) have come up as a new channel for communication and control, eliminating the need of physical input, opening doors to a wide array of applications in terms of assistive and rehabilitative devices for paralyzed patients and those with neuromuscular disorders. Even with a promising prospect, BCIs and electroencephalograms (EEG) can be very expensive and therefore, they are not practically applicable. For this reason, the purpose of the current study was to come up with a possibility of an inexpensive BCI for rehabilitation of patients with neuro-muscular disorders in Pakistan by using a low-cost and readily available equipment like Emotiv EPOC+ EEG headset and electrical muscle stimulator.

Keywords: Brain computer interface, electrical muscle stimulation, electroencephalography, emotiv EPOC, functional electrical stimulation, neurological rehabilitation.

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Introduction

Neurological disorders are conditions that involve the central or peripheral nervous system including brain, spinal cord, autonomic nervous system, cranial and peripheral nerves, neuromuscular junctions and even muscles. Neurological disorders like stroke, spinal cord injury and multiple sclerosis are not uncommon in Pakistan;[1-3] in fact a study conducted in Karachi, Pakistan reported a prevalence of 4.8% for stroke,[2] which is the highest reported figure in the world.[3] For this reason, advancements in neuro-rehabilitation are necessary to deal with the burden of neurological disorders effectively and efficiently in Pakistan. However, for a developing country, the treatment modalities used must be inexpensive. Thus, the purpose of this study was to devise an inexpensive Brain-Computer Interface (BCI) for rehabilitation of patients with neuro-muscular disorders in Pakistan.

BCI is a computer system operated via input which relies on physical interaction between the user and input devices.[4] This concept is also employed in medical and rehabilitation sciences in the form of Human-Computer Interfaces (HCIs). However, recently, brain-computer interfaces (BCIs) have been deployed as a new channel for communication and control,[5] which are based on electroencephalograms (EEG) by which neuronal activity is recorded and simultaneously fed to the computer system hence, eliminating the need of physical input.[4] This mode of input opens doors to a wide array of applications in terms of assistive and rehabilitative devices for paralyzed patients and those with neuromuscular disorders.[4,6,7]

BCI systems consist of 3 major components, namely the signal acquisition unit (consisting of electrodes and signal processing unit which amplifies the acquired signals and removes the artifacts), the signals analysis unit (responsible for feature extraction) and lastly the action unit (which produces discrete control signals that can be used to control any equipment or application or to give feedback).[7] BCI systems can be either invasive (direct implantation of electrodes in the brain) or non-invasive (capturing signals through surface EEG).[6] Non-invasive BCI systems being harmless and not requiring any surgery, offer promising potential in the areas of neurological rehabilitation.[6]

Even though the applications of BCI are numerous, most of this technology is still limited to research labs because of large and expensive EEG systems and the need of skilled human resources.[4] Despite promising prospects, BCIs and EEG systems can be very expensive and are not practically applicable in Pakistan. Fortunately, with advancements in technology all sorts of equipment and gadgets are

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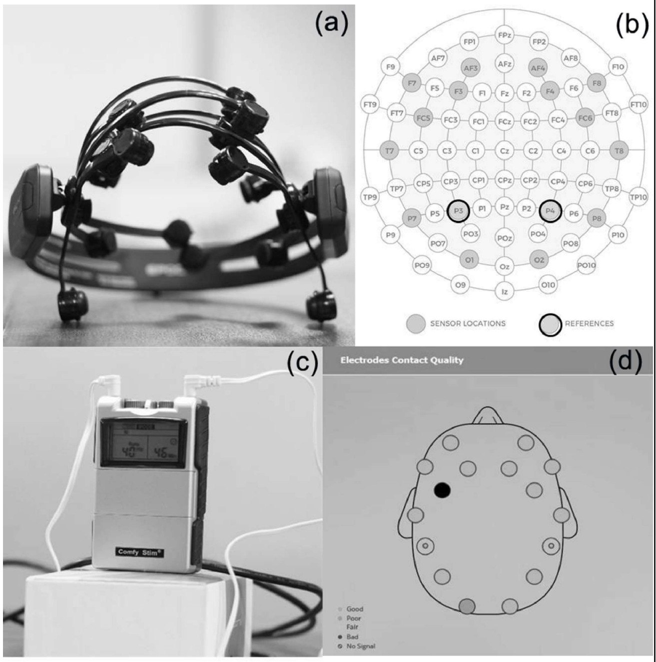

Figure-1: (a)Emotiv EPOC+ headset, (b) Emotiv EPOC+ sensor placement locations according to the international 10-20 system of electrode placement, (c) Electronic Muscle Stimulator (EMS), (d) Emotiv EPOC+ giving feedback regarding the contact quality of electrodes (12).

becoming smaller in size and economical. Recently, some low-cost portable EEG devices have become available such as Emotiv EPOC+, which is a compact wireless EEG headset that was initially aimed for the gaming market. Even though, it is not classified as a medical equipment but numerous researchers have adopted it for a variety of applications including but not limited to bio-feedback, mental imagery, robot control, wheel chairs, neuro-prosthesis and exoskeletons.[4,6-11]

The purpose of this study was to develop an inexpensive brain-computer interface for rehabilitation of patients with neuro-muscular disorders in Pakistan.

Emotiv EPOC+ is a portable EEG headset with 14 sensors set according to the international 10-20 system of electrode placement (Figure-1).[4,12] Moreover, it is cheap as compared to most of the professional/clinical EEG systems, with a price tag of $799 only.[12] Even though EPOC+ is not as good as a professional or clinical EEG system, it does capture actual EEG and the artifacts can be reduced by the use of techniques such as averaging.[13] EEG signals are transferred from bluetooth to a computer which are then decoded by the EmoEngine software which processes the data, consisting of 3 brainwave processing suites namely "Expressiv", "Affectiv" and "Cognitiv".[4,12] "Expressiv" suite is concerned with detection of facial expressions, "Affectiv" suite detects emotions while "Cognitiv" suite recognizes the thoughts directly relating to motor image formation.[4,12] Martinez-Leon J-A[11] states in his study that when using the same number of sensors and sensor positions, EPOC+ offers comparable results to the bench mark for a mental motor imagery of the cognitive processes. However, EPOC+ does not offer any sensor at the C3 and C4 sensor positions (Figure-1) which are located over the motor cortex area, and it is also the location for a finest discrimination of mental motor image signals.[11]

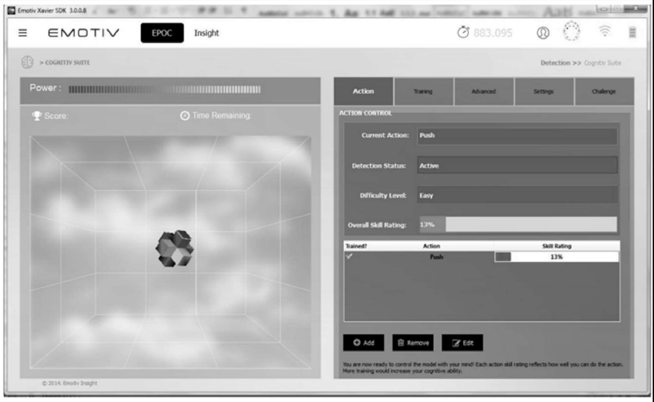

Figure-2: "Cognitiv" suite for Emotiv EPOC+ giving visual feedback via visual cube on the left hand side, and skill rating percentage for action training on the right hand side.

Unlike the other two suites, "Cognitiv" suite (Figure-2) cannot make detections automatically and requires training on specific thoughts.[4] Once trained, the software will process the brain waves and match them to the patterns of the specific thought processes that are under consideration. It is most effective for conscious thoughts concerning mental imagery.[4] For the system to be able to detect thoughts the software must initially sample the EEG in a relatively relaxed state of mind, called the neutral or base state.[14] This system then compares the trained thoughts to the neutral state and then the user can train the system to detect different actions based on the user's thoughts.[4] The cognitive suite offers 13 different possible actions to be trained in terms of movement including 6 directions, 6 rotations and 1 visualization i.e. disappear.

Methods and Results

This study was conducted from August 2016 to January 2017 and, the components used to make a low cost BCI included an Emotiv EPOC+ headset worth $799, Comfy

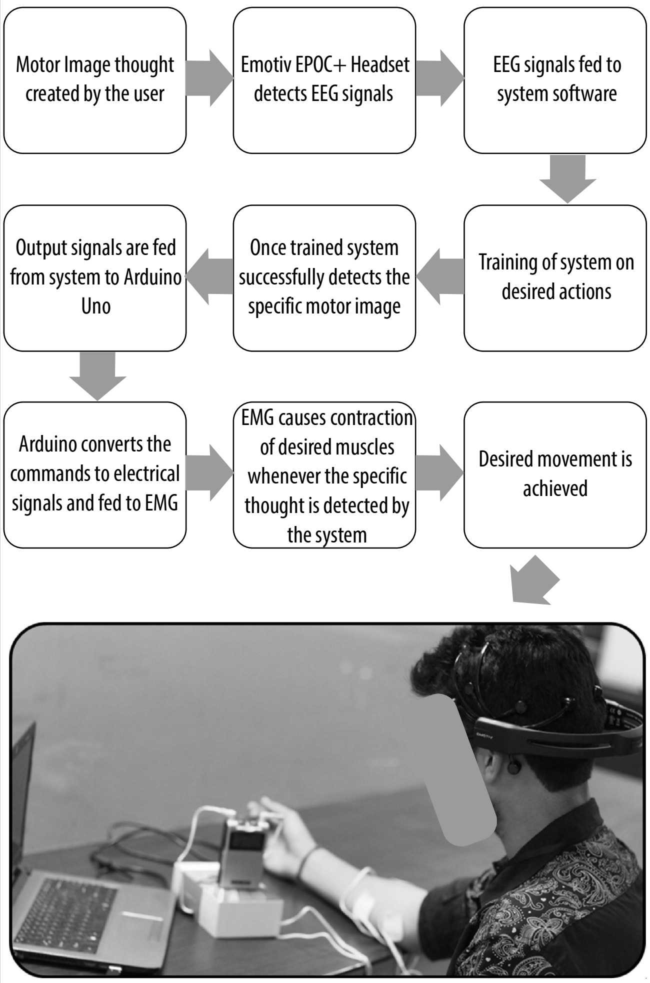

Figure-3: Schematic diagram showing the working of Emotiv EPOC+ fed electrical muscle stimulation system.

Stim TENS/EMS EV-806 worth Rs. 5,000, Arduino Uno R3 worth Rs. 1,000 and a computer. The researchers themselves served as users for the calibration of the equipment. Emotiv EPOC+ was used to collect EEG signals from the user's brain, which were then transferred to a computer via bluetooth. Signals received from the EPOC+ were used to train the software for specific thoughts such as flexion and extension of the wrist. However, the system software for EPOC+ only has 13 preset possible actions. For this reason, during the training of the thoughts, up and down, user was trained to think of flexing and extending the wrist instead of moving the virtual cube up and down. In this way the action titled "Down" was calibrated for "Flexion of the wrist" and the action titled "Up" was calibrated for "Extension of the Wrist" and the brain waveforms were then recorded. The same method can be used to train for any muscle action or movement in a similar manner.

Once the system was trained for actions and a suitable skill rating was achieved every time a waveform similar to that recorded for "Up" or "Down" appeared as a thought in the user's mind, the system detected it successfully. These waveforms were than fed as commands to Arduino which converted them into electrical signals and was later used to control the Electrical Muscle Stimulator (EMS). In this way, EMS did not send signals to either the wrist flexors or the extensors continuously as it occurs in the conventional electrical muscular stimulation. Instead only the wrist flexors were electrically stimulated and made to contract when a motor image of wrist flexion was created in the user's mind and detected by the EEG headset and vice versa (Figure-3). In this way, the user can either flex or extend his/her wrist just by creating a mental motor image in his mind or any other movement for that matter. The EMS electrodes were placed on the ventral aspect of the forearm for wrist flexion and dorsal aspect for the wrist extension. The settings of EMS during training of the muscles via mental imagery depend upon the targeted goals and muscles. A low frequency of <18 MHz activates the slow twitch fibers and can be used for endurance training, whereas, a frequency of 30-50 MHz activates the fast twitch fibers. Thus, a higher frequency can be used for the purpose of strength training.[15] Moreover, a pulse duration will dictate the depth of the penetration of signals so for small muscles the pulse duration should be kept <200µs, whereas, a greater pulse duration is more suited for the activation of bigger muscles.[15] Similarly, the intensity should also be altered depending on the user and the targeted muscle.[15]

This BCI uses the Cognitiv suite of EPOC+ and thus is based on the creation and detection of mental motor image to achieve a desired movement or muscle contraction. Therefore, this equipment can be used for mental imagery in the rehabilitation of paralyzed patients and patients with neurological disorders[16] by training them to create a mental image of the desired action. This can be done either by performing that movement via electrical muscle stimulation or by training a paralyzed patient for a specific movement/task in a virtual biofeedback setting without the contraction of the muscles.

This current system is superior to conventional EMS because it operates on the concept of functional electrical stimulation (FES) which works on the electrical stimulation of a muscle to produce a functionally useful movement and is found to be effective in the management of numerous neuro-muscular disorders.[17] The current system is expected to be even superior to FES as the commands to contract the muscle is generated by the patient/user him/herself in the form of a mental image. It offers a more functional approach to rehabilitation as it involves a person's own thought process to generate a command and carry out a functional movement, creating both mental and muscle memory in the process. For this reason, BCI can be used for training in terms of both paresis and paralysis.

The current system can also be used in terms of 'Virtual reality' training because of the virtual feedback which is becoming increasingly popular in terms of motor, neurological and stroke rehabilitation and also in the balance, cognitive, geriatric training and conditioning.[18-22] The current system can also be employed as a bio-feedback training system as the patient / user can create a mental image and train to improve overall skill rating of any activity. They can also get a virtual feedback from the system software regarding the skill rating of a motor image as well as the visual feedback in the form of contraction of the desired muscle or performance or desired movement via EMS.

Limitations and Recommendations

The current system consists of a wireless input unit for EEG signals as well as a portable EMG unit, both of which can be used as portable devices. However, the computer is connected to Arduino which is then connected to EMS with wires rendering it importable, thus, limiting its practicality. Moreover, the EMS used in this system has a 2 channel output only. This limits the number of muscles stimulated such as when only flexor carpi ulnaris is stimulated it results in flexion with ulnar deviation and when flexor carpi radialis is stimulated it results in wrist flexion with radial deviation so a system with a greater number of output channels will be able to stimulate numerous muscles at once and results in a more functional movement, hence, increasing the efficacy of the BCI.

This BCI is currently a crude concept on which more work needs to be done in terms of determining the minimum skill rating level to carry out a desired muscle contraction and movement. Observational studies need to be carried out to determine the average time required to achieve a specific level of skill rating and differences among healthy individuals and patients in terms of skill rating. Moreover, interventional studies need to be carried out to determine the efficacy of this system in the management of different neurological disorders and also to compare the effects of BCI training with conventional modalities such as EMS, mental imagery and FES.

Conclusion

BCIs have surfaced as a new channel for communication and control eliminating the need of physical input, opening doors to a wide array of applications in terms of assistive and rehabilitative devices, offering a promising potential in the areas of neurological rehabilitation. Unfortunately, BCI systems can be very expensive and are not practically applicable. However, Emotiv EPOC+ fed electrical muscle stimulation system can possibly serve as an inexpensive brain-computer interface for neurological and neuro-muscular rehabilitation.

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