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Perspective Study

Brain-computer interface applications to decrease phantom limb pain

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Abstract

Phantom limb pain is mainly experienced in people who have suffered limb amputation, its study and analysis are relevant to know the causes and help patients to reduce pain. On the other hand, brain-computer interfaces encode brain signals and decode them for communication with a device. Through the motor imagination of the movement of the amputated limb and with the help of a brain-computer interface, an amputee patient can reduce or eliminate pain. The objective of this paper is to give an introduction to brain-computer interfaces as a tool for the reduction of phantom limb pain. Therefore, the applications of interfaces in relation to pain are highlighted, some related studies are discussed, and their benefits and disadvantages are analyzed. Finally, it is established that phantom limb pain research benefits from incorporating brain-computer interfaces as part of non-pharmaceutical therapy because it is a tool that provides feedback on the reconfiguration of the cerebral cortex in relation to pain.

Pain is a sensory experience caused by tissue injury, neurologically initiated by stimulation of nerve endings called nociceptors, this stimulation travels through the brainstem, reaches the thalamus and is distributed mainly to the somatosensory cortex and cingulate cortex [1].

One type of pain is Phantom Limb Pain (PLP), which occurs in 85% of patients who undergo limb amputation and is characterized by a sharp pain sensation in the missing limb [2]. The magnitude of the pain is mainly related to the patient's age, the severity of the injury, and the pain prior to the amputation. However, the cause of PLP is not known with certainty, some studies suggest that this phenomenon originates following the alteration of signals received in the spinal cord and brain caused by changes in the periphery [3].

This is a problem that affects the patient because PLP generates depression and anxiety in people who suffer from it, which impairs their quality of life since it interferes with daily activities including the quality of sleep [4]. There are several treatments to counteract pain which are mainly pharmacological such as analgesics and antidepressants; Rehabilitation such as analgesic electrotherapy, and massages [5]; Neuropsychological such as eye desensitization and reprocessing techniques and the mirror technique [6].

Recently, the development of Brain-Computer Interfaces (BCI) has been focused on as a tool to detect and reduce pain [7]. BCIs are systems that communicate neural activity with an external device. Their applications are developed in the field of neurorehabilitation and control. They work with four main stages, which are the acquisition of brain activity, processing, classification and finally application [8].

In neuropsychological applications to counteract PLP, BCIs have focused on the Motor Imagination (MI) technique. This technique consists of imagining the movement of a limb without executing it, so it is useful in the treatment against PLP for the imagination of the movement of the amputated limb. During this activity, the somatosensory, premotor and primary motor cortexes contralateral to the phantom limb are activated [9].

One of the most widely used acquisition techniques is the

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Electroencephalogram (EEG). The EEG technique consists of recording brain signals through sensors placed on the scalp, according to systems 10 - 20, this technique is noninvasive. For pain detection, it has been shown that electrodes placed in the central and parietal regions provide greater variation in nociceptive stimuli [2].

For the development of BCIs, EEG signals are acquired during the performance of MI tasks, which mainly consist of imagining the movement of the amputated limb for a period of time. From which enough trials are acquired to create databases. These signals are filtered and processed to remove artifacts and acquire their main features. They are then classified for two main purposes. The first one is PLP detection as the study by Lendaro, et al. [9] uses the Common Spatial Pattern (CSP) algorithm to extract the main features of the signal, subsequently, classify it with different machine learning algorithms [9]. The second one is the decrease in pain as in the case of Limakatso, et al. [4] who analyzes the decrease in pain using MI in people with PLP [4].

On the other hand, the literature focuses on creating applications for the control of physical prostheses or using virtual reality. These studies are aimed at creating new neural connections that help to reduce pain, to know the intensity of pain and the brain regions involved in its generation [10].

Some studies show that BCIs are efficient in pain reduction since they show feedback concerning pain. Such is the case of Yanagisawa, et al. [11], who demonstrated that pain is directly proportional to the patient's ability to control the virtual movement of the missing limb [11].

Research conducted with BCIs applied to the reduction of phantom limb pain has provided relevant information. However, the area of knowledge is still under development, so it is important to deepen the research, since, unlike conventional techniques such as pharmacology, rehabilitation, and conventional neuropsychology, BCIs have the ability to give feedback about the perceptual, cognitive and physiological state of the patient during training, while influencing the reduction of pain.

BCIs to reduce PLP do not require moving the intact limb to receive feedback, in contrast to mirror therapy, which enhances cortical neuroplasticity of the pain-related area of the brain, so better results can be achieved. For example, in [7], disengagement of the phantom limb through linkage with the robotic arm was demonstrated. However, within nonpharmacological techniques, the cost of a BCI tends to be high relative to techniques such as mirror therapy.

In order to achieve greater reliability of BCI for PLP, it is necessary to conduct research with a large population size, since the related studies have experimented with between seven and eleven patients, which is too few to validate the effectiveness of the method. In addition, long-term research is required, for example, the study [12], shows a three-day training with analgesic durability of one month, so it is necessary to increase the training time and follow-up patients to increase the long-term effects.

In addition, within the implementation of BCI for the decrease of PLP are the ethical aspects, although a BCI would help to enhance the patient's quality of life through the decrease of pain, it is also important to safeguard the patient's brain activity, so it is necessary to protect the privacy of the patient's data [13].

Conclusion

BCIs are a promising method for the reduction of phantom limb pain, due to the fact that they are still in the development phase more research needs to be done with patients suffering from it comparing the advantages and disadvantages with respect to other methods such as pharmaceuticals. In addition, future research is required to prove its effectiveness when combined with other treatments, as well as to test it with a larger population, which would help its future democratization.

Therefore, due to the results shown in the literature, it is considered that BCIs are very useful for the reduction of pain, since the patient receives feedback that helps to reconfigure the cerebral cortex, replacing the amputated limb with a virtual or robotic one.

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