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Preliminary Results of a Methodology for Measuring Pain Threshold Associated with Low Competitiveness in Industry

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Abstract. This research shows the preliminary results of tests based on a proposed methodology consisting in the acquisition of electroencephalographic signals (EEG), by means of electrotherapy techniques as stimuli of changes in the brain activity of test subjects in steady state. The purpose of the tests is to identify the changes that occur in the brain activity through the application of electrical (painful) stimuli and verify that the brain activity presents a change under the stimuli. The paper presents the methodological proposal for the application of the tests as well as the results obtained from their application. Then, results are applied in the evaluation of the perception of physical pain influenced by work-related fatigue, driving the brain activity through a brain computer interface. This proposal is intended to subsequently generate a tool for the measurement of the pain threshold in order to study the work-related fatigue in the industry.

Keywords: Brain activity, pain threshold, BCI, work-related fatigue, smart manufacturing.

1 Introduction

Mental fatigue is a psychobiological state caused by prolonged periods of demanding cognitive activity [1]. Although fatigue represents a major risk factor for the workers, few organizations or governments currently manage work-related fatigue in a systematic or quantitative way [2].

Work-related fatigue occurs basically in people who have an excess of physical or intellectual work, where a great mental effort or physical activities are required that involve repetitively: handle or move objects, understanding, reasoning, resolution of problems, among others.

When fatigue appears at work, there is a significant decrease in the attention levels, slowing thinking processes that, in turn, decreases the level of response to problems, generating a significant decrease in motivation towards work. As a result of work fatigue, there is a decrease in professional performance, the activity level is reduced, increasing the execution errors of the tasks, which in turn, increase and change the perception of physical pain [3].

This is a problem highly associated with smart manufacturing, becoming visible through physical pain, it cannot be associated with a specific disease or cause and it is difficult to measure or generate any indicator. Pain is an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage. This experience is considered a chronic problem when it persists or occurs repeatedly over a period of three to six months [4] and it is a severe and disabling condition (often associated with physical and psychological comorbidities) that negatively impacts the quality of life in about one fifth of the adult population in the western world [5]. It has been found that chronic pain is significantly related to the functioning and structural reorganization of the nervous system [6] as well as resulting from the activation of multiple areas of the brain, which is described as a pain matrix [7].

This situation creates a recurring problem in the industry due to absenteeism, bad performance, impaired quality of services and products, and the dropout of personnel [8]. Also is difficult the objective determination of who should go to the medical service after experiencing pain as well as the classification if that pain is light or deep. Studies have shown that mental fatigue due to a high level of stimulation causes an increase in pain ratings, while the mental fatigue due to low stimulation level causes a decrease in pain ratings [3].

Considering the relationship between brain activity and pain, various pain study techniques have been developed using electroencephalography. Most of the cases that handle these techniques have used specialized laboratory equipment [9]–[11] studies are expensive, inaccessible and with specialized knowledge requirements for the use of the equipment. Talking about cost, EEG hardware has a high monetary cost, between US $1,000 and US $25,000 [12]. Regarding studies related to fatigue, researchers have made efforts by using electroencephalogram (EEG) and event-related potential (ERP) measures, to examine the physiological changes related to fatigue and attention [13].

With the development of new technologies in the field of brain computer interfaces (ICC or BCI), a field has opened to exploration in the area of brain activity measurement. The technological advances in recent years have allowed the implementation of new mechanisms for the design of adaptive user-interfaces, which seek to cover a greater degree of satisfaction of users when interacting with them [14]. A brain computer interface provides a communication channel that interconnects with the brain through an external device. In particular for BCI's based on electroencephalograms (EEG), the electrical potentials recorded from electrodes placed on the scalp provide a direct measure of the brain activity [15].

Considering the techniques used for pain analysis based on brain activity and the technology available in BCI's of scientific context, a methodological proposal was developed for the acquisition of EEG signals in test subjects while they are in a steady state, while simultaneously receive a series of stimuli based on electro stimulation [16] for generating muscle pain in the subject.

The purpose of these tests is to evaluate whether electro stimulation can be used as a painful stimulus for the study of the perception of pain due to work-related fatigue and to analyze the results that can be obtained using the equipment for the acquisition of EEG signals. Once this is analyzed, it is proposed to subsequently develop a protocol to visualize the changes presented in the brain activity and to identify the behavior of the signals to be applied in the development of pain indicators, as a measurement of work-related fatigue.

2 Materials and Methods

2.1 Computer Brain Interface (BCI)

It is proposed to acquire the EEG signals using the Emotiv EPOC+ device. This is a neuroelectric detection system that captures and amplifies brain waves generated by different mental "actions." This device can obtain 14-channel signals: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4, based on the international 10-20 system, which It is an approved method to describe the location of the electrodes on the scalp, for the registration of EGG. This device also handles a filter for frequencies from 0.2 to 45 Hz, which can take up to 128 samples per second on each channel [17].

2.2 Software

Among the tools that Emotiv provides with the BCI EPOC +, is the Emotiv Xavier software development kit (SDK). This is composed of the Emotiv Xavier control panel, version 3.3.2 and the Bench Emotiv Xavier Test, version 3.1.20. The control panel allows the user to visualize the communication status between the BCI and the computer, as well as the connection status of each of the 14 signal acquisition channels. The Bench Test is the platform on which the acquired signals can be displayed in real time and where the person in charge of obtaining the signals can establish the acquisition parameters (Figure 3). The software provided by Emotiv will be used to know the connection status of the device and to perform a visual analysis of the behavior of the signals.

2.3 Electro Stimulator

Electrotherapy is a discipline within physiotherapy that consists of different ways of applying electromagnetic energy to the body, in order to produce biological and physiological reactions. An electro stimulator is a current generator, which produces electrical impulses with enough energy to generate an action potential (PA) in excitable cells: muscular or nervous (sensitive with analgesic and efferent results with motor results), and thus modify their most frequent state, which is rest [18].

The device to be used in the application of these tests is the Twin Stim Plus 3rd Edition equipment. This system is capable of generating 4 types of electro stimulation but for the purpose of this test and considering the recommendation of an expert, the study only considers the ones that are described in Table 1.

Table 1. Types of electro stimulation applied.

Acronym	Meaning	Description
TENS	Transcutaneous Electrical Nerve Stimulation	Tiny electrical impulses sent through the skin to nerves to modify your pain perception [16].
EMS	Electrical Muscle Stimulation	Impulses through the skin that stimulate the nerves in a treatment area. When the muscle receives this signal it contracts as if the brain has sent the signal itself [16].
Russian	Russian	Medium frequencies to provide electrical stimulation to muscles groups and is used to reduce muscle spasms as well as for muscle strengthening [16].

3 Methodology

The proposed methodology for the implementation of preliminary tests consists of the following steps:

1. Survey application to verify that the test subject complies with the requirements where the following conditions are basically excluded:
   a. People with pacemakers.
   b. People with tumors and metastases.
   c. People with thrombosis, thrombophlebitis and varicose veins.
   d. Diabetic and epileptic people.
   e. People with sensitivity disorders.
   f. People with bleeding processes.
   g. People in febrile and / or infectious states.
   h. Pregnant women.
   i. Hypersensitive or very nervous people.
   j. Children under 10 years.
2. Explanation of the process to the test subject and request with signed consent:
   a. It will be explained verbally, and the format will be provided with instructions and consent to be signed.
3. Electrode placement for forearm electrotherapy.
4. BCI set-up:
   a. Moisten electrodes.
   b. Installation of electrodes.
   c. Place BCI in test subject.

   d. Verification of connection status on all channels.
   e. Time taken in which the 14 channels show a good signal.

5. Placing plugs for noise in order to prevent noise from interfering with the results.
6. Relaxation process:

   a. Relaxation request through visual instructions.
   b. Time taken when the signals of the 14 channels are stable.

7. Encouragement application:

   a. The stimulus will initially be applied at level 1 managed by the Twin Stim Plus system.
   b. The stimulus level will be elevated in intervals of 5 in 5 based on level.
   c. The stimulus will be applied to the level in the test subject exterminates discomfort.

8. Measuring scales:

   a. The verbal rating scale will be used for the subject to express the level of pain after feeling.
   b. A record of the activity of the test subject will be made during:
      - Rest
      - Stimulus application.

9. Close the test:

   a. The BCI of the test subject will be removed.
   b. Electrodes will be detached from the forearm of the test subject.

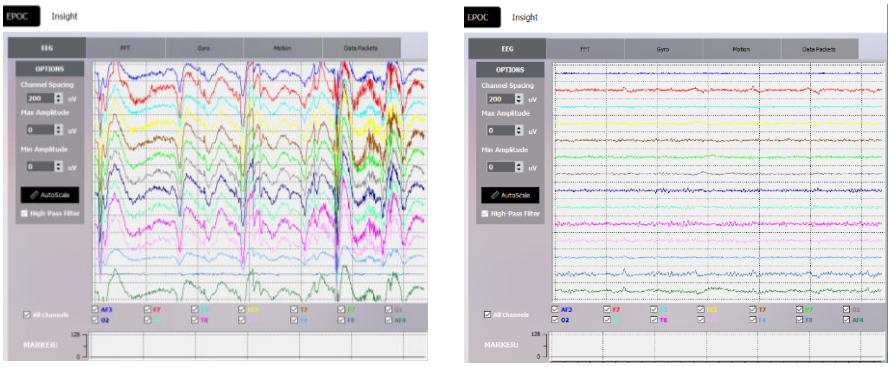
The test was applied to a sample of the population of 5 healthy subjects (3 women and 2 men) to whom the procedure was explained in detail and their consent was requested to carry out the tests. All subjects agreed to participate and signed the consent letter. To evaluate this proposal, preliminary tests were carried out considering the instruments and equipment mentioned above and strictly following the proposed protocol.

4 Results

Table 1 presents the information obtained. It shows the connection time, the time the system Emotiv EPOC+ takes to establish a good quality connection. The Relax time represents the time that the subject takes to relax, and this can see through the behavior of signals (Figure 3). Type of electro stimulation applied, EMS, TENS and Russian.

Table 2. Preliminary study results.

Subject of study	Connection time (min)	Relax time (min)	Type of electro stimulation applied (painful stimulus)	Electro stimulation that generates pain	Max Pain level
1	11:47	**8:33**	TENS/EMS/ Russian	EMS	1
2	3:24	3:00	TENS/EMS Russian	EMS	1/2/2
3	**22:19**	3:00	TENS/EMS Russian	EMS	2/2/2
4	10:39	4:15	TENS	NA	NA
5	4:10	3:15	TENS/EMS Russian	EMS	1/2/1



a) b)

Fig. 1. EEG signals obtained through Emotiv EPOC+. (a) Subject in normal state. (b) Subject after relax process.

Electro stimulation that generates pain, in this case, it is asked to the subject which of the three kind of stimuli applied they felt painful. Max Pain Level is the level that the subject said based on the verbal rating where 0 is for no pain, 1 for mild pain, 2 for moderate pain and 3 for intense pain.

The EEG response is different in every moment of the study. The Figure 1a shows the signal when the subject is not relaxed and the Figure 1b, shows the EEG signals when the subject is relaxed.

After the application of stimuli, the signals have different behaviors, but one relevant change was in one study subject in the channel AF4 (Figure 2). Is important to

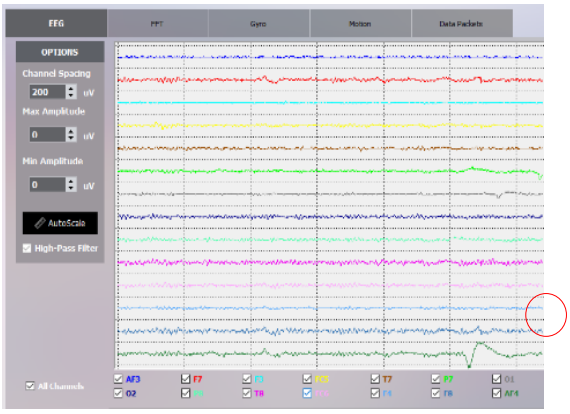


Fig. 2. EEG signals obtained through Emotiv EPOC+ with change in the channel AF4 after the application of EMS stimuli.

take into consideration, this change can be attributed to electromyography because is presented in the frontal area, so that can be the representation of the eyes blinking, but the subject was blinking along the study and this change is clear (graphically) when the level of the electrotherapy goes up. To identify these changes, a detailed analysis is made using technics of signal processing.

5 Discussion

The results of this methodological proposal are the questionnaires used for the application of tests, as well as the methodology established in order to standardize the tests in the study subjects. Although the preliminary test was applied to healthy volunteers, the generality of the proposal can be tested under diverse volunteers. The maximum level of pain obtained was 2 (moderate pain), and all the subject said that the only electro stimulation that is felted as a painful stimulus was the EMS.

About test times, the longest connection time was 22:19 minutes and the least 3:24 minutes, in this case it is important to note that the shortest time occurred in a man with little hair and the longest in a major with abundant hair.

The study subject that got the longest time to relax took 8:33 minutes and two study subjects relaxed in at least 3:00 minutes. It is proposed to repeat the study in a group of subjects with mental fatigue to visualize the possible changes in the results and integrate a test to determine the fatigue level in order to establish a correlation between fatigue level, pain level and EEG behavior.

It is also important to establish that this study proposes the use of a scientific context, BCI which offers advantages such as portability, easy placement and low cost, but sacrifices information in the bandwidth due to the fact that it manages a bandwidth of 0.5 at 50 Hz and it has been reported in pain studies that the frequencies associated with physical pain range between 30 and 100 Hz [19], so that incomplete information could be obtained when using this equipment.

6 Conclusions and Future Research

This preliminary test showed that the application of electro stimulation is considered a painful stimulus but in a range of low pain level, for this reason it could be consider another type of stimulus. For this, we proposed to continue with this work with additional conditions as, considering a population sample with work-related fatigue condition, application of a questionnaire to evaluate the level of fatigue, acquisition of EEG signals under conditions of stress. This work could contribute to determinate the relation between fatigue and pain perception and establish a pain threshold to determinate effective actions in the industrial environment.

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