# EEG-based Nociceptive Pain Detection Using Machine Learning

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**Objetive**

Use electroencephalography to record the brain response originated by nociceptive pain caused by a thermal stimulus. Then, machine learning techniques are applied to find a relationship between 3 proposed conditions (no-pain, stimulus begin and pain).

**Material & Methods**

The current study finds a significant relation among 3 conditions related to nociception caused by a controlled non-traumatic thermal stimulus in healthy participants. This study was held in the Instituto Tecnológico de Estudios Superiores de Monterrey. Before each experiment an informed consent letter was given to the participants and all the protocol was explained clearly.

The experiment has been carried out with the support of 10 healthy subjects (3 females and 7 males with an average age of 23) who were exposed to a controlled and non-invasive pain stimulus. This stimulus is similar as the Cold Pressure Test (CPT) used by many researchers but instead of using cold water as a stimulant, an ice block was applied. This change was done because the lack of pain response using the normal CPT with the participants due that water can vary its temperature over time when the hand is in it, the use of a block of ice allows to have a better control of its temperature, that must be below 0°C and nociception occurs when the temperature is below 4°C. The subjects were asked to sit in front of a screen which showed the instructions for the experiments.

There were 3 visual instructions:

- **+:** This cross is used to advise the participant to focus on it and try to relax before the experiment begins. This task lasts 10 seconds and is performed to obtain the prestimulus response of the brain.
- **On-Ice:** The hand is placed on the ice block and is retired whenever the subject wants. This instruction lasts 60 seconds for men and 2 minutes for women.
- **Rest:** This is the last instruction. Here the participant rests for 10 seconds and then the experiment ends.

Each subject repeats this procedure 5 times per hand. Between trials there is a resting time of 5 minutes depending on the subject response to low temperatures. In this resting time, a verbal questionnaire is applied to each subject to know if they are feeling a pain. If subjects are not responding to pain, as is the case for most women, the signals are discarded. This experiment has the intention to cause a response to pain with gradual behavior, which allows to take different segments of the EEG signal from the moment the experiment begins until the hand is removed from the ice to have enough information and be able to discriminate between the 3 proposed conditions (prestimulus, beginning of stimulus, end of stimulus). To have a controlled time of the events, a camera is recording all the experiment and a UNIX timestamp is running on the video to synchronize all the events.

**Data Collection**: For data collection, a high-performance neuroscience research system was used, the g.USBamp by g.Tec. This device supports 16 simultaneously sampled bio-signal channels at a sampling rate of 256 Hz and a notch filter of 60 Hz is used to avoid electrical artifacts.

**Pre-processing** is applied to the raw data to clean it and to prepare the data for the feature extraction step. In this step a Butterworth bandpass filter from 2 to 60 Hz is applied. This frequency range is defined in order to have the information of all the frequency bands of interest. The frequency bands of interest are Delta (2-4 Hz), Theta (4.1-8 Hz), Alpha (8.1-12 Hz), Beta (12.5,31) and Gamma (31.1 - 60 Hz). After filtering the data, the signal still contains noise that usually comes from ocular or muscular movements. Unlike an article published by our laboratory previously, in this case we used Independent Component Analysis (ICA) as an additional method for data cleaning to each one of the trials.

After this, the data is now prepared to be splited into 3 conditions. These are the first 5 seconds of pre-stimulus as condition 0 (when the cross is on the screen) the first 3 seconds that the hand is placed on the ice as condition 1 and the last 3 seconds before removing the hand due to intolerance to the pain generated as condition 2.

Even when the raw data was filtered and ICA was applied, some artifacts are still present. To solve this problem and at the same time have more information for classification, every condition of the 3 mentioned before is divided into 0.5 seconds windows and every window will be analyzed to know if that section of the signal is an artifact or not

**Future Extraction**: The power band summarizes the contribution or appearance of a specific frequency band in the overall frequency band. This is done by calculating the power spectral density, a specific number which is useful for machine learning applications where one wishes to extract key features that summarize a particular aspect of the data. A band-pass filter is used on the signal to obtain a frequency band of interest, then the resulting filtered signal is squared to obtain an estimate of the power spectral density (PSD) of the signal and finally the signal is averaged over time, in windows of 0.5 second or 10 second windows depending on the study of interest. For this work, the power for each of the 5 frequency bands is calculated for every window. Delta (2-4 Hz), Theta (4.1-8 Hz), Alpha (8.1-12 Hz), Beta (12.5-31) and Gamma (31.1 - 60 Hz) having a matrix of 80 components, 5 band powers per channel by a certain number of trials.

**Classification:** At the end of the data processing stage, the features extracted are organized in a matrix of 80 characteristics (5 features for each one of the 16 channels) by a certain number of observations (trials) depending on how many were removed in the bad trial removing step. So, the last database has 80 columns of characteristics and 1 column of tags numbered by the type of condition (0,1,2) by a certain number of rows which are composed by all the good trials of the hand repetitions (left, right or together). These structures are recorded for each subject. To achieve a discrimination between the 3 conditions, a Narrow Neural Network and a SVM was used.

**Results & Discussion**

The experiments provided a first approach to pain detection with EEG and the use of machine learning to classify among 3 different response conditions, pain, and non-pain states. In the case of subject 3, the classification accuracy was the highest obtained with an 80% using both hands and an 84% with the left hand, while Subject 9 had the lowest percentage with less than 60% in all the hands. This may be due to the exposure time and the quality of the recording. Also, for subject 9 and 10, the channel 1 had to be removed as it was noisy due to poor connection. This also affects the amount of information to sort. For all participants, having an accuracy percentage higher than 70% is satisfactory as a first experiment and motivates us to continue with this research. Most of the works focused on EEG and pain is limited to identifying or classifying between pain and non-pain. In a future work, the intention is to go beyond this and to be able to analyze the signal in depth. Also, the use of power bands as a feature for classification, make this work distinctive in comparison to prior work. To conclude, this project is an experiment prior to a larger research work in which we want to find features in the brain signals when subjecting participants to this type of gradual (tonic) pain in amputees. The goal in this type of research is to create a Brain-Computer Interface capable of detecting pain in real time, which is where this whole field of research is heading. The results obtained so far are a reference of where we are and what we can improve for future work. Still, as a first experiment it is motivating to find differences between the 3 proposed conditions.