# Auditory Emotions Evoked Potentials

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## 1. ABSTRACT

This project was developed throughout the course Signal Processing in Bioengineering 2020. The aim was to characterize the Auditory Emotions Evoked Responses by analyzing the possible changes in the brain electroencephalography to neutral and emotive content brief stimuli. For this, Matlab and EDFbrowser were used to analyze and process EEG from five different subjects. These subjects were exposed to a set of neutral and non-neutral auditory stimuli. The EEGs were firstly pre-processed using the ICA method, to remove eye blink artifacts, and the notch filter, to remove noise of 50 Hz. A temporal analysis, by averaging the post-stimuli signal, was performed to try to obtain a stereotyped response. Furthermore, a spectral analysis using HHT, STFT and FFT was conducted to find patterns in the response to emotive content auditory stimuli. The main results obtained were that there is a different response to neutral and non-neutral auditory stimuli, that a greater difference is found in the absolute power of delta, theta and alpha waves between the before and after stimuli, and that the frontal area of the brain was more activated after stimuli. The data available was, however, insufficient to characterize the Auditory Emotions Evoked Responses and extrapolate major conclusions.

## 2. PROBLEM AND MOTIVATION

The development of this project aimed to characterize the Auditory Emotions Evoked Responses (AEER) by analyzing the possible changes in the brain electroencephalography to neutral and emotive content brief stimuli.

Although there are a lot of experiments and studies made characterizing auditory evoked response potentials, both normal and related to auditory and neuropsychological (associated with language or reading) disorders, there is still a huge lack of information related to the characterization of AEER.

Nevertheless, it is unquestionable that AEER field is very interesting and promising, as it could have a lot of clinical and non-clinical applications. In fact, AEER analysis could lead to evaluation of emotional sensitivity, impulsivity and other social related problems. [1]

Therefore, we feel like more projects like this one should be conducted, employing both pre-processing and processing tools as ways of quantitatively and qualitatively analyze several responses to auditory emotive stimuli.

## 3. BACKGROUND AND RELATED WORK

Late Auditory Evoked Potential (LAEPs) usually occur between 50 and 600 ms after sound onset and are associated with psychological factors such as attention and expectation. Long-latency ERPs are comprised of a series of positive and negative peaks that constitute P1-N2-P2 complex, mismatch negativity (MMN) and P300 response. [2]

The P1-N2-P2 (50, 100 and 250 ms after the stimuli onset, respectively) complex is sensitive to stimulus frequency, location, duration and intensity, being N1 the most reliable. It is related with perception of the auditive stimuli. It is bigger in frontocentral electrodes responses. [2]

The mismatch negativity (MMN) constitutes a measure of sensory memory and discrimination performance – it happens when the stimulus deviates from previous stimuli and does not correspond to the expected one. The MMN is done by computing the difference wave between the LAEP elicited by the standard and the deviant sounds and it is usually detected 150-250 ms after stimulus onset. Its amplitude positively correlates with the magnitude of the acoustic change and is bigger in the frontocentral electrodes. It is thought that MMN generation is dependent on both sensory memory (i.e., immediate past) and sensitive to long-term representations. However, although a contribution of the hippocampus (that plays important role in the consolidation of information from short-term memory to long-term memory) to change detection has been proposed in animals, hippocampal damage did not affect discrimination performance and MMN elicitation in humans. [2]

P300 is a positive deflection with a latency of roughly 250 to 500 ms at the midline parietal site that is most commonly found during oddball experiments in which a participant is asked to identify a specific stimulus in a sequence of standard stimuli. The P300 is elicited in the process of discrimination and decision making and depends on the subject's ability to respond to the predefined target stimuli. The number of trials needed to obtain a reliable P300 range from 10 to 100. The P300 has contributions from various brain regions, however, the signal is typically measured most strongly by the electrodes covering the parietal lobe. [2]

Although there are a lot of experiments and studies made characterizing auditory evoked response potentials, both normal and related to auditory and neuropsychological (associated with language or reading) disorders, there is still a huge lack of information related to the characterization of the auditory AEER.

About the expected spectral behaviour after an auditory stimulus related to an emotion, there are different ideas in literature. One study, that analysed the power spectral performance of EEGs during an emotional auditory experiment found significant differences post-stimulus on the high alpha band in the prefrontal, central, temporal and parietal regions, beta band in all cerebral areas except prefrontal region and finally gamma band in frontal, central, parietal and occipital regions. [3]

It was also found that attractiveness and averseness to an event is associated with transient frontal alpha asymmetry - alpha power differences between the left and right frontal hemispheres. [4] The processing of unpleasant sounds is associated with higher power in the alpha band in the right frontal hemispheric regions, whereas pleasant sounds are associated with higher power in the same band in the left frontal hemispheric regions. [5], [6]

However, another study only found an overall effect of the emotional stimulus on the power spectrum and no interhemispheric frontal differences in spectral power.[4]

Finally, a study conducted to analyze the spectral dynamic of auditory information processing found that event-related synchronization (amplitude enhancement) effects were greatest in frequency bands delta, theta and to a lesser extent, alpha at the frontal and frontocentral and temporal regions. [7][8]

All the different conclusions found reinforce the idea already mentioned about how undiscovered Auditory Emotions Evoked Responses' field still is.

# 4. APPROACH AND UNIQUENESS

## 4.1 Material

MATLAB, version 2020a, was used as programming software for the processing of the signals together with the EDFBROWSER that was used to visualize the entire EEG data through channels for each subject.

Six EEG, of six different subjects, in EDF files were provided for this project. One of the files was not used because EEG was not complete. All these EEG were acquired while a trial of audios was performed. For all the subjects the trial of audios used had the same pattern. In general, the trial of audios for each set was composed by three series of neutral stimuli with twelve stimuli each and three series of non-neutral stimuli with six stimuli each. The non-neutral stimuli used included the sound of thunder, a phone ringing, a baby crying, a laugh, a sunny day and rain. The neutral stimuli were sounds of a beep with duration of 1 second in average.

## 4.2 Methods

Different pre-processing methods, DWT, EMD and ICA, were performed to a sample of signal in order to choose the most suitable one to remove artifacts from the given EEG files. After the appropriate pre-processing method was found, the signals were segmented in relevant portions and analyzed using the HHT, STFT and FFT methods. A correlation analysis was also performed. A statistical analysis using ANOVA was conducted beforehand, to ensure the validity of the results.

## 4.3 Proposed solution

To get the evoked potential for the auditory stimuli, three procedures were performed in order to obtain the responses for neutral and non-neutral stimuli for each subject and the evoked potentials for all the subjects for each non-neutral stimulus. The results were obtained by averaging the 2 seconds of post-stimulus signals. The goal of this approach was to find patterns that allowed us to characterize the response to neutral and non-neutral stimuli and find differences between the responses to the different non-neutral stimuli.

To analyze the frequency response, STFT, FFT, HHT methods were applied to 2 seconds pre and post-onset of the stimuli segments in order to find similarities and differences in the frequency domain caused by the auditory stimuli. In some cases, the results were plotted, and figures analyzed whereas in others the relative and absolute power of each brain wave were calculated, means and relative differences were computed, and a correlation analysis was performed.

All of these analyses were conducted for the signal pre-processed using ICA, for the removal of eye blinks, and a notch filter for the removal of noise of 50 Hz.

# 5. RESULTS AND CONTRIBUTIONS

Regarding the temporal response, various evoked potentials were obtained. In general, different individuals presented different responses in terms of delay and amplitude. For neutral stimuli, in general, a positive deflection between 100ms and 300ms was found in most subjects, visible in most channels, but sometimes stronger in the central ones. A negative deflection between 1150ms and 1350ms was also found in most subjects. For non-neutral stimuli, there seemed to be a pattern of a positive deflection around 800 ms. When the mean was applied along all the subjects for each stimulus, it was possible to visualize a peak, in general, present for all the non-neutral stimuli in the fronto-central channels between 400ms to 800ms. A pattern between attractive and aversive stimuli was not found. An example of an evoked potential obtained is presented in figure 1.

*Figure 1 - Evoked Potential for Non-Neutral Stimuli. Each plot depicts the mean of the responses acquired by each EEG channel. The horizontal axis represents time (2 seconds after the onset of the stimuli) and the vertical axis represents the amplitude of the signal*

Regarding the spectral analysis, from the HHT analysis, it was possible to observe that for some of the stimuli, the response comes later and is more intense for the first sequence of stimuli than for the following two.

For the STFT analysis, difference spectrograms (spectrogram of the post-stimulus portion minus spectrogram of the pre-stimulus portion, all divided by spectrogram of the pre-stimulus portion) were analyzed and no pattern was found along subjects or stimuli.

With FFT, different analysis were conducted. Regarding the evolution in time after the onset of the stimulus of the absolute power of different brain waves, the results were not conclusive. By comparing the absolute powers of each brain waves one second before and after the onset of the stimuli, greater differences were found for the delta, theta and alpha waves.

Finally, by calculating the correlation coefficients between the before and after stimulus spectrum, it was concluded that there was a different response between neutral and non-neutral stimuli and that there was a bigger response to non-neutral stimuli in the frontal cortex. No significant differences between different non-neutral stimuli were found with the correlation analysis.

## 6. DISCUSSIONS AND CONCLUSIONS

In the temporal analysis, it was possible to visualize the evoked potentials caused by the auditory stimuli. For the mean of the neutral and non-neutral stimuli, every subject presented different responses in terms of delay and amplitude of the evoked potential. However, some common peaks were found in the same time intervals in different subjects. Additionally, with the mean of the evoked potential for all the subjects for one stimulus it was possible to observe a common peak for the frontal-central channel. A pattern between attractive and aversive stimuli was not found. This temporal analysis presents, however, several limitations such as the limited number of subjects and trials per subject that do not allow the acquisition of a completely stereotyped response.

The spectral analysis, especially as regards to HHT, STFT and evolution of FFT along time, was not conclusive because it was not possible to find any pattern between series of stimuli and between different subjects' performance. By comparing the FFT of the before and after the onset of the stimuli, a greater difference was found in the absolute power of delta, theta and alpha waves. Through a correlation method, it was possible to conclude that there is a different response to neutral and non-neutral auditory stimuli and that the frontal area of the brain was identified as the most activated in this trial, which was according to what was expected.

To overcome the inconsistency in the results, it would be good to obtain more information about the hearing condition of the subjects and the conditions in which this experience was performed. Furthermore, to find an association between an auditory stimulus and the emotion that it provokes on the subject by analyzing the change in the brain waves or the evoked potential, it could be an improvement to get information by asking questions to the individuals about what they felt when they listened the auditory stimulus.

Moreover, to reach solid conclusions, it would be necessary to increase the number of subjects that performed the experience, as only 5 individuals and 3 series of non-neutral stimuli per subject do not allow the extrapolation of general conclusions.

To sum up, as regards to the task of characterizing the Auditory Emotions Evoked Responses, several challenges were faced. On the one hand, as mentioned before, the data provided had limited information to reach conclusions and on the other hand, there is very little information, studies and experiments in this field.

Nevertheless, it is unquestionable that the Auditory Emotions Evoked Responses field is very interesting and promising, as it could have a lot of clinical and non-clinical applications. That being said, we feel like more studies like this one should be conducted.

## 7. REFERENCES


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