EEG-based biomarkers and emotional response to the Ultimatum Game

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Abstract

This paper presents a basic neuro-experiment to explore the possibility of the application of EEG-based biomarkers to analyze emotional response to the ultimatum game. Using a basic EEG registration tool (Emotiv EPOC technology), the paper presents two EEG-based biomarkers (F8-EP and ALPHA8-AP) obtained from an evoked potential and accumulated power approaches, which seem to be related with the responder's emotions when facing an unfair offer in the Ultimatum Game.

1. Introduction

This paper explores the possibility to define neuro-based biomarkers that could be associated to emotional states related to unfairness. For this purpose, we employed the ultimatum game introduced by Güth, Schmittberger and Schwarze (1982) and apply basic EEG technology to measure two specific biomarkers.

Ultimatum game is widely used to examine the beneficiary's tolerance for unfairness. According to Fakuda, Shiomi, Nakagawa and Ueda (2012) in the ultimatum game, one of two players (the proposer) receives a sum of money, which he or she is to divide between himself or herself and the other player (the responder). The proposer can split the money any way he or she wants and can even opt to keep everything for him or herself. The responder can then either accept or reject the offer: if the responder accepts, the money is divided as proposed; if the responder rejects, on the other hand, both players receive nothing. According to the self-gain maximization principle, responders should accept any offer, as something is better than nothing. Although this is economically optimal, this is not how real people behave. When faced with unfair divisions, responders often reject offers. This demonstrates that social and emotional response to unfair offers leads our irrational decision-making. A key focus of recent ultimatum game research has been to understand why responders reject low offers and which is the role played by emotions in this rejection. In this sense, different studies demonstrate the impact of emotions in the decisions process. For instance, Loewenstein and Lerner (2003) divide emotions during decision-making into two types: those anticipating future emotions and those immediately experienced while deliberating and deciding. Pfister and Böhm (2008) believe that the issue of rationality should be based on the validity of emotional evaluations rather than on formal coherence.

The application of a neuroeconomics approach in the analysis of rejection in the ultimatum game seems promising as it shown by the results of recent papers. For instance, Neys, Novitskiy, Geeraerts, Ramautar and Wagemans (2011) conclude that subjects with high cognitive control (measured by EEG technology) tend to behave more in line with the perfect rationality and accept unfair offers in the UG. Another example is provided by Boksem and Cremer (2010), who used the ultimatum game and recorded the decisions with EEG technology and the results showed that MFN amplitude was more pronounced for unfair offers compared to fair offers and moreover, this effect was shown to be most pronounced for subjects with high concerns for fairness.

Although there is a wide range of technologies that can be used to define neuro-based biomarkers, in this paper we focus in Electroencephalography (EEG) based biomarkers. We chose this technology for three main reasons: (1) it is relatively inexpensive; (2) it is noninvasive, and therefore it can be used in humans, (3) it has a very high temporal resolution, thus enabling the study of the dynamics of brain processes. Although the way of recording EEG signals may be less rich than that of imaging techniques, there have been significant advances in the methodology for analyzing EEG data. These methods open a new gateway to the study of high-level cognitive processes in humans with noninvasive techniques and at no great expense.

The paper is organized as follows. Section 2 presents the materials and methods, including the experimental design and the methodology applied for the recording and processing of the EEG signals. Section 3 defines the EEG-biomarkers to be used in the analysis (namely, F8-EP and ALPHA8-CP) and presents the procedure applied to obtain them from the raw EEG signals. Finally, section 4 shows the results of the paper trough a visual comparison of the biomarkers for fair and unfair offers and the discussion on the convenience of further research closes the paper.

2. Materials and methods

2.1. Experimental design

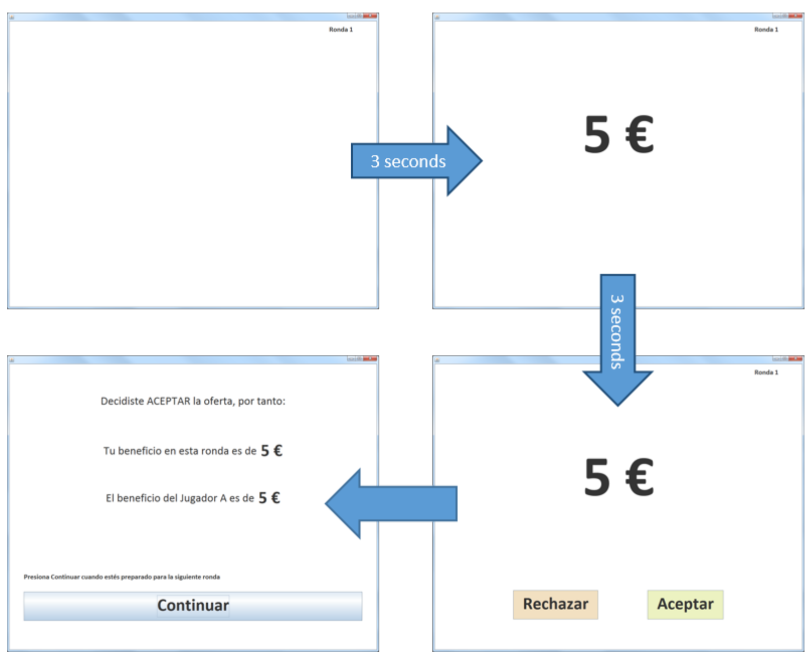
An experiment was designed and implemented to record Electroencephalography (EEG) of responders in an ultimatum game. Specifically, responders were exposed to fourteen offers provided by twelve different proposers. These offers are classified as fair (≥4€) an unfair (<4€) in order to explore the existence of a biomarker that could be associated to the emotions that arise when facing unfair offers. Eighteen subjects participated in this first exploratory experiment, twelve acting as proposers and six as responders.

The experiment took place in two steps:

1. **Collection of offers from proposers.** Twelve subjects were recruited and invited to attend an experimental session at LINEEX (Laboratory for Research in Experimental Economics). The subjects were randomly assigned to a computer in the laboratory and the instructions were read to the participants. In this experimental session subjects were invited to make an offer to a responder, according to the rules of the ultimatum game. Proposer endowment was 10 euros. Proposers made two offers in two identical and independent rounds. Proposers received the show up fee (5 euros) at the end of the session and were invited to come back one week after for the payments obtained after acceptance or rejection of their offers by responders. Since the behavior of proposers is not studied in this paper, the potential perturbations in proposers' incentives that may be caused for the delay between the session and the payment are not considered.

2. **Responders' acceptance or rejections of the offers.** Six subjects were recruited and invited to attend LINEEX, each one at a different moment of the time. The researcher informed them about the use of EEG technology and the subject had to sign a consent form before the beginning of the experiment. Once the subject signed the consent form, the researcher adjusted the Emotive EPOC and read the instructions of the experiment to the subjects. Each participant was asked to respond to 14 offers (14 rounds) selected from the pool of offers generated by the proposers. The EEG of the responder was recorded during the presentation of the proposal and the decision-making. Each of the 14 round was structured in separate phases: (1) a white window appeared only with the number of round in the upper corner and, after three seconds, the offer was revealed to the responder; (2) three seconds later, two bottoms appear in the screen with the two possible options of acceptance and rejection and finally (3) the payoffs for both players (proposer and responder) in the round were revealed. This sequence is presented in Figure 1. The earnings screen had a continue bottom, if the subject pressed it means that he was ready to the next round. In this moment, a technician checked that all the channels for the EEG were transmitting a good signal and shift for the next round. At the end of the session, each responder received the payment corresponding to her or his decisions during the experiment.

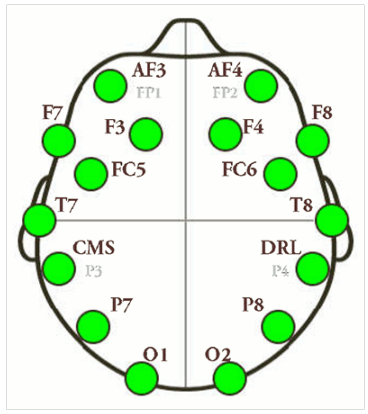
Figure 1. Structure of the experimental session for responders (screenhots)



2.2. EEG recording and processing

Continuous EEG recordings were obtained with Emotiv EPOC technology. This basic neuroheadset features 14 EEG channels plus 2 references. Channel names based on the international 10-20 electrode location system and uses sequential sampling method, single ADC, at a rate of 128 samplings per second.-Emotiv EPOC operates at a resolution of 14 bits per channel with frequency response between 0.16 - 43 Hz (figure 2).

Figure 2. Scalp locations covered by Emotiv EPOC.



The EEG signal processing was implemented in EEGLAB an interactive Matlab toolbox for processing continuous and event-related EEG, MEG and other electrophysiological data incorporating independent component analysis (ICA), time/frequency analysis, artifact rejection, event-related statistics, and several useful modes of visualization of the averaged and single-trial data.

3. Proposal of biomarkers

As stated before, the goal of this paper is to explore the existence of EEG-based biomarkers that may be associated to the emotion induced by the reception of unfair offers in the ultimatum game. In this section, we present the definition of two biomarkers (EP-F8 and ALPHA-AP), as well as the transformations of the raw signals obtained from the EEG that are applied to obtain the biomarkers for each proposal of each responder.

3.1. Definition of the biomarkers

We will consider two complementary methods to define biomarkers from EEG readings, namely evoked potentials and accumulated power:

- **Biomarker F8-EP.** In many scientific fields, one very useful way to learn about a system is by studying its reactions to perturbations. In brain research, it is also a common strategy to see how single neurons or large neuronal assemblies, as measured by the EEG, react to stimuli. Evoked Potentials (EP) are the changes in the ongoing EEG activity due to stimulation. They are time locked to the stimulus and they have a characteristic pattern of response that is more or less reproducible under similar experimental conditions. In summary, EP are very useful to study high level cognitive processes, their main advantages over other techniques being their low cost, their non invasiveness and their good temporal resolution. For this exploratory analysis, we will focus in the analysis of evoked potential in the frontal channel

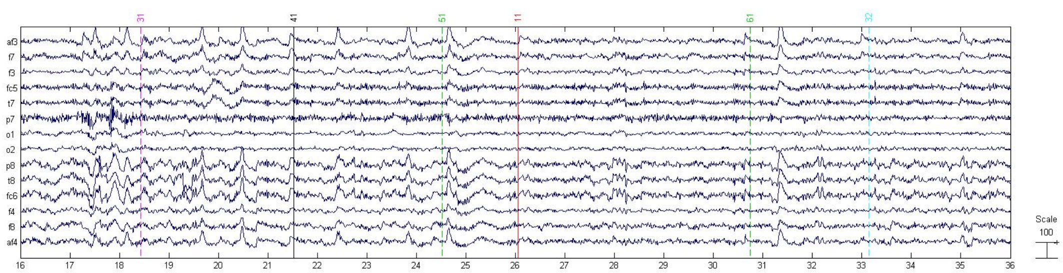
F8, measuring brain activity in the right dorsolateral prefrontal cortex (See figure 2). This channel was chosen following Knoch et al. (2006), who suggest that this area plays an important role in overriding self-interested impulses related to costly punishment decisions.

- **Biomarker ALPHA8-AP.** In frontal areas, an anticipatory activity characterized by a decrease in low frequencies (delta and theta) and an increase in high frequencies (alpha and beta) of the electroencephalography (EEG) has been observed in some works such as Cohen et al. (2009). As a tentative biomarker, we will consider the change in the accumulated power of the spectrum within the alpha waves (8-14 Hz) in channel F8 before and after the presentation of an offer to the responder.

3.2. Obtaining biomarker F8-EP.

With the aim to obtain F8-EP for each subject, EEG signals were preprocessed using a 1-40 Hz band-pass filter (Figure 3). Artifacts were detected by visual inspection of the signal and the trials that contained them were removed. Eye blinks were identified by a threshold criterion of ±100 µV.

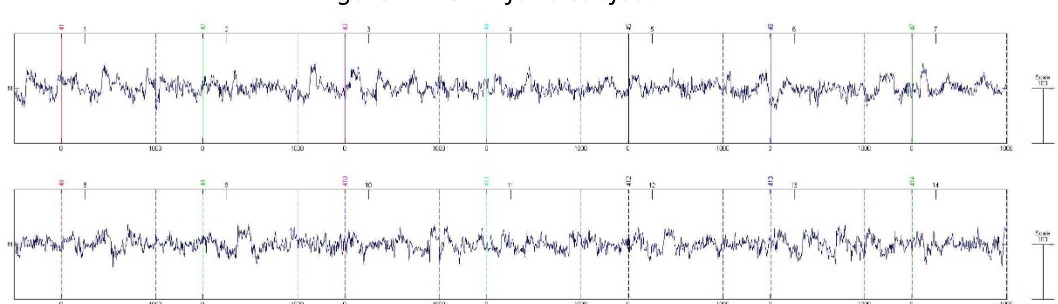
Figure 3. Continuous EEG recording preprocessed using a 1-40 Hz band-pass filter.



EEG dynamics of continuously recorded data for each responder were divided in 14 independent epochs, each one associated to one of the offers. The epoch's limits are 1 second before the stimuli and 2 seconds after it.

As an instance, Figure 4 presents the signal from frontal channel F8 for a subject after the process. The continuous colored lines represent the moment when the offer is presented to the responder and the dotted lines separate the seven epochs of the same player presented in each row.

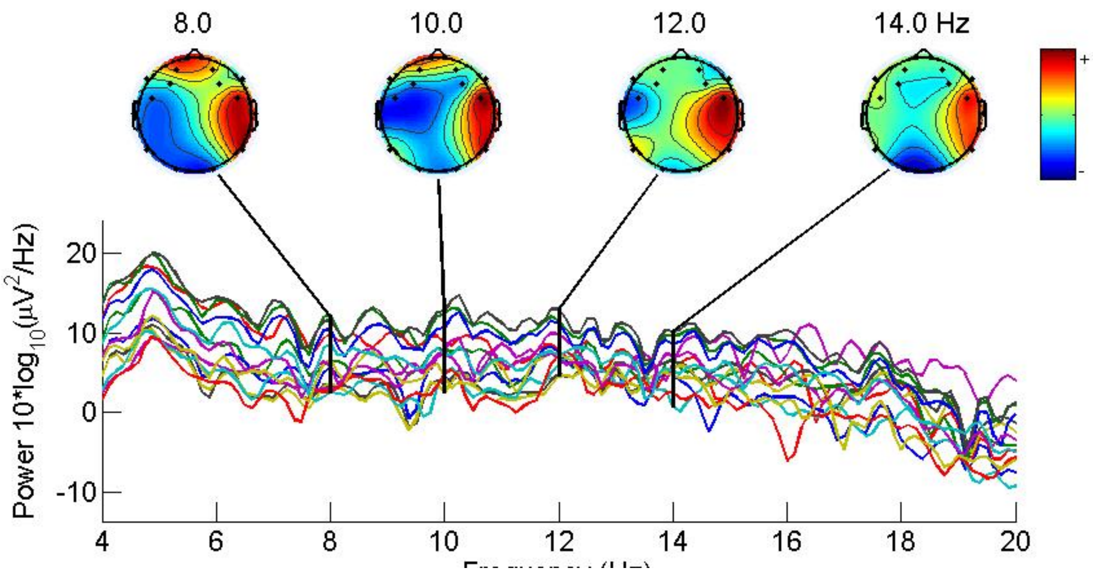
Figure 4. F8-EP for a subject.



3.3. Obtaining biomarker ALPHA8-AP.

To measure biomarker ALPHA8-AP, raw signals were preprocessed using a 4-20 Hz band-pass filter and then power spectra was obtained trough the corresponding Fourier transform. Figure 5 presents the spectrum of the activities in the 14 channels. The figure also shows the topographical localization of the power levels (presented according to a color code where dark blue represents the lowest power levels and dark red the highest). The leftmost scalp map shows the scalp distribution of power at 8 Hz, which in these data is concentrated on the frontal and transversal line. The other scalp maps indicate the distribution of power at 10 Hz, 12 Hz and 14 Hz.

Figure 5. Channel spectra and associated topographical maps.

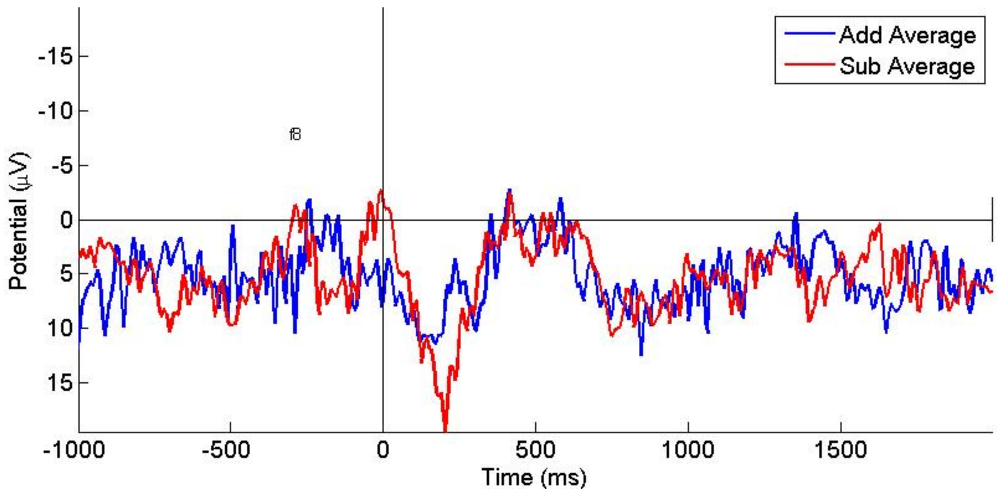


In a similar way to that follow for the previous biomarker, we selected channel F8 and extracted data epochs from one second before to two seconds after offer is shown. The aim is to study power changes in the alpha channel (8 – 14 Hz) before and after the stimuli. To this end, two packages of data were created, the first one with the data recorded one second before the stimuli and the second one, one second after it. Biomarker ALPHA8-AP will represent the difference of the accumulated power in alpha channel between these two packages of data.

4. Results

The goal of the paper is to carry out a descriptive visual analysis of the existence of a relation between biomarkers F8-EP and ALPHA-AP and the presence of emotions induced by unfair offers in the ultimatum game. To this end, the 14 epochs obtained for each responder have been classified in two different groups, corresponding to fair (upper or equal to 4€) and unfair (lower or equal to 3€) offers. We average the results of F8-EP together in each of these groups, causing random brain activity to be averaged out and the relevant waveform to remain, called the ERP. ERPs for the fair and the unfair offers are show by Figure 6. As this figure shows, when unfair offers were proposed, biomarker EP-F8 seems larger than when the fair offers were proposed.

Figure 6. Biomarker F8-EP of fair offers (line blue) and unfair offers (line red).



To present biomarker ALPHA-AP visually we will follow a time-frequency approach. Time-frequency analysis comprises those techniques that study a signal in both the time and frequency domains simultaneously, using a time-frequency representation. Rather than viewing a 1-dimensional signal and some transform, time–frequency analysis represents a wave as a two-dimensional signal – a function whose domain is the two-dimensional real plane, obtained from the signal via a time – frequency transform. The motivation for this study is that functions and their transform representation are often tightly connected, and they can be understood better by studying them jointly, as a two-dimensional object, rather than separately.

Specifically, figure 7 shows the potential level – represented by a color code from dark blue for the lowest potentials to dark red for the highest potentials - of the signal in channel F8 at each combination of frequency and time. The values represented in the figure have been obtained through a Fourier transform. The figure placed at the left represents the average values for fair offers and that in the right for the unfair offers. The time labeled as 'zero' represent the moment in which the offer is shown to the responder. The parallel black lines identify the frequency domain of the alpha channel (8 to 14 Hz) for F8, in other ways biomarker ALPHA8-AP.

A visual analysis suggests the presence of higher values of ALPHA-AP8 between 200 and 600 milliseconds after facing unfair offers. This effect can be observed in the orange-red area that appears in the graph at the right of figure 7.

Figure 7. Channel Time-Frequency of F8. The left one is the result of the fair offer and the right one of the unfair offer.

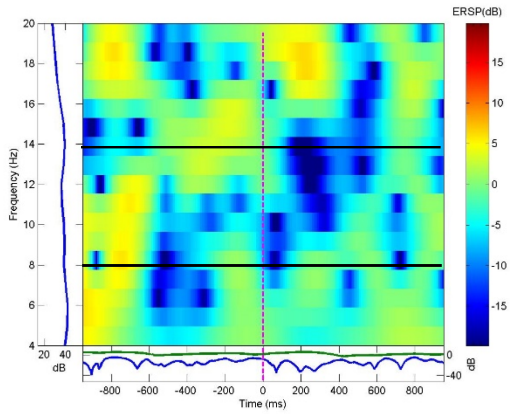


Figure 7.a. Fair offers

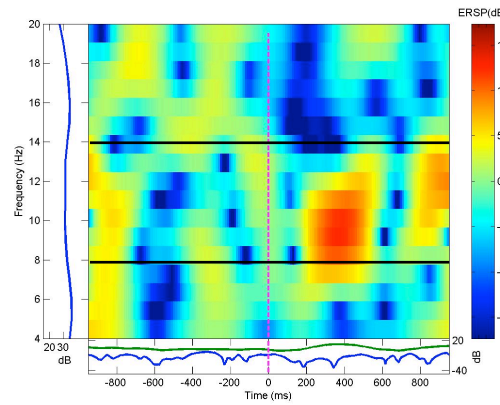
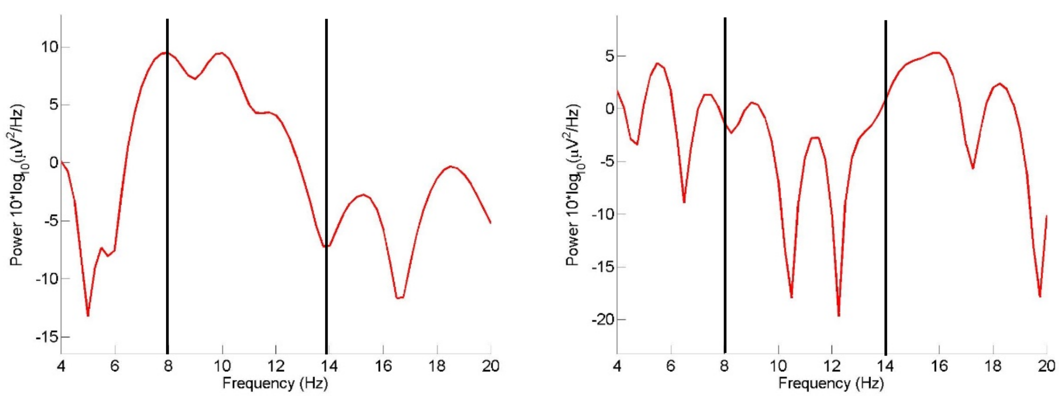


Figure 7.b. Unfair offers

This effect can be also observed in the representation of the power spectrum before and after facing an unfair offer, as shown in Figure 8. Power levels in this figure have been obtained from the coefficients of the Fourier transform of signal from channel F8. The change in biomarker ALPHA8-AP can be observed through the lower values of power between the parallel back lines – that delimit the frequency range of channel alpha – after receiving an unfair offer.

Figure 8. Power spectrum *of F8 before and after of an unfair offer.*



4. Discussion

This paper presents a basic neuro-experiment to explore the possibility of the application of EEG-based biomarkers to analyze emotional response to the ultimatum game. Using a basic EEG registration tool (Emotiv EPOC technology) and small sample of six responders, the paper shows that there are at least two biomarkers (F8-EP and ALPHA8-AP) that seem to be related with the responder's emotions when facing an unfair offer. The results of the analysis are encouraging and suggest the convenience of the implementation of further research with more sensitive EEG reading devices and larger samples.

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