EEG Signals–Active Visual Oddball Stimuli

Analysis of P300 Amplitude and Latency

*Group #*38

Abstract:

This study delves into the intricacies of the human brain, focusing on the P300 event-related potential (ERP), a positive deflection in the scalp-recorded electroencephalogram (EEG) occurring in response to specific stimuli under defined conditions.
The P300 ERP is explored through an in-depth analysis of amplitude and latency. The research involved 40 neurotypical young adult subjects in a visual stimuli session.
The findings reveal significant amplitude differences between standard and oddball events, with topographic distribution analysis revealing spatial variations in P300 across the scalp. Moreover, the study explores gender differences in P300 amplitudes, finding no statistically significant distinctions.
Overall, this research contributes valuable insights into P300 ERPs, showcasing their promise in developing accessible and reliable BCIs for addressing CNS-related challenges.

Keywords:

ERP, P300, Neuroengineering, BCI, EEG, Brain, Visual stimuli.

I. INTRODUCTION

Neuroengineering represents a specialized field dedicated to the advancement of technologies aimed at comprehensively analysing the human brain. This pursuit is pivotal for unravelling the intricacies of human cognition and effectively addressing neurological disorders. The methodologies employed for brain analysis can be broadly classified into two main categories: hemodynamic and electrical. While hemodynamic techniques such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) offer indirect insights by monitoring blood flow dynamics, electrical techniques, exemplified by electroencephalography (EEG), directly capture the brain's electrical activity.

Despite the non-invasiveness of surface EEG, it presents limitations in spatial resolution and susceptibility to interference from muscular activity. Invasive EEG, while enhancing spatial resolution, necessitates surgical intervention and entails associated risks [1]. One approach to study the brain involves stimulation through the presentation of a paradigm.

The P300 Event-Related Potential (ERP) represents a distinct electrophysiological response activated by a stimulus, leading to neuronal firing. This stimulus can emanate from a specific psychological event or a sensor, and the resulting ERP is synchronized with the event, manifesting as a sequence of positive and negative voltage shifts in the EEG. The P300, a positive shift following the stimulus, is elicited by visual, auditory, or tactile stimuli, offering a direct assessment of the brain's reaction to specific stimuli and yielding valuable insights into cognitive processes.

The P300 exhibits variability in latency, ranging from 250 to 750ms. This variability signifies that the P300 is triggered by a decision, potentially unconscious, that an infrequent event has occurred. Research indicates that the less likely the stimulus, the larger the response peak's amplitude. Typically, the P300 is most prominent over the central parietal scalp, and it diminishes as the distance from this area increases [2].

The Oddball Paradigm, employed to elicit the P300 ERP, encompasses three key characteristics [3]:

- A series of events (stimuli) presented to a subject, each belonging to one of two categories.
- Events from one category occur less frequently than those in the other.
- The subject classifies each event into one of the two categories.

Oddball events, representing the less common category, trigger a P300. Any stimulus and classification task can elicit a P300 if the experimental design incorporates the three characteristics of the oddball paradigm. Notably, the two categories need not be different types of stimuli, as demonstrated by Sutton et al. [4]. A P300 can be triggered by an event involving the absence of a stimulus, provided it aligns with the oddball paradigm conditions. In essence, a P300 ERP is triggered by infrequent events defying the subject's expectations, with visual or auditory stimuli being commonly used [2].

In 1988, the P300 found its initial application as the foundation for a brain-computer interface (BCI) [3], and ongoing research explores its diverse BCI applications [1]. BCIs translate brain activity into artificial output, modifying interactions between the central nervous system (CNS) and the environment. P300-BCIs, leveraging the amplitude and latency of the P300, present promising solutions for challenges arising from injury or disease, spanning compensation to potential enhancement of natural neural functions [5]. These BCIs are non-invasive, easily parameterized for new users, require minimal training, and boast broad usability, providing basic communication and control functions with high reliability [2].

P300 BCIs excel in selection applications, with common uses including the P300 speller and control commands for tasks like moving a cart or wheelchair, making phone calls, operating a television, controlling lights, playing music, or managing doors and windows [1]. In our present research context, our objective is to scrutinize the amplitude and latency of the P300, detect potential trends and explore variations related to gender, given its significant promise in the development of P300-BCIs.

II. MATERIALS AND METHODS

Experimental Setup

The study involved the recruitment of 40 neurotypical young adult subjects. Participants were instructed to sit in a comfortable chair facing a screen and minimize unnecessary movements. The experiment comprised a session of visual stimuli, where four letters (A, B, C, D, and E) could randomly appear with equal probability (0.2). One letter was designated as the target (oddball event), while the remaining four served as non-targets (standard event) to highlight the P300 component. Participants were required to respond whether the displayed letter was a target or non-target. Each session included the recording of electroencephalographic signals lasting 5 to 10 minutes. During this period, subjects viewed visual stimuli (200ms duration) with variable inter-stimulus intervals ranging from 1450ms to 1500ms.

EEG signals were acquired using the Biosemi ActiveTwo recording system. The EEG cap featured 30 electrodes arranged according to the international 10-20 system (FP1, F3, F7, FC3, C3, C5, P3, P7, P9, PO7, PO3, O1, Oz, Pz, CPz, FP2, Fz, F4, F8, FC4, FCz, Cz, C4, C6, P4, P8, P10, PO8, PO4, O2); PO1 served as the common mode sense (CMS) electrode, and PO2 as the driven right leg (DRL) electrode. Additionally, electrooculogram (EOG) signals were recorded:

- Horizontal EOG (HEOG) from electrodes positioned at the outer canthus of each eye.
- Vertical EOG (VEOG) from an electrode below the right eye.

All signals were sampled at 1024Hz with 24-bit resolution, filtered with a low-pass filter (LPF) at 204.8Hz, and downsampled to 256Hz for computational efficiency.

Signal Analysis and Processing

In our analysis, we utilized the MATLAB® software, specifically employing the "Signal Processing Toolbox.". Each signal underwent the following filtering steps:

- High-pass filter (HPF): a fourth-order Butterworth HPF at 0.1Hz was applied to remove low-frequency trends.
- Low-pass filter (LPF): a sixth-order Butterworth LPF at 35Hz was implemented to eliminate unnecessary frequency components.

The choice of 35Hz was informed by examining the power spectral density (PSD) of the ERP, revealing frequency content up to 20Hz during the oddball event's mediated epoch. To err on the side of conservatism, a higher frequency of 35Hz was selected to account for potential variability and maintain the integrity of the signal. Both filters were applied in a dual-pass manner to prevent phase distortions inherent to the infinite impulse response (IIR) filter. Any "not a number" (NaN) values were replaced with zeros to prevent processing issues.

Offline referencing to the electrode placed on the right mastoid site (P9) was performed [6].

To mitigate scalp mapping polarizations due to artifacts like eye blink, FP1 and FP2 electrodes were turned off, being the closest to the eyes and more susceptible to this artifact. Attempts were made to eliminate this artifact using techniques such as independent component analysis (ICA) and principal component analysis (PCA). However, even after removing components closely related to the three EOG signals (cross-correlation coefficient > 0.9), crucial components for event-related potential (ERP) identification were also removed. Consequently, these techniques were abandoned.

Epoch Identification and Averaging

To identify epochs of standard and oddball events, only trials where subjects made no errors were considered. In fact, analysis revealed that none of the 40 subjects made errors during the test. Analysed epochs had a duration of 1000ms: 200ms before the event and 800ms after. To investigate P300 amplitude, the averaging technique with jitter correction was employed:

1. Jitter detection: one peak was identified for each analysed epoch and then approximated as P300. The latency (time between the pseudo P300 and the event onset) was recorded. The search for the maximum was conducted between 200ms and 500ms after the event. Jitter was defined as the difference between all epoch latencies of the channel and the latency of the first epoch.
2. First averaging: to reduce subject variability, both oddball and standard events were divided into three subgroups, each containing 1/3 of the analysed events. Epochs in each subgroup were then averaged, correcting for jitter.
3. Baseline correction: to mitigate biases arising from the background EEG signal, we performed baseline correction. Specifically, we subtracted the mean value of the signal in the 200ms period preceding the event to the mediated epoch.
4. Second averaging: the averaged epochs from the three subgroups, obtained at point 2, were further averaged, resulting in two mean amplitude values for each channel in each subject: one for the standard event and one for the oddball event.

Topographic Distribution Analysis

To assess the topographic distribution of P300 amplitudes, a two-dimensional scalp topographic map was generated. The electrodes adhered as closely as possible to the international 10-20 system. For aesthetic purposes, dummy electrodes were introduced in regions where the colour map was absent on the scalp.

III. RESULTS

In our analysis, the findings from the literature became evident. We demonstrated that the amplitude of the P300 potential, elicited by oddball events, is higher compared to standard events (Fig. 1 a), with statistical significance observed in 70% of cases ($p < 0.05$). Our graphs depicted the five channels that contain the most informative content regarding P300, consistent with literature.

As previously explained, we categorized both standard and oddball events into three subgroups: first stimuli, middle stimuli, and last stimuli, each comprising one-third of the events. However, Fig. 2 clearly shows that there is no significant trend ($p > 0.05$) in the behaviour of P300 amplitudes for both standard and oddball events as the number of stimuli increases. In fact, the data displays jagged signals with a constant average (Fig. 2).

To mitigate biases originating from the blink artifacts illustrated in Fig. 4 and Fig. 5, and to enhance the realism of the topographic representation, we chose to compute the amplitude difference between oddball and standard events. This strategy was selected to effectively address the previously mentioned finding. Following this, we produced topographic maps illustrating the mean amplitudes of both oddball and standard events, as well as their disparity. These results offer a comprehensive insight into spatial variations in P300.

Furthermore, we explored potential differences in P300 amplitudes between genders. Fig. 9, comparing the mean amplitudes between females and males, unequivocally demonstrates the absence of statistically significant differences ($p > 0.05$) between the two groups.

A. Figures

In this section, we present the outcomes of our study. Each figure is carefully annotated to provide a detailed understanding of the observed trends and relationships within the data.

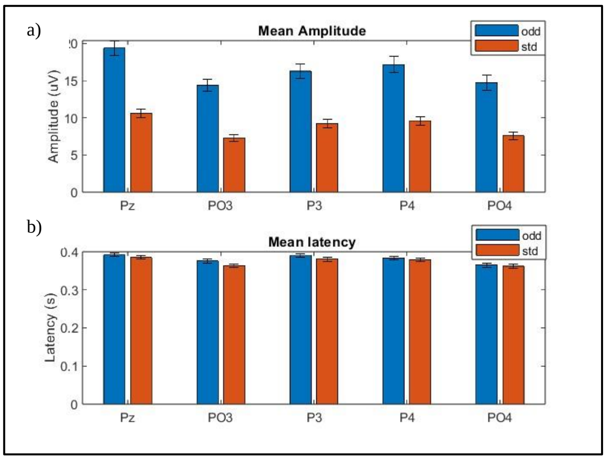

Fig. 1: a) P300 amplitude (mean of all subjects) oddball vs standard events; b) P300 latency (mean of all subjects) oddball vs standard events.

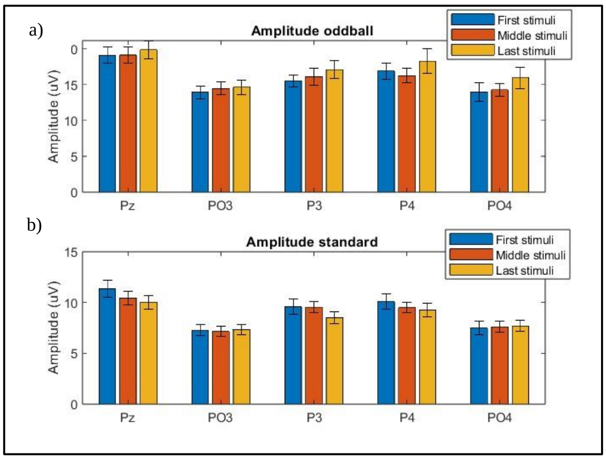

Fig. 2: a) Trend of amplitude for oddball events (mean of all subjects); b) Trend of amplitude for standard events (mean of all subjects).

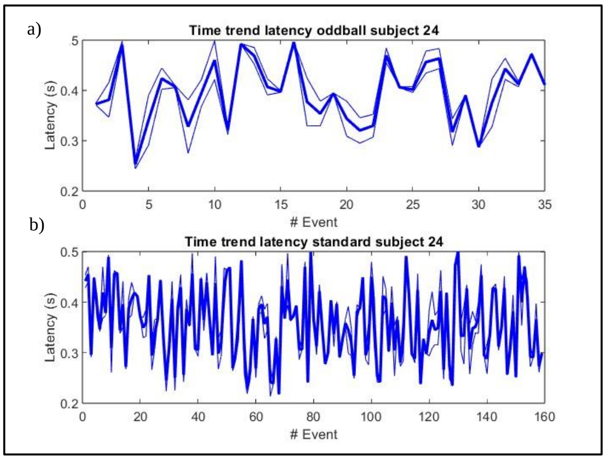

Fig. 3: a) Trend of latency for oddball events in Subject 24; b) Trend of latency for standard events in Subject 24. Thick line: mean; thin line: ± standard error.

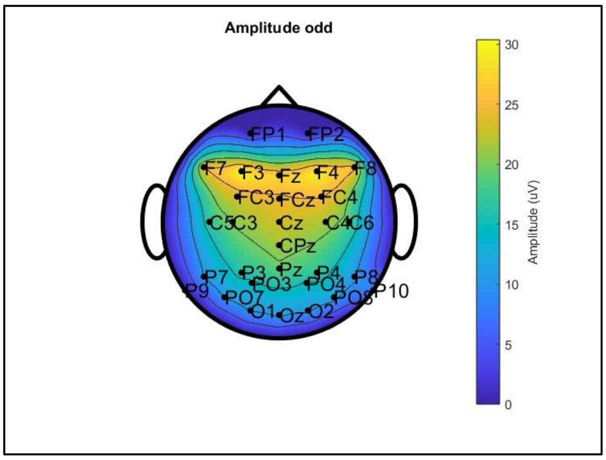

Fig. 4: Topographic distribution of P300 amplitude (mean of all subjects): oddball events.

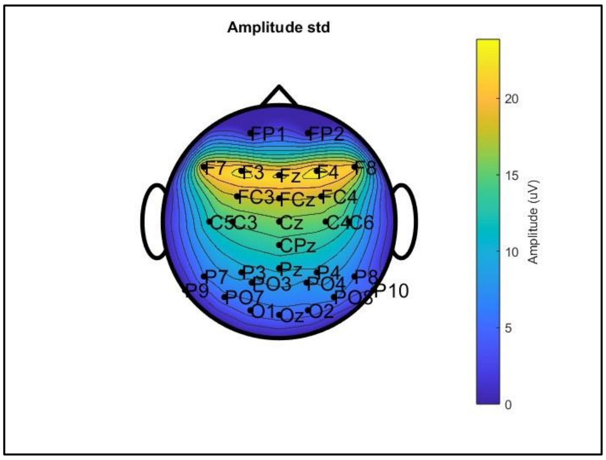

Fig. 5: Topographic distribution of P300 amplitude (mean of all subjects): standard events.

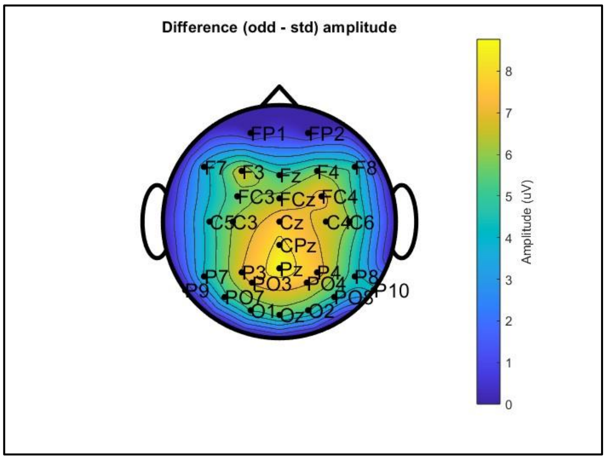

Fig. 6: Topographic distribution of P300 amplitude (mean of all subjects): difference between oddball and standard events.

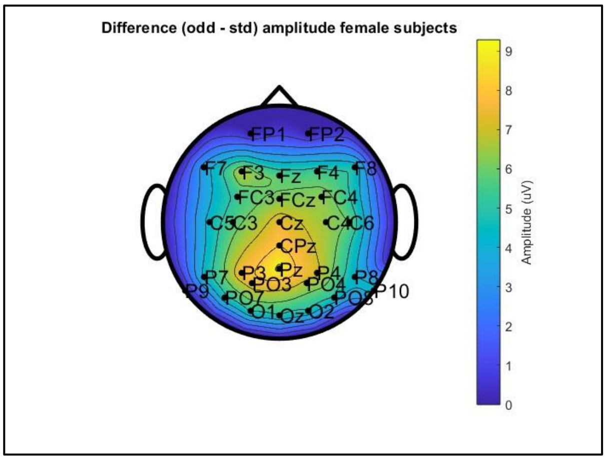

Fig. 7: Topographic distribution of P300 amplitude (mean of all female subjects): difference between oddball and standard events.

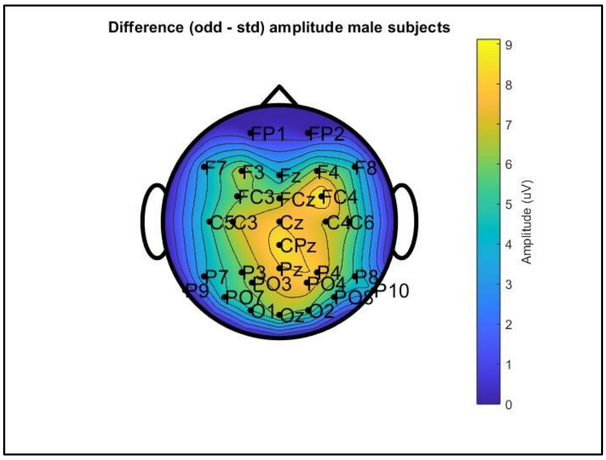

Fig. 8: Topographic distribution of P300 amplitude (mean of all male subjects): difference between oddball and standard events.

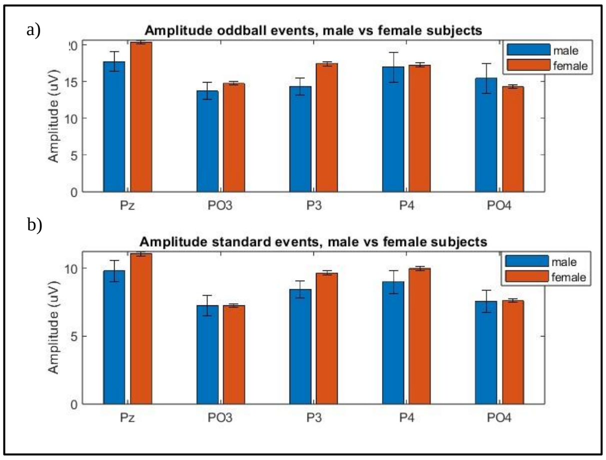

Fig. 9: a) Comparison of P300 amplitude (oddball events) between males and females; b) Comparison of P300 amplitude (standard events) between males and females.

IV. DISCUSSION

This study delved into the complexities of the P300 event-related potential (ERP) in the human brain, focusing on amplitude, latency, and topographic distribution. A detailed analysis involving 40 neurotypical young adults in a visual stimuli session provided insights into the functioning of the P300 ERP.

The results revealed significant amplitude differences between standard and oddball events, emphasizing the distinctive brain response to rare stimuli. This reflects the role of the P300 in manifesting the decision-making process triggered by unexpected events. The variability in latency underscores the dynamic nature of the decision-making mechanism associated with the P300, revealing nuances in the brain's response to specific stimuli.

The practical implications of the research are promising, especially in the context of P300-based BCIs. Their non-invasiveness, rapid calibration time, and high usability make them attractive for various applications, from basic communication to post-stroke recovery support. The study contributes to ongoing efforts to harness the potential of P300 in addressing challenges related to the central nervous system.

Contrary to expectations, the absence of statistically significant differences in P300 amplitudes between genders suggests a level of universality in the brain's response to the presented stimuli. This finding has implications for the development of P300-based brain-computer interfaces, emphasizing their potential applicability across diverse demographic groups.

Two-dimensional topographic maps unveiled spatial variations in P300 amplitudes, highlighting the involvement of diverse brain regions in processing rare events. This spatial information is crucial for understanding the neural networks engaged in the P300 response and contributes to a broader comprehension of cognitive processes associated with oddball paradigms.

The methodological approach, including signal processing techniques and electrode placement, played a crucial role in obtaining meaningful results. However, it is essential to recognize limitations associated with artifacts, such as blink artifacts, and challenges in their elimination. Future research could explore advanced signal processing techniques and alternative paradigms to overcome these limitations and deepen the understanding of the P300 ERP.

In conclusion, this research advances our understanding of the P300 ERP, emphasizing its role in decision-making processes and showcasing its potential in developing practical solutions, particularly in the field of BCIs. The universality of P300 responses across genders adds to its appeal as a reliable neurophysiological marker, opening avenues to refine methodologies and explore diverse applications of P300-based BCIs to address challenges related to the central nervous system.

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