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AMPLITUDE-TIME CHARACTERISTICS OF WOMEN'S BRAIN ACTIVITY ASSOCIATED WITH THE MOTOR RESPONSE IN THE STOP-SIGNAL TASK PARADIGM

CHARAKTERYSTYKA AMPLITUDOWO-CZASOWA AKTYWNOŚCI MÓZGU KOBIET ZWIĄZANEJ Z REAKCJĄ MOTORYCZNĄ W PARADYGMACIE ZADANIA STOP-SIGNAL

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zaplanowanie badań
B. Data collection/entry
zebranie danych
C. Data analysis/statistics
dane – analiza i statystyki
D. Data interpretation
interpretacja danych
E. Preparation of manuscript
przygotowanie artykułu
F. Literature analysis/search
wyszukiwanie i analiza literatury
G. Funds collection
zebranie funduszy

Summary

Background. The amplitude-temporal characteristics of the event-related potentials of the cortex associated with the motor response were studied in women using the Stop-Signal task paradigm.

Material and methods. The research involved 48 healthy, right-handed female volunteers between the ages of 18 and 23 years. Event-related potentials in the frontal, central, and parietal cortices were analyzed. The latency periods of the N2 and P3 components as well as the amplitudes of the N2 and P3 waves were determined.

Results. The performance of the motor task in the Stop-Signal task paradigm was accompanied by a predominance of the N2 latency component in the parietal cortex areas, primarily in the right hemisphere, and the P3 component amplitude in the frontal area of the left hemisphere. A bilateral cortex response was revealed in the P3 latency component and the inter-peak amplitude of the P2N2 event-related potential interval. The local potential shift in the N2P3 peak interval was recorded in the right central and parietal areas, with a higher amplitude in the left hemisphere.

Conclusions. The established characteristics of induced brain activity in women may support the idea of the multistage inhibitory process, which can require additional reassessment and categorization of the stimulus at the time of transition from the stage of an action's "suspension" to its complete "cancellation."

Keywords: Stop-Signal task, manual movements, brain activity, event-related potentials, EEG

Streszczenie

Wprowadzenie. Stosując paradygmat zadania stop-signal, zbadano charakterystykę amplitudowo-czasową potencjałów wywołanych kory mózgowej związanych z odpowiedzią ruchową u kobiet.

Materiał i metody. W badaniu uczestniczyło 48 zdrowych, praworęcznych ochotniczek w wieku od 18 do 23 lat. Analizie poddano poznawcze potencjały wywołane w korze czołowej, środkowej i ciemieniowej. Określano okresy latencji składowych N2 i P3 oraz amplitudy fal N2 i P3.

Wyniki. Wykonaniu zadania motorycznego w paradygmacie zadania stop-signal towarzyszyła przewaga składowej latencji N2 w obszarach kory ciemieniowej, głównie w prawej półkuli oraz amplitudy składowej P3 w obszarze czołowym lewej półkuli. Obustronna odpowiedź kory mózgowej ujawniła się w komponencie latencji P3 i amplitudzie międzyszczytowej interwału potencjału wywołanego P2N2. Lokalne przesunięcie potencjału w odstępie między szczytami N2P3 odnotowano w prawej okolicy środkowej i ciemieniowej, z większą amplitudą w lewej półkuli.

Wnioski. Ustalone cechy indukowanej aktywności mózgu u kobiet mogą potwierdzać ideę wieloetapowego procesu hamowania, który może wymagać dodatkowej ponownej oceny i kategoryzacji bodźca w momencie przejścia od etapu „zawieszenia" działania do jego całkowitego „anulowania".

Słowa kluczowe: zadanie Stop-Signal, ruchy manualne, aktywność mózgu, potencjały wywołane, EEG

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Introduction

One of the current scientific trends in neurophysiology is researchers' significant interest in the course of brain processes and specific neural mechanisms that ensure the implementation of motor inhibition at the central level. An analysis of the scientific literature has shown that a modified version of the Go-No-Go paradigm, known as the Stop-Signal task paradigm, is the most common method for studying the processes associated with motor response inhibition [1,2]. The modern scientific community has already conducted a great deal of research and outlined some patterns in the mechanisms of motor response inhibition. However, there are still many unclear aspects of the course of brain processes under these conditions. In particular, the associated model of horse racing behaviorally describes braking as a race between two stochastically independent Go and Stop processes, where the processes of movement and inhibition compete with each other, and the process that "wins the race" determines the result [3]. The main speed indicator of the Go and Stop processes, in this case, is the stop signal reaction time (SSRT). The degree to which the inhibition process succeeds depends on the speed of the "Go" reaction, the speed of the inhibition process, and the delay between the start of the two processes. At the behavioral level, using this paradigm, it has been shown that SSRT is age-dependent and is higher among children and the elderly [4,5]. In addition, some authors consider the inhibition rate in the Stop-Signal task a real clinical marker for patients with various mental and neurological disorders, including behavioral control disorders [6,7].

It has been observed that the main assumption of independence between the inhibition and movement processes was violated in more complex versions of Stop-Signal tasks [8-10]. This has led to the study of additional parameters of such processes and the use of alternative research methods. In studying the temporal and spatial dynamics of inhibition control, scientists are increasingly using the technique of event-related potentials (ERPs) [11], paying attention to the latency and amplitude characteristics of their components: N2 and P3. In the Go-No-Go paradigm, the N2 component of the wave is interpreted as the preliminary motor index of inhibitory control. It is also associated with conflict resolution and task difficulties [12,13]. The late, positive P3 component (range: 300-400 ms), as noted, reflects the control function of attention, memory and decision-making in response to external stimulation [11]. Some researchers suggest correlating this component with the start or inhibition of a motor program [14].

Summarizing the results of neurophysiological and behavioral studies, we can conclude that there is still controversy about the amplitude-temporal parameters of the central mechanisms of brain processes in the context of the motor program inhibition of manual movements. Moreover, some of the few existing studies are marked by methodological problems, as there have been cases where the results cannot be reproduced. There is also a lack of information on gender mainstreaming to determine the specific mechanisms of motor response inhibition. Although such results generally suggest that the N2 and P3 components of ERPs may be markers of response inhibition in their amplitude and/or delay, some conceptual issues still need to be further clarified.

The purpose of this study was to establish the amplitude-temporal characteristics of cortical responses during the implementation of motor tasks in the paradigm of the running women's motor program cancellation of manual movements (Stop-Signal task).

Established electroencephalography (EEG) markers of brain processes that are directly related to the motor response to "Stop" and "Stop-Change" signals could represent an important practical application, in particular, for improving the early diagnosis of cortical dysfunction of the neuromotor system. In addition, the EEG markers of motor commands and their features can increase the number of degrees of freedom in the creation and implementation of neurocomputer interfaces as an information exchange system between the human brain and an electronic device, including the development of new technological prostheses, which can recognize and execute brain commands like normal limbs.

Material and methods

Participants

A total of 48 women – between ages of 18 and 23 years, healthy according to the medical professional advisory opinion (certificate 086-o), and with normal hearing – participated in the study. Inclusion criteria for the cohort included an absence of craniocerebral injuries or psychoneurological disorders, good health status at the time of the study, and a right-handed profile of manual and auditory asymmetries. The examination was conducted during the luteal phase of the menstrual cycle, when – according to the scientific literature – the level of women's brain excitability directly depends on the influence of sex hormones [15]. More precisely, in the late follicular phase the nervous system is more excitable due to estrogen, while in the luteal phase, the overall level of women's brain excitability is at the lowest point during the ovulation cycle because of progesterone, which exerts an inhibitory effect.

The experiment was conducted in the mornings on work days, in the Laboratory of Aging Neurophysiology of the Department of Human and Animal Physiology of Lesya Ukrainka Volyn National University, Ukraine. It consisted of two stages: psychophysiological and electroencephalographic.

Procedure

Psychophysiological testing

In the first stage, the level of fatigue (well-being) and the emotional state (mood) of the participants were assessed using the Well-being, Activity, Mood (WAM) questionnaire. The profile of manual asymmetry was determined with motor and psychoacoustic tests and the value of the manual and auditory asymmetry coefficient (K_{as}) [16]. At the second stage of the experiment, 48 women had a right-handed profile of motor and auditory asymmetry and a K_{as} value that was positive and higher than 50%. Once the psychophysiological testing was completed, the participants had 20 minutes to rest, which prevented the development of fatigue and monotony.

Electroencephalography

During the electroencephalographic (EEG) study, the participants were in a specially equipped sound- and lightproof room, in a supine position with their eyes closed. EEGs were recorded using the hardware/software complex "Neurocom" (TU U 33.1-02066769-001-2002, State Registration Certificate No. 6038/2007, dated 26.01.2007). EEG recording was performed monopolarly; the active electrodes were placed according to the 10-20 international system with 19 leads on the scalp. The interelectrode resistance was no more than 1.5-2 kO. The combined electrodes on the earlobes, the electrodes between the anterior and lateral frontal leads (Ref), and the electrodes between the right and left anterior frontal leads (N, nazion) were used as reference electrodes. Artifacts were removed from the native EEGs through ICA analysis.

EEG testing

The experimental procedure consisted of the participants' motor response to sound stimuli according to the Stop-Signal task paradigm. Sound stimuli (pure tones) were introduced in a series of 100 pairs. Two categories of stimulus pairs were used: with low sounds (600 Hz) and with both low and high (600 Hz and 1600 Hz) sounds (Figure 1). The ratio of stimulus pairs with low sounds versus stimulus pairs with both low and high sounds in the sample was 70/30, respectively. The duration of each sound signal was 50 ms; the interval between stimuli pairs was 5000 ms [17]; the delay between the first and second signals in the stimulus pair was 140 ms. This period includes sensory and partially motor components of the sensory-motor response, associated with signal perception, analysis, decision-making about the movement, and initiation of the motor program [18,19].

Sound stimuli were supplied binaurally using four speakers, placed in different corners of the room at a distance of 1.2 m from the right and left ears of the participants. The volume of the speakers at the output did not exceed 55 dB above the audibility threshold (measured with a noise meter [DE-3301 No. 050701882]). All our examinees had normal hearing according to the medical examination. The frequencies of 600 and 1600 Hz used in the study are within the range of normal human audio sensitivity (20–20,000 Hz). The above-mentioned organization of phonostimulation provides a comfortable perception of the sound stimuli, consistent with the literature [17,20].

Each participant received instructions to press the left button of the remote control with the help of the index finger of the right hand when they hear the first sound of the stimulus pair (600 Hz). If the next signal in the stimulus pair was identical to the first (600 Hz), they should continue pressing with their finger. In the case of a high-pitched signal (1600 Hz) as the second in the stimulus pair, the participant was asked to release the button. Thus, the second sound in the stimulus pair was important for the participant, because it showed confirmation (Go; 600 Hz) or rejection of the previous action (Stop; 1600 Hz) (Figure 1).

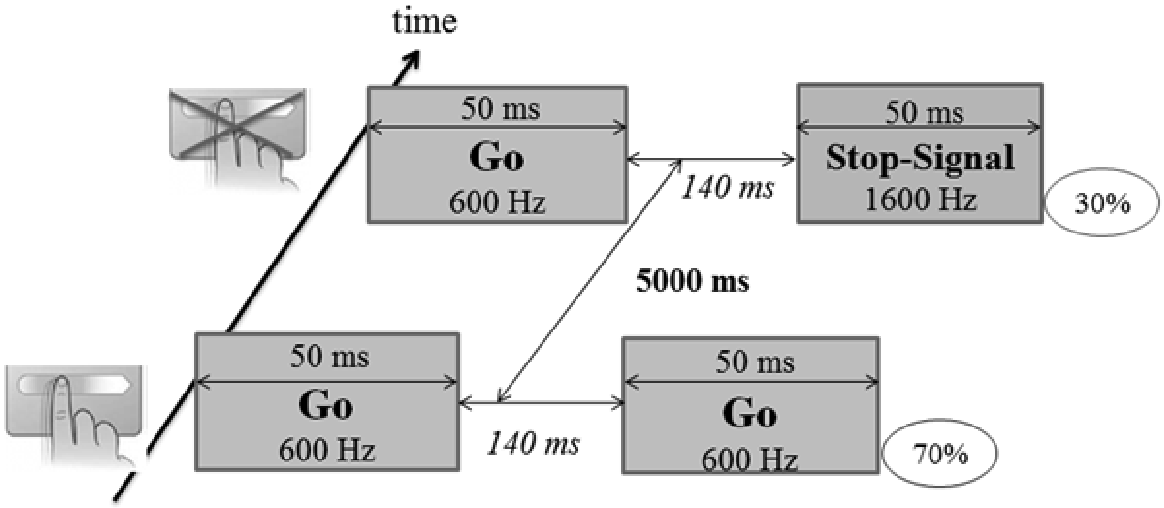

Figure 1. Scheme of the experimental stop-signal task

Notes: Go – the first sound in the stimulus pair, in response to which the examinee should start moving; Go, Stop-Signal – the second sound in the stimulus pair, to confirm (Go) or cancell the movement (Stop-Signal); 70% and 30% – correlation between stimulus pairs in the sample.

Analysis of the human brain-induced activity

The participants' responses to significant (Stop-Signal) and insignificant (Go) stimuli were reflected as a differential curve of event-related potentials (CEP). We analysed individual ERP curves grand averaged across all the participants in the F3, F4, C3, C4, P3, and P4 leads. The latency periods (LP) of the N2 and P3 components of the ERP, the amplitudes of the N2 waves (as the inter-peak interval P2-N2), and P3 (as the inter-peak interval N2-P3) were determined. The analyzed epochs were 150 ms long before the stimulus and 5000 ms after the stimulus, and the sampling frequency was 500 Hz. A graphical representation of the resulting differential instrumentation curves was created in the Matlab software environment (MathWorks, 2015).

Statistical processing of the research results

Samples of the data were checked for compliance with the normal distribution using the Shapiro-Wilk test (W, at $p>0.05$). Because the data distribution was not normal, the median values with the 25th and 75th percentiles (Me [25%; 75%]) were used as a descriptive statistic. The Wilcoxon signed-rank test was used to compare the dependent samples. The established differences were considered significant when the value of the reliability criterion was $p\leq0.05$ (STATISTICA 7, StatSoft).

Compliance with ethical standards

Participation in the experiment was voluntary and complied with all generally accepted bioethical rules and principles. All procedures conducted with participatory research met the ethical standards of the Institutional and National Research Committee and the 1964 Declaration of Helsinki and its subsequent amendments or comparable ethical standards. The study was approved by the Bioethics Commission of Lesya Ukrainka Volyn National University (approval number 1, dated 23.10.2020). All participants gave written informed consent to take part in the study. Necessary measures were taken to ensure the anonymity of the respondents.

Results

In our study, higher latency indicators of the N2 component were found in the parietal leads, especially in the right hemisphere ($p \leq 0.05$). Topographic specificity and interhemispheric differences of the LP of the P3 component was not established (Table 1, Figure 2).

Table 1. Latent periods of components N2 and P3 of event-related potential associated with stopping the running motor program of manual movement, Me (25%; 75%), ms

Leads	N2	P3
F3	198 (180;250)	377 (354;396)
F4	199 (186;254)	366 (340,396)
C3	201 (176;250)	382 (360;400)
C4	203 (184;246)	373 (352;398)
P3	205 (188;246)	378 (284;416)
P4	214 (190;254)*	377 (276;420)

Notes: * interhemispheric differences, $p \leq 0.05$.

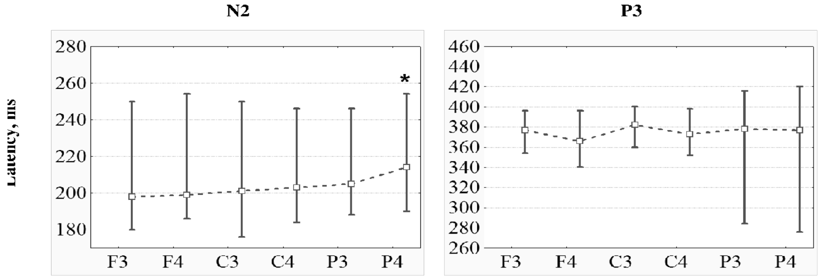

Figure 2. Latent periods of components N2 and P3 of event-related potentials in women, associated with stopping the running motor program of manual movement

Notes: The graphs show the value of Me (25%; 75%); * interhemispheric differences, $p \leq 0.05$.

The values of the N2 component amplitude (inter-peak amplitude of the P2N2 interval) had no interhemispheric differences, while the inter-peak amplitude of the N2P3 interval (P3 component) was higher in the left hemisphere, statistically significantly so in the frontal lobe ($p \leq 0.05$) (Table 2, Figure 3).

Table 2. Amplitude of components N2 and P3 of event-related potential, associated with stopping the running motor program of manual movement, Me (25%; 75%), ms

Leads	N2	P3
F3	5.59 (3.91;9.55)	16.45 (10.3;19.3)*
F4	6.66 (3.8;9.84)	14.1 (10.6;18.8)
C3	6.45 (3.57;9.68)	17.5 (11.1;23.1)
C4	6.63 (4.19;11.7)	15.95 (11.7;22)
P3	6.66 (3.96;8.63)	12.35 (8.25;19.3)
P4	6.55 (3.69;8.72)	13.85 (8.95;19.4)

Notes: * interhemispheric differences, $p \leq 0.05$.

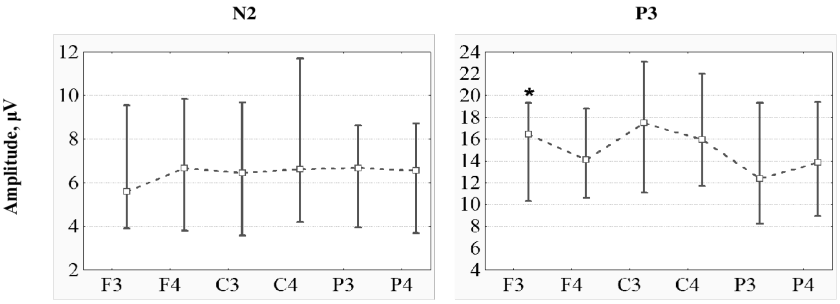

Figure 3. Amplitude-time characteristics of components N2 and P3 of event-related potentials in women, associated with stopping the running motor program of manual movement

Notes: The graphs show the value of Me (25%; 75%); * interhemispheric differences, $p \leq 0.05$.

We also recorded a local potential shift in the interpeak interval N2P3, especially in the right central and symmetrical parietal areas. The latency indices of this potential shift varied in the range of 275-319 ms and the amplitude was 1.02-1.96 μV. The latency indices did not reveal significant interhemispheric differences. The amplitude values were higher in the left parietal area ($p \leq 0.05$) (Table 3, Figure 4).

Table 3. Latent periods (ms) and amplitudes (μV) of the potential shift in the inter-peak interval N2P3, associated with stopping the running motor program of manual movement (Stop-Signal task), Me (25%; 75%)

Leads	Latency	Amplitude
C4	292 (275;316)	2.80 (1.14;1.76)
P3	292 (276;318)	2.06 (1.39;1.93)*
P4	297 (278;319)	1.72 (1.02;1.96)

Notes: * interhemispheric differences, $p \leq 0.05$.

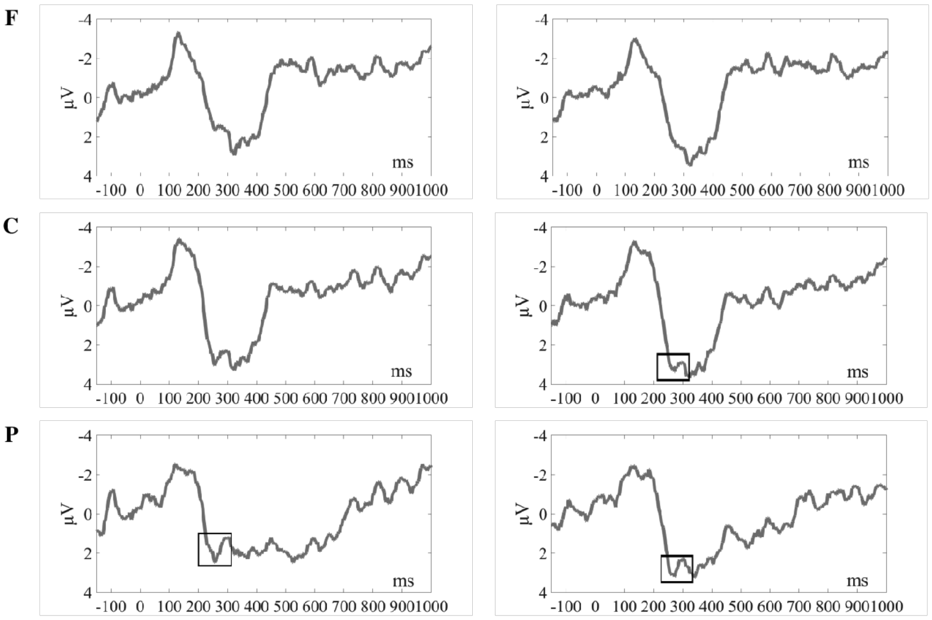

Figure 4. Schemes of event-related potentials in the frontal (F), central (C), and parietal (P) leads, associated with stopping the running motor program of manual movement in women

Notes: The area of the potential's shift in the inter-peak interval N2P3 is observed in the square; * interhemispheric differences, $p \leq 0.05$.

Thus, the performance of the motor task in the stop-signal task paradigm was accompanied by a predominance of the N2 component latency in the parietal cortex areas, especially in the right hemisphere, and the amplitude of the P3 component in the frontal area of the left hemisphere. Bilateral cortex response in terms of the P3 component latency and the inter-peak amplitude of the P2N2 ERP interval were also revealed. A local potential shift in the N2P3 interpeak interval was recorded in the right central and parietal cortical areas with a higher amplitude in the left parietal area.

Discussion

Our study revealed the specific amplitude-temporal characteristics of women's cortical responses associated with the motor response in the Stop-Signal task paradigm. An increase in the fronto-parietal gradient of latency of the N2 negative component was established. The longest delay (or latency) of the N2 component was recorded in the parietal leads, especially in the right hemisphere. Such topography is obviously due to the fact that the parietal cortex areas participate in the processes of sensory-motor integration [21] and the internal representations update based on new sensory information to initiate [22] or suppress actions [23]. It should be noted that some authors more often associate N2 with the occurrence of conflicts in information processing, such as a conflict of response or deviation from the expected results of actions [11,24]. Therefore, increasing the latency of such a component may indicate the occurrence of conflict during the processing of sensory information or even the development of inhibition of initiating subsequent actions [11].

The results of other authors state that N2 and P3 are usually greater in inhibition action than in "Go" responses [25]. The latency of the P3 component and the inter-peak amplitude of the P2N2 interval did not show interhemispheric differences, which may be a reflection of a certain generalization of brain processes that are often observed in this gender group.

The inter-peak amplitude of the N2P3 interval was higher in the left frontal lead. According to Fonken [26], the involvement of the frontal cortex modulates and can facilitate the cessation of motor response.

A local potential shift in the interpeak interval N2P3 was observed in the right central and parietal areas. In the Go-No-Go paradigm, similar potential shifts in "No-Go" samples relative to "Go" samples in the P300 interval in the central parietal areas are interpreted by some authors [27] as a P3b subcomponent. From a functional point of view, its occurrence is associated with the functions of the parietal cortex, namely, the categorization of stimuli and the renewal of working memory [28]. We assume that in the experimental Stop-Signal task, the presence of such a potential shift can be explained in terms of the model of multistage motor inhibition process [29]. In particular, during the time of the local potential shift recorded in our study, the participants could perform additional reassessment and categorization of the stimulus associated with the transition from the stage of "suspension" to complete "inhibition" [29]. In other words, it is possible that the brain processes associated with motor programming and action initiation during this time period chose the "Go" or "Stop" function.

Thus, the formation of brain activity in the Stop-Signal task paradigm occurred with significant use of inhibitory frontal control elements and an enhanced role of the right hemisphere; it required additional reassessment and categorization of the stimulus during the transition from "suspension" to complete "cancellation" (potential shift in the peak interval N2P3). Our analysis of the brain potentials recorded under the conditions of the Stop-Signal task paradigm leads to future interest in a more thorough study of such processes and a sex-based comparison of amplitude-temporal parameters of the event-related potentials associated with activation and inhibitory processes in the cerebral cortex.

Conclusions

1. Higher latency of the N2 component was found in the parietal areas of the cortex – especially in the right hemisphere – with higher amplitude of the P3 component in the frontal area of the left hemisphere during the cancellation of the motor program of manual movement.
2. A local potential shift in the interpeak interval N2-P3 in the right central and parietal cortical areas with higher amplitude in the left parietal area was revealed.

Disclosures and acknowledgements

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