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Ya. Subin, Master Student,
M. Chernykh, PhD Student,
I. Zyma, Dr. Sci. (Biol.)
ESC "Institute of Biology and Medicine", Taras Shevchenko National University of Kyiv, Kyiv, Ukraine

EEG DYNAMICS DURING EMOTIONAL FACE PERCEPTION UNDER THE VARIABLE PRESENTATION TIME: AN ERP STUDY

The face is one of the most significant elements of non-verbal communication, which allows humans to quickly get various types of information about a specific person. Therefore, understanding facial expressions is crucial for normal social interaction, as it lets us determine the emotional states and intentions of other people. The purpose of this study was to investigate the influence of the time factor on the happy and fearful facial expression processing, reflected in the structure and components of event-related potentials (ERPs). Accordingly, two parallel examinations were conducted with stimulus presentation periods of 500 ms and 100 ms. For the obtained data, two separate analyses (for happy and fearful faces) of the averaged ERP curves corresponding to different stimulus exposure periods were executed. The initial stages of processing (EPN, P3) demonstrated that the difference in the structure and amplitude characteristics of the ERP curve was not that significant, but it demonstrated an increase in attentional resources involvement and a strengthening of the primary emotional analysis. Later ERP components (N400, LPP) showed a more compelling difference, that reflected the complexity of semantic decoding, subsequent conscious evaluation, and processes related to decision-making. Thus, reducing the time of image display from 500 ms to 100 ms created the expected difficulties for the perception and processing of emotional facial expressions and was not sufficient for the normal course of these processes.

Keywords: ERP; EPN; P3; N400; LPP.

Introduction. The face is one of the most significant elements of nonverbal communication for human social interactions, that allows the rapid acquisition of various featuresof a specific person (age, gender, race, etc.) and the environment (for example, a frightened facial expression warns others of potential danger). Also, understanding facial expressions is crucial for determining the psycho-emotional states and intentions of other people. Therefore, the exchange of such social cues is important for the implementation of almost all life aspects [1]. Since the processing of emotional stimuli tends to be relatively fast and dynamic, the method of event-related potentials (ERPs) is one of the best options for studying these processes.

ERPs reflect bioelectrical activity in response to a certain event (sensory, motor, cognitive), which is the total activation of excitatory and inhibitory postsynaptic potentials generated by large populations of neurons. They are determined by averaging a certain number of segments of EEG data recorded with synchronization to a specific stimulus or event presentation. This method provides the best temporal resolution, but it lacks precision in terms of spatial characteristics [2].

Several parameters are distinguished in the ERP curve: latency (time indicator of the response appearance after exposure to a stimulus), amplitude (magnitude of voltage change), polarity (positive or negative), and topographic distribution over the scalp (for example, frontal, occipital). This activity is identified and named due to its polarity, approximate latency, topography (P300, early posterior negativity), as well as functional value (error-related negativity) [3].

Early posterior negativity (EPN) occurs within 250–350 ms, reaching its maximum in the occipital cortical regions. EPNs are usually associated with mechanisms of attention and emotional processing [4]. Thus, the influence of emotional facial expressions compared to neutral ones on the EPN modulation was demonstrated [5].

P300 (or P3) is a positive component of the ERP curve, which occurs approximately 300 ms after the presentation of the stimulus and can be registered in all areas of the cerebral cortex. It is usually recorded during task performance (for example, the oddball paradigm) in which frequent (standard) and rare (target) stimuli are presented, with larger amplitude values generated in response to the latter [6]. It can also be divided into two separate components – P3a and P3b. The first usually has a frontocentral localization and is an indicator of attention distribution. The second is characterized by a parietal-temporal distribution and is associated with memory-related processes [7].

The N400 (or N400-like activity) usually has a centro-parietal localization, reaching its peak around 400 ms. Originally described in linguistic research in the context of match/mismatch, it has also been found in paradigms that used faces as stimulus material. It is considered an index of general semantic evaluation [8].

The late positive potential (LPP) occurs in the time interval of 300–700 ms after the stimulus onset. In general, theamplitude increase effect was demonstrated for emotional stimuli (pleasant and unpleasant) compared to neutral ones [9]. In particular, this was observed for images of facial expressions (for example, happy and scared) [10]. However, some studies did not confirm similar effects on LPP amplitude values [11].

The purpose of this study was to investigate and assess the influence of the presentation time factor on the processing of happy and scared facial expressions, reflected in the structure and corresponding components of the ERP curve. Therefore, two separate examinations were conducted with different stimulus presentation periods: 1) 500 ms – often used and sufficient for normal discrimination and processing of facial expressions; 2) 100 ms – common exposure time reduced by five times.

Materials and Methods. 20 healthy volunteer subjects (10 men and 10 women;) aged 18 to 25 years participated in this study. EEG data recording was carried out using the hardware and software complex "Neurocom" (Kharkiv Aerospace Institute, Kharkiv, Ukraine). Electrodes were placed on the scalp according to the "10–20 %" international system.

The experimental structure was designed as follows: a resting state recording with eyes closed (3 min), a resting state recording with eyes open (3 min), and the presentation of two series of images (10 min each), during which the recording of cognitive ERPs was performed. The first series consisted of neutral and positive facial expressions, while the second series included neutral and negative stimuli.

The stimuli were selected from KDEF (Karolinska Directed Emotional Faces) [12] and FACES [13] databases. Valence-neutral photographs of human faces were selected as frequent stimuli, while positively- and negatively-valenced images (pictures of happy and fearful faces, respectively) were selected as rare stimuli. Passive oddball was chosen as a paradigm. The participants were instructed to "look carefully at the screen and perceive images of people's faces". Averaged ERP curves were constructed based on reactions to rare stimuli (emotional facial expressions), and frequent stimuli served to create a neutral context for a better understanding of the demonstrated emotional stimuli.

Rare stimuli were displayed in a random pattern with a probability of 30 % (tracking period – 3 s. ± 30 %, number of stimuli in one series – 100). The examinees were divided into two equal groups (10/10). In the first demonstration series of the stimulus material, the exposure periodwas 500 ms (4 men, 6 women; group 1), while in the second – 100 ms (6 men, 4 women; group 2). Processing of the obtained data was performed using the EEGLAB software package based on the MATLAB environment. Segments of 150 ms before and 1000 ms after stimulus onset were selected for analysis. Filtering (0.1 – 30 Hz), detection and rejection of artifact components, ICA analysis, and subsequent visualization of the obtained averaged ERP curves were performed.

Two statistical comparisons were performed: the first was between the averaged ERP curves corresponding to the presentation of 100 ms and 500 ms stimuli for rare positive stimuli; the second involved rare negative stimuli, respectively. The FDR criterion was used to identify areas with statistically significant amplitude differences ($p < 0.05$).

Results and Discussion. Comparison of responses to different valenced stimuli (happy and fearful facial expressions) of different presentation periods generally demonstrated a difference in the ERP structure and component amplitude values. A stimulus presentation time of 500 ms is widely used in research with emotional material and is quite sufficient for normal perception and cognitive processing. In contrast, reducing the display time to 100 ms created difficulties (lack of time) for these processes, which is reflected in the ERP structure differences mentioned above.

When the stimuli were exposed for 500 ms (group 1), in the time interval of 200–350 ms, positive components of the ERP appeared generally all over the scalp, with maximum values (Fig. 1) in the frontocentral cortical areas (Fz/Cz = +4.7 μV). Within these latencies (250–330 ms), a negative component also arose, reaching its maximum in the occipital regions (O1 = -6.5 μV for happy faces). Therefore, taking into account the temporal-occipital distribution (Fig. 2) and the latent period of the component, it is quite possible to assume that this wave corresponds to early posterior negativity (EPN).

It is known that EPN is a negative wave that occurs within 250–350 ms and has a temporal-occipital distribution [4]. This component is not always associated with a specific peak, and sometimes is defined as a decrease in amplitude within a certain time interval [14]. In our studies, EPN enhancement was demonstrated for both fearful and happy facial expressions compared to neutral ones. Therefore, it can be assumed that this component reflects the enhancement of emotional processing localized in the occipitotemporal areas (possibly including the superior temporal sulcus, occipital and fusiform gyri) [15]. However, such an EPN effect was also observed while displaying images of complex visual scenes and words [16]. This evidence gives reason to consider this component as one of the indices of general (non-specific) processing of emotions, which can reflect the use of attentional resources concerning visual stimuli (including emotional information integration and attention direction) [17].

Initially, the positive activity described above appears in the occipital areas, reaching its peak magnitude around 245 ms. In some studies, within the specified latencies, the P250 component (modulated by emotional facial expressions) is distinguished, which has a parieto-occipital (sometimes occipitotemporal) distribution [18] and a separate early frontocentral P3, or is indicated in general as an early P3 (P3a) [19]. Considering also the occurrence of EPN in this interval, it is quite difficult to distinguish these two components separately. In addition, in the studyby Schupp et al. [17], EPN was described as a negative deviation in the temporal-occipital areas and a corresponding change in polarity in the frontocentral regions.

P3a itself reaches its maximum in the mid-frontocentral areas and is considered a marker of directed attention [20]. Pieces of evidence of attentional redistribution have been associated with the detection of feature changes for rare stimuli; a greater discrepancy to standard stimuli will correspond to an increase in amplitude [6]. Given the above, activity in the time interval of 200–350 ms may correspond to the direction and use of attentional resources for rare (and at the same time motivationally important stimuli) to facilitate further stages of processing, as well as the initial stage of emotional determination of the stimulus.

In the case of the 100 ms presentation period (group 2), in the time interval of 200–350 ms similar ERP pattern was observed. Positive components were also most pronounced in the mid-frontocentral areas (Cz = 5 μV). In general, withinthe two groups, the difference between the amplitude value did not exceed 1 μV or was equal. In group 2, the EPN had a similar localization, reaching its maximum in the occipital areas (Fig. 2), demonstrating an increase in amplitude compared to group 1 (so the largest difference was 2.8 μV in the O2 lead for fearful faces perception). In this case, the increase in amplitude characteristics can be explained by an increase in attentional resources for stimulus processing and an enhancement of emotional processing. However, no statistically significant differences were found within 200–350 ms latency.

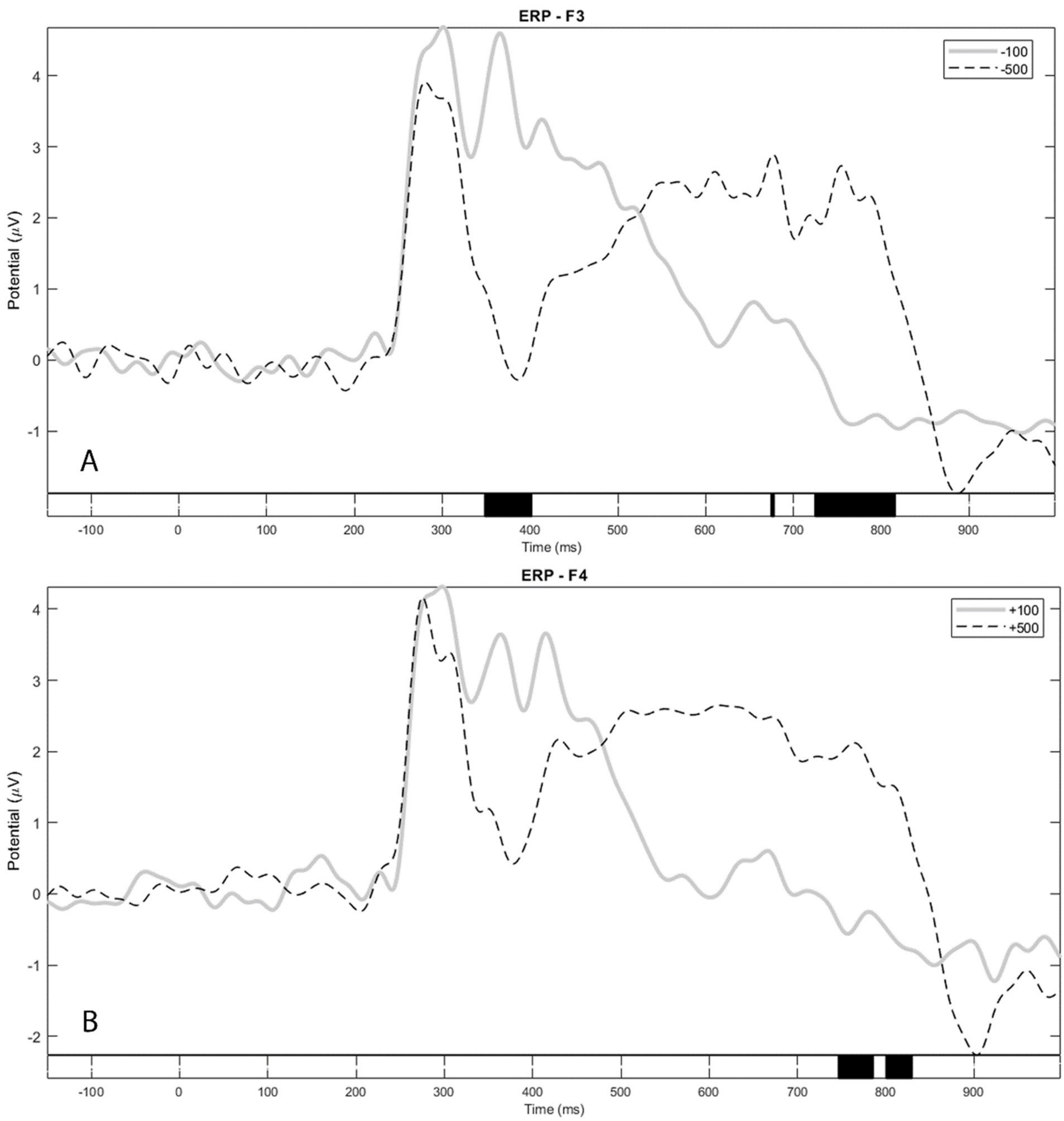

Fig. 1. Averaged ERP curves for fearful face perception in the left frontal area (A) and for happy face perception in the right frontal area (B), when presented in a neutral context. The response of group 1 is marked with a dotted black line, and the response of group 2 is marked with a grey line. Theregions of statistically significant difference are marked with black color ($p < 0.05$)

The ERP data of group 1 demonstrated the appearance of the negative component N 400, which reached its peak at 400 ms latency and was observed generally over the cortex. The largest amplitude values were registered in the occipital (O2 = -7.9 μV, happy faces) and parietal (-5 μV) zones (Figs. 2 and 3). For group 2, the N 400 was most pronounced in the occipital, parietal, and posterior temporal regions. The highest amplitude values were found in the occipital areas (O2 = -11.2 μV, happy faces). Also, the largest difference for this component was observed in the occipital zones (3–5 μV in two comparisons). However, it should be noted that when comparing data from the parietal and occipital areas of two subject groups, the first group demonstratedthe maximum amplitude values within 400 ms, while group 2 reached the peak values at about 500 ms (Fig. 3).

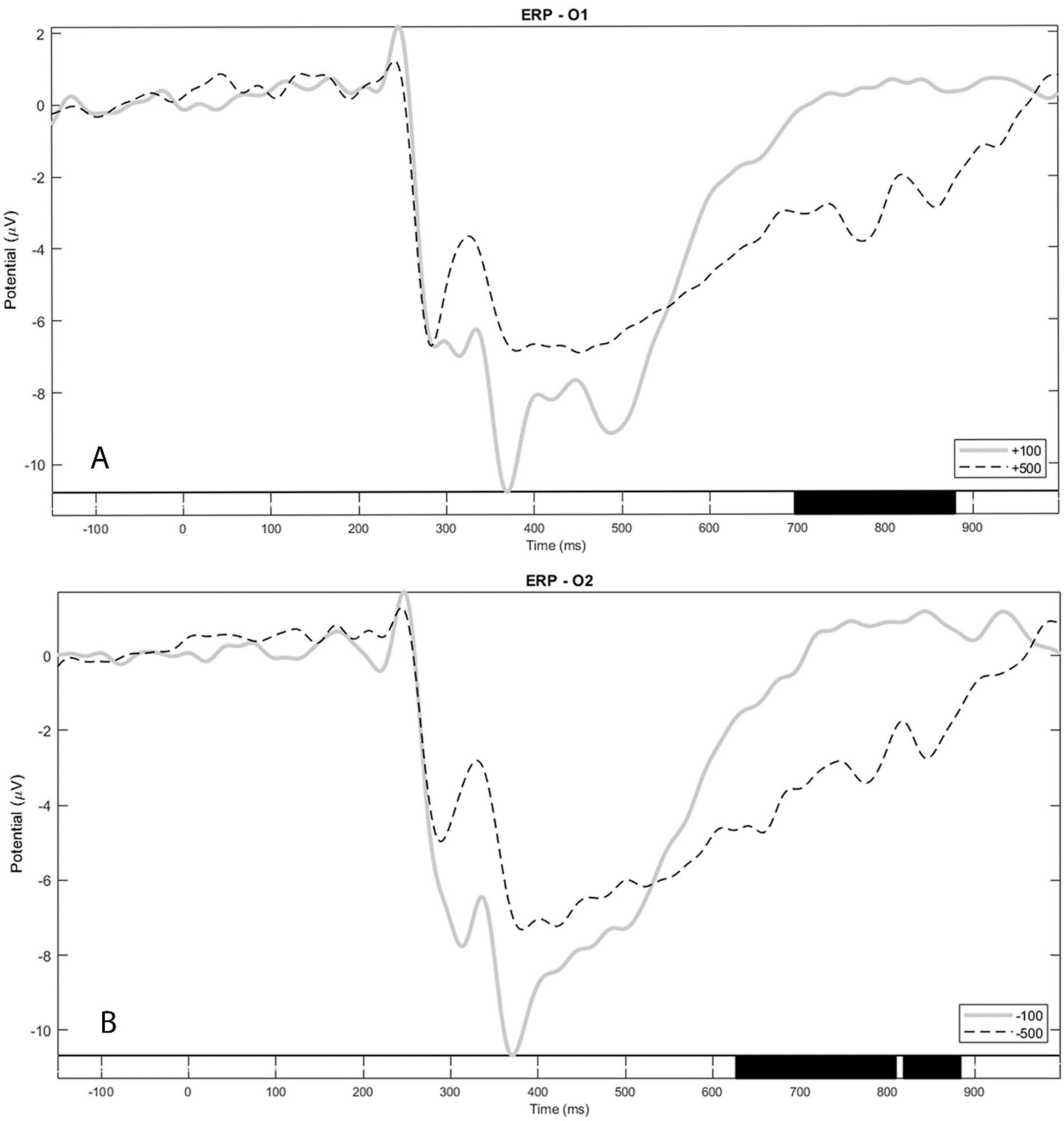

Fig. 2. Averaged ERP curves for happy face perception in the left occipital area (A) and for fearful face perception in the right occipital area (B), when presented in a neutral context. The response of group 1 is marked with a dotted black line, and the response of group 2 is marked with a grey line. Theregions of statistically significant difference are marked with black color ($p < 0.05$)

It is considered [8] that N400 is a general index of semantic search in available conceptual knowledge related to any meaningful stimulus. This search depends on already stored representations and received search signals created by the previous context. Thus, an increase in amplitude will correspond to an increase in semantic processing [21]. Taking this into account, the increase in N400 amplitude values in occipital areas during 100 ms stimulipresentation may correspond to the difficulties of obtaining the meaning of emotions in the created neutral context. It may also imply the recruitment of additional semantic information to compensate for the short duration of the stimulus presentation. In addition, 500 ms presentation is apparently a sufficient time interval for normal perception and discrimination of emotional stimuli, that is, it allows to involve a larger number of areas for semantic decoding and evaluation of information.

Next, in the time interval of 400–800 ms, a late positive potential (LPP) appeared in group 1, with maximum amplitude values (Fig. 1) in the frontocentral areas (Fz = 3.5 μV – happy faces). It is believed [9] that LPP characteristics are significantly affected by the emotional aspect of stimuli. Therefore, emotional stimuli cause an increase in amplitude values compared to neutral ones (for example, facial expressions, images of complex scenes, and gestures). It has been hypothesized that the LPP reflects the processing of emotion-eliciting stimuli, including conscious appraisal, enhancedworking memory encoding, and decision-making processes [17].

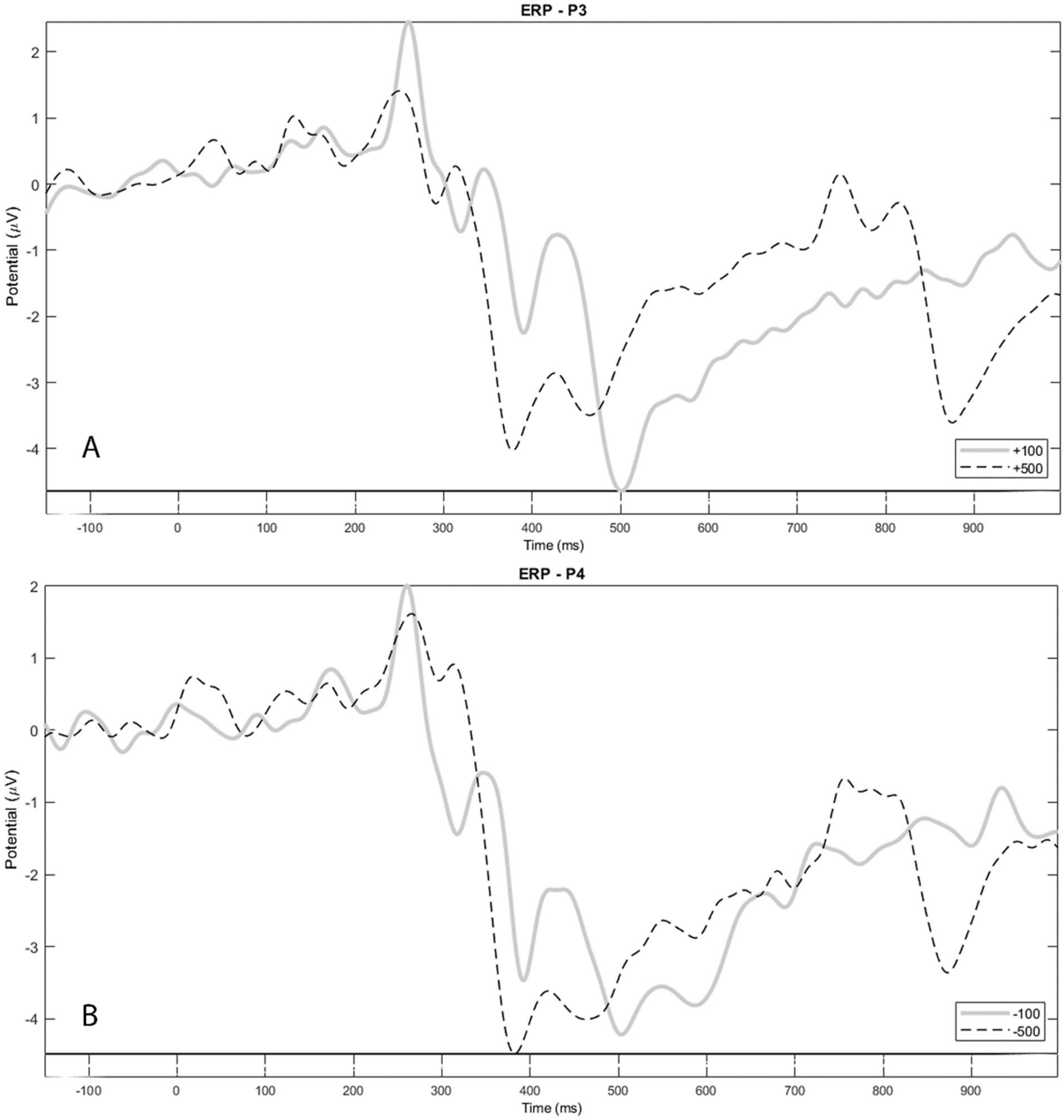

Fig. 3. Averaged ERP curves for happy face perception in the left parietal area (A) and for fearful face perception in the right parietal area (B), when presented in a neutral context. The response of group 1 is marked with a dotted black line, and the response of group 2 is marked with a grey line. Theregions of statistically significant difference are marked with black color ($p < 0.05$)

It can be seen that for group 2, the LPP lasts within 350–700 ms and reaches the maximum amplitude values (Fig. 1) in the frontal areas (F3 = 4.6 μV – fearful faces). Overall, the two comparisons showed higher LPP amplitude values for group 2, especially for fearful faces. Although LPP is usually described in the context of parieto-occipital localization, the importance of the prefrontal cortex in the generation of this component has also been demonstrated [22]. For example, areas of the ventrolateral and dorsomedial prefrontal cortex are associated with executive functions that reflect the processes of obtaining relevant knowledge about the stimulus and choosing among competing interpretations [23].

In general, in subjects of group 2, this component appeared earlier and lasted less than in group 1. The dependence of LPP time frames on the duration of stimulus presentation was also described in some studies: it can be expressed during the entire period of the stimulus presentation and several hundred milliseconds after [9]. Also, at the beginning of this component, in several cortical areas (F7, F3, F4, Fz, F8, C3, C4, Cz, T3, T4), statistically significant differences were found in the interval of 350-400 ms only for fearful faces. In these scalp areas, a positive peak occurred within the indicated latency (Fig. 1), while for group 1, N400 activity was observed (semantic analysis). Other statistically significant differences were found between 700–800 ms for fearful (Fp1, Fp2, F3, F4, Fz, F8, Cz, C4) and happy facial expressions (F7, F3, Fz, F4, C3, Cz, C4, T3). Similar differences were found in two comparisons in occipital regions within 650–900 ms (Fig. 1).

Conclusions

Thus, reducing the image presentation time from 500 ms to 100 ms created the expected difficulties for the perception and processing of emotional facial expressions (500 ms vs 100 ms) andthe 100 ms period is not sufficient for the normal course of these processes. At the initial stages of ERP (EPN, P3), the difference in the structure and amplitude characteristics was not so noticeable, but it demonstrates an increase in attentional resources and an increase in primary emotional processing. Later stages (N400, LPP) showed a more pronounced difference, which was manifested in the complexity of semantic decoding, subsequent conscious evaluation, and processes related to decision-making.

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**Я. Субін, магістр,
М. Черних, асп.,
І. Зима, д-р біол. наук
ННЦ "Інститут біології",
Київський національний університет імені Тараса Шевченка, Київ, Україна**

ДИНАМІКА ЕЕГ ПІД ЧАС СПРИЙНЯТТЯ ЕМОЦІЙНИХ ВИРАЗІВ ОБЛИЧ ЗА РІЗНОГО ЧАСУ ДЕМОНСТРАЦІЇ: ДОСЛІДЖЕННЯ ПОТЕНЦІАЛІВ, ПОВ'ЯЗАНИХ ІЗ ПОДІЯМИ

Обличчя є одним із найзначніших елементів невербальної комунікації, який дозволяє швидко отримати різноманітні типи інформації про конкретну особу. Тому розуміння виразів обличчя має вирішальне значення для нормальної соціальної взаємодії, оскільки дозволяє визначати емоційні стани та наміри інших людей. Метою цього дослідження було вивчення впливу фактору часу на процес обробки щасливих і наляканих виразів облич. Цей вплив відображений у структурі та відповідних показниках потенціалів, пов'язаних із подіями (ППП). Для цього було проведено два паралельні обстеження із часом демонстрації стимулів 500 мс та 100 мс. Для отриманих даних було здійснено два окремих порівняння (для щасливих і для наляканих облич) усереднених кривих ППП між різним часом експозиції стимулів. Початкові етапи обробки (EPN, P3) демонструють, що відмінність у структурі та амплітудних характеристик ППП не є настільки помітною, проте вказує на збільшення ресурсів уваги та посилення первинного емоційного аналізу. Пізніші ж етапи (N400, LPP) підтверджують значнішу різницю, що виявляється у складнощах семантичного декодування, подальшої свідомої оцінки та процесах, пов'язаних із прийняттям рішень. Таким чином, скорочення часу демонстрації зображень від 500 до 100 мс створює очікувані труднощі для сприйняття й обробки емоційних виразів облич та не є достатнім для нормального перебігу цих процесів.

Ключові слова: ППП; EPN; P3; N400; LPP.