DOI 10.1007/s11055-018-0672-7
Neuroscience and Behavioral Physiology, Vol. 48, No. 9, November, 2018

Properties of EEG Responses to Emotionally Significant Stimuli Using a P300 Wave-Based Brain–Computer Interface

I. P. Ganin, E. A. Kosichenko, and A. Ya. Kaplan

UDC 612.821.2, 612.821.8

Translated from Zhurnal Vysshei Nervnoi Deyatel'nosti imeni I. P. Pavlova, Vol. 67, No. 4, pp. 453–463, July–August, 2017. Original article submitted March 1, 2017. Accepted May 3, 2017.

A P300 wave-based brain–computer interface (BCI-P300) allows a person's focus of attention to a particular stimulus on the computer screen to be detected in terms of characteristic EEG features which discriminate reactions to target and nontarget stimuli. In the standard BCI-P300 paradigm, the subject's attention on one or another stimulus is dictated by clear practical interest in the stimulus, the experimenter's instructions, or the deviance of this stimulus resulting from clear differences from other stimuli. We report here studies of the characteristics of the perception of stimuli presented in the oddball paradigm with subjective emotional significance for the subject. The possibility of using the BCI-P300 to detect unclear foci of attention is tested. This technology can presumptively be used to assess people's ability to perceive emotiogenic stimuli, which may be useful for the instrumented diagnosis of accentuated states or impairments to emotional perception, for example in autism. The study in 14 subjects showed that the recognition accuracy of emotiogenic stimuli using the BCI on passive presentation (in the absence of a stimulus discrimination task) was statistically significantly greater than the random level by a factor of greater than two. Furthermore, the features of the components of potentials were identified on presentation of images with different contents and in conditions of low and elevated levels of attention to the stimuli being presented. The results confirm the hypothesis that the BCI-P300 paradigm can be used to detect unclear foci of attention on external stimuli in humans and supplement existing knowledge of the cerebral mechanisms responsible for the unconscious perception of subjectively significant stimuli.

Keywords: brain–computer interface (BCI), electroencephalogram (EEG), event-related potentials (ERP), visual attention, P300 wave.

Introduction. Brain–computer interface (BCI) technology allows people to learn to control external executive devices on the basis of extracting command features from the electroencephalogram (EEG) without activation of motor nerves or muscles [Wolpaw, 2007]. BCI technology is now most in demand in medicine, due to its potential to be used for controlling robotic devices – manipulators and wheelchairs [Alqasemi and Dubey, 2010; Lopes et al., 2011] – and for rehabilitation – as an additional set of procedures directed to restoring lost motor functions after trauma and stroke [Vidaurre et al., 2016], as well as providing such patients with the ability to communicate when speech and movement functions are impaired or lost [Nijboer et al., 2008]. To control the BCI, the user has to comply with instructions to carry out mental tasks in several functional states for which echoes can be extracted from the EEG signal and transformed into commands associated with these states.

In BCI based on the P300 wave (BCI-P300), selection of commands is based on analysis of event-related potentials arising in response to presentation of a set of external stimuli to the user. These BCI can consist of a matrix of letters and other symbolic objects or stimuli whose individual elements can be illuminated separately [Farwell and Donchin, 1988]. To select the desired symbol, the user has to pay active attention to its illumination, at the same time ignoring illumination of all other symbols. The moment at which the stimulus on which the user is focusing attention appears is accompanied by a specific reaction – increases

Department of Human and Animal Physiology, Faculty of Biology, Lomonosov Moscow State University, Moscow, Russia; e-mail: ipganin@mail.ru.

in the amplitudes of the P300 wave and other components of event-related potentials (ERP). Comparison of ERP responses to different stimuli allows the BCI to extract the user's focus of attention on the significant (target) symbol and execute a command previously linked with it, for example, printing the corresponding letter on the screen.

An important condition for the appearance of specific responses in the EEG, determining successful command selection in the classic BCI-P300 technology, is the significance to the user of the target stimulus specified by the instructions, which generates active selective attention to this stimulus. However, the P300 wave in EEG reactions can be induced by stimuli attracting a person's attention in an unclear manner, i.e., without prior instructions or which lack clear practical interest. This involuntary (automatic) attention can occur when these stimuli have subjective significance for the person, due to personal experience, emotional status, or biological need [Ohman et al., 2001]. For example, for respondents with particular dependencies, increases in the amplitude of ERP components were demonstrated in passive responses to stimuli associated with the dependence: presentation of images of chocolate [Asmaro et al., 2012] or drugs [Asmaro et al., 2014] to people with powerful predilections for chocolate or regularly consuming marijuana, respectively.

Thus, the stimulus presentation paradigm with the BCI-P300 is in many ways suitable for studies where the detection of EEG reaction characteristics for particular classes of stimuli and the predictive capacity of the EEG in terms of assigning one or another stimulus to particular classes are important. Stimuli with biological significance or emotional coloration induce reactions not requiring conscious processing [Ohman et al., 198; Ohman et al., 2001]. However, regardless of whether the process of perception of such stimuli is conscious or not, they are significant for the subject, thus being discriminated from other background stimuli, and can therefore regarded as significant (or "target") in the context of the BCI. This opens up the possibility of instrumented detection of target or emotionally significant stimuli in terms of specific components of the EEG reaction.

Selecting stimuli for the BCI-P300 in this way and modifying some details of the methodology allowed us to create a system for recognition at the level of unclear foci of attention rather than voluntary intentional commands.

Such involuntary displacement of attention to a particular stimulus can result from the psychophysiological characteristics of the individual and his or her personal experience, so systems of this type can be used as additional means for the instrumented diagnosis of states due to the subject's psychoemotional status and, perhaps, various mental disorders.

In particular, these systems can be used for the automatic detection of states of increased arousal in people working in the responsible professions with high emotional loadings [Singh et al., 2015]. It is also known that emotiogenic stimuli can have different effects on the focusing of attention in subjects with severe anxiety disorders, inducing differences in ERP as compared with nonanxious subjects [Wang et al., 2013]. Furthermore, impairments to the recognition of emotions and memory for faces have been demonstrated in subjects with clinically high risk of development psychosis [Skugarevskaya and Khomenko, 2013] and such mental disorders as autism [Hobson et al., 1988]. Impairments to the mechanisms of social-emotional perception are characteristic not only of individuals with autistic disorder, but are also seen in subclinical signs of autistic behavioral features where, as in autism, the electrophysiological features of the perception of emotiogenic stimuli are identified [Stavropoulos et al., 2016].

Thus, the aims of the present work were to identify the features of ERP in response to presentation of subjectively significant stimuli to humans in the absence of active attention to them due to instructions and to test the hypothesis that the subject's attention to the subjectively significant stimuli can be detected on the basis of BCI-P300 technology.

Experimental verification of hypotheses used presumptively significant stimuli consisting of two standardized basic photographic images of a neutral stimulus and an emotional stimulus: one consisted of photographs of different themes and subjects and the other included only photographic images of human faces. Assessment of the subjective emotional significance of the stimuli presented to each subject was based on personal questionnaires.

Methods. A total of 14 healthy subjects aged 19–25 (median 21) years took part in the study – five men and nine women. After familiarization with the details of the study, all subjects signed informed consents. The study was approved by the Bioethics Committee, Lomonosov Moscow State University.

Visual stimuli were presented sequentially using the oddball paradigm at the center of a 24″ LCD monitor with angular dimensions of 36° × 23°. Stimulus material consisted of photographs of human faces (Psychological Image Collection at Stirling, PICS [Hancock, 2008]) or photographs of different themes and subjects (International Affective Picture System, IAPS) [Lang, 2008]). Stimuli of size 9.2° × 13.8° (faces) and 12.9° × 9.6° (images) were presented on the dark gray background of the screen. Stimulus presentation duration was 200 msec and the interval between two neighboring stimuli was 500 msec during which the screen was empty. EEG traces and stimulus presentation were run in BCI2000 (www.bci2000.org) [Schalk, 2004]. The study included a total of three blocks, each of which was divided into 10 EEG traces with stimulus presentation:

(1) "Passive attention. Faces." Subjects were instructed to watch the center of the screen, where the stimuli appeared so as to see them clearly. Subjects were also told that they would then have to perform some task with the stimuli that they saw. Stimuli were photographs of human faces from the PICS collection.

(2) "Passive attention. Images." The instruction was analogous, but stimuli were images from the IAPS collections.

(3) "Active attention." One of the images at the beginning of the trace was designated the target and the subject was instructed make a clear mental note of the moment at which the target stimulus appeared. Stimuli were the same set of images from the IAPS collection as used in block (2).

Stimuli for each block were grouped into sets of six for each trace. The order of stimulus sets in all traces within each block was specified randomly for all subjects. Stimulation was delivered as sequences of stimuli, each of which included presentation of all six stimuli in the set once each in random order. One trace contained 10 stimulus sequences, corresponding to presentation of each of the six images 10 times in random order. In total, each was block thus consisted of presentation of 600 stimuli. The order of the blocks was alternated randomly for all subjects with the condition that block (3), with active attention, was always last.

Stimulus sets were formed in such a way that each set contained images with different emotional colorations, most of which were neutral, while one or two could carry different (positive or negative) emotional colorations for the subjects. After completion of the first two blocks and before starting the last block, subjects evaluated all the images seen on a visual analog scale. Images were sequentially presented on the screen for 1000 msec, after which the subjects had to assess the image by placing a mark on a scale of length 100 mm with the extreme values "Did not produce any emotion" / "Produced emotion." The group of emotiogenic stimuli in each block was formed on the basis of the results of the subjects' subjective assessment of the stimuli: the image with the highest points score on this scale was regarded as emotiogenic and was taken as the minimum threshold calculated for each subject. In block (3), the target stimulus in each trace was always the most neutral image, which was also monitored after subjects completed the scales. Thus, the first two blocks provided for analysis of ERP in response to emotiogenic stimuli in conditions of the passive attention paradigm and the third block for analysis of ERP with an increased level of attention to the task, both for emotiogenic stimuli outside the focus of attention and for neutral target stimuli to which attention was focused by instruction.

The EEG was recorded in 24 channels: F3, Fz, F4, FC5, FC1, FC2, FC6, C3, Cz, C4, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, PO7, POz, PO8, O1, and O2. The combined reference electrodes were positioned on the mastoid processes. ERP analysis of the EEG signal after removal of oculomotor artifacts was by band filtration in the range 0.5–20 Hz (Butterworth filter), followed by individual averaging of epochs for emotiogenic/target stimuli and nontarget stimuli. Before averaging, the number of epochs in the two classes was equalized: a number of nontarget epochs was removed randomly from the EEG trace. Component amplitudes were calculated from difference ERP (emotiogenic/target minus nontarget) as maximal (P300, P200) or minimal (N170) values of the signal in an individually selected window (in view of the extensive variations in peak latencies). On average, the latency of the N170 component was 160–200 msec, that of the P200 component 200–300 msec, and that of the P300 component 300–400 msec. When there were difficulties in identifying particular components, the subjects concerned were excluded from the analysis of that component. Components were analyzed in the leads where they had the greatest values: P300 and P200 in Cz and Pz, and N170 as the average of leads PO7, PO8, O1, and O2.

The classification efficiency of responses to emotiogenic and target stimuli was evaluated using the BCI-P300 approach with a classifier based on Fisher linear discrimination. Classification testing was by cross-validation with analysis of signals in the most typical leads for BCI–P300: Cz, P3, Pz, P4, PO7, PO8, O1, and O2. The classifier was trained using the whole set for all traces in one block, apart from traces used for testing the classifier; the next trace was tested at each iteration, with repeat training of the classifier on the set obtained after exclusion of data from the test trace. Training was performed using two classes – target (emotiogenic) stimuli and nontarget (neutral) stimuli. On testing the classifier at the training stage, weightings were applied to the test properties of the signal, and so-called "output" of the classifier was calculated for each of the six unique stimuli in the trace. By analogy with the classical BCI-P300 approach, "target" stimuli were those for which the "output" value, averaged for the 10 stimulus sequences in the trace, was maximal. If this stimulus was the emotiogenic stimulus, (blocks 1 and 2) or the target stimulus as specified by the task (block 3), the classification was regarded as successful. Results were analyzed in MatLab R2013b (8.2) (MathWorks) using scripts written for these studies and in Statistica 7.0 (StatSoft).

Results. Group average amplitudes for ERP components P300, P200, and N170 were analyzed to compare responses to presentation of emotiogenic stimuli in conditions of passive attention and active attention (with instructions to note target neutral stimuli) in blocks (2) and (3) (Fig. 1). The amplitudes of the P300 (in Cz and Pz) and P200 (in Pz) components, as well as the amplitudes of the N170 component in response to emotiogenic stimuli among neutral stimuli, showed no differences in the absence and presence of active attention to the stimuli being presented ($p > 0.05$, paired Student's test). The amplitude of the P200 component (in Pz) in response to emotiogenic stimuli in the task with active attention was 1.99 ± 0.20 μV (mean ± standard error of the mean) and was greater than that in the task with passive attention (1.13 ± 0.30, $t(12) = -2.44$, $p < 0.05$).

In block (3), with active attention, the amplitudes of ERP components in responses to emotiogenic stimuli outside the focus of attention and neutral stimuli which were identified by instructions to subjects as target stimuli were analyzed (Fig. 1). The amplitude of the P300 component in response to target stimuli in lead Cz was 4.39 ± 0.36 μV,

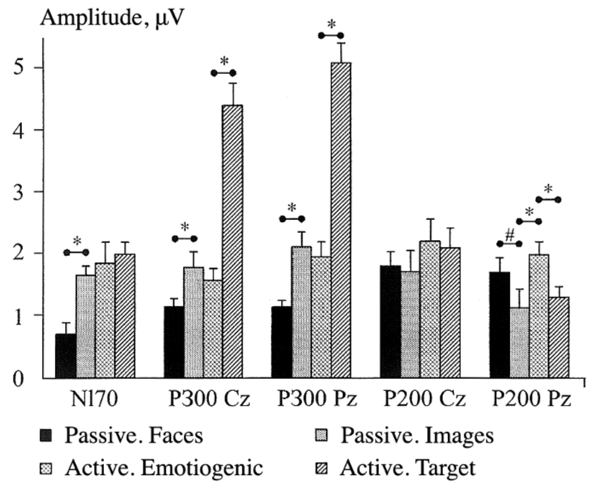

Fig. 1. Mean amplitude of the N170 (n = 13), P200 (n = 13), and P300 (n = 14) components in blocks with passive attention (emotiogenic stimuli) and in the block with active attention (emotiogenic and target neutral stimuli). Means and standard errors of the mean are given. $^{*}p < 0.05$, $^{\#}p < 0.1$.

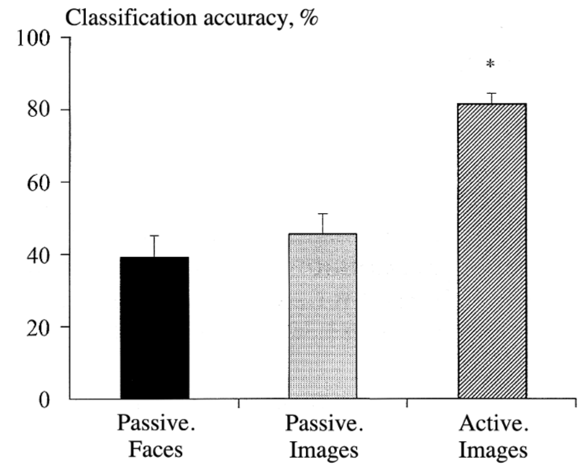

Fig. 2. Classification accuracy for emotiogenic (in blocks with passive attention) and target (in blocks with active attention) images for all subjects (n = 14). Means and standard errors of the mean are shown. *Difference from regime with passive attention ($p < 0.05$).

compared with 5.08 ± 0.31 μV in lead Pz, and was greater than that in response to emotiogenic stimuli (1.58 ± 0.19 μV, t(13) = 7.97, $p < 0.01$ and 1.95 ± 0.24 μV, t(13) = 10.45, $p < 0.01$, respectively). The amplitude of the P200 component (in Cz) and the N170 component did not differ between the target and emotiogenic stimuli ($p > 0.05$). However, the amplitude of P200 in lead Pz in response to emotiogenic stimuli was 1.99 ± 0.20 μV and was greater than that in response to target stimuli (1.30 ± 0.17 μV, t(12) = –2.22, $p < 0.05$).

The type of stimulus material in blocks (1) and (2) was compared with passive attention by analyzing the amplitudes of ERP components in responses to emotiogenic stimuli based on photographs of human faces and images (Fig. 1). The amplitude of the N170 component for image stimuli was –1.66 ± 0.15 μV and was greater than that for face stimuli (–0.70 ± 0.19 μV, t(12) = 3.98, $p < 0.01$). The amplitudes of the P300 component in leads Cz and Pz for image stimuli were 1.78 ± 0.25 and 2.11 ± 0.25 μV and were also greater than for facial stimuli (1.14 ± 0.14 μV, t(13) = –3.30, $p < 0.01$ and 1.13 ± 0.11 μV, t(13) = –4.82, $p < 0.01$, respectively). The amplitude of the P200 component in lead Cz showed no difference between the two types of stimulus ($p > 0.05$), though Pz showed a tendency to differences: P200 amplitude for facial stimuli was 1.70 ± 0.24 μV, while for image stimuli it was 1.13 ± 0.30 μV (t(12) = 2.04, $p = 0.06$).

Figure 2 shows results on the classification accuracy of target/emotiogenic stimuli in the three blocks. In blocks with passive attention, the mean recognition accuracy of the classifier for the most emotiogenic stimuli was 45.7 ± 5.5% and was not significantly different from that for the block with facial stimuli (39.3 ± 6.2%, Z = 0.84, $p > 0.05$, paired Wilcoxon test). Classification accuracy for target stimuli in conditions of active attention in blocks with image stimuli was 81.4 ± 2.9% and was greater than that for emotiogenic stimuli with passive attention (Z = 3.07, $p < 0.01$). Classification accuracy for regimes with passive attention was more than twice the random level of 16.7% (selection of one of six stimuli) and the significance of these differences was confirmed by the permutation test with random shuffling of epochs on training the classifier: $p < 0.01$ for both regimes. Despite the low mean accuracy, about a third of subjects in blocks with passive attention achieved accuracies of 60–80%. The classification accuracy of stimuli based on photographic images of faces correlated directly with the amplitude of the N170 component in response to these stimuli (R = 0.59, $p < 0.05$). In the blocks with active attention, accuracy correlated directly with the amplitude of the P300 component in responses to target stimuli (R = 0.58, $p < 0.05$ for Cz and R = 0.68, $p < 0.05$ for Pz).

Discussion. The aims of the present work were to identify the features of ERP in response to presentation of emotionally colored stimuli to humans without active attention to them and to explain whether and how reliably a passive attention reaction to such stimuli can be classified in the framework of existing BCI-P300 algorithms. The main result was that the ERP response to such emotiogenic stimuli had a number of features and even without active attention to these stimuli they could be extracted among other stimuli using the BCI with accuracy statistically significantly exceeding the random level.

In selecting a command using the BCI-P300, the user usually consciously focuses attention on the target stimuli, following instructions to count the number of presentations, ignoring nontarget stimuli. Recognition accuracy for the target command generally approaches 90% [Guger et al., 2009; Ganin and Kaplan, 2014]. Modeling of this paradigm in the present study gave a mean classification accuracy for one of the six stimuli which the subjects consciously counted of more than 80%, which was significantly greater than the random level of classification (17.6%). At the same time, the mean classification accuracy of the most emotiogenic stimulus of each set presented in blocks with passive attention, when the subject was not instructed to count any particular stimulus, was no greater than 46%, i.e., about half the accuracy in the block with active attention (Fig. 2). The quite high classification accuracy when subjects paid active attention to stimuli as determined by EEG responses, as demonstrated by ourselves and in other studies, appears to be determined by the direct relationship between the extent of the P300 component and the significance of the stimulus, as instructed, in the context of the operator task [Picton, 1992].

In turn, the significant but low values of classification accuracy for emotiogenic stimuli may be due to the low amplitudes of P300 and other ERP components in responses to stimuli presented without prior instructions, i.e., without the context of the recognition task. This is supported by the existence of a significant correlation between the detection accuracy of emotiogenic/target stimuli in the BCI and the amplitude of P300 only in the block with active attention, in which P300 for target stimuli was more than double that for emotiogenic stimuli (Fig. 1). The sensitivity of P300-based technology is evidently conserved even when the subject does not consciously focus active attention on the stimulus if its deviance in some way significant for the subject is preserved and if this stimulus is perceived at the unconscious level [Polich et al., 1989; Bernat et al., 2001]. Emotiogenic stimuli are known to induce specific EEG responses due to increased levels of attention to such stimuli, which is apparent as increases in the amplitude or the appearance of particular ERP components [Schupp et al., 2003]. The more than twofold increase over the random level on classification of emotiogenic stimuli is evidence that ERP reactions can be used in BCI-P300 technology for detection of the subjective significance of test stimuli, i.e., the occurrence of attention not apparent to the subject.

In the most widespread approach, including in the present studies, the BCI-P300 classification algorithm does not use a priori information on specific components, analyzing ERP during the time window after stimulus delivery. Classification accuracy is therefore determined by the overall set of all components whose amplitudes for emotiogenic/target stimuli differ from the amplitudes of nontarget stimuli. The studies reported here show that the most informative components for classification of EEG reactions to different types of stimulus are the ERP components N170, P200, and P300. The P200 component showed the most interesting effects in relation to emotiogenic stimuli.

In particular, in the task used in the present study, which is somewhat similar to the three-stimulus oddball paradigm [Katayama and Polich, 1999], P200 amplitude in response to emotiogenic stimuli outside the focus of attention was greater than in the task with passive attention to the same sets of stimulus material (Fig. 1). On the one hand, in the block with active attention, subjects received the instruction to note the target stimulus, and this task could attract the main attention resource to processing target but not emotiogenic stimuli. On the other hand, in the block in which subjects passively observed stimulus presentation, the overall level of attention to stimuli was lower, as there were no active stimulus discrimination tasks. These differently directed effects could arise because ERP amplitude in response to emotiogenic stimuli could be greater in one case or the other, or could be the same, if these factors compensated for each other. However, the higher level of attention to the task evidently led to clearer differences in responses to emotiogenic and neutral stimuli, while the processing of emotionally significant stimuli occurred independently of the processing of target stimuli. This is consistent with results reported in [Asmaro et al., 2012; Asmaro et al., 2014] and supports the ability of emotionally colored stimuli to evoke responses in conditions of conscious processing of the target stimulus [Ohman et al., 2011].

Another important result in relation to the P200 component is that in block (3) its amplitude in response to emotiogenic stimuli outside the focus of attention was greater than in responses to the target neutral stimuli which the subject had to note (Fig. 1). Although P200 is a component with considerable similarity to P300 and given that both are sensitive to the stimulus having target signs [Luck, 2005], the P200 component reflects not only processing of the characteristic signs of the stimulus, but is also connected with the processes of perception of emotionally colored stimuli [Carretie et al., 2004]. This sensitivity of the P200 component to the existence of involuntary attention to the emotiogenic stimulus, particularly at high levels of attention to the stimuli being presented, allows this component to be regarded as a potentially significant characteristic for detection of an unclear focus of attention to emotiogenic stimuli. For technical reasons it was not possible to analyze classification accuracy separately for emotiogenic stimuli in block (3) with active attention to neutral stimuli, with the aim of comparing it with the accuracy for emotiogenic stimuli in block (2). However, the results presented here suggest that in block (3), with active attention, the accuracy for emotiogenic stimuli could be higher and could even correlate with P200 amplitude.

In this study, the amplitudes of the N170 and P300 components in blocks with passive attention in response to emotiogenic stimuli were greater for image stimuli (block 2) than for face stimuli (block 1) (Fig. 1). The use of stimuli based on images of faces is because some of the characteristics of ERP are linked with recognition of the face as a structure [Cauquil et al., 2000] and with differences in the emotional coloration of such stimuli [Sprengelmeyer and Jentzsch, 2006]. Differences in the amplitudes of components between the two types of stimulus can be explained by the clear fixation of gaze on the stimulus in the case of images, which is the most critical factor for N170 amplitude [Treder et al., 2011; Frenzel et al., 2011], for example because of the greater uniformity of the composition of stimuli based on photographs of faces than stimuli based on images containing multitudes of details. A higher amplitude of this negative component on subthreshold stimulus presentation for object stimuli than for face stimuli was also seen in one study [Mitsudo et al., 2011]. Classification accuracy for images was also somewhat higher than for photos of human faces (although differences were not significant), which appears to be due to the higher amplitude of ERP for images. However, correlation with accuracy was found only for the N170 component in the block using photographs of faces. This component had specificity for processing of stimuli based on images of human faces [Cauquil et al., 2000], its amplitude usually being greater for emotiogenic faces [Sprengelmeyer and Jentzsch, 2006], while use of these stimuli in the BCI-P300 even demonstrated increased recognition accuracy for target commands [Kaufmann et al., 2013]. The functional role of this component was confirmed in our study by its correlation with the classification accuracy of emotiogenic faces and the lower absolute amplitude values as compared with images can be explained in terms of its greater sensitivity to stimulus type itself (faces) than to the fact that it contains an emotional coloration, which is reflected in the differences between ERP analyzed here. In addition, the processes of affective processing are primary only when the corresponding emotional facial features can be detected quickly and easily [Mueller et al., 2017], so it is therefore possible that the differences in ERP amplitudes between facial stimuli and images seen in the present studies were due to less intense emotiogenicity of facial stimuli than image stimuli. In contrast to the other components, the amplitude of the P200 component (in Pz) was greater for facial stimuli than for image stimuli (Fig. 1), which on the one hand is confirmed by existing data on the processing of these stimuli [Rossion et al., 2003] and, on the other, increases the significance of the use of this component for detecting foci of attention to emotiogenic stimulus based on the BCI-P300 noted above. It should be noted that ERP correlates start to appear with this latency (about 200 msec) when attention is displaced from the unconscious level to the conscious [Genetti et al., 2009]. The absence of active involvement in the first two blocks appears to have been the most critical factor for the low amplitude of ERP components in these blocks: for example, a relationship between the level of awareness of the stimulus and ERP amplitude was demonstrated for facial stimuli [Genetti et al., 2009].

Despite the existence of a number of studies making attempts to classify visual stimuli in terms of their emotional coloring, including stimuli from the IAPS collection [Mathieu et al., 2013; Singh et al., 2013; Singh et al., 2015], the duration of stimulus presentation in all was 1–2.5 sec, which was significantly longer than in our experiments (200 msec with 500-msec intervals). The greater duration of stimulus presentation increased the time cost for data accumulation, which may be critical for systems for automatic detection of emotional foci of attention and is tedious for the user. Despite the fact that the mean parameters for classification of emotiogenic stimuli in conditions of passive attention in our study were not large, they were comparable with the results identified above in other similar reports, though often cannot be compared directly with each other because of the use of a binary classification in many studies (with a random level of 50%). It should also be noted that this study did not address the task of identifying the influence of the type of emotional coloration of the stimuli, while the stimuli being classified in many similar reports were discriminated in terms of the valency and strength of emotions. At the same time, the results obtained here, taken with the results of other studies on the characteristics of ERP produced in response to emotionally colored stimuli, allow the most suitable stimulus material, presentation paradigm, and classification technique to be selected, overall promoting creation of the most effective systems for detecting emotional foci of attention.

Conclusions

1. Classification accuracy for emotionally colored stimuli presented in the passive attention paradigm in the BCI-P300 context was more than double the random level and individual subjects achieved higher levels, as compared with the command selection accuracy in BCI-P300 with active attention to the target stimulus.

2. The amplitude of the P200 component in responses to emotiogenic stimuli outside the focus of attention was greater in the presence of higher levels of attention to the task. P200 amplitude was also greater in response to emotiogenic stimuli outside the focus of attention than in responses to target neutral stimuli when attention to them was clearly attracted on the basis of instructions given to the subjects.

3. The amplitudes of the N170 and P300 components in responses to stimuli with images with different themes and subjects were greater than in responses to stimuli with photographic images of human faces. At the same time, stimuli based on photographic images of faces had specific features in their emotional perception: the amplitude of the P200 component was greater than that for images and classification accuracy correlated directly with the amplitude of the N170 component.

This study was supported by the National Technological Initiatives Foundation “Neironet” Program.

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