ПСИХОЛОГИЯ

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EMOTIONAL CONTENT EXTRACTION AND COMPETITION FOR ATTENTIONAL RESOURCES IN HUMAN VISUAL CORTEX

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Abstract

In our visual environment, emotional stimuli play an important role. They provide pivotal information about potential danger or threat that trigger defensive actions, or, conversely, prompt approach behaviour when confronted with pleasant and appetitive stimuli. A long lasting debate revolves around the question as to whether emotional stimuli have the potential to attract attention involuntarily, and thus, bias attentional resources in their favour in order to gain preferential stimulus processing. Furthermore, it is not yet known to what extent that competition for processing resources relies on higher-order cognitive processes, such as the extraction of the emotional content of a certain image. In a series of four electrophysiological studies that we review here, we aimed to investigate to what degree attentional resource allocation towards emotional stimuli is linked to the higher-order process of emotional cue extraction. Our results strongly indicated that the speed at which emotional cue extraction can be performed influences the latency of the attentional resource bias in early visual cortex. Moreover, affective images are required to be displayed for sufficient time that allows for emotional content identification, in order to result in neural facilitation for emotional compared to neutral images in early visual areas of the human brain. The present findings open further insights into affective stimulus processing speed and highlight frequency tagging technique that allows extracting the so-called steady-state visual evoked potential as a powerful tool in investigating neural dynamics in visual cortex activity.

Keywords: human electroencephalography (EEG), steady-state visual evoked potentials (SSVEPs), event-related potentials (ERPs), N170, N1-EPN complex, attention-emotion interaction, temporal dynamics of competition for visual resources, emotional cue extraction.

In everyday life, the human visual system is confronted with a challenging amount of visual information projected onto the eye's retina. Due to the limited capacity of the visual system, not all information can be processed equally well and various visual stimuli undergo *neural competition* for a restricted amount of processing resources [1]. Notably, stimuli that convey emotionally significant information relative to other visual stimuli are considered strong competitors due to their intrinsic motivational significance resulting in the ability to attract attention, or "bias" processing resources involuntarily because of their behavioural relevance [2–4]. For example, an image of an angry face or a terrible car crash scene can capture attention even if we focus on other information in our visual environment. Several important questions arise with regard to neural competition between attention and visual emotional cues. What is the time course of competitive interactions for processing resources between emotional stimuli that act as distractors and other non-emotional stimuli within the focus of attention? Do different visual emotional stimuli produce similar distracting effects on attention in a comparable time course and magnitude? What is the time required for the brain to extract an emotional content of a stimulus and, hence, is there a certain presentation time of emotional cues necessary for attentional resources to be shifted towards those stimuli? Here we review a series of experiments that were conducted to shed further light on these important questions. Given the review character of this chapter, we will not focus on specific details of the experimental designs and analyses used and want to refer the interested reader for more details to the respective publications [5, 6].

Two types of visual stimuli which are commonly employed to study emotional content discrimination and its interplay with attention are emotional scenes (i.e., picture scenes from the International Affective Picture Set (IAPS, [7])) and faces. A wealth of studies in affective neuroscience have repeatedly shown that both types of these affective cues are associated with changes in visual event-related potentials (ERPs) reflecting the electrical activity of the brain evoked by visual stimuli and measured by means of electroencephalography (EEG). These ERP changes are related to the emotional content discrimination of affectively-laden picture or face stimuli following the stimulus presentation onset [8]. Interestingly, emotional face expressions and more complex image scenes seem to differ from each other on the speed at which their affective content can be discriminated. For example, one of the first robust neural markers of face discrimination [9; 10] that is also sensitive to facial affect [11–13] is the N170 component which occurs at about 140–180 ms following presentation of a face stimulus. The N170 has a negative amplitude peak over occipito-temporal electrode sites and has been reported to be more pronounced when emotional compared to neutral faces are presented [11–13]. Differently to the time range of emotional face discrimination, for more complex emotional scenes, one of the most commonly observed ERP components related to the discrimination of affective content, the so-called early posterior negativity (EPN), occurs later in time, developing about 200-360 ms after stimulus onset as a more negative amplitude deflection for emotional than neutral images [8, 14, 15]. The EPN serves as a robust indicator of extraction of emotional image content [16]. However, in several studies [8] emotional discrimination of affective IAPS is seen even earlier, already at the level of the N1 [17, 18], with a variation of the peak latency between 160 to 190 ms [19], and thus the neural signature of emotional cue extraction of IAPS images may be better described as early negativities [19], or an N1-EPN complex [20]. Taken together, these findings give grounds to suggest that these two types of emotional stimuli produce distinct effects on visual attention.

The previous evidence, with regard to distracting effects of emotional complex image scenes on visual attention, has suggested that affective images exert interference with a primary visual task at early stages of processing around 400 ms after the emotional image onset [21, 22]. The neural competition between the highly arousing emotional information and the concurrent visual attention task lasts for several hundreds of milliseconds. In a typical distraction paradigm utilized in those studies, participants were engaged in an attentional task in which they had to attend to constantly flickering and moving square dots and detect their occasional coherent motion (target), while ignoring distracting and task-irrelevant emotional or neutral complex images that appear in the background. The flickering dots that form the task elicit the steady-state visual evoked potential (SSVEP), a neural oscillatory response that has the same frequency as its driving stimulus and can be easily measured in EEG [23]. Importantly, the SSVEP provides a continuous measure for temporal dynamics of the competition for attentional resources in human visual cortex, because its amplitude increases or decreases dependent on whether attention is focused on the flickering stimulus or withdrawn, respectively [24, 25]. Notably, the findings revealed that the occurrence of task-irrelevant emotional relative to neutral background images resulted in a significant reduction in amplitude of SSVEPs driven by the task-relevant dots. The greater amplitude reduction with unpleasant and pleasant distracter images relative to their neutral counterparts reflected a withdrawal of attentional resources from the foreground task by affective as compared to neutral stimuli around 400 ms after their presentation for a period of time lasting up to 1 sec. Significantly, this timing of the emotional distraction effect in early visual areas was also paralleled in the behavioural data: detection of coherent motion decreased considerably following the presentation of emotional relative to neutral distracter images [21, 22]. Although these findings provided support for the view that emotional cues involuntarily attract visual attention and bias processing resources in favour of affective information, the role of affective content discrimination process in the time course of such attentional resource bias was less clear.

To provide an answer to the question as to whether different types of visual emotional stimuli, such as emotional faces and more complex picture scenes, produce dissimilar distracting effects on attention, i.e., can withdraw attention resources and produce distraction effects from the concurrent attention task at distinct speeds, we conducted an experiment utilizing similar distraction paradigm as described above (see Fig. 1). Crucially, we concurrently recorded and analyzed not only the SSVEP elicited by the task stimuli, but also the visual ERP response evoked by the appearance of the background distracting emotional images – faces and complex pictures (see [6] for more details). Such a combined measurement allows to examine, on the one hand, the attentional resource allocation towards flickering stimulus over extended time periods, and, on the other hand, the latency at which emotional content discrimination of the two types of distracter images occurs. Based on the previous findings cited above, we expected that affective discrimination should occur earlier for faces (at ~170 ms, as indexed by the N170 component) than for IAPS images (~200–360 ms, N1-EPN complex). Importantly, we hypothesized that the latency of the attentional shift toward task-irrelevant affective distracter images away from the concurrent visual task, as reflected in a greater SSVEP amplitude reduction for emotional compared to neutral distracter images, is not fixed in time but dependent on the type of stimulus and the speed with which its affective content will be extracted. In other words, is the time for the dynamic shift of attentional resources related to the latency of emotional cue extraction, such that emotional cue extraction precedes competitive interactions between the foreground task and the emotional distractor in visual cortex?

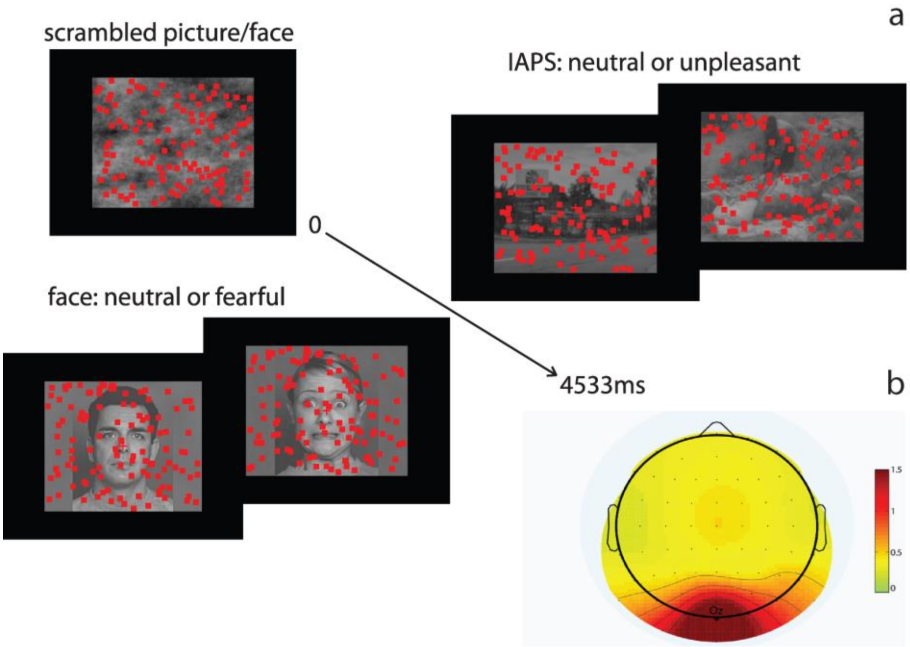

Fig. 1. Schematic layout of experimental design and iso-contour voltage map of the grand average SSVEP. a) A trial started with the presentation of the scrambled view of the image. After a variable time interval it changed to the intact view of either a neutral or a fearful facial expression or a neutral or unpleasant IAPS picture. Superimposed red squares constituted the foreground visual task. b) Topographical distribution of the grand average 15 Hz SSVEP amplitude across all subjects and conditions for the time interval of 1 sec before and 2 sec after the image change, with a clear peak around electrode Oz. For illustrative purposes, an example for unpleasant and neutral pictures is taken from the GAPED database [26]

The results indicated that attentional resources were withdrawn from the visual task only after the affective content for both stimulus types was identified. Importantly, the emotional content of facial expressions was discriminated faster than that of complex scenes. This was reflected in the emotional modulation of the N170 with faces and N1-EPN complex for IAPS images, which occurred, as predicted, at ~170 ms and 200–360 ms, respectively, as a more negative amplitude deflection with affective than neutral face/image contents (see Fig. 2). Crucially, this was accompanied by differences in the time course of SSVEP amplitude modulation: a greater SSVEP amplitude reduction with emotional compared to neutral background images occurred earlier for faces (~ 180 ms) than for IAPS pictures (~ 550 ms, see Fig. 3).

Taken together, the results from that experiment are consistent with emotion-related re-allocation of attentional resources following emotional cue extraction rather than being linked to a time-fixed shifting process. Specifically, the results showed that affective bias in visual resources at early visual areas as indexed with SSVEP amplitude modulation with emotionally-laden images follows affective content extraction. However, the question as to whether the process of emotional cue extraction is mandatory to drive the modulation of the SSVEP amplitude when affective images are viewed was not clear. We addressed the issue as to whether the period of time necessary for their discrimination can critically influence modulation of visual attention with emotional content in three further experiments.

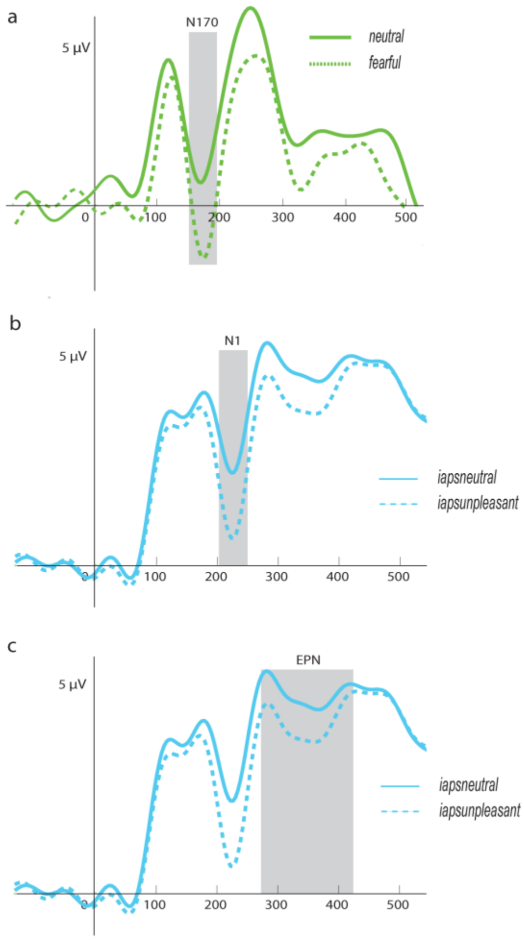

Fig. 2. Time courses of ERP waveforms for N170, N1 and EPN components in microvolts (μV). a) Grand mean N170 waveform averaged across all subjects for fearful (dashed line) and neutral faces (solid line) across parietal electrodes P9 and P10. b) Grand mean N1 waveform averaged for unpleasant (dashed line) and neutral pictures (solid line) across the cluster of 12 parieto-occipital electrodes (I1, I2, P7, P8, P9, P10, P07, PO8, PO3, PO4, O1 and O2). c) Grand mean EPN waveform averaged for unpleasant (dashed line) and neutral pictures (solid line) across identical electrodes as for the N1

The following three experiments took advantage of the main property of the SSVEP as a continuous measure of attentional resource allocation and its amplitude sensitivity to affective stimuli: SSVEP amplitude increases when emotional relative to neutral stimuli are presented [27, 28]. The goal was to determine whether the emotion-related SSVEP amplitude modulation during affective image viewing requires emotional content extraction of each individual image, or reflects the integration of emotional picture valence across the entire image presentation period [5]. To address this, rapid serial visual streams of negative and neutral images were shown at two different rates of 15 Hz (67 ms per image) or 6 Hz (167 ms per image). In both experiments, a new image was presented at each presentation cycle of the image stream (see Fig. 4, upper panel). Two alternative hypotheses were considered. If SSVEP amplitude changes were driven by the extraction of emotional content at each presentation cycle,

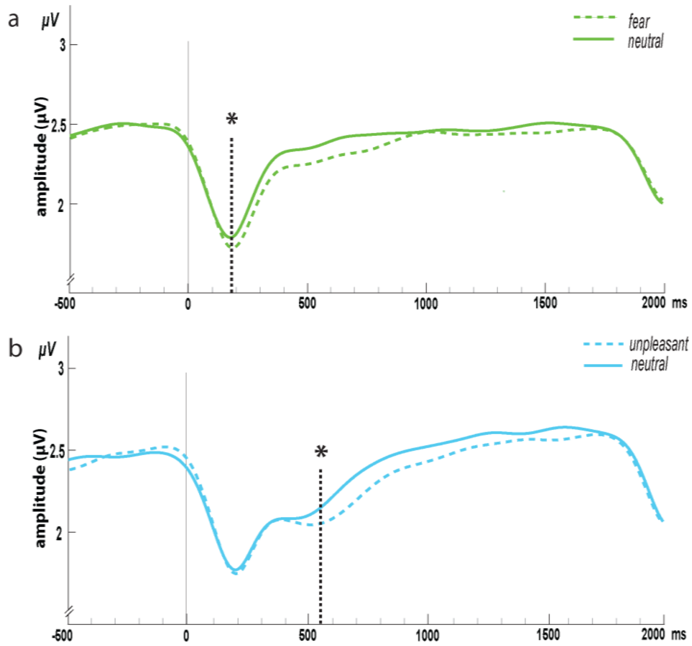

Fig. 3. Gabor filtered SSVEP time course for emotional face or IAPS background images. a) Grand average of SSVEP amplitudes for neutral (solid line) and fearful background faces (dotted line) at electrode Oz. b) Grand average of SSVEP amplitudes for neutral (solid line) and unpleasant IAPS pictures (dotted line) at electrode Oz. The vertical gray line at time point zero in both panels indicates the onset of the face/picture (change from the scrambled version of an image to the intact one). The vertical dotted lines with an asterisk show the onset of significant ($p < 0.05$) SSVEP differential amplitude effects between emotional and neutral background images

the amplitude modulations would only be expected with a rate that allows for emotional cue extraction for each individual image (around the N1-EPN complex latency, in the 140–160 ms range). Hence, at a presentation rate that does not provide sufficient time for the extraction of content, no SSVEP amplitude modulation as function of emotional valence was expected, given that faster rates are more likely to cause disruption of processing of individual images due to masking by the following and preceding images. Alternatively, if the rapid presentation of different images of the same valence category were instead integrated as either “emotional” or “neutral” across the entire stimulation period, shorter presentation times would suffice to drive differential SSVEP amplitude effects. Additionally, as a control study, “scrambled” image versions were shown at 6 Hz, with low-level physical parameters preserved but any content-related information distorted (see Fig. 4, lower panel).

In line with the idea that emotional cue extraction is required for deploying attentional resources to an emotional image, we found no SSVEP amplitude modulation for the 15 Hz stimulation rate. However, as depicted in Fig. 5, with the presentation rate of 6 Hz, SSVEP amplitude increased significantly when the picture stream changed from neutral to unpleasant pictures, and decreased when the presentation of images of negative content switched to that of neutral ones (lower panel). When we presented an entire stream of either emotional or neutral images, continuously greater

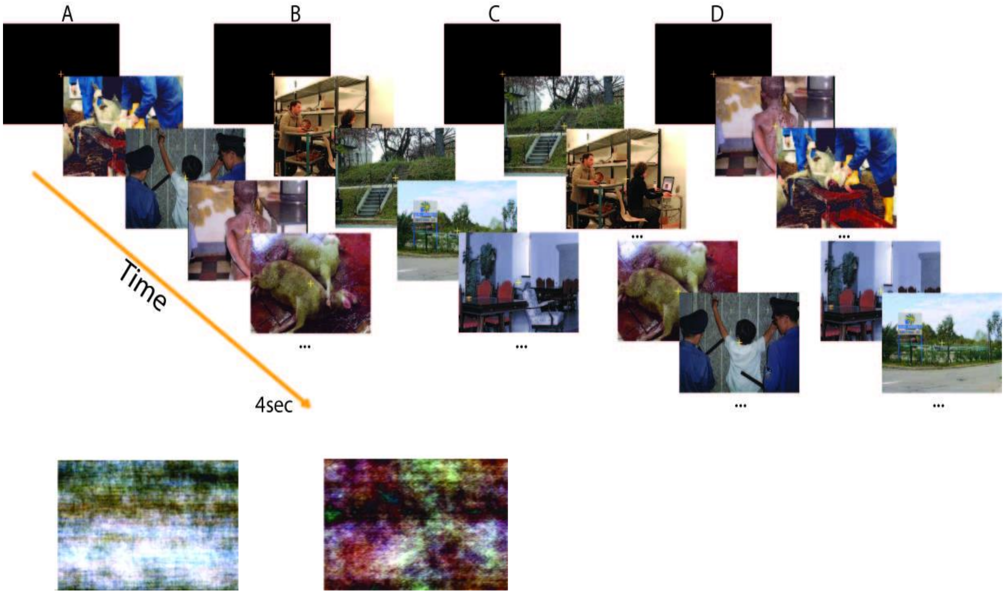

Fig. 4. Experimental design. Upper panel. Unpleasant and neutral picture scenes presented in a rapid visual serial presentation for ~67 ms (15 Hz) or ~167 ms (6 Hz, also used for the scrambled versions of the images). a) Trial without a change in affective content of images: only unpleasant pictures are shown. b) Trial without a change in affective content of images: only neutral pictures are shown. c) Trial with a change from unpleasant to neutral. d) Trial with a change from unpleasant to neutral. Lower panel. Left: Example of spectrally equivalent, phase-scrambled image with a neutral content. Right: Example of spectrally equivalent, phase-scrambled image with an unpleasant content. Examples for unpleasant and neutral pictures are taken from the GAPED database [26]

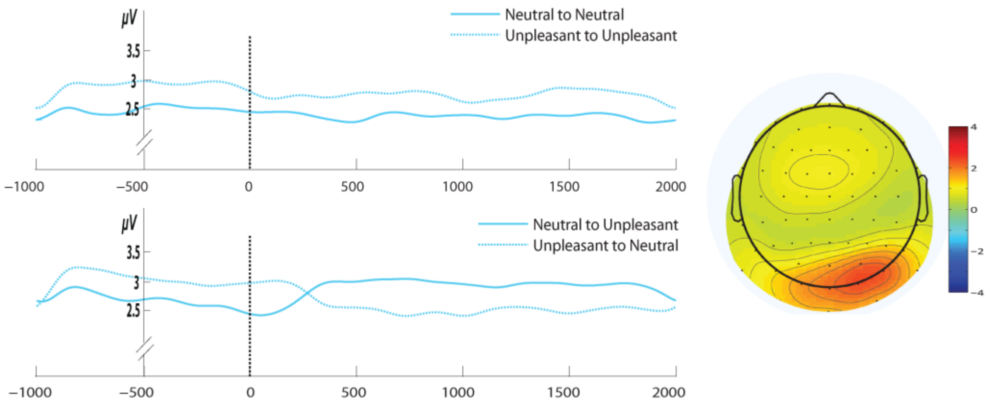

Fig. 5. Left: Gabor filtered time course of 6Hz SSVEP amplitudes for the stream of unpleasant and neutral pictures with a change in emotional content (upper panel) and without such a change (lower panel). Time point zero shows the onset of change in emotional content. Right: The grand average of 6 Hz SSVEP amplitude across all subjects and conditions for the time period of 1 sec before and 2 after the change in emotional content

SSVEP amplitudes were observed for affective compared to neutral images (upper panel). This result is insofar important, because it indicates that there is no habituation of the SSVEP to emotional content, resulting in a greater deployment of attentional resources to emotional relative to neutral stimuli for as long as they are presented. Additionally, we were able to demonstrate that SSVEP amplitudes did not differ between emotional and neutral images when we presented them in a scrambled version, not allowing to extract any content. Thus, our effects were not driven by possible differences in low-level features between the two image categories, such as spatial frequency or different colour content.

To summarize, the results from these experiments supported the idea that presentation duration for emotional pictures is critical for neural facilitation of early visual cortex activity that resulted in increased SSVEP amplitudes for emotional compared to neutral images. Interrupting content extraction by a new image, even if the image is of the same valence category, seems to disrupt individual content extraction. Thus, the findings clearly demonstrated that emotional cue extraction of each individual image, rather than an integration process of emotional valence, seems to be required to drive SSVEP affective modulations in early visual areas, and this emotional modulation seems to be elicited by differences in picture valence and not by their low-level featural composition. Hence, the establishment of the affective SSVEP amplitude modulation in early visual areas is likely to be contingent on the process of emotional information extraction.

In conclusion, our electrophysiological findings highlight the importance of affective cue identification in the mechanisms of attention capture with emotional stimuli when they pose as task-irrelevant distractors or are passively viewed. The data obtained strongly suggests that the attentional resource bias observed in early visual cortex in favour of emotional images is contingent on higher-level discrimination of visual affective cues. Firstly, the speed of affective cue extraction has an impact on the temporal dynamics of affective bias in visual attention. Secondly, emotional images need to be displayed for sufficient time allowing for emotional cue extraction, in order to drive affective modulation at early visual areas with SSVEP response. Thus, our results clearly demonstrate that at least in case of complex scenes, emotional images need to be displayed for sufficient time to have an effect upon attentional resource bias as well as upon neural facilitation in early visual cortex. This poses further questions for research regarding temporal limits of affective processing, thus challenging the view under which emotional stimuli are considered as processed automatically, even when presented subliminally, for an extremely short duration. Future research has now a powerful technique in hand to elaborate on these fundamental questions.

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Резюме

В.Д. Бехтерева, М.М. Мюллер. Восприятие эмоционального содержания и конкуренция за ресурсы внимания в зрительной коре головного мозга человека.

Эмоциональные стимулы играют важную роль в зрительном восприятии окружающей действительности, передавая головному мозгу ключевую информацию о потенциальной опасности или угрозе, что, в свою очередь, вызывает защитные действия или же, наоборот, реакцию приближения в случае, если указанные стимулы воспринимаются как приятные и привлекательные. В течение долгого времени ведется дискуссия о том, могут ли эмоциональные стимулы привлекать внимание человека на подсознательном уровне и тем самым завладевать ресурсами внимания с целью получить приоритет в восприятии по сравнению с другими стимулами. Кроме того, до сих пор неизвестно, в какой степени такая конкуренция за ресурсы внимания опирается на когнитивные процессы высшего порядка, например, в восприятии эмоционального содержания изображения. Нами проведена серия четырех электрофизиологических экспериментов, обзор которых приведен в настоящей статье, с целью изучить зависимость распределения ресурсов внимания под воздействием эмоциональных стимулов от высших процессов восприятия эмоциональной информации. Результаты нашего исследования доказывают, что скорость, с которой происходит извлечение эмоциональной информации, влияет на скрытое смещение фокуса внимания в первичной зрительной коре головного мозга. На восприятие аффективных изображений требуется определенное время, достаточное для идентификации их эмоционального содержания, чтобы облегчить распознавание эмоциональных образов от нейтральных в первичных зрительных областях головного мозга человека. Полученные данные расширяют существующее представление о скорости обработки эмоциональных стимулов и подчеркивают важность радиочастотного анализа, позволяющего определять так называемый зрительно вызванный потенциал устойчивого состояния в качестве мощного инструмента для изучения нейронной динамики в ходе активности зрительной коры головного мозга.

Ключевые слова: электроэнцефалографическое исследование человека (ЭЭГ), зрительно вызванные потенциалы устойчивого состояния (SSVEP), событийно обусловленные потенциалы (ERP), N170 и N1-EPN комплексы, взаимодействие внимания и эмоций, временная динамика конкуренции за зрительные ресурсы, извлечение эмоциональной информации.

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