

Time Course of Competition for Visual Processing Resources between Emotional Pictures and Foreground Task

Matthias M. Müller¹, Søren K. Andersen¹ and Andreas Keil²

¹Institut für Psychologie I, Universität Leipzig, Seeburgstr. 14-20, D-04103 Leipzig, Germany and ²National Institute of Mental Health Center for the Study of Emotion and Attention, University of Florida, Gainesville, FL 32611, USA

High-arousing emotional stimuli facilitate early visual cortex, thereby acting as strong competitors for processing resources in visual cortex. The present study used an electrophysiological approach for continuously measuring the time course of competition for processing resources in the visual pathway arising from emotionally salient but task-irrelevant input while performing a foreground target detection task. Steady-state visual evoked potentials (SSVEPs) were recorded to rapidly flickering squares superimposed upon neutral and emotionally high-arousing pictures, and variations in SSVEP amplitude over time were calculated. As reflected in SSVEP amplitude and target detection rates, arousing emotional background pictures withdrew processing resources from the detection task compared with neutral ones for several hundred milliseconds after stimulus onset. SSVEP amplitude was found to bear a close temporal relationship with accurate target detection as a function of time after stimulus onset.

Keywords: attention, biased competition, emotion, human EEG

Introduction

Adaptive behavior requires the rapid selection and evaluation of relevant stimuli. It has been proposed that stimuli in the environment compete for processing resources due to their limited availability (Desimone 1998). Emotional stimuli generate affective reactions and can be seen as strong competitors for visual processing resources. In this framework, emotional content may be regarded as 1 factor acting to facilitate a stimulus' representation at the cost of concurrent non-emotional stimuli (Keil et al. 2005). There is an ongoing debate, however, whether or not emotional stimuli attract resources in an automatic fashion, even when outside the focus of selective attention and conscious awareness (Vuilleumier 2005). Supporting automatic resource allocation to emotional stimuli, Öhman et al. (2001) have demonstrated that highly arousing phobic stimuli facilitate visual search, irrespective of the size of the search array. Similarly, electrophysiological work (Pourtois et al. 2005) has pointed to preattentive facilitation of orienting toward fear stimuli. Although this work demonstrates that affectively arousing visual scenes may attract attentional resources, it does not imply that emotional stimulus features are processed without attention or perceptual resources. Accordingly, recent functional magnetic resonance imaging (fMRI) experiments have suggested that the processing of emotional faces requires selective attention and suffers from demanding concurrent tasks (Pessoa et al. 2002, 2005). Given these data, 2 questions arise. First, how can the interaction between highly arousing visual information and a concurrent cognitive task be quantified and analyzed? Second, what is the time course of involuntary resource allocation to emotionally

arousing information? An impressive number of studies addressed the first question using a wide spectrum of experimental designs and emotional stimuli. Importantly, many studies of emotion-attention interactions have in common that emotional stimuli, mostly emotional faces, were spatially well separated from task stimuli (e.g., Pessoa et al. 2005). Although emotional faces are known to evoke overall weaker responses and rarely evoke an emotional experience (Davidson and Irwin 1999; Ochsner et al. 2002), the spatial separation between emotional face and task might have resulted in different spatial arrangements of the attentional focus, such as a division between noncontiguous zones of the visual field (Müller et al. 2003) or selective suppression of information at the center of the display (Müller and Hübner 2002). Thus, spatial arrangement of competing stimuli is crucial, which was addressed by using spatially overlapping stimuli in the present study.

The second question mentioned above relates to the time course of competition between a cognitive foreground task and emotional stimuli. Indirect evidence from behavioral studies has suggested that emotional information exerts interference with a primary task at early stages of processing and that interference may last for several hundreds of milliseconds (Most et al. 2005). There is, however, no direct evidence taken from a continuous measure of visual attention to the primary task as has been employed in the present study.

In the present study, we superimposed the task upon emotional images, such as mutilated bodies and attractive nudes and neutral pictures from the standardized International Affective Picture System (IAPS) (Lang et al. 1997a), and obtained valence and arousal ratings of the presented images from participants (see Materials and Methods). Arousing unpleasant and pleasant IAPS pictures are known to evoke strong emotional reactions (Lang et al. 1993). Furthermore, high arousing IAPS images strongly activate areas in occipital cortex, such as Brodmann Area 18 and anterior/inferior cortex (Lang et al. 1998; Bradley et al. 2003; Moratti et al. 2004), and this activation is considerably greater as compared with the activation evoked by emotional faces, which was comparable to the activation of neutral images (Bradley et al. 2003). Thus, competitive strength of high-arousing scenes may yield higher sensitivity to bias in favor of emotional content.

Frequency-coded steady-state visual evoked potentials (SSVEPs) to continuously presented randomly moving squares, flickering at 7.5 Hz were recorded. These squares provided a challenging foreground task, superimposed upon the pictures. The SSVEP is the electrophysiological response of the visual cortex to a flickering stimulus (Regan 1989). It has a sinusoidal waveform with the same temporal frequency as the driving stimulus, and its amplitude is substantially increased

with attention (Müller et al. 1998; Müller and Hübner 2002; Müller et al. 2003). Thus, SSVEP amplitude provides an objective electrophysiological tool to investigate attentional resource allocation to a flickering stimulus.

Previous studies that used inverse modeling to identify the cortical sources of the SSVEP attention effect found enhanced activity in early visual areas and areas of the temporal lobe when a flickering stimulus was attended (Hillyard et al. 1997; Müller et al. 1998; Müller et al. 2006). A more detailed picture of the sources that generate the SSVEP elicited by 6-Hz pattern-reversal stimulation was provided by a recent fMRI study from Di Russo et al. (2007). This study reported major contributions to the generation of the SSVEP from primary visual cortex (V1) and MT (V5) with additional activity in midoccipital (V3A) and ventral occipital (V4/V8) visual areas. A superimposition of these findings onto the areas that had been reported to be activated with emotional IAPS pictures (see above) seem to suggest that attending to flickering stimuli activate similar areas in visual cortex as watching arousing IAPS pictures. According to the biased competition model this should result in a strong competition for processing resources when both stimuli are presented together and even more so when they overlap spatially (Desimone 1998). Thus, if high arousing background pictures consume processing resources, we expect a reduction in SSVEP amplitude elicited by the foreground task compared with neutral background pictures.

A further advantage of the SSVEP is the ongoing waveform that indexes neural changes in attention continuously (Müller et al. 1998). By studying the time course of SSVEP amplitude changes after stimulus onset, we were able to investigate for the first time the duration of the competition for processing resources in visual cortex. Target detection rates as a function of time after stimulus onset were calculated for 3 successive time windows 1 s each as a behavioral index of the time course of competing interactions.

Materials and Methods

Subjects

Informed consent was obtained from 10 right-handed university students (5 females; 20–26 years of age) with normal visual acuity. The students received class credits for participation. The study conformed the Code of Ethics of the World Medical Association.

Stimuli

Stimuli were presented centrally on a 19-inch computer monitor with a refresh rate of 60 Hz (i.e., 16.67 ms). A total of 100 yellow squares

(each 0.46×0.46 degrees of visual angle) were superimposed upon color pictures from the IAPS (Lang et al. 1997a) subtending a viewing angle of 12.2×9.2 degrees at a viewing distance of 80 cm. Squares were distributed in a homogeneous but random fashion across pictures and flickered with 7.5 Hz (see Figure 1 for 2 examples with pleasant background pictures).

Squares were “on” for 5 frames and “off” for 3 frames. All squares were continuously in motion throughout the trial, and each square changed its position in a random direction by 0.04 degrees every frame of screen refresh (i.e., every 16.67 ms). On a random 25% of the trials, squares produced a 35% coherent motion (targets). This coherent movement could take place in 1 of 4 cardinal directions (up, down, left, or right) at random. In order to produce a difficult and demanding detection task, coherent motion lasted only for 2 successive cycles of 7.5 Hz (i.e., 267 ms). Such targets occurred unpredictably once or twice in a given trial, equally distributed across all experimental conditions and 3 successive time windows 1 s each. Minimum separation between 2 successive targets was 1000 ms, and the first possible period of coherent motion was 267 ms (i.e., 2 cycles) after stimulus onset. Squares and pictures were presented simultaneously and each trial lasted for 3067 ms. Fixation was facilitated by presenting a fixation cross at the middle of the screen.

For each valence category, 40 color pictures were selected based on normative valence and arousal ratings from the Self-Assessment Manikin (SAM; Bradley and Lang 1994) 9-point scale. According to these ratings, valence and arousal ratings for neutral pictures were 5.81 and 3.96, for pleasant 7.17 and 5.32, and for unpleasant images 2.47 and 5.92, respectively. Pictures were also controlled for visual complexity and luminance. JPEG size was used as a measure of perceptual complexity and was 546 ± 211 kb (pleasant), 572 ± 196 kb (neutral), and 566 ± 189 kb (unpleasant). Furthermore, in this picture set, neutral pictures were of similar picture content complexity, such as landscapes or group of people. This is important because earlier studies using IAPS often used neutral pictures with less complex content, such as simple household objects like a cup or a basket, which creates confounds in cross-category comparisons. Luminance was measured at fixation and for the entire screen and was 17.2 cd/m^2 on average. Luminance did not differ between categories at fixation and for the entire stimulus array.

All pictures were presented in randomized order. Over the whole experiment, each picture was presented 2 times with the restriction that they never occurred twice within the same experimental block, resulting in 80 trials per experimental condition. The experiment was divided in 8 blocks of 30 trials each. Subjects were instructed to ignore the background pictures and to respond accurately and fast to targets by pressing a button. Responding hand was changed halfway through the experiment, and the sequence of hand usage was counterbalanced across subjects.

Before the experiment, subjects performed 30 practice trials to get used to the stimulation and task. In the practice block, the number of trials with targets was 50% in order to have a higher number of targets for detection training. IAPS pictures used for practice trials were different from the ones used in the experiment.

After the experiment, subjects viewed the 120 different pictures again in pseudorandomized order to rate each picture on the dimensions of affective valence and arousal on the 9-point SAM scale

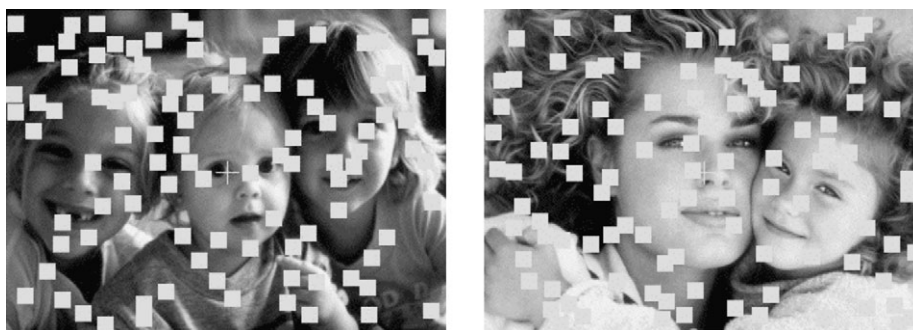


Figure 1. Example of 2 pleasant background pictures with superimposed squares. Background pictures were in color and superimposed squares were yellow.

Electroencephalography Recordings

Electrical activity of brain was recorded from 30 scalp electrodes mounted in an elastic cap (F3, F7, C3, CP1, CP5, P1, P3, PO3, PO7, PO9, O1, F4, F8, C4, CP2, CP6, P2, P4, PO4, PO8, PO10, O2, Fz, Cz, Pz, POz, Oz, and Iz and the right mastoid of the extended international 10–20 system) all referenced to the left mastoid. Vertical eye movements and blinks were monitored with a bipolar montage positioned above and below the left eye (vertical electrooculogram). Lateral eye movements were monitored with a bipolar outer canthus montage (horizontal electrooculogram). Electrode impedances were kept below 5 k Ω . The electroencephalography (EEG) was recorded with a sample rate of 250 Hz and a band pass of DC–100 Hz and stored on disk for off-line analysis.

Data Analysis: Behavioral Data and SAM Ratings

Only button presses occurring between 200 and 1000 ms after target onset were accepted as correct detections. For every subject, mean target detection rates and reaction times were calculated for each time window of 1 s, for each experimental condition. SAM ratings were tested by planned comparisons (paired *t*-tests). Target detection rates and reaction times were first tested by a repeated measures analysis of variance (ANOVA) comprising the factors of Valence (pleasant, neutral, and unpleasant) and Time (seconds 1, 2, and 3) followed by planned comparisons (paired *t*-tests).

Data Analysis: EEG

Individual trials were rejected from further analysis on the basis of blink or electromyography artifacts in the scalp channels or when excessive eye movements occurred. Due to the long epochs and these stringent rejection criterions, the mean rejection rate across all conditions was 40%. In order to ascertain the time course of SSVEP amplitude changes, artifact-free EEG epochs were averaged separately and algebraically rereferenced to averaged mastoids by subtracting one-half of the averaged signal recorded from the right mastoid from the averaged signals at each scalp site. The averaging epochs extended from 100 ms before to 3000 ms after stimulus onset. The 100 ms prior to stimulus onset served as baseline, and the mean amplitude was subtracted from each data point before transformation into frequency domain.

SSVEP amplitudes were extracted from the EEG signal by means of complex demodulation (Regan 1989; Müller et al. 1994). This procedure extracts a modulating signal from a carrier signal. The functions

$$\begin{aligned} x_s(t) &= \text{EEG}(t) \cdot \sin(F(\text{Hz}) 2\pi t(s)) \text{ and} \\ x_c(t) &= \text{EEG}(t) \cdot \cos(F(\text{Hz}) 2\pi t(s)) \end{aligned} \quad (1)$$

are first computed from the averaged EEG traces, $\text{EEG}(t)$. In Equation 1, it is assumed that the time is in seconds. Center frequency (F) is the driving frequency of the stimuli, here 7.5 Hz. Then, a 2-Hz low-pass filter was applied. This procedure resulted in a temporal resolution of 500 ms (full width at half maximum).

The amplitude $A(t)$ of the modulating signal is then determined according to:

$$A(t) = 2 \times \sqrt{x_{s\text{filt}}(t)^2 + x_{c\text{filt}}(t)^2}. \quad (2)$$

Similar to our previous study in which we investigated the time course of SSVEP amplitude as a function of spatial shifting of the attentional spotlight (Müller et al. 1998), mean SSVEP amplitudes were calculated for sequential 50-ms bins of the complex demodulated waveform (resulting in overlapping time segments in time domain) starting at 250 ms and lasting to 1250 ms after stimulus onset for Oz. This electrode exhibited the overall greatest SSVEP amplitudes for all subjects across all experimental conditions (see Figure 4). Given the temporal resolution of ± 250 ms, the first bin in frequency domain integrated data from stimulus onset to 550 ms after stimulus onset in time domain. These successive 50 ms averages for pleasant and unpleasant pictures were tested against neutral pictures by means of paired *t*-tests in order to determine the first and last bin that showed a significant amplitude change relative to neutral.

To depict the topographical distribution of maximum SSVEP amplitude across all conditions and the effect of arousing background

pictures upon the foreground task, voltage maps were plotted using the spherical spline algorithm of Perrin (1989).

Results

SAM Ratings

Based on the 9-point SAM Scale (see Materials and Methods), subjects rated unpleasant ($t_9 = 7.6$, $P < 0.0001$) and pleasant ($t_9 = 8.1$, $P < 0.0001$) pictures significantly more arousing as opposed to neutral pictures and unpleasant pictures were slightly more arousing as pleasant ones ($t_9 = 2.6$, $P < 0.05$). Valence ratings differed significantly between each picture category ($t_9 = 7.9$ [neutral vs. pleasant], $t_9 = 8.0$ [neutral vs. unpleasant], $t_9 = 14.6$ [pleasant vs. unpleasant] all P values < 0.0001), and unpleasant pictures were rated as most unpleasant.

Behavioral Data

The distracting effect of high-arousing background pictures upon the foreground task was reflected in target detection rates (Fig. 2).

The repeated measures ANOVA resulted in significant main effects of Valence ($F_{2,18} = 4.1$, $P < 0.05$) and Time ($F_{2,18} = 11.6$, $P < 0.001$). Target detection rates were significantly lower for pleasant ($59.62 \pm 3.9\%$) and unpleasant ($59.13 \pm 3.5\%$) as compared with neutral background pictures ($73.71 \pm 5.1\%$; mean \pm standard error [SE], respectively) during the first second ($t_9 = 2.4$ and 2.5 , P values < 0.05). For high arousing background pictures, target detection rates showed a steep increase from the first to the second time window after stimulus onset ($t_9 = 2.8$, $P < 0.05$ for pleasant; $t_9 = 6.8$, $P < 0.0001$ for unpleasant). This was not the case for neutral pictures ($t_9 = 1.6$, $P > 0.15$). During second 3, behavioral detection rates remained stable with no statistically significant difference compared with the second time window. Given the short duration of coherent motion, all subjects reported that the task was difficult and demanding, which required fully attending to the squares for best performance.

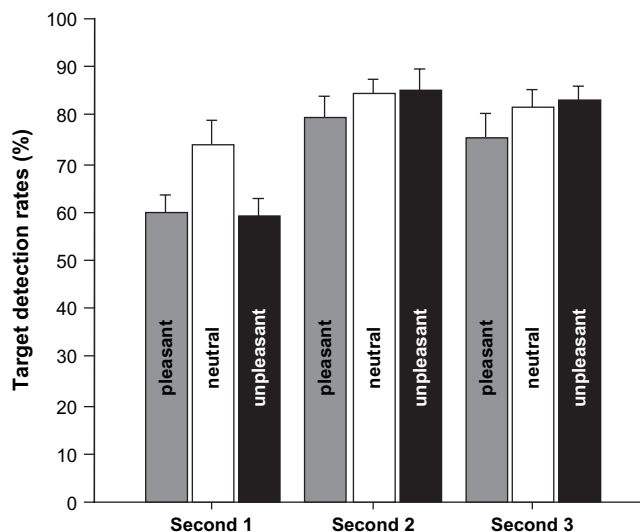


Figure 2. Mean target detection rates in percent and SE averaged across all subjects for pleasant (gray bars), neutral (white bars), and unpleasant pictures (black bars) for 3 successive windows of 1 s each.

With respect to reaction times, we found no such pattern. The repeated measures ANOVA resulted in a significant main effect of Time ($F_{2,18} = 8.8$, $P < 0.005$). Neither was there any significant difference between experimental conditions during the first second nor was there any significant difference between the first and second second for individual conditions. In general, subjects reacted faster for later targets as opposed to earlier ones (window 1: 604 ± 10 ms; window 2: 575 ± 10 ms; window 3: 561 ± 9 ms; mean \pm SE, respectively; window 1 vs. window 2 $t_9 = 3.9$, $P < 0.005$; window 1 vs. window 3 $t_9 = 3.9$, $P < 0.005$). This effect might be attributed to the fact that early targets during the first second right after flicker onset are somewhat harder to detect. On the other hand, the overall reduction in reaction times with the shortest times during the last second of stimulation indicates that subjects were attending to the display over the whole time period of stimulation.

SSVEP Amplitude

The principle of complex demodulation as used here is illustrated in Figure 3. The figure depicts the SSVEP for 1 subject at electrode Oz and the resulting complex demodulated waveform when this subject performed the task with unpleasant background pictures.

The complex demodulated waveform envelopes the baseline-to-peak amplitude of the SSVEP with a temporal resolution of 500 ms. The initial peak in the demodulated amplitude time series results from the decomposition of the visual evoked potential (VEP) to stimulus onset, which comprises the elements of background picture and squares onset plus flicker and motion onset of the squares. As in our previous studies with central stimulus presentation (Müller and Hübner 2002; Müller et al. 2006), the greatest SSVEP amplitudes were found at occipital scalp sites with a maximum at electrode Oz (Figure 4).

The baseline corrected time course of SSVEP amplitude changes after stimulus onset, averaged across all 10 subjects, is depicted in Figure 5 for pleasant, unpleasant, and neutral background pictures for 10 posterior electrode locations, electrode Fz, and a zoom-in for electrode Oz. As mentioned above and shown in Figure 3, the initial peak resulted from the decomposition of the stimulus onset VEP.

The SSVEP elicited by the attended flickering squares showed a sharp decrease in amplitude after the initial peak for all picture categories with a sharper decrease for pleasant and unpleasant background pictures at occipital sites, most pronounced at electrode Oz (Fig. 5). Against neutral pictures, the decline in SSVEP amplitude became significant slightly earlier for unpleasant (time bin 350–400 ms, ($t_9 = 2.5$, $P < 0.05$) than for pleasant background pictures (time bin 400–450 ms, $t_9 = 2.5$, $P < 0.05$). Given the temporal resolution of the complex demodulation, these bins refer to a starting point of amplitude decrease of “not earlier” than 100 ms for unpleasant and 150 ms for pleasant pictures in the time domain. Both, for pleasant and unpleasant background pictures, the decrease in SSVEP amplitude remained statistically significant up to the time bin 950–1000 ms after stimulus onset (all P values < 0.05). Given the temporal resolution, this bin refers to 700–1250 ms after stimulus onset in time domain. Tests of the remaining time bins up to 1200 ms resulted in no significant differences between arousing and neutral background pictures. The time

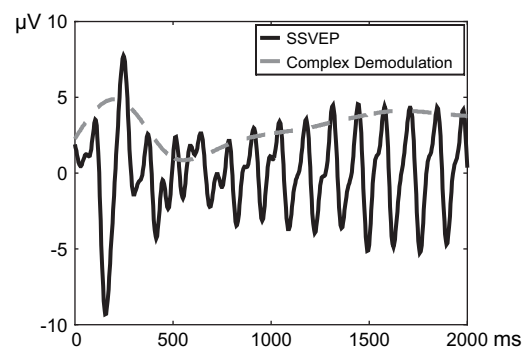


Figure 3. SSVEP of 1 subject averaged across trials when this subject performed the task with unpleasant background pictures (black line). The complex demodulated waveform (gray dotted line) represents the baseline-to-peak SSVEP amplitude with a temporal resolution of 500 ms.

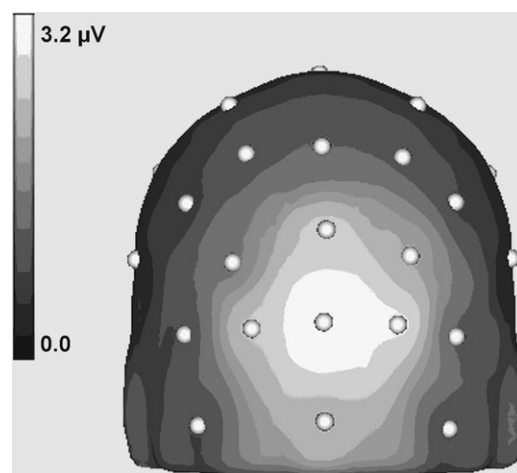


Figure 4. Grand mean topographical distribution of SSVEP amplitude across all subjects, averaged across all 3 conditions and the time window between 1200 and 2200 ms after stimulus onset. Note the maximum amplitude at electrode position Oz.

window of significant SSVEP amplitude reduction for arousing compared with neutral background pictures is indicated by the vertical lines in Figure 5 (zoom-in for Oz). Paired t -tests of SSVEP amplitude averaged across the window between 400 and 1000 ms against neutral background pictures revealed a significant amplitude reduction with pleasant and unpleasant background pictures ($t_9 = 3.7$, $P < 0.005$). Most importantly, this reduction in SSVEP amplitude with emotional background pictures was present in 9 out of our 10 subjects. This clearly points to a very robust effect.

Figure 5 also shows a difference in SSVEP amplitude between conditions at the initial peak. A closer inspection of the peak revealed a significant amplitude reduction with pleasant compared with neutral background pictures ($t_9 = 2.3$, $P < 0.05$). However, it has to be kept in mind that the peak represents a complex signal resulting from the onset of 3 events: stimulus, flicker, and motion.

Figure 6 shows the topographical distribution of the difference amplitudes between neutral and arousing background pictures. These maps depict the difference of the averaged SSVEP amplitude in frequency domain between 500 and 900 ms after stimulus onset. The effect of reduced SSVEP

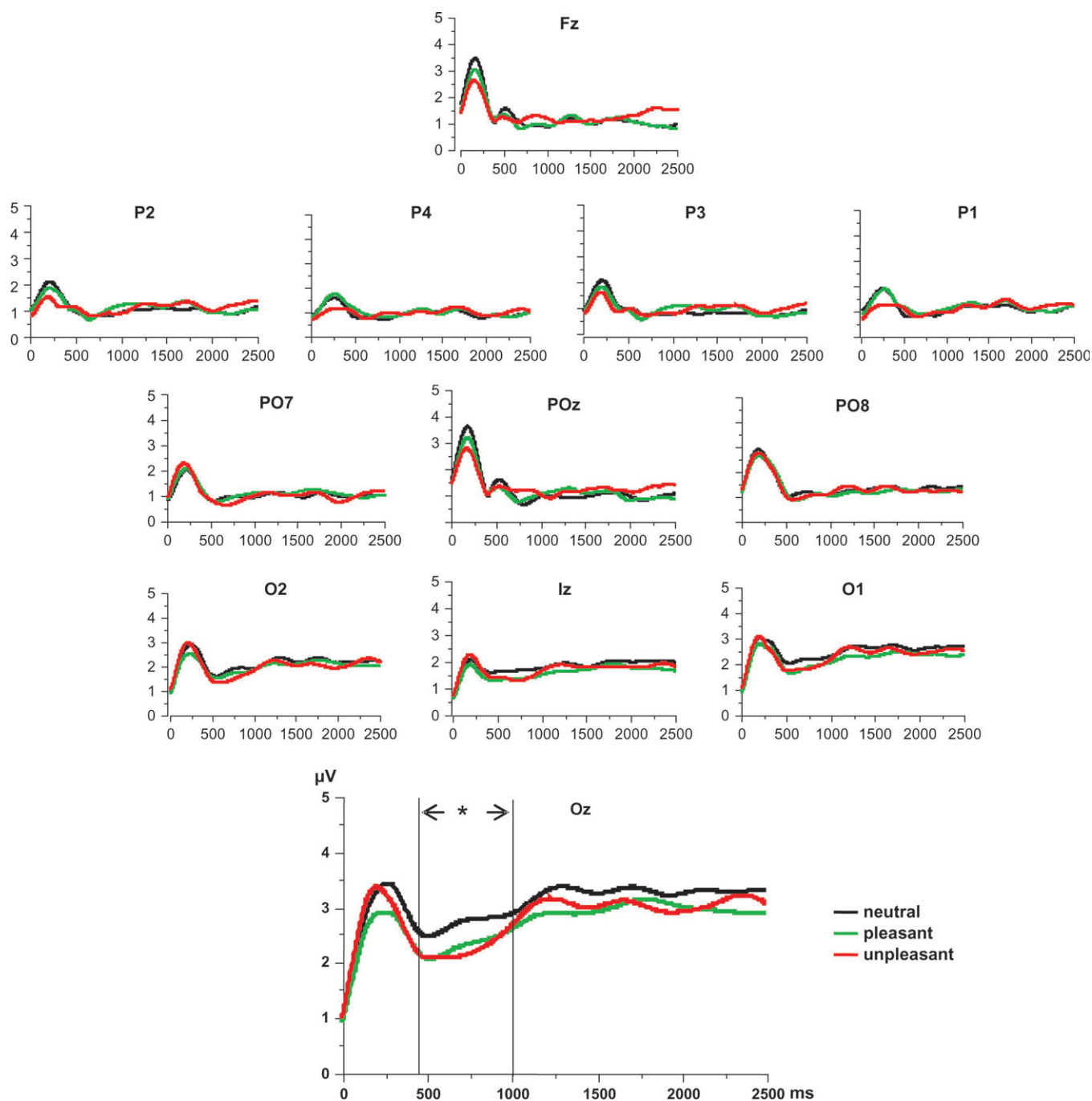


Figure 5. Time course of SSVEP amplitude in frequency domain obtained by complex demodulation averaged across all subjects for a subset of posterior electrode locations and Fz. Zoom-in of SSVEP at electrode Oz that was used for statistical analysis. Black line is for neutral, green line for pleasant, and red line for unpleasant background pictures. Vertical lines at Oz indicate time window of significant amplitude reduction for emotional compared with neutral background pictures.

amplitude of arousing compared with neutral pictures is very much focused at electrode location Oz.

Discussion

The present study investigated the time course of competition for processing resources between a demanding foreground target detection task and task irrelevant but emotionally

arousing background pictures. We found significantly reduced target detection rates for arousing pleasant and unpleasant compared with neutral pictures during the first second of stimulus presentation. Target detection rates for arousing pictures increased significantly during second 2 with no further increase during the third second of stimulus presentation. The display of neutral background pictures resulted in no significant changes of target detection rates throughout

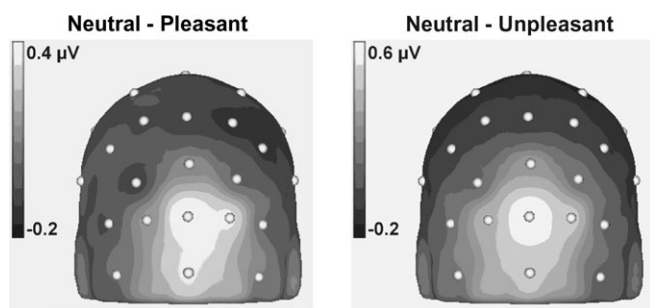


Figure 6. Grand mean topographical distribution of SSVEP amplitude difference between neutral and pleasant (left) and neutral and unpleasant (right) averaged across a time window between 500 and 900 ms after stimulus onset across all subjects. Scales used are different.

the presentation time. Time course of SSVEP amplitude paralleled behavioral performance. Emotionally arousing background pictures consumed processing resources from the superimposed demanding foreground task, which was reflected in significantly reduced SSVEP amplitudes compared with neutral pictures. This competition of processing resources in visual cortex started very early after stimulus onset and lasted for several hundred milliseconds. Thus, the present results support the idea that under conditions of spatially overlapping presentation of emotional pictures and foreground task stimuli, emotional stimuli act as strong competitors, which effectively withdraw processing resources for several hundred milliseconds even under conditions of a high perceptual load task.

Many previous studies of emotion-attention interactions in support of the notion that emotional stimuli require selective attention have in common that emotional stimuli, mostly emotional faces, were spatially well separated from task stimuli (cf. Pessoa et al. 2002; Eimer et al. 2003; Pessoa 2005). This was also the case in a behavioral study using IAPS (Erthal et al. 2005). In such designs, spatial separation between emotional stimuli and task might have resulted in different spatial arrangements of the attentional focus, such as a division between noncontiguous zones of the visual field (Müller et al. 2003), selective suppression of information at the center of the display (Müller and Hübner 2002), or focusing at a small area in the center of the display in cases where the task was presented in the center of the screen such as in the study by Eimer et al. (2003). Therefore, spatial separation between task and emotional stimuli might have been 1 potential variable that affected the way in which emotional content competed for processing resources. Our present data suggest that in visual scenes characterized by overlapping, cluttered stimuli, affectively arousing content may be capable of attracting attentional resources despite competing tasks.

Task difficulty has been suggested as another important variable that determines whether or not emotional stimuli are processed, and thus enter the competition for resources (Pessoa 2005). In the present study, we used a difficult detection task, in which target detection rates with concrete background pictures were comparable to difficult tasks in previous studies (cf. Pessoa et al. 2002). Despite the difficulty of the task, the system was biased toward emotional background pictures for several hundred milliseconds. The effect of task difficulty in a central task on neural activation evoked by

peripheral stimuli has recently been shown in fMRI (Schwartz et al. 2005). Interestingly, this study reported center-surround suppression of peripheral stimuli in a radius of about 8 degrees of visual angle under difficult task conditions. From these findings the question emerges whether this center-surround suppression occurs as well in the case of close spatial proximity between task and emotional faces and might have accounted for the findings by Eimer et al. (2003), where the task was in the center of the display and emotional faces were left and right in the periphery?

In the present study, subjects had to perform 1 identical task throughout the experiment, which is also different from previous studies in which different experimental conditions were compared (Pessoa et al. 2002; Eimer et al. 2003; Pessoa et al. 2005). In these studies, subjects were either instructed to identify the gender or emotional expression of faces or to identify the orientation or length of bars. This resulted in the comparison of neural activation between a rather easy and a rather difficult task, which might have accounted for some of the findings.

Given the time uncertainty in the frequency domain, the onset time for competition in the present study might have been as early as 100–150 ms after stimulus onset. Previous electrophysiological studies are supportive for such an early onset for competition. These studies demonstrated differences in the P1 amplitude of the evoked potential between neutral, pleasant, and unpleasant IAPS pictures with a latency of about 120 ms (Smith et al. 2003) or an early posterior negativity, starting with a latency of about 150 ms (Schupp et al. 2003). More recently, such discriminative effects have been reported even earlier in a time interval between 70 and 90 ms after stimulus onset (Pourtois et al. 2005; Stolarova et al. 2006). This rapid discrimination has been linked to the concept of “motivated attention” (Lang et al. 1997b), which suggests that visual features of affective or motivational relevance attract processing resources. In the framework of the biased competition approach (Desimone 1998), this implies that emotional stimuli can bias the competition for processing resources and that this competition is greatest when conflicting stimuli activate identical visual areas as this was the case in the present study.

In the present study, we also found a very early amplitude difference between pleasant and neutral background pictures related to the stimulus onset VEP. As mentioned above, given the complexity of the conditions that generated the onset VEP, it is mandatory to interpret that effect with caution. However, there are reports that erotica prompt a very early posterior negativity compared with neutral pictures in the time range between 150 and about 300 ms (De Cesare and Codispoti 2006; Schupp et al. 2007), possibly due to the tendency that these pictures have a relatively simple perceptual organization (i.e., low complexity), in which key features “pop out” more rapidly compared with pictures with other affective or neutral content (Bradley et al. 2007). Whether or not erotic pictures are linked to faster drawing of processing resources from a foreground task compared with other affective pictures must be studied in a future experiment in which erotic and other affective pictures are systematically varied and the very early brain response is not contaminated by the onset VEP.

Importantly, the competition for processing resources lasted several hundred milliseconds and was not consistent with a short-lasting orienting response toward the emotional

stimulus. The temporally extended decrease of SSVEP amplitude as observed in our study suggests that an early orientation mechanism, possibly reflected in the time window of the P1 or even earlier (Pourtois et al. 2005; Stolarova et al. 2006), is followed by a more sustained attention mechanism enhancing neural responses in visual cortex in order to optimize the analysis of the emotional significance associated with the respective stimulus (Calvo and Lang 2004; Pourtois et al. 2005).

Possible differences in visual complexity between neutral and arousing pleasant and unpleasant pictures seemed to be 1 limitation of using IAPS pictures to study emotion-attention interactions. As discussed in the Materials and Methods section, neutral pictures in the set used for the present study were of similar picture content complexity, such as landscapes or groups of people. A recent study investigated the role of IAPS picture complexity upon the evoked potential (Bradley et al. 2007). Although picture complexity affected the early P1/N1 complex, which were not strongly modulated by emotional content, the late positive potential starting about 400 ms after picture onset, was not influenced by complexity but by the emotional content. Regardless of complexity emotional pictures elicited a larger positivity than neutral pictures.

In sum, the present results are supportive for the hypothesis that strong emotional stimuli attract attention involuntarily possibly to allow prioritized responses to survival-relevant stimuli. In the present study, this resulted in a competition for processing resources in visual cortex, which lasted up to 1 s after stimulus onset. The rather long time course supports the idea that competition for processing resources is a slow interactive process in a highly parallel circuitry with many reentrant connections (Desimone 1998). Findings supporting the inability of affectively arousing stimuli to attract attentional resources might be limited to very circumscribed experimental conditions. One might be the spatial separation of a demanding task and emotional stimuli within a certain radius (Schwartz et al. 2005) and the focus of attention to a confined area in space with less than 1 degree of visual angle. In everyday life however, exploring the environment for behaviorally relevant stimuli requires not to focus attention to such a restricted spatial area. A further condition might be to present emotional stimuli, which evoke relatively weak activity in visual cortex. Generally, evidence for automatic processing has been observed mainly with stimuli bearing high relevance for the observer, that is, phobic stimuli (Öhman et al. 2001) or affective scenes high in emotional arousal (Bradley et al. 2003). This is in line with the recent finding that it is not perceptual load per se that determines selective attention but that salience of the distracters plays an important role for target detection and identification (Eltiti et al. 2005).

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Notes

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Address correspondence to Matthias Müller, Institut für Psychologie I, Universität Leipzig, Seeburgstr. 14-20, D-04103 Leipzig, Germany. Email: m.mueller@rz.uni-leipzig.de.

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