



Time course of affective bias in visual attention: Convergent evidence from steady-state visual evoked potentials and behavioral data

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ABSTRACT

Selective attention to a primary task can be biased by the occurrence of emotional distractors that involuntarily attract attention due to their intrinsic stimulus significance. What is largely unknown is the time course and magnitude of competitive interactions between a to-be-attended foreground task and emotional distractors. We used pleasant, unpleasant and neutral pictures from the International Affective Picture System (IAPS) that were either presented in intact or phase-scrambled form. Pictures were superimposed by a flickering display of moving random dots, which constituted the primary task and enabled us to record steady-state visual evoked potentials (SSVEPs) as a continuous measure of attentional resource allocation directed to the task. Subjects were required to attend to the dots and to detect short intervals of coherent motion while ignoring the background pictures. We found that pleasant and unpleasant relative to neutral pictures more strongly influenced task-related processing as reflected in a significant decrease in SSVEP amplitudes and target detection rates, both covering a time window of several hundred milliseconds. Strikingly, the effect of semantic relative to phase-scrambled pictures on task-related activity was much larger, emerged earlier and lasted longer in time compared to the specific effect of emotion. The observed differences in size and duration of time courses of semantic and emotional picture processing strengthen the assumption of separate functional mechanisms for both processes rather than a general boosting of neural activity in favor of emotional stimulus processing.

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Introduction

Complex environmental settings require humans to interact in a highly adaptive manner by extracting sensory information relevant for a current task and ignoring other task-irrelevant information. According to several theoretical accounts the neuronal processing of multiple stimuli involves competition for a limited pool of processing resources. This competition among stimuli for neural representation can be biased, both by bottom-up sensory driven mechanisms such as stimulus salience and attentional top-down signals (Desimone and Duncan, 1995). Emotional stimuli relative to other visual stimuli are assumed to have competitive advantages due to their intrinsic stimulus significance. A number of studies using different experimental paradigms, including attentional blink (Anderson and Phelps, 2001; Keil and Ihssen, 2004; Keil et al., 2006) and visual search tasks (Öhman et al., 2001a,b) demonstrated the capacity of emotional stimuli to rapidly and involuntarily draw attention. Further evidence came from event-related potential (ERP) studies which reported emotion-specific amplitude modulations of early and late components (Cuthbert et al., 2000; Junghöfer et al., 2001; Schupp et al., 2004b) and

from functional magnetic resonance imaging (fMRI) studies where emotional arousing stimuli elicited increased activation in occipital and inferior temporal cortical areas (Junghöfer et al., 2006; Sabatinelli et al., 2005). But not only emotional stimuli are linked to increased activation in early visual areas. It is well known that any non-emotional stimulus that receives attention increases activity in a number of early visual areas in the human brain (cf. Andersen et al., 2008; Hopfinger et al., 2000; Müller and Hillyard, 2000). Thus, attention to non-emotional stimuli as well as emotional stimuli per se has the capacity to “boost” neural responses (Schupp et al., 2003), leading to the highly interesting question of attention–emotion interactions (Pessoa et al., 2002). While the “net result” seems to be very similar the underlying neuronal pathways that are responsible for that effect probably differ (Vuilleumier and Driver, 2007).

Despite the close link between emotion and attention, there is mixed evidence to what extent unattended emotional stimuli are processed. Recent fMRI experiments have shown that an enhanced blood-oxygen-level-dependent (BOLD) signal in emotion-sensitive areas like the amygdala in response to fearful facial expressions was preserved even when focal attention was directed away from the face and toward a distractor stimulus (Anderson et al., 2003; Vuilleumier et al., 2001; Williams et al., 2005). However, other fMRI studies which varied the level of difficulty of the attentional task at hand found an

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ffective modulation of the BOLD signal restricted to low task demands. When task demands were high and depleted attentional resources, processing of emotional stimuli was suppressed as much as for neutral stimuli (Bishop et al., 2007; Pessoa et al., 2002, 2005; Silvert et al., 2007). However, since functional MRI measures integrate over a rather long time window they fail to detect subtle and transient effects of emotional stimulus processing. Electroencephalography (EEG) and magnetoencephalography (MEG) provide higher temporal resolutions and may therefore be better suited to reveal such effects.

Studies using event-related potentials found that both short-latency and sustained longer-latency ERP emotional effects were evident when laterally presented faces were attended for an emotional judgment task. However, these effects were eliminated when faces were ignored and subjects focused their attention on a central pair of lines for a line length comparison task (Eimer et al., 2003; Holmes et al., 2003). In other studies where emotional stimuli, in particular faces, remained within the focus of spatial attention, emotion-related early and late ERP modulations have been observed despite the fact that the faces were entirely task-irrelevant (Holmes et al., 2006, 2009; Pourtois et al., 2004) or at least no emotional judgment upon the faces was required (Ashley et al., 2004; Eger et al., 2003). For example, Holmes et al. (2006) found dissociated emotion effects depending on the time scale of emotional processing. In this study, an emotion effect was found at early processing stages (between 160 and 220 ms after stimulus onset) independent of attention which was eliminated at later stages beyond 220 ms when attention was directed to the concurrent task. Contrary, in the ERP study of Santos and colleagues (2008) in which pictures of faces and houses were transparently superimposed, so that object-based attention could be manipulated a sustained positivity in response to fearful faces emerged around 160 ms which was not affected by attentional manipulations. Interestingly, this effect was not observed for faces of disgust probably because disgust is less functionally significant than fear (Santos et al., 2008).

One reason for the mixed evidence in ERP studies might be differences in the attentional manipulation. Apart from the last study by Santos and coworkers (2008), the majority of ERP studies on emotion–attention interactions manipulated attention in the spatial domain where emotional stimuli were spatially well separated from task stimuli and placed either foveally (Holmes et al., 2006) or peripherally in the visual field (Eimer et al., 2003). This probably weakened direct competition between task-relevant and task-irrelevant stimuli and thus may have facilitated the filtering of emotional stimuli by spatial attention. A recent EEG study which used steady-state visual evoked potentials (SSVEPs) in order to investigate the effects of emotional background pictures on a superimposed attentional task reported prolonged emotional interference for up to 1 s which was interpreted as first direct evidence for obligatory and continuous interference of emotional stimuli with the foreground task over a longer time period (Müller et al., 2008).

Previous research on attention–emotion interactions has raised several important issues: first, different stages of emotional processing might be differently modulated by selective attention thus emphasizing the time course of emotion–attention interactions (Holmes et al., 2006). Second, attentional processes might have different influences across various emotions (Santos et al., 2008). Third, the opportunity for filtering of emotional distractors by spatial attention and the manipulation of voluntary attentional allocation are important factors guiding competition between attentional and emotional processes.

So far, a common approach to measure the competition for processing resources between emotional stimuli and task-relevant processing is the comparison to neutral stimuli. In this regard, the extent to which neutral stimuli themselves are processed has attracted little interest. Recent behavioral and physiological studies that investigated the mechanisms of high-level visual processing have shown that the detection of familiar objects (VanRullen and Thorpe, 2001), in particular human faces (Eimer and Holmes, 2002; Li et al., 2002), as the “gists” of semantic scenes (Biederman, 1972) is extremely rapid and can be done

without focal attention (Li et al., 2002; Peelen et al., 2009). However, there is also evidence for an impaired categorization of complex scenes when attentional resources were limited under dual-task conditions (Walker et al., 2008). The present study sought to further investigate the extent to which task-irrelevant pictures per se are processed and to compare it to the specific effect of emotion on voluntary attention. By using this approach we are able to more precisely estimate the size and specificity of the effect that emotional pictures have on task-relevant behavior. In particular, we aimed to examine the nature of perceptual, including emotional features that affect different stages of visual processing under conditions of inattention. Similar to the previous study by Müller et al. (2008) the experimental design consisted of a primary task which was superimposed upon task-irrelevant neutral and emotional pictures from the International Affective Picture System (IAPS, Bradley et al., 2005). To study the extent of general semantic information processing we introduced a second control condition in which phase-scrambled IAPS pictures were used as background pictures. Thus, we are able to compare the effect of motivational relevant (i.e. emotional) pictures to that of motivational irrelevant (i.e. neutral) pictures and the effect of semantic context information (i.e. emotional and neutral pictures) to the effect of a non-meaningful context (scrambled pictures). We used the SSVEP as a measure of selective stimulus processing which allows to continuously record electrocortical brain responses to visual stimuli by means of an external pace maker (i.e. the flicker frequency). Given that the SSVEP provides a continuous measure of stimulus processing (i.e. the flickering dots) it provides a direct and objective electrophysiological measure of the time course of attentional resource competition between the foreground task and the background picture. Contrary to “typical” ERP studies that measure the processing of a transiently presented stimulus, here we do not examine the processing of emotional distractors per se but its consequence on attentional resource allocation upon the primary task.

Contrary to the previous study by Müller and coworkers (2008) in which task and emotional stimuli were presented with trial onset, here we included an experimental baseline in which all background pictures were initially presented in scrambled view. That baseline period avoided to have the onset ERP right in the time window that is of interest (i.e. the time course of competitive interactions with the presentation of a background picture). The big advantage compared to our previous study is that we were now able to analyze behavioral responses and the EEG signal on a more precise time scale after the change. A further improvement of the present compared to the previous study was that we included a change from a scrambled to a scrambled picture to control for the effect of a change in the background and to have a direct measure to what extent neutral pictures compete for processing resources as well.

Based on findings from previous studies that applied non-spatial attentional manipulations and showed that emotion-related ERP (Eimer et al., 2003; Santos et al., 2008) and SSVEP modulations (Müller et al., 2008) were present even when emotional stimuli were not task relevant we hypothesized that task-related SSVEP amplitudes are strongly reduced in response to emotional background pictures and that this bias lasts for a prolonged period of time. In addition, general semantic information was assumed to influence task-related processing too (neutral compared to scrambled background pictures), whereas size and duration of this effect might differ from the effect of emotion (Schupp et al., 2004a).

Materials and methods

Participants

Fifteen subjects (9 female) with a mean age of 25.4 years (standard deviation [SD] = 5.5 years) with normal or corrected to normal visual acuity participated in the experiment. All subjects provided informed consent prior to testing. The study was approved by the local ethics committee and was conducted under the provisions

of the Declaration of Helsinki. To prepare subjects for the forthcoming pictures they would get exposed to, the written instruction contained three example stimuli, one from each picture category. These three pictures represented a household scene for the neutral condition, an erotic scene for the pleasant condition and a severe injury scene for the unpleasant condition, respectively. Based on these pictures, one participant refused to participate. All subjects received class credits or a monetary compensation for participating in the experiment.

Stimuli

Task-stimuli consisted of an array of 100 randomly distributed moving yellow dots (each $0.6^\circ \times 0.6^\circ$ of visual angle) overlaid on pleasant, unpleasant, neutral and scrambled pictures ($12.2^\circ \times 8^\circ$ or $8^\circ \times 12.2^\circ$) from the International Affective Picture System (Bradley et al., 2005). A centrally located yellow cross served as fixation and was present throughout the experiment. For each valence category, a picture set consisting of 45 pictures was used (see Appendix for picture identification). Picture selection was based on normative valence and arousal ratings provided by the IAPS set. According to these ratings, mean valence and arousal ratings were 5.60 and 3.72 for the neutral picture set, 7.21 and 5.65 for the pleasant set and 2.22 and 6.24 for the unpleasant picture set. To control for visual complexity, we carefully scanned the picture contents for the amount of objects included in a scene in order to obtain almost similar complexity between pictures sets. For instance, in case of the neutral picture set, several complex scenes (e.g. office scenes) were included instead of portrait pictures or pictures with simple household objects with typically less complex figure-ground segregation. In addition, we also measured the luminance of the entire stimulus array (i.e. picture together with the yellow dots), which was 26.4 cd/m^2 on average and did not differ between valence categories.

The valence of the background pictures resulted in three experimental conditions: neutral, pleasant and unpleasant. An additional experimental condition resulted from the scrambled background pictures. Scrambling of pictures was performed by a Fourier transform, yielding the amplitude and phase components of each image. Before rebuilding the image with an inverse Fourier transform, the original phase spectrum was replaced with random values, keeping the amplitude spectrum of the image unaltered. The resulting pictures were characterized by equal global low-level properties of the original image (luminance, spectral energy), while any content-related information was deleted. Similar to the other picture categories the scrambled condition (picture change from scrambled view to another scrambled view of the same picture) consisted of 45 pictures which were randomly selected from the entire picture set, counterbalanced across all three valence categories across trials. Scrambling was performed twice on the selected picture, once before picture change and the next after picture change, respectively. This procedure was done to ensure that all experimental conditions had an observable picture change at any point in time.

Experimental procedure and design

Stimuli were centrally presented against a black background on a 19-inch computer screen with a refresh rate of 60 Hz at a viewing distance of 80 cm. Yellow dots flickered at a rate of 7.5 Hz and were presented together with a background picture for a total period of 4533 ms, thus containing 34 cycles each with 4 frames 'on' and 4 frames 'off.' For every frame of refresh (i.e., every 16.67 ms) each dot moved in a random direction (up, down left or right) by 0.04° . This entirely random motion was interrupted by short intervals (2 cycles of 7.5 Hz or $\sim 267 \text{ ms}$) of coherent motion of 35% of the dots in one of the four cardinal directions (targets). During a single trial, between zero and four such coherent motion targets could occur unpredictably for the subject. Participants were instructed to attend to the dots in order to detect these coherent motion targets and to respond as fast

and accurately as possible by button press while ignoring the background pictures which were irrelevant for that task. Responses that occurred within a time window from 200 to 1000 ms after target-onset were counted as hits. The responding hand was changed halfway through the experiment and counterbalanced across subjects. In order to allow for an analysis of the time course of the behavioral data, targets were distributed within small time windows of 1 cycle or $\sim 133 \text{ ms}$ each. Over the entire experiment the occurrence of such targets was equally distributed across all experimental conditions. Subsequent trials were separated by presentation of a fixation cross on an otherwise blank screen for a randomly chosen interval from 1000 up to 1500 ms.

At the beginning of each trial all pictures were presented in a scrambled view. At a certain time point pictures changed to normal view (neutral, pleasant or unpleasant condition) or to another scrambled view of the same picture (scrambled condition). To avoid any anticipation effects associated with the time point of picture change, the change was randomly assigned to an early (13% of trials, 133–1067 ms), middle (60% of trials, 1200–2267 ms), or late (27% of trials, 2400–4400 ms) time window after stimulus onset. The relative smaller proportion of trials with an early and late time window for the change served as 'catch trials' and were not included in the data analysis. For these trials we choose additional IAPS pictures that were different from the ones that were presented in trials that entered the final analysis. All pictures of trials that entered the final analysis were presented twice throughout the experiment in randomized order (no repetition within the next three pictures) resulting in 360 trials (90 per experimental condition) plus 240 'catch trials' (i.e. early or late time point of change). Thus, all together we presented 600 trials that were divided into 10 blocks (60 trials each) separated by a short break. After each block, feedback on task performance was provided. Before the experiment, subjects performed up to 3 practice blocks until they became familiar with the task and reached an acceptable target detection rate ($>60\%$). Practice and catch trials involved IAPS pictures, which were not used in the experimental trials that entered the data analysis (see above).

After EEG-recordings subjects viewed the IAPS pictures again in randomized order and were asked to rate them on the two dimensions of affective valence and arousal on the 9-point Self-Assessment Manikin (SAM) scale provided by the IAPS set (Bradley and Lang, 1994). Valence ratings ranged from 1 (very unpleasant) to 9 (very pleasant) and arousal ratings ranged from 1 (very calm) to 9 (very excited).

Analysis of behavioral data and SAM ratings

We calculated mean target detection rates within time bins of 267 ms from the beginning up to the end of the trial. This bin size was identical to target duration (2 cycles of 7.5 Hz). To test for possible differences in target detection rates between conditions we calculated a repeated-measures analyses of variance (ANOVA) for the period before and after picture change, respectively, comprising the within-subjects factors of Valence (pleasant, unpleasant, neutral and scrambled background pictures) and Time (3 time bins before and 8 after picture change, respectively). Significant main effects and interactions were tested by means of paired *t*-tests. Mean valence and arousal SAM ratings obtained for pleasant, unpleasant and neutral pictures were subjected to paired *t*-tests.

Electrophysiological recording and data processing

We recorded brain electrical activity at a sampling rate of 256 Hz from 32 scalp electrodes mounted in an elastic cap using a BioSemi ActiveTwo amplifier system (BioSemi, Amsterdam; The Netherlands). According to the international 10–20 system (Jasper, 1958) the following electrode positions were used: F7, F3, Fz, F4, F8, T4, T6, TO1, TO2, T3, T5, TP9, TP10, C3, Cz, C4, CT5, CT6, CP1, CP2, P3, Pz, P4, PO1, PO2, POZ, IN3, INZ, IN4, O1, Oz and O2. Two external electrodes served as offline reference and were affixed to the left and right earlobes. Vertical and lateral eye movements

and blinks were monitored with a bipolar montage positioned above and below the right eye (vertical electrooculogram) and at the outer canthi (horizontal electrooculogram).

Epochs of 1500 ms before to 2500 ms after picture change were extracted. Trials with excessive eye movements, blinks or other artifacts (exceeding $\pm 100 \mu\text{V}$ at any electrode) were excluded from analysis resulting in a mean rejection rate of 7% across conditions. The number of remaining trials did not differ between experimental conditions. Artifact-free epochs were re-referenced to the averaged signal of the ear lobe electrodes and were then averaged separately for each experimental condition. In a next step, data was detrended (removal of mean and linear trends). The time course of SSVEP amplitudes was extracted from the EEG signal by means of a Gabor filter centered at the stimulation frequency of 7.5 Hz. A frequency resolution of ± 1.7 Hz full width at half maximum (FWHM) was applied resulting in a time resolution of ± 130 ms. Fig. 1 depicts an example for one subject at electrode Oz before and after the employment of the Gabor filter.

To define the electrode at which activity was analyzed we calculated spline-interpolated voltage maps on the basis of the mean of SSVEP amplitudes across the whole trial of the scrambled condition for each subject. In agreement with previous reports (Müller et al., 2008), electrode Oz exhibited the maximum amplitude for the majority of subjects (see Fig. 2). As individual amplitude maxima were also observed at electrodes PO1 or PO2 above and lateral to Oz these electrodes were included in the possible selection to ensure maximum SSVEP amplitudes for all subjects. Hence, SSVEP amplitude analyses were based on the individually best electrode out of electrodes Oz, PO1 and PO2.

SSVEP amplitudes of all four experimental conditions were baseline corrected by subtracting the averaged amplitude of a small data segment (500 ms to 200 ms) before picture change from each data point. A repeated-measures ANOVA comprising the factor of Valence (neutral, pleasant and unpleasant) was calculated for the mean SSVEP amplitude of a time interval between 400 and 1000 ms after picture change. This time window was selected and defined on the basis of running consecutive paired *t*-tests between single data points in order to determine the first and last time point that showed significant amplitude changes between emotional and neutral conditions (see Results). To test the influence of general semantic context information paired *t*-tests were performed to test for differences between the neutral and scrambled condition, on the basis of which a further ANOVA was calculated testing the SSVEP mean amplitudes of these two conditions across a time interval from 130 ms to 2000 ms after picture change. The starting point of this time window was chosen with the temporal resolution of the Gabor filter (± 130 ms FWHM) in mind, i.e. by starting 130 ms post picture change it is ensured that this time window is not contaminated by the data range before the picture change.

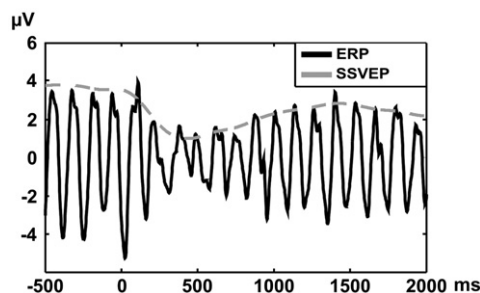


Fig. 1. Example of ERP (black line) and SSVEP amplitude time course resulting from Gabor filtering (gray dotted line) for one subject at electrode Oz for the condition when at time point zero the scrambled background picture changed to an unpleasant one. The Gabor filtered time course represents the baseline-to-peak SSVEP amplitude with a temporal resolution of ± 130 ms.

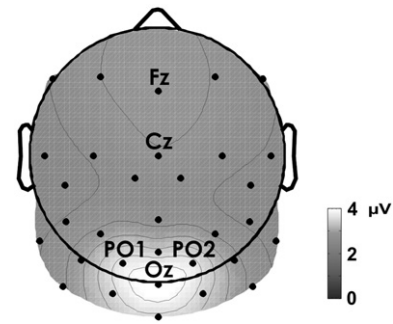


Fig. 2. Spline-interpolated voltage map of SSVEP amplitude averaged across all subjects for the "scrambled changed to scrambled" condition averaged across a time window between 200 ms before to 2000 ms after picture change. The occipital peak around electrode Oz is clearly visible.

Results

SAM ratings

As expected, SAM valence ratings revealed significant differences between picture categories. Unpleasant pictures were rated as less pleasant (mean pleasure rating 2.09, SD=0.60) than neutral pictures (mean pleasure rating 5.52, SD=0.63; $t_{14}=17.02$, $p<0.0001$) whereas pleasant pictures were rated as more pleasant (mean pleasure rating 6.71, SD=0.73) than neutral pictures ($t_{14}=-17.68$, $p<0.0001$). Likewise, arousal ratings were higher for unpleasant pictures (mean arousal rating 6.45, SD=1.00) compared to neutral pictures (mean arousal rating 2.77, SD=0.95; $t_{14}=-13.88$, $p<0.0001$), and also pleasant pictures were rated as more arousing (mean arousal rating 4.01, SD=0.76) when compared to neutral pictures ($t_{14}=-5.26$, $p<0.0001$).

Target detection rates

Before picture change we found no significant differences for the main factors of Valence ($F_{3,42}=2.495$, $p>0.1$) and Time ($F_{2,28}=0.225$, $p>0.5$) and Valence \times Time interaction ($F_{6,84}=0.354$, $p>0.5$). That differed in the time period after picture change. As depicted in Fig. 3C, overall target detection rates are reduced for concrete background pictures (main effect Valence: $F_{3,42}=28.786$, $p<0.0001$). More precisely, across time, the scrambled background pictures were the least distracting with average target detection rates of 72.51% followed by neutral (64.27%), unpleasant (59.10%) and pleasant (57.49%) background pictures. While target detection rates did basically not vary with time when scrambled background pictures were presented, that was not the case for concrete pictures, which gave rise to the significant main effect of Time ($F_{7,98}=13.746$, $p<0.0001$). Most importantly, target detection rates dissociated between emotional and neutral and scrambled background pictures in a certain time period (interaction Valence \times Time: $F_{21,294}=5.149$, $p<0.0001$). Both pleasant ($t_{14}=-3.063$, $p<0.01$) and unpleasant pictures ($t_{14}=3.154$, $p<0.01$) relative to neutral pictures yielded significant decreases in task performance from picture change to 267 ms after change (e.g. first time bin). For pleasant pictures, this effect lasted up to the second time bin ($t_{14}=-2.780$, $p<0.05$). Unpleasant pictures elicited an even more extended decrease which lasted up to the third time bin from 534 ms to 801 ms after picture change ($t_{14}=3.055$, $p<0.001$), see also Fig. 3C.

SSVEP amplitudes

The time course analysis of SSVEP amplitudes revealed considerable differences between experimental conditions (Fig. 3B). After picture change, SSVEP amplitudes of the neutral, pleasant and unpleasant conditions showed a general reduction irrespective of picture valence. This was followed by a significant emotion effect as reflected in a

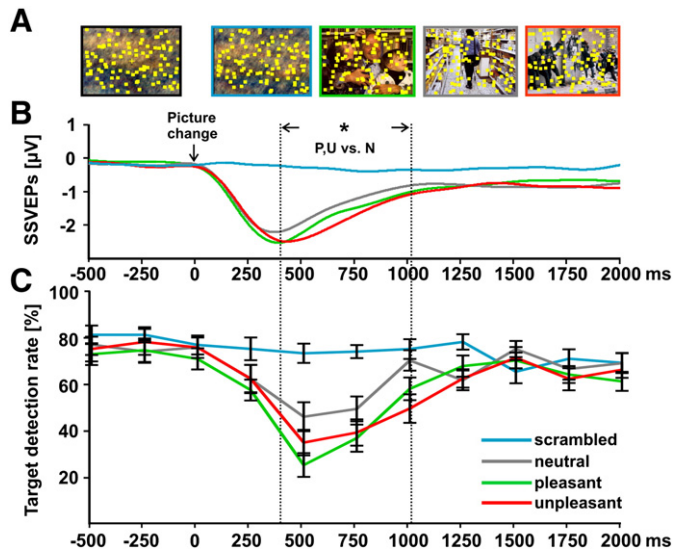


Fig. 3. Experimental design, time course of SSVEP amplitudes and target detection rates as a function of time. (A) Black framed scrambled picture represents baseline at the beginning of each trial. Pictures subsequently changed to another scrambled (blue framed), pleasant (green framed), neutral (gray framed), or unpleasant (red framed) view. The superimposed yellow dots constitute the primary task. (B) Grand mean Gabor filtered time course of SSVEP amplitudes for the change to a scrambled (blue line), neutral (gray line), pleasant (green line) or unpleasant background picture (red line) averaged across all subjects for occipital electrodes (see [Materials and methods](#)). Picture change was at time point zero. Vertical dotted lines indicate time period for which SSVEP amplitudes with pleasant and unpleasant pictures differed significantly from neutral background pictures. (C) Mean target detection rates in percent and corresponding standard errors for 11 successive time bins (3 before and 8 after picture change) averaged across all subjects for all experimental conditions (same colours as SSVEP amplitudes). Picture change was at time point zero.

significantly stronger reduction of SSVEP amplitudes for emotional relative to neutral background pictures starting for pleasant pictures at 387 ms ($t_{14} = -2.15$, $p < 0.05$) and for unpleasant pictures at 412 ms after picture change ($t_{14} = 2.16$, $p < 0.05$).¹ This difference between emotional and neutral background pictures continued up to 1035 ms. At this point the difference between pleasant and neutral pictures still yielded a statistical trend ($t_{14} = 1.75$, $p < 0.1$) whereas the difference between unpleasant and neutral pictures was statistically significant ($t_{14} = 2.15$, $p < 0.05$). Accordingly, the ANOVA calculated for the chosen time window from 400 to 1000 ms yielded highly significant SSVEP amplitude differences between emotional and neutral conditions ($F_{2,28} = 7.519$, $p < 0.005$). The time window is indicated by the dotted vertical lines in [Fig. 3B](#). To further test the stability of this effect across time and to avoid the risk of false positive results (i.e. alpha error inflation) we calculated paired t -tests at three distinct time points within the analyzed time window, at 400, 700 and 1000 ms after picture change, which corresponded to the first, middle and last time point, respectively. For pleasant versus neutral pictures, all but the last comparison of SSVEP amplitudes were significant (time point 1: $t_{14} = 2.23$, $p < 0.05$; time point 2: $t_{14} = 2.51$, $p < 0.05$; time point 3: $t_{14} = 1.59$, $p > 0.1$). For unpleasant versus neutral pictures, differences of SSVEP amplitudes showed a trend for the first time point ($t_{14} = 1.99$, $p = 0.06$) and were statistically significant at the remaining two other time points (time point 2: $t_{14} = 3.78$, $p < 0.005$; time point 3: $t_{14} = 2.34$, $p < 0.05$). For the scrambled condition, the SSVEP amplitude showed no modulation albeit also in this condition background pictures changed from one scrambled view to another scrambled view.

The time course of SSVEP amplitudes clearly suggests two different phases of competitive interactions between background and task. First, SSVEP amplitudes decreased as a consequence of change to a

concrete picture, irrespective of valence and in the second phase they dissociated between emotional and neutral pictures. To examine these two phases that might be related to different processing mechanisms more clearly, we calculated two difference curves that are depicted in [Fig. 4](#).

The general consequence of semantic context information on SSVEP amplitudes is best represented by the time course of 'neutral minus scrambled pictures.' The specific effect of emotion is represented by the difference 'mean of emotional minus neutral pictures.' Running t -tests for the first difference curve revealed significant differences at time point 130 ms after change ($t_{14} = 6.54$, $p < 0.0001$) and persisted for the entire trial length (at time point 2000 ms after change: $t_{14} = 2.99$, $p < 0.01$). An ANOVA testing the mean amplitude for the selected time window from 130 ms to 2000 ms further confirmed the highly significant difference ($F_{1,14} = 20.763$, $p < 0.0001$). Thus, the occurrence of a meaningful picture immediately affected task-related activity. In clear contrast, the comparison of SSVEP amplitude time courses between emotional (mean of pleasant and unpleasant) and neutral background pictures became significant at a much later point in time, namely 385 ms after picture change ($t_{14} = 2.1575$, $p < 0.05$) and lasted up to 1140 ms ($t_{14} = 2.1452$, $p < 0.05$).

Biased competition claims that competitive interactions are strongest when stimuli compete for processing resources in the same cortical areas. While we assured spatial identity by superimposing task-relevant stimuli upon our pictures, SSVEP amplitude time course does not exclude that competition might be a consequence of neural interactions of different cortical areas during the time window when competition was strongest. If that was the case, one must assume that the topographical distribution of SSVEP amplitudes differ between the two time points. According to that, spline-interpolated isocontour voltage maps of the 7.5 Hz SSVEP amplitudes should differ between the time period when competition was present (400–800 ms) and a late window with no obvious competitive interaction (1600–2000 ms) for neutral, pleasant and unpleasant background pictures. As shown in [Fig. 5](#), there is no apparent change in the topographical distribution for any of the three experimental conditions. Rather, voltage maps revealed SSVEP amplitudes augmentation from early to late time windows for all conditions. Also note that the topographical distribution is almost identical to the one depicted in [Fig. 2](#) for scrambled background pictures. Based on the current knowledge about the neural generators of the SSVEP signal ([Andersen et al., 2008; Andersen et al., 2009; Müller et al., 2006](#)), these topographies indicate that the differences observed in SSVEP amplitudes here stem from sources in early visual areas.

Discussion

In the present study we investigated the impact of task-irrelevant affective stimuli (pleasant and unpleasant pictures) on the concurrent processing of flickering dots which provided a demanding primary task. Our findings clearly demonstrate that highly arousing emotional pictures consume considerably more processing resources relative to neutral pictures over a prolonged period of time. At the behavioral

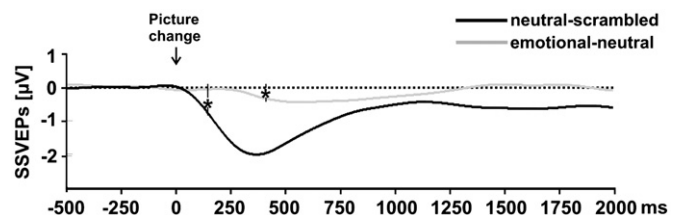


Fig. 4. Time course of the difference SSVEP amplitude curves for neutral minus scrambled (black line) and for the mean of pleasant and unpleasant minus neutral (gray line) across all subjects for occipital electrodes (see [Materials and methods](#)).

¹ Please note that all calculated t -tests correspond to either the first or last data point that revealed significant differences between experimental conditions.

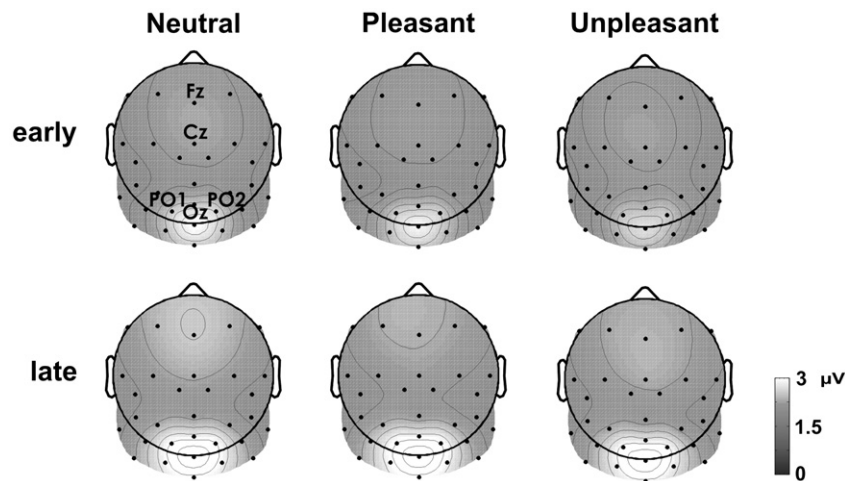


Fig. 5. Grand mean spline-interpolated voltage maps of SSVEP amplitudes averaged across all subjects with neutral, pleasant and unpleasant background pictures averaged across the time period between 400 and 800 ms when competition was greatest (upper row) and a late time window when competition with emotional compared to neutral background pictures was no longer present (1600–2000 ms after picture change).

level we found significant decreases in target detection rates when emotional compared to neutral pictures were concurrently presented in the background. This decline in task performance lasted for several hundred milliseconds. In the same vein, SSVEP amplitudes directed to the primary task exhibited a stronger decrease for emotional relative to neutral pictures in a similar time window as observed for the behavioral data. The earliest starting point of this affective amplitude deflection was at 270 ms, which is in good accordance with ERP findings on affective picture processing that reported an early posterior negativity (EPN) at about 200–300 ms for arousing compared to neutral pictures. The EPN typically consists of a negative amplitude deflection over fronto-central sites and a positive going waveform over temporo-occipital sites (e.g. Schupp et al., 2004a) and is interpreted as an index for ‘motivated attention.’ According to the concept of ‘motivated attention’ pleasant and unpleasant stimuli activate neural circuits, which mediate appetite and defense and were therefore associated with the capture of attentional resources and the enhanced perceptual processing of such motivationally relevant stimuli (Lang et al., 1997). The finding that affective amplitude modulations persist for a prolonged time window strongly implies enhanced encoding processes for emotionally arousing stimuli (Olofsson et al., 2008), even when they had to be ignored.

A second finding of the present study was that SSVEP amplitudes showed a general reduction in response to the appearance of an intact picture irrespective of its valence. This effect occurred much earlier in time and was considerably stronger compared to the specific effect of emotion on task-related processing. Studies on object perception have shown that the onset of a new object produces a strong capture of attention (Yantis and Jonides, 1984) which was not related to luminance changes (Yantis and Hillstrom, 1994) but probably reflects processes of figure-ground segregation including feature detection, structural encoding, and perceptual categorization (Thorpe et al., 1996). The early onset of the effect is in good agreement with previous studies that reported enhanced amplitudes in early category-specific ERP components from 120 to 170 ms in response to intact familiar objects (e.g. cars, butterflies) relative to phase-scrambled versions (Allison et al., 2002; Allison et al., 1999). The present study showed that the amplitude reduction elicited by neutral pictures covered roughly the same time window as observed for emotional pictures while scrambled pictures on the contrary did not modulate the SSVEP response at all. Thus, the appearance of a concrete picture that contains at least one object is potent enough to elicit an involuntary shift of attention (Schreij et al., 2008). This effect is reflected in the decrease of SSVEP amplitude when neutral background pictures were

presented. We cannot definitely rule out that the early onset of the semantic effect does not include a pop-out effect due to local homogeneity differences of luminance which are considerably more pronounced for the scrambled to intact picture change compared to the change from a scrambled to a scrambled picture. However, the duration of the effect, which covered a time window from 130 to 2000 ms after picture change clearly speaks against a pure pop-out effect. Rather, this finding indicates that even task-irrelevant neutral pictures received enhanced processing that went well beyond an ‘initial classification’ state.

Task difficulty, and, thus, the amount of attentional resources that have to be bound to the task for successful performance seems to be a relevant variable for distractor processing (Lavie, 2005). In line with this idea, recent ERP studies, which investigated the processing of emotional information in task-irrelevant stimuli under the manipulation of load, reported an attenuated effect of emotion when load or difficulty of the task was high (Doallo et al., 2006; Schupp et al., 2007; but see Hajcak et al., 2007). However, as with previous studies (Hsu and Pessoa, 2007; Pessoa et al., 2002; Pessoa et al., 2005) it is difficult to compare the manipulation of load, given the diversity of tasks that were employed, and, as will be discussed below in many of these studies stimuli were spatially separated allowing for spatial filtering or even splitting of the attentional spotlight (Müller et al., 2003). In the present study we did not directly manipulate task difficulty. Instead, we used a demanding target detection task that was expected to consume a large amount of attentional resources. All our subjects reported in the post-experiment interview that the task was extremely demanding. Importantly, the nature of stimulus attributes to be attended was held constant and subjects had to perform the identical task throughout the experiment. This also varies significantly from previous studies, in which either the emotional stimulus per se had to be attended or ignored (Anderson et al., 2003; Holmes et al., 2003, 2006; Pessoa, 2005; Santos et al., 2008; Silvert et al., 2007; Vuilleumier et al., 2001). Moreover, the occurrence of up to 4 targets within one trial further ensured maintenance of attention throughout the entire trial. Despite the use of a challenging primary task which strongly limited the availability of processing resources we observed an emotion-induced reduction of SSVEP amplitudes which is clearly at odds with the suggestion that the capture of attention by emotional distractors is contingent on top-down attentional control. This fits well with recent ERP studies that reported similar emotion-related effects in early (P1, EPN) (Holmes et al., 2009) and late (LPP) ERP components (Hajcak et al., 2007) that were not affected by task load.

As mentioned above, a further possible factor which might contribute to the varying effects of task relevance on emotion-induced

ERP modulations is the extent to which experimental designs provide the opportunity for the filtering of emotional stimuli by spatial attention (Holmes et al., 2009). For example, some studies reported early ERP effects of emotional faces that were abolished when attention was directed away from the faces towards spatially well-separated task-relevant stimuli (Eimer et al., 2003; Holmes et al., 2003). In some other cases this effect of spatial filtering became apparent only at later ERP components at post-perceptual processing stages such as the late positive component (Holmes et al., 2006; Holmes et al., 2009). However, when spatial filtering was not possible because target and distractor stimuli were presented at the same location, emotion-induced ERP modulations were found from 160 ms onwards, independent of attentional demands (Santos et al., 2008; but see Schupp et al., 2007). Here, we also used a non-spatial attentional manipulation and observed sustained amplitude reductions from approximately 270 ms onwards in the EEG signal that was driven by the foreground task stimuli. Notably, the later starting point in our study compared to that reported by Santos et al. (2008) might be related to the different methodological approach. Contrary to the ERP study of Santos et al. (2008) we did not measure the EEG response to the onset of the emotional stimulus. Rather, our EEG signal was associated with the primary task and the processing of emotional distractors was examined by the extent to which these distractors interfered with the primary task. Thus, we did not examine the processing of emotional distractors per se but its consequence on attentional resource allocation upon the primary task.

In summary, the results of the present study demonstrate two important points. First, task-irrelevant emotional pictures (pleasant and unpleasant) were found to more strongly interfere with a demanding primary task compared to pictures of neutral valence. This effect involved a significant reduction of task-related SSVEP amplitudes which lasted for several hundred milliseconds up to 1 s. The electrophysiological data was paralleled by the behavioral data showing a stronger decrease in task performance in response to emotional relative to neutral pictures, which was strikingly similar in terms of latency to the observed SSVEP response modulations. Second, we found that task-irrelevant neutral pictures strongly suppressed task-related processing, too. In fact, the effect of a meaningful picture irrespective of its valence emerged considerably earlier in time and was much greater when directly compared to the effect of emotion. This strongly indicates that even neutral stimuli are processed beyond an early perceptual stage that is most likely unaffected by attentional top-down manipulations given the short latency. The present findings provide new evidence that emotional distractors receive prioritized processing despite strongly limited attentional resources. We were also able to show that this effect was of relatively small size when directly compared to the detrimental effect of general picture processing on task-related activity. Together, the present results provide new evidence for the extent and timing of involuntary depletion of attentional resources in competitive interactions between foreground task and processing of concrete pictures that served as task-irrelevant distractors.

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Appendix A. IAPS numbers

Neutral: 1601, 1670, 2102, 2190, 2191, 2221, 2235, 2240, 2250, 2272, 2320, 2370, 2372, 2393, 2396, 2435, 2441, 2442, 2480, 2485, 2512, 2560, 2570, 2580, 2749, 2840, 2850, 4100, 4542, 7140, 7491, 7500, 7550, 8010, 8032, 8090, 8205, 8232, 8250, 8330, 8460, 8465, 8475, 8620, 9210.

Pleasant: 1650, 1710, 2058, 2071, 2160, 2209, 2216, 2311, 2340, 2341, 2345, 2398, 2530, 2550, 2665, 2660, 4220, 4250, 4599, 4610,

4611, 4617, 4623, 4626, 4640, 4641, 4653, 4659, 4660, 4670, 4680, 4681, 4687, 4690, 4695, 4800, 5260, 7502, 8080, 8090, 8161, 8179, 8186, 8193, 8200.

Unpleasant: 1200, 1300, 2375, 2661, 2683, 2691, 2703, 2710, 2730, 2800, 2811, 3030, 3053, 3060, 3064, 3101, 3110, 3120, 3130, 3170, 3220, 3225, 3230, 3266, 3301, 3350, 3500, 3530, 6022, 6213, 6313, 6360, 6510, 6550, 6560, 8230, 9040, 9042, 9181, 9250, 9254, 9300, 9410, 9433, 9520.

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