

Emotionally arousing stimuli compete for attention with left hemispace

Kaisa M. Hartikainen^{a,c,d}, Keith H. Ogawa^b, Maryam Soltani^a and Robert T. Knight^a

^aHelen Wills Neuroscience Institute and Department of Psychology, Tolman Hall, University of California, Berkeley, ^bSaint Mary's College of California, John Magaddino Neuroscience Laboratory, Moraga, California, USA, ^cDepartment of Neurology and Rehabilitation, Tampere University Hospital and ^dFaculty of Medicine, Physiology, University of Tampere, Tampere, Finland

Correspondence to Kaisa M. Hartikainen, Faculty of Medicine, Physiology, University of Tampere, FIN-33014, Finland
Tel: + 358 40 410 7077; fax: + 358 3 3551 6170; e-mail: kaisa.hartikainen@uta.fi

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Rapid interaction of the emotional and attentional networks is critical for adaptive behavior. Here, we examined the effects of emotional stimulation on hemifield attention allocation using event-related potential and behavioral measures. Participants performed a visual-discrimination task on nonemotional targets presented randomly in the left or right hemifield. A brief task-irrelevant emotional (pleasant or unpleasant; 150-ms duration) or neutral picture was presented centrally 350 ms before the next target (150-ms duration). Unpleasant stimuli interfered with the

left visual field attention capacity, slowing behavioral responses to attended left field stimuli. In keeping with the behavioral data, event-related potential responses to nonemotional attended left field stimuli were reduced over the right parietal regions when preceded by an unpleasant event. The results provide electrophysiological and behavioral evidence that unpleasant, emotionally arousing stimuli interfere with the right hemisphere-dependent attention capacity. *NeuroReport* 18:1929–1933 © 2007 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Introduction

In unpredictable environments, emotions provide rapid modulation of behavior in a purposeful, fine-tuned, and flexible manner. From an evolutionary perspective, emotions provide a modulatory control system that facilitates survival and reproduction. Reflex-like reactions to emotional events can occur before attention is paid to them. For the flexible modulation of behaviors, however, attention is required. Attention directs limited brain-processing resources to events of biological, motivational, or emotional significance. A robust neural mechanism thus allows attention to be quickly and reliably directed towards objects or spatial locations of emotional significance, which is adaptive for survival.

The interaction of emotion and attention might be subserved by close anatomical interconnections. Neuropsychological evidence supports a right hemisphere bias for emotional and attentional processing in humans. Right hemisphere lesions are frequently accompanied by the neurological syndrome, hemispatial neglect, which is marked by a severe inability to attend to objects in the contralateral (left) hemispace [1]. Further, right hemisphere lesions lead to a variety of emotional deficits from reduced emotional arousal to an inability to perceive, identify, and express emotions [2–5]. Neuroimaging evidence from healthy participants also supports right lateralized emotion and attention networks, with partly overlapping activation patterns [6]. A right hemisphere frontoparietal network has been especially implicated in emotion-processing functions and in attention allocation to the left hemispace. Over-

lapping brain regions or those in close proximity might subserve the integration of emotion and attention, and provide an anatomical base for the privileged access of emotional stimuli to attentional networks. Partially shared brain structures might also be predicted to render attention to the left hemispace, which is liable to a cost owing to competition with emotional resource allocation.

We have previously reported the slowing of behavioral responses to left visual field (LVF) targets due to the preceding task-irrelevant emotional stimuli [7]. The current study evaluated whether competition for attentional resources could explain the diminished LVF discrimination performance in the setting of a preceding emotional event. We hypothesized that there is an initial automatic allocation of right hemispheric attentional resources to affective stimuli, which transiently renders other right hemisphere-dependent processing activities susceptible to reduced attentional resources. To assess this attentional resource-allocation hypothesis we measured the event-related potentials (ERPs) in participants performing a rapid hemifield visual-discrimination task, in which they were required to discriminate between brief, emotionally neutral target stimuli. Emotionally laden stimuli with no task-relevant spatial information were presented centrally, preceding lateralized target stimuli (see Fig. 1).

ERPs allow the assessment of the attentional resource-allocation hypothesis, given that the P3 amplitude reflects the amount of attentional resources allocated to the processing of the stimulus [8–10]. Larger N2-P3 responses are evoked by novel events, which capture more attentional

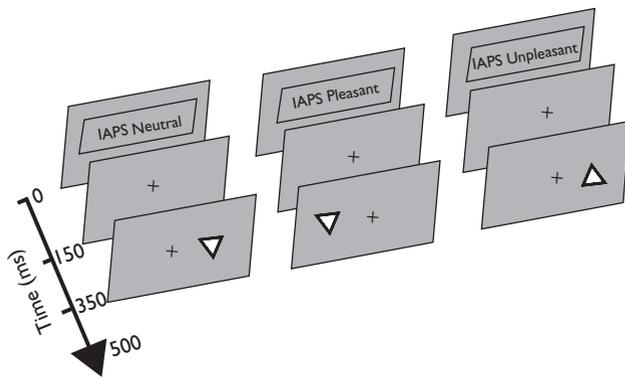


Fig. 1 Task and stimulus presentation paradigm. Participants discriminated between upright and inverted triangles (target). Targets were randomly presented in the left (LVF) or right visual hemifield (RVF, 150 ms). Task-irrelevant emotional (pleasant or unpleasant; 150 ms) or neutral stimuli using the International Affective Picture System (IAPS) were presented centrally 350 ms before target presentation. Some trial types in which IAPS stimuli were not followed by a target as well as those in which targets were not preceded by IAPS stimuli took place, but are not shown here.

resources and lead to greater exploratory behavior, than by repetitive stimuli, suggesting that the N2-P3 component reflects the activity of a neural system that regulates the allocation of attentional resources [11].

In support of the attentional competition model, we predicted a reduced N2-P3 amplitude to target stimuli that were preceded by affective stimuli in comparison with those preceded by neutral stimuli. Specifically, we predicted N2-P3 reduction in response to LVF targets, which would support the hypothesis that emotional stimuli predominantly engage the right hemisphere resources, and that they transiently compete with attention to the left hemisphere.

Methods

Participants

Ten healthy right-handed women (mean age, 19.4 years; range, 18–21), with normal or corrected vision and no history of neurological or psychiatric abnormalities, were recruited, and were paid for their participation. Participants gave their consent according to the University Guidelines. The study was approved by the Ethics Committee of the Institutional Review Board.

Stimuli

Three sets (pleasant, unpleasant, and neutral) of 48 colored pictures were chosen from the International Affective Picture System (IAPS) [12]. Each picture was presented equally in its original form and as a mirror image, to exclude any possible effects due to image asymmetries.

Paradigm

Participants were seated in a sound-attenuated booth facing a computer screen at a distance of 1 m. Participants were instructed to keep their eyes on a fixation cross in the middle of the screen throughout the presentation of the stimuli. Participants were asked to discriminate between upright and inverted triangles (target; 150-ms duration)

randomly presented in the left or right visual hemifield (RVF). Owing to the organization of the visual pathways, targets presented in the LVF are initially processed by the right hemisphere and vice versa. Presenting stimuli in the LVF or RVF thus allows for the investigation of the initial processing in the right (RH) or left hemisphere, respectively. The targets occurred 8° from fixation, and extended to 12° horizontally from the visual angle. A brief emotional (pleasant or unpleasant) or neutral picture (150-ms duration) extending to 9° from the visual angle was presented centrally 350 ms before the next target (Fig. 1). Eighteen percent of the targets were not preceded by any stimuli, and 27% of the pictures were not followed by a target. Different trial types were used to prevent the participants from forming a response pattern or an expectation, and to create subtraction waveforms. Participants were asked to ignore the pictures and to respond as quickly and as accurately as possible to the orientation of the triangle. The response hand was counterbalanced.

Event-related potential recording and analysis

Electroencephalography (EEG) was recorded with Ag–AgCl electrodes placed at 30 scalp sites according to the standard 10–20 configuration referred to the linked mastoids. Horizontal electro-oculograms were recorded from the outer canthi of each eye, and vertical electro-oculograms from below the left eye and the Fp1. Impedances were maintained below 5 k Ω . The EEG was amplified (band pass 0.1–80 Hz) and sampled at 250 Hz. Trials containing blinks, horizontal eye movements, or EMG artifacts were excluded from the analysis. EEG signals were averaged offline and time-locked to the stimulus onset. Epoch length was 1600 ms, including a baseline of 100 ms before stimulus presentation.

Difference waveforms

We used ERP difference waveforms (DW) to assess our hypothesis on attentional resource competition between task-irrelevant affective stimuli and task-relevant nonaffective stimuli. The DWs created reflect target-related processing, and the modification of the same by the preceding affective stimuli. DWs allowed us to remove large effects of the IAPS-related visual processing from the ERP waveforms. DWs further enabled control for any physical differences in the IAPS stimuli of different categories. We created three TargetDWs by subtracting the ERPs to identical sets of IAPS stimuli presented alone from the ERPs to those presented with an accompanying target. Three TargetDWs were created by the following subtractions:

$$\text{TargetDW}_{\text{Neutral}} = \text{ERP}_{\text{NeutralTarget}} - \text{ERP}_{\text{Neutral}}$$

$$\text{TargetDW}_{\text{Pleasant}} = \text{ERP}_{\text{PleasantTarget}} - \text{ERP}_{\text{Pleasant}}$$

$$\text{TargetDW}_{\text{Unpleasant}} = \text{ERP}_{\text{UnpleasantTarget}} - \text{ERP}_{\text{Unpleasant}}$$

Where, $\text{ERP}_{\text{NeutralTarget}}$, ERPs to neutral stimuli followed by a target; $\text{ERP}_{\text{Neutral}}$, ERPs to neutral stimuli not followed by a target; $\text{ERP}_{\text{PleasantTarget}}$, ERPs to pleasant stimuli followed by a target; $\text{ERP}_{\text{Pleasant}}$, ERPs to pleasant stimuli not followed by a target; $\text{ERP}_{\text{UnpleasantTarget}}$, ERPs to unpleasant stimuli followed by a target; $\text{ERP}_{\text{Unpleasant}}$, ERPs to unpleasant stimuli not followed by a target.

Event-related potential measurements

As a reflection of attentional allocation to target processing, we measured the N2-P3 peak-to-peak amplitude from TargetDWs. Theoretical and empirical evidence suggest that P3 amplitude reflects the amount of attentional allocation [9]. TargetDWs were used for measurements instead of the original ERPs, to examine target-related processing without the superimposed effect of IAPS-related processing. IAPS stimuli and targets were presented so close together in time (interstimulus interval 200 ms) that the ERP responses to the IAPS stimuli and to the targets overlapped in the original ERP waveforms. In addition to controlling for ERP effects due to mere physical differences in the different categories of IAPS stimuli, DWs also remove any effect of reference. Peak-to-peak measurement was used to account for any possible baseline shifts.

As the P3 potential has its maximum in the parietal region, the N2-P3 peak-to-peak amplitudes for the targets were measured at one left and one right centroparietal

electrode, CP3 and CP4. The amplitude of the N2 was defined as the lowest negative peak within a time window of 230–330ms, and the amplitude of P3 as the highest positive peak 350–650 ms after the target onset.

Statistical analysis

SPSS software (Chicago, Illinois, USA) program was used for statistical analysis. Repeated-measures analysis of variance (ANOVA) was performed on ERPs, reaction times (RT), and accuracy. Any significant interaction effects were decomposed by additional ANOVAs. Posthoc tests were carried out by further ANOVAs or independent-samples *t*-test. Greenhouse–Geisser epsilon correction was applied for multiple comparisons when appropriate.

Target difference waveforms

TargetDWs were analyzed by measuring N2-P3 peak-to-peak amplitudes at CP3 and CP4 for the left and right

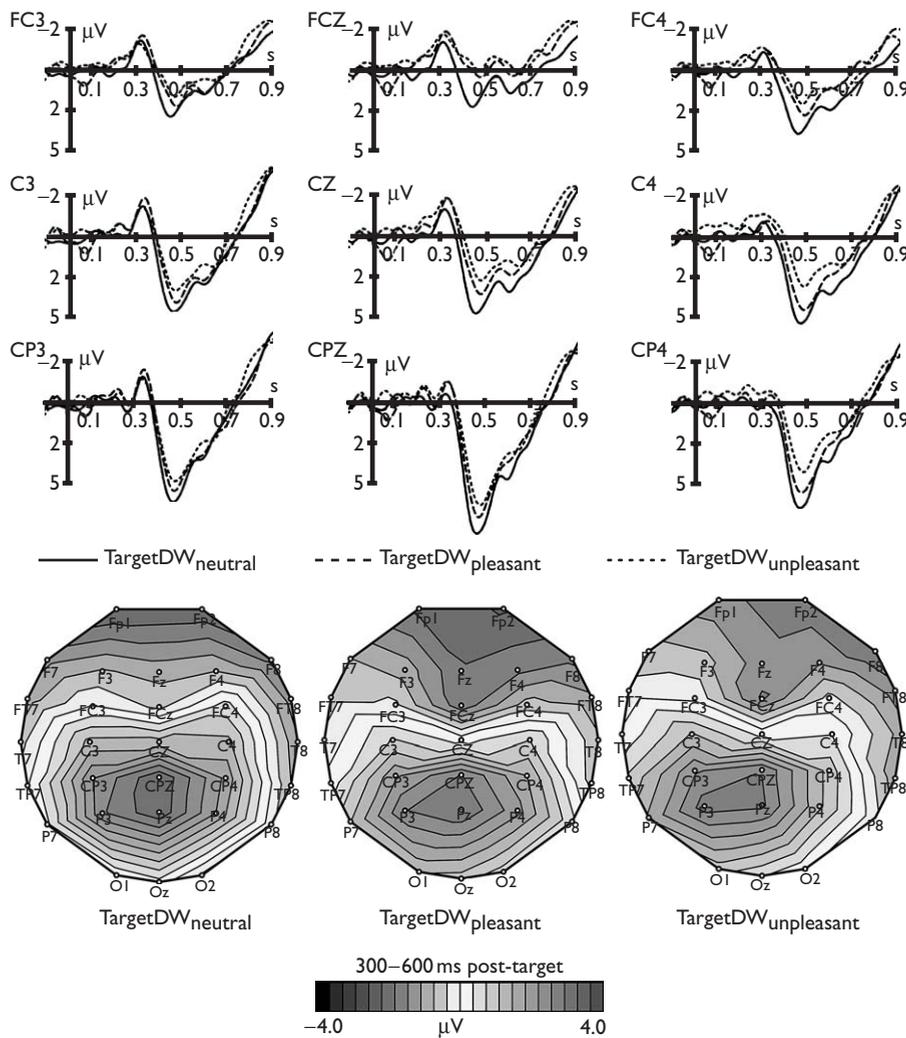


Fig. 2 Emotional modulation of target processing. Diminished frontoparietal brain responses to left visual field (LVF) targets due to preceding unpleasant stimuli with pronounced effects over the right hemisphere (RH). Difference waves (DWs) and their topographic maps are presented. TargetDWs reveal the effect that affective processing has on subsequent target processing: the effect of mere International Affective Picture System (IAPS) image processing has been subtracted. TargetDWs are obtained by subtracting the event-related potentials (ERPs) to neutral, pleasant or unpleasant stimuli not followed by a target from the ERPs to targets that were preceded by neutral, pleasant, or unpleasant stimuli. TargetDW_{Neutral} accounts for the effect of preceding complex visual stimuli on target processing in general.

hemispheres, respectively. The factors for TargetDWs were Emotional Valence (Pleasant, Unpleasant, and Neutral), Target Hemifield (LVF and RVF), and Hemisphere [Left (CP3) and Right (CP4)].

Behavioral analysis

For RT and response accuracy, the factors were Emotional Valence (Pleasant, Unpleasant, and Neutral) and Target Location (LVF and RVF). On the basis of our previous work (Hartikainen *et al.* [7]), a closer investigation of our hypothesis on emotional competition for right hemisphere attentional resources was performed using LVF targets, comparing each valence pair (Neutral \times Pleasant; Neutral \times Unpleasant; and Pleasant \times Unpleasant).

Results

Event-related potential results

Targets

Difference waves, showing target detection-related parietal activity subsequent to the IAPS pictures, revealed that the N2-P3 amplitude responses to targets were smaller when preceded by affective stimuli than by neutral stimuli [Valence: $F(2,18)=4.9$, $P<0.02$, Fig. 2]. Unpleasant emotional stimuli reduced the N2-P3 amplitude, especially in response to LVF targets [Valence \times Target Hemifield; $F(2,18)=5.8$, $P<0.01$, Fig. 2]. Further, the reduction was greatest over the right hemisphere [Valence \times Target Hemifield \times Hemisphere; $F(2,18)=4.6$, $P<0.02$, Figs 2 and 3].

Behavioral results

Responses were slower to targets in the LVF ($479\text{ ms} \pm 69$), compared with responses to those in the RVF in all conditions [$461\text{ ms} \pm 59$, $F(1,9)=16.65$, $P<0.003$]. Compared with neutral stimuli, affective stimuli slowed down RTs to all targets [$F(2,18)=3.77$, $P<0.042$]. The increase in RT reached significance only for targets presented in the LVF [$F(2,18)=4.47$, $P<0.026$], with slower RTs to targets being preceded by unpleasant stimuli ($463\text{ ms} \pm 63$) than by pleasant [$455\text{ ms} \pm 61$, $F(1,9)=6.5$, $P<0.030$] or neutral stimuli [$457\text{ ms} \pm 63$, $F(1,9)=5.4$, $P<0.044$]. Accuracy was not affected by the valence of the preceding picture.

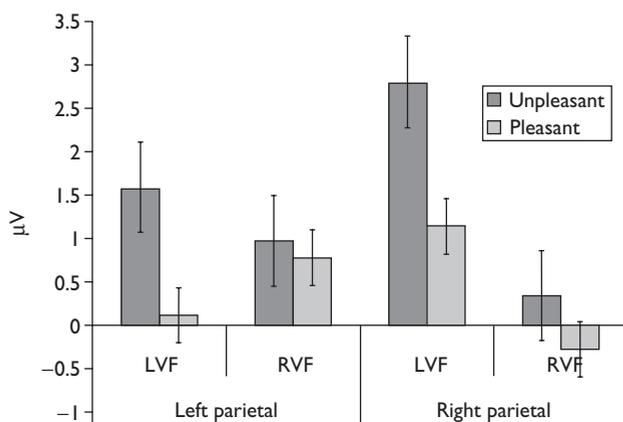


Fig. 3 Emotional cost of hemifield attention allocation. Unpleasant stimuli lead to the greatest reduction in target-related brain responses to left visual field (LVF) targets, particularly over the right parietal region. The amount of N2-P3 peak-to-peak amplitude reduction in target event-related potentials (ERPs) due to preceding unpleasant and pleasant stimuli, compared with preceding neutral stimuli.

Discussion

The current study provides electrophysiological and behavioral evidence that task-irrelevant emotionally arousing stimuli compete for attentional resources. Target detection-related ERP responses were diminished to targets that were preceded by affective stimuli in comparison to targets preceded by neutral stimuli. The reduction of target-related activity over the RH was maximal after unpleasant stimuli, and was predominantly observed for targets in the LVF. Finally, RTs to LVF/RH targets were slower after unpleasant emotional stimuli than after pleasant or neutral stimuli. These results provide novel evidence that unpleasant affective stimuli preferentially engage the right hemisphere and compete for its attentional resources.

The engagement of the attention network increases activity in the right parietotemporal region, [13] and it evokes a parietal potential called the P3 in healthy participants [14]. In patients with lesions in the parietotemporal regions the P3 is reduced, suggesting that the parietotemporal region is the main source for the potential [15]. Neuroimaging studies, lesion studies, and intracranial recording provide further support for frontoparietal involvement in attention allocation [16]. P3 amplitude is thought to reflect the amount of attentional resources allocated to the processing of the stimulus [8–10]. In dual tasks that manipulate attentional allocation by a task load, P3 amplitude to the secondary task diminishes as the first task taxes more resources [17]. Similarly, attentional capture by affective stimuli has been thought to explain the reduced P3 amplitude responses to auditory startle probes during emotionally arousing stimuli [18]. The decreased P3 amplitude responses to target stimuli that were preceded by emotional (compared with neutral) stimuli in this study suggests the decreased allocation of attentional resources to targets preceded by unpleasant emotional stimuli. We believe this to be due to emotionally arousing stimuli readily capturing right hemisphere resources and rendering subsequent processing vulnerable to a cost.

RH laterality ERP effects have been previously reported for both pleasant and unpleasant stimuli [19], for unpleasant stimuli [20], and for negative attitude [21]. The electrophysiological evidence for right lateralized emotional processing has, however, been inconclusive, with several studies reporting mixed or no laterality effects for emotion [22–25]. We obtained novel evidence for a right hemisphere bias during the processing of unpleasant emotional information by examining the effects of emotional stimuli on performance and brain activity while attention was being paid to lateralized nonaffective stimuli.

Conclusion

Affective stimuli diminished RH attentional capacity, supporting the key role of the RH in the interplay between attention and emotion. These findings support the prediction that emotional stimulation and attention to the left hemifield engage and compete for the same neural resources, suggesting partially overlapping right lateralized emotion–attention networks.

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