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First published on: 05 October 2010

To cite this Article Baijal, Shruti and Srinivasan, Narayanan(2011) 'Emotional and hemispheric asymmetries in shifts of attention: An ERP study', Cognition & Emotion, 25: 2, 280 — 294, First published on: 05 October 2010 (iFirst)

To link to this Article: DOI: 10.1080/02699931.2010.492719

URL: http://dx.doi.org/10.1080/02699931.2010.492719
Emotional and hemispheric asymmetries in shifts of attention: An ERP study

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Inhibition of return (IOR) refers to the larger response time to cued targets appearing at long cue-to-target intervals. Given emotion–attention interactions and associated visual field (VF) asymmetries, we examined the effects of emotions and hemispheric processing on object- and location-based IOR. We expected reduced IOR and right hemispheric bias accompanied by differences in event-related potentials (ERPs) including lack of suppression of cued N1 and enhancement of Nd components for sad targets. Reaction times and ERPs were recorded in an exogenous cuing detection task using happy and sad schematic faces. Results revealed reduced IOR for left compared to right VF with sad faces but no such asymmetry for happy faces. Cued N1 amplitudes were suppressed for happy targets but not for sad targets presented to the left VF. Nd amplitudes were enhanced for right-hemispheric sad faces especially with object-based IOR. The results indicate right-hemispheric advantage in the capture of attention by negative emotion especially with object-based selection.

Keywords: Attention; Emotion; Inhibition of return; Sad; Happy; ERP.

INTRODUCTION

Exogenous cuing results in faster responses to a target at the cued compared to the uncued location for stimulus onset asynchronies (SOAs) less than 300 ms but slower responses are observed for SOAs greater than 300 ms (Posner & Cohen, 1984). The slowness in response times observed at longer SOAs is termed inhibition of return (IOR). The phenomenon of IOR is considered adaptive assuming that the bias to facilitate orienting towards new locations results in more efficient visual search (Klein, 2000). In addition to location, IOR has also been observed with several object-based properties such as colour, shape, and size (Pratt, Kingstone, & Khoe, 1997; Riggio, Patteri, & Umilta, 2004; Soto & Blanco, 2004; Tipper, Driver, & Weaver, 1991).

Object-based IOR was shown in a cuing paradigm in which one of the two boxes on a display was cued (using peripheral flash) before movement and the targets were presented in one of the boxes subsequent to the movement (Tipper et al., 1991). At longer intervals between cue and target (greater than 400 ms), IOR was observed for the cued object (object-based IOR) rather than the cued location. Inhibition has been found with both cued objects and locations, suggesting the existence of object-based and location-based components of IOR that reflect the operation of two partially separate...
inhibitory mechanisms (Abrams & Pratt, 2000; Tipper et al., 1997). IOR can be object specific; the magnitude of IOR was greater for faces compared to non-face targets (Theeuwes & van der Stigchel, 2006).

IOR is also modulated by emotional information. Emotional cues (angry, happy or neutral schematic facial expressions) affected the cueing effects in an attentional cueing paradigm (Fox, Russon, & Dutton, 2002). Fox et al. (2002) measured IOR using emotional faces as cues and neutral targets to test attentional disengagement from emotional cues. IOR was less with threatening compared to happy or neutral schematic faces and was explained in terms of an increased dwell time for negative stimuli. In other words, since attention was held for a longer duration by the negative emotional cues, the IOR for the targets at that location was reduced. However, it is unclear whether there is a bias in the capture of emotional targets presented at the inhibited locations. To our knowledge, no previous reports have measured IOR with emotional targets. Therefore, we examined the effects of emotional targets on the magnitude of IOR.

Previous studies have shown differences in emotion–attention interactions. For example, sad emotion affects the temporal dynamics of attention by producing longer attentional dwell times (Srivastava & Srinivasan, 2010), efficient allocation of attentional resources (Ogawa & Suzuki, 2004) and narrowing of attentional focus (Fenske & Eastwood, 2003) compared to the happy emotion. These results indicate that sad and happy emotional information may also be associated with differences in IOR.

One factor that affects the processing of emotions in the brain is laterality. A right hemispheric bias has been observed in the processing of emotional information in many studies (Ahern et al., 1991; Alpers, 2008; Hartikainen, Ogawa, & Knight, 2000). The lateralisation of emotional processes is dependent upon emotional valence (valence hypothesis). Studies show that negative emotions facilitate performance on tasks that rely on the right hemisphere and the reverse is true for positive emotions (Davidson, 1992; Heilman, 1997). More recent studies have argued for the existence of hemispheric biases in the processing of negative emotions but not in the processing of positive or neutral stimuli (Hartikainen, Ogawa, Soltani, & Knight, 2007; Simon-Thomas, Role, & Knight, 2005; Smith & Bulman-Fleming, 2005). For example, when the participants had to identify letter targets preceded by negative or neutral stimuli, the negative emotional stimuli positively primed the right hemispheric targets resulting in better performance (van Strien & Morpurgo, 1992). Emotional compared to neutral distractors interfered with a simple discrimination task when targets were presented to the left VF or the right hemisphere (Hartikainen et al., 2000). Interestingly, the interference for targets appearing in the left VF was greater with negative distractors indicating a bias for negative emotions towards the right hemisphere (Hartikainen et al., 2000).

Besides the left–right biases, asymmetries in upper–lower VFs have been obtained for perceptual processing and visual attention (Christman & Niebauer, 1997; Sdoia, Couyoumdjian, & Ferlazzom, 2004). It has been argued that attentional resolution is better in the lower VF (He, Cavanagh, & Intrilligator, 1996) and this might be linked to potential differences in processing associated with near space/lower VF with far space/upper VF (Previc, 1990). Reaction times were faster to targets presented in the lower VF in a visual search task in which targets were presented in either of the two VFs (Ellison & Walsh, 2000). Processing in the upper and lower VFs have been linked with the parvo (P) and magno (M) pathways respectively with the faster M pathway aiding processing in the lower VF (Cheng, Éysel, & Vidyasagar, 2004; Christman & Niebauer, 1997). However, the relationship between processing in upper–lower VFs and emotional information remains unclear.

Neural mechanisms underlying emotion–attention interactions have been investigated in several event-related potential (ERP) studies (Carreti’e, Mercado, Tapia, & Hinojosa, 2001; Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2004; Smith, Cacioppo, Larsen, & Chartrand, 2003). Emotional information has been found to
differentially modulate attention-related ERP components such as frontal-central P1, frontal-central N100, posterior P160, anterior P200 and P2, and frontal-parietal N2, with larger amplitudes for negative compared to positive stimuli (Carreti‘e et al., 2001; Delplanque et al., 2004; Luo, Feng, He, Wang, & Luo, 2010; Smith & Bulman-Fleming, 2005; Smith et al., 2003; Williams, Palmer, Liddell, Song, & Gordon, 2006). The enhanced response for the negative compared to positive stimuli has been interpreted as a negativity bias in attention allocation in the extrastriate visual cortex (Carreti‘e et al., 2001; Smith & Bulman-Fleming, 2005; Smith et al., 2003) that occurs even when the arousal dimension is low (Delplanque et al., 2004).

There is also some evidence to indicate that the negativity bias occurs especially in the right hemisphere (Hartikainen et al., 2007). During a visual discrimination task with non-emotional stimuli, the negative distractors interfered by slowing the behavioural responses when they preceded the non-emotional targets in the left VF. This was also accompanied by the reduced ERP responses in the right parietal areas when negative distractors preceded the non-emotional targets in the left VF. No such effect was found with the positive stimuli. These results indicate biased allocation of attentional resources to the processing of negative stimuli in the right hemisphere. These ERP effects that occur early in the visual stream, within about 300 ms from the appearance of the emotional stimuli, may also indicate early sensory gating mechanisms (Mangun & Hillyard, 1990), reflecting the influence of spatial attention in visual processing.

More importantly, ERP studies investigating IOR have shown reduced amplitudes of P1 and/or N1 over the posterior scalp for targets presented at the cued compared to uncued locations (McDonald, Ward, & Kiehl, 1999; Prime & Ward, 2004, 2006). Prime and Ward (2006) showed that the IOR effect observed as suppression of ERP responses for cued compared to uncued trials was erratic for the P1 component but consistent for the N1 component. Hence, the P1 effects due to cuing might not be linked to IOR. For example, Hopfinger and Mangun (1998) found a significant P1 reduction accompanied by a non-significant IOR effect in reaction time. Conversely, Hopfinger and Mangun (2001) found a significant 13 ms IOR effect with a non-significant P1 reduction in a subsequent study. The authors concluded that IOR was independent from P1 reduction. Besides this, Wascher and Tipper (2004) showed that neither P1 nor N1 reflect behavioural IOR effects and the reduction in P1 amplitudes for cued targets was independent of facilitation or IOR (Wascher & Tipper, 2004). Even Chica and Lupiánuez (2009) found that with a discrimination task, the P1 amplitude was diminished even when no IOR was present.

Effects of spatial attention have been shown over frontal and midline electrode sites in the Nd (negative difference) component obtained by subtracting the ERP of the invalid (cue information and the actual location of the target do not match) trials from that of the valid (cue information and the actual location of the target match) trials. The Nd component was found to be sensitive to changes in SOA with higher amplitudes at shorter SOAs during which facilitation, or at least no inhibition occurs (McDonald et al., 1999). There is some indication that IOR may be associated with the suppression of Nd250 and the enhancement of Nd310 components (Wascher & Tipper, 2004).

Wascher and Tipper (2004) found that at long SOAs, Nd250 amplitudes were enhanced when the IOR effect was small (sustained attention cues) compared to when the IOR effect was large (transient cue). Based on these results, it was proposed that Nd250 reflected a facilitator process that compensates for earlier inhibition on the cued or valid trials. This implies that Nd250 may depict shift of attention indicated by inhibition of return. On the other hand, Nd310 amplitudes were enhanced in response to transient cues when behavioural IOR was observed at long SOAs. The Nd250 and Nd310 effects are similar to the suppression of P2 (between 200 to 300 ms) followed by enhancement of P3 amplitudes for targets at cued locations (McDonald et al., 1999).
McDonald et al. (1999) proposed that the suppression of Nd might be independent of the suppression of P1 during IOR and Nd might reflect sensory refractoriness. However, other studies (e.g., McDonald, Hickey, Green, & Whitman, 2009) have reported an ERP component (N2pc) of comparable latency to Nd that was suppressed in response to targets appearing at cued locations compared to uncued locations. Other studies, too, have indicated reliable IOR-related effects on Nd indicating the usefulness of this component in studying IOR (Prime & Ward, 2004, 2006).

Given the differences in emotion–attention interactions between happy and sad faces, we investigated the effects of emotional processing on IOR. The neural mechanisms of IOR were examined by measuring multiple ERP components associated with IOR. We expected to observe: (i) the influence of positive (happy) and negative (sad) emotion displayed by target faces on the magnitude of IOR; (ii) hemispheric biases; and (iii) the effects of emotions on space-based and object-based selection. The present study addressed these issues by combining both aspects of object-based and location-based components of IOR in a double-cueing IOR paradigm that used a static display (McAuliffe, Chasteen, & Pratt, 2006) with schematic happy and sad faces as targets. If a sad face captures attention more efficiently (even when present at the inhibited location), then IOR would be reduced for the sad compared to the happy face. If negative emotions are biased towards the right hemisphere (Hartikainen et al., 2000, 2007; Simon-Thomas et al., 2005; Smith & Bulman-Fleming, 2005), the magnitude of IOR for the sad face would be particularly reduced in the right hemisphere. Given potential differences in upper–lower VFs in terms of attention, less IOR for the lower VF was expected compared to the upper VF. No specific hypothesis was made in terms of possible interactions between upper–lower VFs with emotions.

In terms of ERP components, we hypothesised that the IOR effect would be observed as suppression of the N1 component (similar to McDonald et al., 1999; Prime & Ward, 2004, 2006) especially for the happy face. In addition, since Nd is associated with facilitation in shift of attention (Wascher & Tipper, 2004), it would be enhanced for the sad relative to the happy face owing to the reduced behavioural measure of IOR associated with sad targets. This is also in line with the negativity bias found in other studies (Carreti’ e et al., 2001; Smith & Bulman-Fleming, 2005; Smith et al., 2003). Moreover, since negativity bias has been observed for the right hemisphere (Hartikainen et al., 2000; Simon-Thomas et al., 2005; Smith & Bulman-Fleming, 2005), Nd effects for the sad face are expected to be most prominent in the right hemisphere.

MATERIALS AND METHODS

Participants

Twenty-three male adult volunteers (age range = 17–26 years) participated in the study by giving informed consent. All were right handed with normal or corrected-to-normal vision. Data from two participants were removed from the analysis due to corruption of their EEG data. Eleven participants performed one part of the experiment (placeholders in upper–lower VFs) and ten participants performed the other part (placeholders in left–right VFs).

Stimuli and procedure

The participants were seated comfortably in front of the monitor where preparations were done for the electrophysiological recording. The basic sequence of the trial is depicted in Figure 1. A constant display that remained throughout the experiment comprised two placeholder boxes placed each in either left–right or upper–lower VFs. The trials in which the cue and target appeared in the placeholder boxes were considered object-based trials whereas the trials in which cue and target appears in the empty locations were considered location- or space-based trials. For one group of participants, placeholder boxes were presented in the left–right VFs. For another...
group of participants, placeholder boxes appeared in the upper–lower VFs leaving the left–right locations empty. The location of the placeholder boxes was manipulated as a between-subjects variable given the large number of trials that would have resulted in presenting the placeholder boxes in both the left–right and lower–upper VFs to an individual participant.

All stimuli were presented in white on a black background. The initial display consisted of two placeholder boxes (1.8” by 1.8”) centred at 5.4” from the central fixation dot aligned either vertically or horizontally (see Figure 1). Following a 3000 ms display of the fixation dot, a peripheral location cue (1.4” by 1.4”) appeared for 100 ms at one of the four locations on the horizontal or vertical meridian, centred at 5.4” from the fixation. The cue was uninformative and the participants were instructed that the cue did not reliably predict the location of the targets. After a blank duration of 100 ms, the central fixation dot expanded in size. The large dot remained on the screen until 100 ms then shrunk to its original size and remained on the screen for 250 ms. This was done to reorient the observer to the centre of the display and is considered critical in an IOR paradigm (McAuliffe et al., 2006). Following this, a schematic face target (1.4” in diameter) bearing happy or sad facial expression appeared at one of the four target locations and remained until response.

The participants were instructed to remain fixated at the central dot and respond by pressing a button on the response pad as soon as they detected a face irrespective of emotional content. They were specifically asked not to pay attention to the facial expression, which was irrelevant to the task. The experimental session consisted of a total of 640 trials consisting of 200 object trials and 200 location trials. The cues and targets were equally likely to appear at any of the four target locations. Object trials (cue and targets appear in placeholder boxes) and location trials (cue and targets appear in empty locations) could be valid.

Figure 1. Stimulus sequence in a sample trial.
(cue and targets appear in the same location or placeholder) or invalid (cue and targets appear in different placeholders or locations). There were 80 catch trials in which a target face did not appear after the presentation of the cues and 160 filler trials in which either the cue was in placeholder box with target outside placeholder box or the cue was outside placeholder box with targets inside placeholder box. Filler trials were included to ensure that the target locations could not be predicted (McAuliffe et al., 2006). Only object and location trials were included in the analysis.

**EEG acquisition and processing**

Stimulus presentation was performed with the STIM² software (Neuroscan Inc., USA) and responses were obtained using a response pad. The continuous EEG was recorded using a 64-channel system (SCAN 4.3, Neuroscan Inc., USA) referenced to the left and right ear lobes. The horizontal EOG activity was recorded from two bipolar electrodes positioned on the outer canthi of both eyes. Vertical EOG activity was recorded from two bipolar electrode sites, above and below the right eye. The impedance at each electrode site was maintained below 10 kΩ. The raw EEG data recorded during the trials was digitised at a 1000 Hz sampling rate and a 50 Hz notch filter was applied to remove noise due to current line.

The raw EEG data were pre-processed using a band-pass filter (1 to 30 Hz). The filtered data were segmented into target-locked epochs between −50 ms to 600 ms. The epochs were baseline corrected using a pre-stimulus interval (−50 to 0 ms). The muscle movement artefacts and ocular artefacts (exceeding 50 μV) were removed from single trials. Only the correct trials were included for analysis. Separate averaged waveforms for each condition were generated. An early negativity (N1) was observed within a 100–250 ms window post-stimulus onset. The negativity was maximally observed over the posterior region: occipitoparietal (PO7, PO8) and parietal sites (P5, P6). The difference waveforms were constructed by subtracting the invalid-trial ERP from the valid-trial ERP. A negativity arising around 250–350 ms was consistently observed in all the participants, which was the Nd component. Nd was most prominent over the C3, C4, F3, F4, FC3 and FC4 electrode sites, which were considered for further analysis. For statistical analysis, the mean amplitudes of the range 100–250 ms for the N1 component at parietal and occipitoparietal electrode sites were used. Similarly, for the analysis of the Nd component, the mean amplitudes within the range 250–350 ms at frontal, central and frontal-central electrode sites were used.

**RESULTS**

**Behavioural results**

Mean reaction time (RT) was computed for all the conditions. Trials with RTs less than 100 ms (too fast) and RTs greater than 1000 ms (too slow) were removed (less than 1% of the total number of trials). Statistical analysis was performed on the IOR magnitude calculated by subtracting the mean RT of invalid trials from valid trials. IOR values for each condition were submitted to a mixed analysis of variance (ANOVA) with Selection (object-based/space-based) as between-subjects factor and Emotion (sad/happy) and VF (left/right) as within-subjects factors. Two separate 2 (Selection) × 2 (Emotion) × 2 (VF) ANOVAs were performed for the upper–lower VFs and left–right VFs. The post hoc comparisons were performed using the Tukey HSD test.

The ANOVA with the upper–lower VFs showed that IOR was greater in the upper VF compared to the lower VF (by 11 ms) as shown by the main effect of VF, $F(1, 19) = 4.83, \text{MSE} = 532.89, p < .05$. The ANOVA with left–right VFs showed that IOR was greater in the right compared to the left VF (by 14 ms) as indexed by the main effect of VF, $F(1, 19) = 4.38, \text{MSE} = 835.64, p = .05$. The reduced IOR observed for the left VF is consistent with the idea that the right hemisphere is better at inhibitory control of attentional processes in the presence of emotional

**EMOTIONS AND IOR**

COGNITION AND EMOTION, 2011, 25 (2) 285
information. The interaction effect of VF × Emotions (see Figure 2) was observed only during the ANOVA with left–right VF, $F(1, 19) = 4.70$, $MSE = 484.49$, $p < .05$. Interestingly, the left–right VF bias was observed only for the sad face with greater IOR for targets presented to the right VF compared to the left VF, $t(19) = 4.935$, $p < .05$, and no asymmetry was observed for the happy face, $t(19) < 1$, ns. Since the upper–lower VFs get information from both the hemispheres, no hemispheric bias was observed in the processing of emotional targets, $F(1, 19) < 1$, ns.

ERPs results

$N1$ analysis. A mixed ANOVA with Selection (object-based/space-based) as between-group factor and Emotion (sad/happy), VF, Validity and Electrode Hemisphere as within-group factors was performed. ANOVA 2 (Selection) $\times$ 2 (Emotion) $\times$ 2 (VF) $\times$ 2 (Electrode Hemisphere) $\times$ 2 (Validity) was done separately for left–right and upper–lower VFs and different electrode locations (parietal and posterior occipital). The analysis with left–right visual fields showed no significant main effects at either parietal or posterior occipital. The analysis with left–right visual fields showed no significant main effects at either parietal or posterior occipital. Figure 3 depicts the N1 waveforms at parietal and occipitoparietal sites. At the parietal electrode site, the interaction effect of Hemispheric × Visual Field, $F(1, 19) = 37.35$, $MSE = 1.79$, $p < .001$, suggesting that spatial attention to a visual field facilitates processing at the contralateral hemisphere. This effect was also significant at the posterior occipital electrode site, $F(1, 19) = 24.99$, $MSE = 1.70$, $p < .001$. At the posterior occipital site, the interaction effect of Hemispheric × VF × Validity was significant, $F(1, 19) = 4.91$, $MSE = 1.18$, $p < .05$, suggesting that the validity effects varied depending upon the visual field and hemisphere to which the targets were presented. This is consistent with the earlier findings that indicate the influence of spatial attention on early sensory processes (McDonald et al., 1999; Prime & Ward, 2004, 2006). At the parietal site, there were significant interaction effects between Selection, Hemispheric and Visual Field, $F(3, 57) = 4.91$, $MSE = 1.47$, $p < .01$, indicating that the sensory processes reflected by N1 amplitudes are modulated by the mode of selection and hemisphere.

The interaction between Emotion, Visual Field and Validity, $F(1, 19) = 9.53$, $MSE = 2.41$, $p < .01$, was also significant at the parietal site. Given the behavioural effects of reduced magnitude of IOR in the left visual field for sad compared to happy targets, we performed separate analyses for the left and right visual fields, with

Figure 2. IOR magnitude (ms) as a function of VF and emotions.
only Emotions and Validity as within-subject variables. Analysis with left VFs revealed a significant interaction between Emotions and Validity, \( F(1, 20) = 7.60, \text{MSE} = 1.36, p < .05 \), at the parietal site. Planned comparisons indicated that the reduction of N1 for the valid compared to invalid trials occurred only for the happy targets, \( t(20) = 3.41, p < .05 \), and not for the sad targets, \( t(20) = 2.12, p = .149 \). Analysis with right-VF trials with Emotions and Validity as within-group factors did not reveal significant effects (\( p > .1 \)), consistent with the behavioural results.

Similarly, at the posterior occipital location, the interaction between Emotion, Visual Field and Validity, \( F(1, 19) = 7.88, \text{MSE} = 2.52, p < .05 \), was significant. Separate analysis for the left visual field only with Emotions and Validity as within-subject variables, revealed a significant Emotion \( \times \) Validity interaction effect, \( F(1, 20) = 4.95, \text{MSE} = 1.43, p < .05 \). A non-significant trend was observed for the reduction of N1 on valid compared to invalid targets for happy, \( t(20) = 2.51, p = .09 \), but not sad faces (\( p = .515 \)).

The suppression of N1 has been shown to indicate the presence of IOR (McDonald et al., 1999; Prime & Ward, 2004, 2006). Therefore, the N1 effects for happy targets in the left visual field are consistent with the behavioural effects of greater IOR for happy compared to sad targets in the left visual field. The analysis with the upper–lower visual fields showed that N1 was reduced in the upper visual field compared to the lower visual field at parietal, \( F(1, 19) = 22.01, \text{MSE} = 2.38, p < .001 \), and posterior occipital, \( F(1, 19) = 18.80, \text{MSE} = 2.71, p < .001 \), sites. This is consistent with the behavioural effects of greater magnitude.

Figure 3. N1 waveforms for valid and invalid conditions in (a) left parietal; (b) right parietal; (c) left occipitoparietal; and (d) right occipitoparietal.
of IOR in the upper visual field. No other main or interaction effects were significant.

At the parietal electrode site, the interaction effect between Emotion, Hemisphere, Visual Field and Validity was also significant, \( F(1, 19) = 5.47, \, MSE = 0.29, \, p < .05 \). The post hoc tests showed that the suppression of the valid N1 amplitude occurred for happy targets presented to the left visual field in both the left hemisphere, \( t(20) = 8.85, \, p < .001 \), and right hemisphere, \( t(20) = 5.95, \, p < .01 \), indicating an IOR effect. The suppression of valid N1 was also observed with sad targets presented to the right visual field in the left hemisphere, \( t(20) = 5.02, \, p < .001 \). These results suggest that while the suppression of the N1 component was evident in both the hemispheres for the happy target, it only appeared in the left hemisphere for the sad target.

**Nd analysis.** A mixed ANOVA with Selection (object-based/space-based) as between-group factor and Emotion (sad/happy), VF (left/right) and Electrode Hemisphere (left/right) as within-group factors was performed. The ERP responses were consistent with the behavioural results in many respects. The mean amplitudes (250–350 ms) were computed for the difference waveform of Nd wave (valid–invalid). ANOVA 2 (Selection) \( \times 2 \) (Emotion) \( \times 2 \) (VF) \( \times 2 \) (Electrode Hemisphere), was separately done for left–right and upper–lower VF and different electrode locations (frontal, central and frontal-central). The analysis of the left–right VF showed that the Nd amplitudes were enhanced for object-based compared to space-based selection, \( F(1, 19) = 5.394, \, MSE = 5.53, \, p < .05 \), and for right hemisphere compared to left hemisphere, \( F(1, 19) = 4.33, \, MSE = 1.11, \, p = .05 \), at central electrode locations. The Selection \( \times \) Hemisphere interaction was significant, \( F(1, 19) = 7.173, \, MSE = 1.11, \, p < .05 \), at the central sites. Post hoc comparisons revealed a hemispheric bias for object-based selection, in terms of higher amplitudes of Nd in the right compared to left hemisphere, \( t(19) = 4.762, \, p < .05 \), with no such bias for space-based selection (Figure 4). Other effects at the central electrode
site include significant interactions between Selection and Emotion observed over the central cortical sites, $F(1, 19) = 4.03, MSE = 7.26, p = .05$. Post hoc comparisons showed that Nd amplitudes were higher for sad compared to happy targets during the object-based selection, $t(19) = 4.03, p < .05$, but not during location-based selection (Figure 5).

The analysis also revealed a significant VF $\times$ Emotions interaction effect at the central electrode sites, $F(1, 19) = 5.212, MSE = 6.32, p < .05$. This interaction effect was close to significance at frontal, $F(1, 19) = 3.673, MSE = 4.96, p = .07$, and frontal central, $F(1, 19) = 3.63, MSE = 5.00, p = .07$, electrode sites. At central sites, planned comparisons revealed visual-field asymmetry existed only for the sad targets, showing greater amplitudes for left visual field compared to right visual field sad targets, $t(19) = 2.84, p = .05$. No such asymmetry was observed for happy targets (see Table 1), which was in agreement with the behavioural results. The ability of the right hemisphere to shift attention to negative emotions was shown by increased amplitudes of Nd for sad targets presented to the left visual field, which is processed dominantly by the right hemisphere.

The frontal-central cortical sites exhibited an interaction effect of Selection $\times$ Emotion $\times$ VF both for left–right VFs, $F(1, 19) = 4.75, MSE = 5.00, p < .05$, and upper–lower VFs, $F(1, 19) = 4.602, MSE = 7.64, p < .05$. The effect was also significant in the frontal cortical sites, $F(1, 19) = 7.474, MSE = 6.42, p < .05$, for the upper–lower VFs. The post hoc comparisons revealed enhanced right-hemispheric amplitudes for sad compared to happy faces during object-based selection, $t(19) = 4.951, p < .05$.

Table 1. Mean amplitudes in $\mu$V (and standard deviation) of central Nd waveforms when sad face and or a happy face target was presented to either right or left visual field

<table>
<thead>
<tr>
<th></th>
<th>Left visual field</th>
<th>Right visual field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sad</td>
<td>$-1.86 (2.0)$</td>
<td>$-0.30 (1.9)$</td>
</tr>
<tr>
<td>Happy</td>
<td>$-0.43 (1.9)$</td>
<td>$-0.58 (2.0)$</td>
</tr>
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Figure 5. Frontal Nd waveforms for sad and happy face targets during object-based selection from (a) left and (b) right hemisphere.
DISCUSSION

The findings of the current investigation show that the capture of attention is modulated by the emotional content of the target even when it is irrelevant to the task and appears at an inhibited location. The effect of emotional content on IOR is consistent with the existing view that object-based properties modulate attention (Pratt et al., 1997; Riggio et al., 2004; Soto & Blanco, 2004; Theeuwes & van der Stigchel, 2006). More specifically, these findings show that shifts of attention interact with emotional content and that visual hemifield anisotropies exist for IOR. The visual hemifield anisotropies are present for sad faces but not happy faces and this effect was present mainly with object-based selection but not with space-based selection, indicating that shifts of attention interact with emotional content especially when object-based selection mechanisms are recruited during the task.

The reduced magnitude of IOR with sad targets especially in the left visual field (or right hemisphere) provides strong evidence for the rapid attentional capture of negative stimuli even when stimuli are presented at an inhibited location. The ERP results showed suppression of N1 elicited for valid compared to invalid trials, as an indicator of IOR (McDonald et al., 1999; Prime & Ward, 2004), for happy targets, but not for sad targets presented to the left visual field. Therefore, the N1 effects were consistent with the reaction-time findings of reduced IOR for sad targets presented to the left visual field. The N1 effects suggest that the early sensory processing that is modulated by spatial attention is also involved in the analysis of the emotional content of the targets. Moreover, the sad targets may overcome the N1 suppression that occurs due to IOR, especially in the right hemisphere. This effect was present as the reduction of N1 amplitudes for sad targets only in the left and not right hemisphere. On the other hand, the IOR effect was represented (N1 suppression) in both hemispheres for the happy targets. This supports the notion that negativity bias occurs for the right hemisphere (Carreti’e et al., 2001; Hartikainen et al., 2007; Smith & Bulman-Fleming, 2005; Smith et al., 2003) and as a result the shift of attention to sad targets is selectively facilitated in the right hemisphere.

Most importantly, the efficient attentional capture of sad targets compared to happy targets was indicated by the enhancement of a later attention-related component of Nd that is elicited at around 250–350 ms after the target presentation. The Nd amplitudes were increased for sad compared to happy target faces in the right hemisphere. The enhancement of Nd amplitudes with reduced magnitude of IOR is consistent with other findings (Wascher & Tipper, 2004). The early differences in ERP (within 350 ms) support the idea that negative stimuli in the visual environment are processed efficiently and rapidly. This is consistent with other findings of efficient shifts of attention to negative stimuli resulting in faster orientation (Fox et al., 2000; Ogawa & Suzuki, 2004) and slower attentional disengagement (Fox et al., 2002; Most, Chun, Widders, & Zald, 2005; Srivastava & Srinivasan, 2010). The results also support the negativity bias observed in other studies (Carreti’e et al., 2001; Smith & Bulman-Fleming, 2005; Smith et al., 2003). We extend the findings of studies that reported increased dwell time for targets in presence of negative (threatening) facial cues resulting in reduced IOR relative to happy or neutral facial cues (Fox et al., 2002). Less IOR for negative compared to positive target faces, especially in right hemisphere, may allow faster responding to negative emotions. This indicates that negative emotional stimuli are capable of capturing attention even when they are presented at an inhibited location.

The findings of higher Nd amplitudes for sad compared to happy targets in the right but not in the left hemisphere could also be due to the uneven distribution of hemispheric resources in processing negative emotion without any asymmetry for positive emotion. The lesser attentional inhibition of right-hemispheric resources by the negative stimuli is in line with the valence hypothesis. However, no direct support for the valence hypothesis was obtained since positive stimuli
did not have any effect on attentional inhibition in the left hemisphere.

The results support the more recent claims that negative emotion affects cognition differently in the two cerebral hemispheres (Hartikainen et al., 2000, 2007; van Strien & Luipen, 1999). Attention-related facilitation in an emotional Stroop task was observed in right-hemispheric target processing following the presentation of negative stimuli (Smith & Bulman-Fleming, 2005). In our study, the effect of hemispheric biases with negative stimuli was confirmed by attention-related ERP components Nd and N1, which showed preferential processing for right hemispheric sad face targets. In addition, the observation of an overall preference for right-hemispheric targets (greater Nd amplitudes) compared to the left-hemispheric ones is consistent with the earlier findings arguing for right-hemispheric bias in processing emotional information (Ahern et al., 1991; Alpers, 2008; Hartikainen et al., 2007). For example, laterality effects were found only for negative emotions with negative stimuli resulting in impaired processing of subsequently presented right-hemispheric targets (Hartikainen et al., 2007). The current study did not use neutral schematic faces. Hence, it is difficult to identify differences in IOR due to the presence of emotions, in general and especially any asymmetries in IOR for faces (non-emotional vs. emotional). However, the current study does show the effect of valence (sad vs. happy faces). Further studies would be needed with faces with and without different emotional expressions to fully understand the shifts in attention and hemispheric asymmetries associated with processing these stimuli.

The laterality effects for negative emotional targets were primarily observed for object-based selection compared to location-based selection. This points to the potential link between object-based selection mechanisms and emotional information processing. We found enhanced brain activity for negative compared to positive target detection with object-based IOR. This suggests that neural mechanisms of IOR, especially the object-based mechanisms, are selectively biased towards negative emotion. The results are consistent with the studies that demonstrate systematic effects of attentional inhibition in evaluation of emotional targets (Raymond, Fenske, & Westoby, 2005). Raymond et al. (2005) showed that the previously ignored distracters were rated more negative than the attended or novel images. Negative affective evaluation was also made for distracting stimuli that were spatially proximal to targets, which are most likely to be inhibited.

Left–right biases have been frequently reported in several studies on attention and emotions. With upper–lower VF presentations, IOR magnitude was greater in the upper VF compared to the lower VF. The N1 effects showing reduced N1 amplitudes in the upper compared to the lower visual field supplemented these behavioural effects. The results are consistent with other studies that have demonstrated better shifts of attention in the lower VF compared to upper VF (Brown, 2009; Chen & He, 2003; Cheng et al., 2004; Christman & Niebauer, 1997; Ellison & Walsh, 2000; He et al., 1996; Simola, Stenbacka, & Vanni, 2009).

A possible explanation of this effect might lie in the anatomical and functional differences between the P and M pathways that provide inputs to the upper and the lower VF respectively (Cheng et al., 2004; Christman & Niebauer, 1997). The greater IOR observed with the upper VF can be attributed to the relatively slower responding P pathway, while the relatively faster responding M pathway (more critical for shifts of spatial attention) may be responsible for reduced IOR in the lower VF. In addition, the differences in attentional shifts, as reflected by IOR with respect to upper and lower fields, is consistent with the finding of greater attentional enhancement in the upper compared to lower VF (Simola et al., 2009). In addition, the IOR magnitudes in upper and lower VFs were also dependent on emotions. Very little is known about potential differences in upper–lower VFs in terms of emotional processing. More studies are needed to understand the potential differences in emotion–attention interactions in the upper–lower VFs and their implications for emotional processing.
In conclusion, the results clearly demonstrate interactions between emotions and attention. The study showed laterality effects in IOR in both left–right and upper–lower VFs indicating asymmetries in brain mechanisms involved in shifts of attention. We show that differences in processing positive and negative emotions in the two hemispheres modulate shifts of attention. Moreover, processing of negative emotion is selectively facilitated by the right hemisphere, especially with object-based selection, resulting in better shifts of attention for stimuli bearing negative emotion. Further studies are needed to understand the neural mechanisms underlying interactions between emotions and attention in relation to hemispheric specialisation.

Manuscript received 6 October 2009
Revised manuscript received 26 April 2010
Manuscript Accepted 26 April 2010
First published online 5 October 2010

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