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Target and distractor processing and the influence of load on the allocation of attention to task-irrelevant threat

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Load influence on attention to task-irrelevant threat

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Abstract

This study investigated the characteristics of two distinct mechanisms of attention – stimulus enhancement and stimulus suppression – using an event-related potential (ERP) approach. Across three experiments, participants viewed sparse visual search arrays containing one target and one distractor. The main results of Experiments 1 and 2 revealed that whereas neural signals for stimuli that are not inherently salient could be directly suppressed without prior attentional enhancement, this was not the case for stimuli with motivational relevance (human faces). Experiment 3 showed that as task difficulty increased, so did the need for suppression of distractor stimuli. It also showed the preferential attentional enhancement of angry over neutral distractor faces, but only under conditions of high task difficulty, suggesting that the effects of distractor valence on attention are greatest when there are fewer available resources for distractor processing. The implications of these findings are considered in relation to contemporary theories of attention.

Keywords: Attentional Capture, Suppression, Load, ERP, Threat, N_T, P_D, N_D, N2pc

1. Introduction

The number of stimuli in our field of view typically exceeds our brain's perceptual capacity and therefore only stimuli located where attention is focussed may be selectively processed (Desimone & Duncan, 1995; LaBerge, 1995). There are different hypotheses as to how attention is allocated to specific locations. One possibility is that attentional capture is purely stimulus-driven, with attention being deployed initially to the most salient item in a scene, irrespective of its task relevance (the *bottom-up saliency hypothesis*; e.g., Theeuwes, 1991, 2010; Theeuwes & Burger, 1998). An alternative hypothesis proposes that attentional capture by physically salient stimuli can be prevented with the deployment of attention being top-down and goal-driven (the *contingent voluntary orienting hypothesis*; e.g., Anderson & Folk, 2010; Bacon & Egeth, 1994; Folk et al., 1992; Folk, Remington, & Wright, 1994). More recently, the *signal suppression hypothesis* (Sawaki & Luck, 2010) proposes that, as with the bottom-up saliency hypothesis, salient singletons always generate a priority signal, referred to as an “attend-to-me” signal, irrespective of their task-relevance. However, this signal can also be suppressed before the item captures attention, consistent with the ‘contingent voluntary orienting hypothesis.’ The active suppression of a stimulus-driven priority signal should allow the goal-driven biasing of items of interest to override the signals elicited by physically salient task-irrelevant items in a display.

The event-related potential (ERP) approach enables a non-invasive investigation of neural processes underpinning attention allocation over time. The N2 posterior contralateral (N2pc) component occurs within the N2 time interval (~175-300 ms), has a lateral posterior scalp distribution and is a well-characterized electrophysiological marker of the covert deployment of visual attention (Luck & Hillyard, 1994a, 1994b; for a review, see Luck, 2012). This component is normally elicited by experimental protocols employing physically balanced stimulus arrays, either with a target singleton in one visual hemifield and a distractor singleton in the opposite hemifield or stimuli evenly spaced around a clock-face type array.

Although bilateral presentation provides a sensory input balance, it is difficult to dissociate target-related neural activity from distractor-related processing. A partial solution has been to place one stimulus in a lateral visual field position and the other on the vertical midline (Hickey et al., 2009). As stimuli on the midline cannot produce differential lateralized activity (Woodman & Luck, 2003), this approach allows for the isolation of separate lateralized activity to the lateral target or distractor. Of course, confounds associated with the physical imbalance across the cortical hemispheres need to be carefully controlled. Using this approach of alternately positioning the target and distractor on the vertical midline, Hickey et al. (2009) decomposed the N2pc into two subcomponents: a) a negativity contralateral to the target (N_T) that is associated with target enhancement; and b) a positivity contralateral to the distractor that is associated with active attentional suppression (P_D). Both subcomponents begin around 100-300 ms after stimulus onset, depending on the specific stimuli and task. It is likely that the N2pc (e.g., Eimer, 1996; Luck & Hillyard, 1994a, b; Woodman & Luck, 2003) and P_D (e.g., Kiss et al., 2012; Sawaki & Luck, 2010, 2011; Sawaki et al., 2012) elicited in earlier studies using balanced display conditions comprised the summation of the N_T and the P_D. An aim of this study was therefore to investigate further whether the N_T and P_D components can be isolated from the N2pc.

The signal suppression hypothesis (Sawaki & Luck, 2010) predicts that a salient distractor generates an attentional priority signal, which is then suppressed in order to prevent capture of attention by the distractor. As noted by Sawaki and Luck (2014, p. 19-20), studies to date have focused on salience as determined by the interrelationships among display items (e.g., a green distractor letter among an array of red letters) as opposed to the intrinsic properties of distractor stimuli. They called for further research to determine whether the same mechanisms of target enhancement and distractor suppression occur to other salient signals. Faces are intrinsically salient stimuli with special biological and human significance. They are prioritized for processing irrespective of their task relevance or attentional demands of the task (e.g., Lavie, Ro, & Russell, 2003; Reddy et al., 2004). Human faces signal intentions and emotional states and have been shown to be located efficiently in visual search tasks (Simpson et al., 2014). Furthermore, substantial neuroscientific evidence suggests that faces are processed by dedicated and specialised neural systems (Kanwisher et al., 1997; Pitcher et al., 2009). Active suppression may not be sufficient to prevent early attentional capture of human faces and other intrinsically salient stimuli. Attention to angry facial expressions, in particular, may be difficult to suppress. Facial representations of hostility convey important evolutionary signals of threat (Öhman, 2009; Öhman et al., 2012) and are subject to preferential, rapid and efficient attentional orienting (Holmes et al., 2009; Mogg et al., 2008; Öhman et al., 2012) often after minimal analysis of the stimulus input (Holmes et al., 2000). Recent ERP findings also support the view that facial threat is processed rapidly and efficiently (e.g., Eimer & Kiss, 2007; Holmes et al., 2009; Pourtois et al., 2004). Pourtois et al. (2013) suggest that emotion signals may enhance the competitive strength of motivationally significant events through gain control mechanisms similar to those of other attentional networks, although mediated by distinct amygdala pathways and interconnected prefrontal regions. A second aim of this study was therefore to test the prediction that face compared with non-face distractor stimuli will attract attention prior to the emergence of the P_D marker of attentional suppression. This earlier attentional capture by the distractor stimulus is expected to be reflected in a negativity appearing contralateral to the distractor face and labelled here as the distractor negativity (N_D; possessing a similar morphology to the N_T). In addition, this N_D is expected to be augmented for angry compared to neutral distractor faces.

Of further interest is whether difficulty of target processing influences the extent of active suppression of irrelevant distractors. Hickey et al. (2009) found that by reducing the perceptual demands of the task from discrimination to detection of a midline target, the P_D to a lateral distractor was effectively eliminated, suggesting that an easier task reduces the need for suppression of potentially interfering stimuli. By contrast, Sawaki and Luck (2010) found that the P_D to an irrelevant salient singleton for a perceptually easy task was effectively abolished when the task was perceptually demanding. These latter findings support Lavie's (2005, 2010) perceptual load theory that active suppression may not be necessary when the perceptual demands of a task are sufficiently high (*high perceptual load*) as compared with low (*low perceptual load*) as salient distractor stimuli are less likely to attract attention (see Cosman & Vecera, 2009; Lu & Han, 2009). In the light of these conflicting findings, a third aim of the study was to investigate the effect of target task demands on the extent of distractor suppression, as measured by the P_D.

The fourth and final aim of the study was to compare attentional capture of threat-related with that of neutral distractor stimuli under high and low perceptual load. Guided by Lavie's (2005, 2010; Lavie et al., 2004) load theory of selective attention, several studies have examined effects of perceptual load on emotion processing. Some studies have shown that under high perceptual load, the processing of task-irrelevant emotional facial information is prevented (e.g. Bishop et al., 2007; Lim et al., 2008; Pessoa et al., 2002, Pessoa et al., 2005). Perceptual load theory would argue that distractor processing is prevented here due to task-related processing exhausting perceptual capacity. However, under low perceptual task demands, spare attentional resources result in the distractors being processed, with effects of face valence being revealed. Such findings are compatible with recent evidence from fMRI and ERP studies indicating that emotional face recognition competes with other attentional operations for processing resources (e.g., Eimer et al., 2003; Fenker et al., 2007; Holmes et al., 2003; Silvert et al., 2007) and suggest that facial emotions may not capture attention automatically when resources are exhausted by some other demanding attentional operation (Anderson et al., 2003). Conversely, other studies have found an opposite pattern of results whereby emotional face distractors are prioritized irrespective of the perceptual load of the task, (e.g., Attar & Müller, 2012; Pourtois et al., 2010; see Vuilleumier, 2005). A recent MEG study has also shown prioritisation, as measured by the N2pc, of angry compared to neutral faces under both high and low perceptual load, although behavioural RT effects were present only under low load conditions (Fenker et al., 2010). Another behavioural study has even shown *enhanced* prioritisation of threat-related face distractors under high relative to low perceptual load in high socially anxious individuals (Soares et al., 2015). These findings have been taken to support strong automaticity accounts of threat processing, in which the processing of environmental danger (e.g., snakes and threat faces) is thought to be prioritized involuntarily and independently of attentional conditions, enabling safe avoidance or escape (e.g., Öhman et al., 2012; Soares et al., 2014). If angry faces interfere only under conditions of low perceptual load, in line with a perceptual capacity account, we would expect an enhanced distractor contralateral negativity (N_D) to angry relative to neutral face distractors in low, but not high, perceptual load conditions. If, on the other hand, the interfering effects of angry faces are present regardless of perceptual load, in line with an automaticity account, we would expect an enhanced N_D to angry relative to neutral face distractors under both low and high perceptual load conditions.

Across three experiments we addressed the four main aims described above: a) to replicate Hickey et al.'s (2009) finding that the N2pc is an aggregate measure of at least two distinct processes relating to the active suppression of distractor stimuli (P_D) and the attentional enhancement of target stimuli (N_T) (Experiments 1 and 2); b) to assess whether intrinsically salient stimuli capture attention involuntarily prior to active suppression as indexed by a distractor negativity (N_D) (Experiments 1 and 2); c) to investigate whether active suppression (P_D) is greater or reduced as a function of the perceptual demands of the task (Experiment

3); d) to assess whether threat-related face distractors attract attention (N_D) under both low and high perceptual load or only under low perceptual load conditions (Experiment 3).

Our task was adapted from the paradigm used by Hickey et al. (2009). Participants viewed visual search arrays containing one green square or diamond and one intact or scrambled face. In Experiment 1, the square/diamond was the target and the intact/scrambled face that was either angry or neutral was the distractor. The target was presented on the vertical meridian and the distractor at a lateralized location. Therefore, lateralised ERP activity should reflect processing of the distractor rather than the target. To minimise low level stimulus confounds (Hansen & Hansen, 1988), we matched all face photographs (scrambled, intact, angry, and neutral) for luminance and contrast energy. We predicted that a P_D would be elicited with no preceding contralateral distractor negativity (N_D) when the lateral distractor was a scrambled face, in line with previous findings (e.g., Hickey et al., 2009; Sawaki & Luck, 2010; 2011; Sawaki et al., 2012). Conversely, we predicted that the P_D would be preceded by an N_D when the lateral distractor was an intact face (i.e. was inherently salient), and that the N_D would be augmented for angry relative to neutral intact faces. We also anticipated the overall presence of a Ppc (Positivity, posterior contralateral; Fortier-Gauthier et al., 2012; Jannati et al., 2013; Leblanc et al., 2008).

The Ppc is typically found over the lateral occipital scalp and is larger contralateral to the location of a singleton than ipsilateral to it and emerges within the P1 time range (75-125 ms) and beyond (N1 time interval: 140-190 ms). This component has been attributed to low-level stimulus-driven processes, emerging as a consequence of laterally imbalanced activity (Luck & Hillyard, 1994a). It has also been suggested to be associated with the pre-attentive representation of the most salient item (as a function of local featural discontinuities) within a salience map, which may help guide the later controlled deployment of visual spatial attention (Fortier-Gauthier et al., 2012; Jannat et al., 2013).

2. Experiment 1

2.1. Participants

Twenty healthy volunteers from the University of Roehampton received course credit for participation (eighteen female; all 18–28 years old; mean age: 20.2 years; SD: 2.67). All participants had normal or corrected-to-normal vision and all were right-handed. This experiment (and Experiments 2 and 3 reported below) was performed in compliance with The University of Roehampton ethics and research guidelines and was approved by the University ethics committee.

2.2. Stimuli and Apparatus

Participants were seated in a darkened cubicle and stimuli were presented on a black background at a viewing distance of approximately 80 cm on a 21-inch ViewSonic computer screen displaying 800 x 600 pixels, with a refresh rate of 75 Hz, connected to a Dell Optiplex computer. Stimulus presentation was controlled with

E-Prime 2.0 software (Schneider et al., 2002). The stimulus array for each trial contained a green outline of a square (RGB = 0, 161, 0; 1.5 cd/m^2) that could be rotated 45^0 to a diamond form (12 mm x 12 mm, subtending ~0.9^0 x 0.9^0 of visual angle), and a photograph of a face. Face stimuli were the same as those used in Holmes et al. (2009). Half of the face stimuli consisted of greyscale photographs of 16 different individuals taken from the NimStim Set of Facial Expressions (Tottenham et al., 2009). Eight female and eight male identities portrayed both angry and neutral facial expressions (32 photographs in total). For the remaining half of the stimuli, each of the 32 images was divided into a 4 x 5 array and randomly scrambled removing configural facial information. Additional photographs of sixteen different individuals (8 female) with neutral expressions from the NimStim set were used for practice items. Each face stimulus measured 4.6 cm high x 3.5 cm wide (subtending ~3.3^0 x 2.5^0 of visual angle) and was centred at the bridge of the nose. Mean luminance energy was calculated for each image and equated across the entire sample of intact and scrambled faces. The total RMS energy of each luminance-equated picture was then calculated and finally the luminance value at each pixel from each image was divided by this value (using standard routines in Matlab 6), resulting in a mean luminance of 7.83 cd/m^2 and Michelson contrast of 0.934.

Face and shape stimuli appeared in locations equidistant from a central fixation cross (5.5 cm; subtending ~3.9^0 of visual angle from the centre of the image to the centre of fixation). Face stimuli appeared laterally at locations 60^o, 120^o, 240^o and 300^o off vertical (c.f. Hickey et al., 2009). The square/diamond was presented on the vertical meridian (i.e., either directly above or directly below fixation).

2.3. Procedure

See Figure 1 for the sequence of events within a trial. Each trial began with a central fixation cross, presented for between 1000 to 1700 ms (with increments of 100 ms). Following this, the critical two-stimulus array (target shape and distractor face) was displayed and remained on the screen until either a response was detected or 1000 ms had passed. There was a blank inter-trial interval of 500 ms before the start of the next trial. Participants maintained a central fixation and identified the target shape (square or diamond) by pressing one of two keys on a response box with their right hand (response mapping was counterbalanced across participants). Participants were instructed to respond as quickly and as accurately as possible. During the experiment, if participants' accuracy dropped below 80%, a message at the end of the block reminded them of the instructions and response mappings. If participants' accuracy reached above 80%, participants were presented with the message "Well done!"

At the beginning of the experiment, participants completed the state and trait sections of the Spielberger STAI (Spielberger et al., 1983) and the Attentional Control Scale (ACS; Derryberry & Reed, 2002). Neither measure is relevant to the present study, but is applicable to exploratory analysis of data collected from an extended participant sample. The experimental task began with a practice block (minimum of 32 trials) in which RT and accuracy feedback was provided on each trial. Participants were required to achieve 80% accuracy before they could proceed to the experiment proper. The experiment consisted of 12 blocks of 96 trials for a total of 1152 trials. On each trial, one face (intact or scrambled) and one shape (square or diamond) were presented simultaneously within either the upper or lower visual hemifield. Within each block, square and diamond stimuli appeared an equal number of times at upper and lower locations along the vertical meridian, and intact and scrambled faces displaying angry and happy expressions appeared an equal number of times in each of the four lateral positions. All combinations of face and shape stimuli (e.g., intact angry face with diamond, scrambled neutral face with square, etc.) were equiprobable across the experiment and trial order was randomised.

Figure 1 about here

2.4. EEG Data Acquisition

EEG was recorded from 32 Ag-AgCl electrodes, with placement according to the international 10-20 system (i.e. FP1, F7, F3, FC3, T7, C3, CP3, P7, P3, Pz, PO3, PO7, O1, Oz, O2, PO8, PO4, P4, P8, CP4, FC4, C4, T8, FC4, Fz, F4, F8, FP2, Cz, A1, A2, AFz (ground)). Horizontal electro-oculography (HEOG) was recorded with bipolar channels from the outer canthus of each eye. Vertical electro-oculography (VEOG) was recorded with bipolar channels from above and below the left eye. The impedance for electrodes was kept below 5 kΩ. EEG and EOG were digitized with a sampling rate of 500 Hz, and EEG was filtered online at DC to 100 Hz and referenced to the vertex (Cz). Data were digitally filtered offline with a bandpass of 0.5 Hz (24 db/oct) to 40 Hz (24 db/oct; zero-phase shift) using Neuroscan software (version 4.5). EEG and EOG were then epoched into 600 ms intervals, from -100 to 500 ms for each stimulus array onset. A baseline adjustment was performed on the pre-stimulus interval and trials with lateral eye movements (HEOG exceeding 30 µV), vertical eye movements, eye-blinks (VEOG exceeding 80 µV), or other artefacts (a voltage greater than 80 µV at any electrode) in the entire epoch were excluded from analysis. Epoched data were then re-referenced to the average of A1 and A2 (ear lobe) electrodes. To assess residual eye movements, separate averaged horizontal EOG waveforms were computed for trials where face stimuli appeared in the left and right visual fields. Participants were replaced if their residual HEOG activity exceeded 4 µV (see Sawaki et al., 2012, for a similar approach). The residual eye movements in the remaining participants were consequently less than 0.25° with a propagated voltage of less than 0.1 µV at posterior scalp sites (Lins et al., 1993). We also replaced participants for whom EEG/EOG artifacts resulted in greater than 25% of trials being rejected (c.f. Sawaki & Luck, 2010, 2011; Sawaki et al., 2012). In Experiment 1, one participant was replaced for exceeding the artifact threshold. Among the final twenty participants, artifacts led to the rejection of an average of 11.4% of trials (range 2.7 – 23.4%).

The ipsilateral waveform was computed as the average of the left-sided electrodes to the left-sided face and the right-sided electrodes to the right-sided face. The contralateral waveform was computed as the average of the left-sided electrodes to the right-sided face and the right-sided electrodes to the left-sided face. The Ppc, N_D, P_D and late N_D were quantified on the basis of ERP mean amplitudes within four successive time windows (Ppc: 56-106 ms; N_D: 120-180 ms; P_D: 180-250 ms; late N_D: 250-300 ms). These time windows were determined on the basis of inspection of individual participant waveforms and prior research involving contralateral attentional components (e.g., Eimer & Kiss, 2007; Holmes et al., 2009; Hickey et al., 2009; Mazza et al., 2009; Sawaki & Luck 2010). Activity was analysed at the following electrodes: P3, P7, PO3, PO7 and O1 for regional analyses of left posterior effects, and P4, P8, PO4, PO8 and O2 for regional analyses of right posterior effects.

3. Results

Non-responses and trials with errors were discarded, as were those with reaction times (RTs) less than 200 ms (5.6% of all responses). For all analyses, Greenhouse–Geisser adjustments to the degrees of freedom were performed where appropriate.

3.1. Behavioural measures

Mean correct reaction times (RTs) and accuracy were analysed in two separate 2 x 2 repeated measures analyses of variance (ANOVA), with factors of distractor type (intact face, scrambled face) and distractor valence (angry, neutral). There were no significant main effects or interactions for either RT (all *F*s < 1.7) or accuracy (all *F*s < 2.1).

3.2. ERP measures

Mean amplitude values for each of the four components were computed (Ppc, N_D, P_D, Late N_D; see Figure 2 for grand averages). For each component a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) was performed with factors of distractor type (intact face, scrambled face), distractor valence (angry, neutral), and laterality (electrodes contralateral to the distractor, electrodes ipsilateral to the distractor).

Figure 2 about here

3.2.1 Ppc: 56-106 ms

There was a significant main effect of laterality ($F(1, 19) = 18.03$, $p < .001$, $\eta^2_p = .49$; mean amplitudes of 0.82 µV and 0.38 µV for contralateral and ipsilateral, respectively). There was also a distractor type x laterality interaction, $F(1, 19) = 13.61$, $p < .001$ ($\eta^2_p = .42$). The laterality effect was significant for both scrambled (means of 0.86 µV and 0.23 µV for contralateral and ipsilateral, respectively; $t(19) = 5.35$, $p < .001$) and intact faces (means of 0.79 µV and 0.53 µV for contralateral and ipsilateral, respectively; $t(19) = 2.27$, $p < .05$). However, the effect size was larger for scrambled than intact faces (*d*s of .43 and .18, respectively). There were no other significant main effects or interactions (all *F*s < 1.5).

3.2.2. N_D: 120-180 ms

There was a distractor type x laterality interaction, $F(1, 19) = 69.51$, $p < .001$ ($\eta^2_p = .79$), with a laterality effect present for intact faces (means of -0.53 µV and 0.15 µV for contralateral and ipsilateral, respectively, $t(19) = 4.35$, $p < .001$) but absent for scrambled ($t < 1$) faces. There were no other significant main effects or interactions (all *F*s < 3.3).

3.2.3. P_D: 180-250 ms

There was a main effect of laterality, $F(1, 19) = 37.44$, $p < .001$ ($\eta^2_p = .66$), as mean amplitudes were more positive for electrodes contralateral (2.15 µV) than ipsilateral to the distractor (0.87 µV) and a main effect of distractor type ($F(1, 19) = 4.65$, $p < .05$, $\eta^2_p = .20$; means of 1.34 µV and 1.69 µV for intact and scrambled faces, respectively). There were no other significant main effects or interactions (all *F*s < 3.6).

3.2.4. Late N_D: 250-300 ms

There was a distractor type x laterality interaction, $F(1, 19) = 10.68$, $p < .01$ ($\eta^2_p = .36$), as there was a laterality effect for intact faces ($t(19) = 2.38$, $p < .05$; means of 2.29 µV and 2.89 µV for contralateral and ipsilateral, respectively) but not for scrambled faces ($t < 1$). There were no other significant main effects or interactions (all *F*s < 2.3).

4. Discussion

Despite clear influences of scrambled and intact face distractors on neural processing, there were no significant influences of these distractors on behavioural performance. The absence of behavioural effects is in line with results from some previous studies (e.g., Fenker et al., 2010; Kappenman et al., 2014), which showed no evidence of behavioural interference from distractors (especially when task-relevant selection operations exhausted attentional resources, i.e., under high perceptual load), whilst ERPs were sensitive to these effects. One reason why the capture of attention by intact faces was reflected by an early negative contralaterality (N_D; see below) but was not evident within the RT and accuracy measures is likely related to the timing of these measures relative to the events in the task. The N_D component appeared within a time window of 120-180 ms after the onset of the visual array, whereas the behavioural response occurred several hundred milliseconds later, following the active suppression of (and, in the case of the intact face, the reorienting of attention to) the distractor. It is therefore not surprising that the behavioural measure, which provides a single data point summating the combined effects of a sequence of many distinct neural processes within a trial, is not necessarily sensitive to early, transient neural events. ERPs, on the other hand, can reveal how the allocation of attention unfolds over the course of a trial as they provide a continuous measure of processing with fine temporal resolution.

As expected, a Ppc (56-106 ms) to distractor stimuli was evident, and this may be due to sensory imbalance across the hemifields (Luck & Hillyard, 1994a). In line with predictions, for scrambled face distractors, the Ppc was followed by a P_D. This positivity (P_D) was maximal in a latency range of 180-250 ms, which is comparable to the P_D findings of Hickey et al. (2009), who used similarly sparse arrays consisting of one midline target and one lateral distractor. It is unlikely that this positivity was related to target processing because lateralized ERP components should not be triggered by stimuli appearing on the vertical midline (Eimer & Grubert, 2014; Eimer et al., 2011; Hickey et al., 2006; Woodman & Luck, 2003). The appearance of a P_D in the absence of the prior emergence of a contralateral negativity is consistent with a number of previous findings (Hickey et al., 2009; Kiss et al., 2012; Sawaki & Luck, 2010, 2011). It also supports Sawaki and Luck's (2010) proposition, as outlined within their signal suppression hypothesis, that task-irrelevant stimuli generate 'attend-to-me' signals, which are then immediately suppressed (as reflected by the P_D) to prevent their attentional selection. These electrophysiological results also converge with previous behavioural data (e.g., Lamy & Egeth, 2003; Lamy et al., 2004; Theeuwes & Burger, 1998). By contrast, the P_D for intact face distractors was clearly preceded by a contralateral negativity (N_D). This suggests that intrinsically salient face stimuli may automatically capture attention before their signals can be suppressed. The N_D occurred between 120 and 180 ms post-stimulus onset, which is slightly earlier than the typical early phase of the N2pc elicited by attended lateral stimuli in conventional visual search experiments (Eimer & Kiss, 2007; Holmes et al., 2009, Holmes et al., 2013). This early emergence of the N_D is likely due to the use of a particularly sparse visual search array, containing only one target and one distractor.

Overall, the results suggest that it may be impossible to suppress an initial shift of attention to a stimulus that possesses intrinsic motivational value. Given that the nature of the distractor was completely task irrelevant and non-predictive with respect to target identity, the presence of an N_D arguably attests true automatic attentional capture (Yantis, 1996), at least in respect of the electrophysiological correlates of attentional focusing. This capture of attention was then followed by active suppression (indexed by the P_D component), which presumably facilitated the subsequent voluntary orienting of attention to the central target. The P_D to the intact faces possessed the same timing and amplitude as the P_D to the scrambled faces. The observation of an N_D to the intact face stimulus, followed by active suppression, is compatible with findings by Sawaki and Luck (2013), in which distractors possessing a target feature were shown to capture attention, as indexed by the N2pc, but were then actively suppressed (P_D) before attention moved to the correct target stimulus.

An effect that was not directly predicted was that the P_D to intact faces was followed by a waveform that was more negative contralateral to the distractor than ipsilateral within a time range of between 250 and 300 ms (late N_D). This effect was not observed, however, for scrambled faces. It is conceivable that this late contralateral negativity may reflect a reorienting of attention towards the intact face, following the preparation of a target response, due to its intrinsic salience and biological significance. Thus, attention may move back to the stimulus for further scrutiny if it is of motivational value or interest. It has often been observed that the attentional prioritisation of motivationally significant stimuli (especially emotion-related stimuli) persists for up to a second and beyond, with several studies indicating that emotion stimuli preferentially attract and 'hold' attention (e.g., Fox et al., 2001; Holmes et al., 2009; Holmes et al., 2013; Miltner et al., 2004; Mogg & Bradley, 1999; Nummenmaa et al., 2009; Rinck et al., 2005). Such holding of attention may confer an evolutionary advantage, as it provides a mechanism for the continued monitoring of potentially novel or significant environmental events. A sustained posterior contralateral negativity (SPCN) has also been observed in previous studies around 400 ms after stimulus onset (e.g., Jolicoeur et al., 2008) and has been suggested to reflect the active maintenance of information in visual short-term memory (VSTM; Corriveau et al., 2012; Luria et al., 2010). This active maintenance in VSTM may be responsible for the 'holding' of attention on important stimuli (see Holmes et al., 2009, 2013) and is arguably what is being observed here in the late N_D.

Contrary to expectations, neither the N_D (attentional orienting) nor the P_D (suppression) components were modulated by face valence (angry versus neutral). This conflicts with some previous findings (e.g., Eimer & Kiss, 2007; Holmes et al., 2009; Pourtois et al., 2004) in which angry or fearful faces have, for example, elicited greater attentional orienting than neutral faces, as indexed by the N2pc, while participants performed tasks in which the faces were incidental. This discrepancy may be due to perceptual load differences between the tasks, with the perceptual load of the current task being *insufficient* to enable effects of emotional facial expression to become apparent (see, e.g., Soares et al., 2015), contrary to the predictions of Lavie's (2005, 2010) perceptual load theory (see fourth aim of the current study in the General Introduction for explanation). This issue will be followed up in Experiment 3.

As mentioned earlier, the Ppc observed in this experiment reflects the presence of sensory hemispheric imbalance. The visual display comprised one stimulus on the vertical midline and the other in a lateral position and was therefore inherently imbalanced in terms of lateral overall luminance. We therefore need to ascertain whether the early N_D for intact faces truly reflects attentional deployment rather than sensory activity. It is unlikely to reflect lateralized sensory activity because, first, scrambled and intact faces were luminance and contrast energy matched and so any effects would be minimal; further, any small residual differences between scrambled and intact faces in terms of high or low spatial frequency discontinuities should have resulted in a greater distractor laterality effect (i.e., greater N_D) for scrambled faces, as they had elicited a larger Ppc. Instead, we found that not only was the N_D greater for intact faces, but it was completely absent for scrambled faces, which is not compatible with a sensory account. However, the additional demonstration of a contralateral negativity (N_T; see Hickey et al., 2009) that is present when spatial attention is intentionally focused toward a target stimulus (scrambled face stimulus) but absent when spatial attention is not focused toward that same stimulus should provide further support for our proposition that an early contralateral negativity to intact distractor faces reflects a transient and involuntary capture of attention. Experiment 2 was designed to test this prediction. For the presence of an early contralateral negativity to a distractor to be argued to reflect the orienting of attention, it should be absent in some specific conditions when a stimulus is to be ignored (as in the case, for example, of the scrambled face) and yet observable when attention is deliberately focused towards that same stimulus (as would be the case if the scrambled face were a target as opposed to a distractor). The same sparse search arrays that were used in Experiment 1 were again used in Experiment 2 but here participants attended the lateral face (scrambled or intact) target stimulus and ignored the central (square/diamond) distractor stimulus. Participants indicated the form of the lateral face image (either intact or scrambled) while ignoring the shape stimulus on the vertical meridian. We anticipated an identical pattern of Ppc effects to the stimuli as found in Experiment 1, as the stimulus configuration is invariant across both experiments. We further predicted the presence of a contralateral negativity (N_T) to both scrambled and intact lateral face targets. We additionally predicted the appearance of a contralateral positivity to the target hemifield (P_T) following the target negativity (N_T). Previous studies have revealed that components that reflect the directing of attention towards a lateralised stimulus (namely the N2pc) are often followed by a contralateral positivity indicating the active termination or completion of an episode of attention. This has been shown following the volitional deployment of attention toward target stimuli (Sawaki et al., 2012; Jannati et al., 2013) as well as in the case of the involuntary orienting of attention towards distractor stimuli (Sawaki & Luck, 2013). We anticipated a similar suppression mechanism to be implemented by participants here.

5. Experiment 2

5.1. Participants

Twenty healthy volunteers from the University of Roehampton received course credit for participation (seventeen female; 18–29 years old; mean age: 20.7 years; SD: 2.9). All participants had normal or corrected-to-normal vision and all were right-handed.

5.2. Stimuli and Apparatus

All stimuli and equipment were identical to those used in Experiment 1.

5.3. Procedure

Whereas in Experiment 1 participants were instructed to indicate the form of the shape (square or diamond) appearing on the vertical meridian, in Experiment 2 they were required to indicate the form of the lateral face stimulus (intact or scrambled) and to ignore the shape. Half of the participants pressed the left button with their index finger when the lateral target was an intact face and the right button with their middle finger when it was a scrambled face image, with the remaining half of participants using the opposite response mapping. All other details were as in Experiment 1.

5.4. Electrophysiological recording and analysis

EEG recording and analysis procedures were as in Experiment 1, except that the ERP components to be analysed were as follows: Ppc (56-106 ms), N_T (120-180 ms); P_T (200-270 ms). In the present experiment, five participants were replaced for exceeding the artifact threshold. Among the final twenty participants, artifacts led to the rejection of an average of 12.5% of trials (range 3.1 – 24.7%).

5.5. Results

Non-responses and trials with errors were discarded, as were those with reaction times (RTs) less than 200 ms (8.9% of all responses). For all analyses, Greenhouse–Geisser adjustments to the degrees of freedom were performed where appropriate.

5.5.1 Behavioural measures

Mean RTs and mean percentages of correct responses for each condition were entered into two separate 2 x 2 repeated measures analyses of variance (ANOVA), with factors of target type (intact face, scrambled face) and target valence (angry, neutral). There were no significant main effects or interactions for either RT (all *F*s < 1.2) or accuracy (all *F*s < 1.5).

5.5.2. ERP measures

Mean amplitude values for each of the three components (Ppc, N_T, P_T; see Figure 3 for grand averages) were submitted to separate 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of target type (intact face, scrambled face), target valence (angry, neutral), and laterality (electrodes contralateral to the distractor, electrodes ipsilateral to the distractor).

Figure 3 about here

5.5.2.1. Ppc: 56-106 ms

There was a main effect of laterality with more positive amplitudes for contralateral than ipsilateral electrodes (means of 0.54 µV and 0.0002 µV, respectively, $F(1, 19) = 24.24$, $p < .001$, $\eta^2_p = .49$) and a target type x laterality interaction, $F(1, 19) = 4.68$, $p < .05$ ($\eta^2_p = .20$). Paired comparisons revealed a significant effect of laterality for both intact (means of 0.43 µV and 0.06 µV for contralateral and ipsilateral electrodes, respectively; $t(19) = 3.11$, $p < .01$); and scrambled (means of 0.64 µV and -0.06 µV for contralateral and ipsilateral electrodes, respectively; $t(19) = 4.78$, $p < .001$). However, the effect size was larger for scrambled than intact faces (*d*s of .47 and .28, respectively.) There were no other significant main effects or interactions (all *F*s < 1).

5.5.2.2. N_T: 120-180 ms

There was a main effect of laterality, $F(1, 19) = 54.68$, $p < .001$ ($\eta^2_p = .74$), as mean amplitudes were more negative for electrodes contralateral to the target (-1.79 µV) compared to ipsilateral (-0.16 µV). There was also a target type x laterality interaction, $F(1, 19) = 42.69$, $p < .001$ ($\eta^2_p = .69$). The laterality effect was observed for both intact (means of -2.17 µV and 0.02 µV for electrodes contralateral and ipsilateral, respectively; $t(19) = 8.35$, p < .001) and scrambled (means of -1.40 µV and -0.34 µV for contralateral and ipsilateral, respectively; $t(19) = -5.10$, $p < .001$) faces, but the effect size was larger for intact than scrambled faces (*d*s of .66 and .35, respectively).

5.5.2.3. P_T: 200-270 ms

There was a main effect of laterality ($F(1, 19) = 5.40$, $p < .05$, $\eta^2_p = .27$; means of 2.62 µV and 2.08 µV for contralateral and ipsilateral electrodes, respectively). There was also a significant target type x laterality interaction, $F(1, 19) = 8.08$, $p < .01$ ($\eta^2_p = .30$), as the laterality effect was observed for both intact (means of 2.56 µV and 1.77 µV for contralateral and ipsilateral, respectively; $t(19) = 3.54$, $p < .01$) and scrambled faces (means of 2.68 µV and 2.14 µV for contralateral and ipsilateral, respectively; $t(19) = 3.68$, $p <.01$), but the effect size was larger for intact than scrambled (*d*s of .22 and .16, respectively). There were no other significant main effects or interactions (all *F*s < 3.5).

5.6 Discussion

As with Experiment 1, there was no behavioural sensitivity to the differential attentional capture effects between the scrambled and intact face targets, despite clear differences in the neural markers of attentional allocation (N_T; see below).

The stimulus configuration was the same as that in Experiment 1, but this time, the shape at the vertical meridian was ignored and the laterally presented face stimulus was attended. As before, a Ppc (56-106 ms) was larger for scrambled than intact faces. This indicates that the Ppc may be insensitive to manipulations of top-down attentional focus and is more likely to reflect low-level sensory characteristics of the stimuli represented even prior to configural, semantic or motivational aspects of stimuli (Luck & Hillyard, 1994a).

Crucially, when the scrambled face was the target, a contralateral negativity (N_T) was obtained within the 120-180 ms post-stimulus interval. This contrasts with the absence of a contralateral negativity within the same time frame in Experiment 1, in which the scrambled face was the distractor. This contralateral negative waveform appears to be responsive to the allocation of visual attention as opposed to the sensory properties of the stimuli, as the displays were identical across Experiments 1 and 2. This finding provides further support for the suggestion that the contralateral negativity (N_D) appearing to the *intact* face distractors in Experiment 1 reflects the involuntary capture of attention, as a consequence of the faces' motivational significance.

In addition, the N_T was greater for intact faces as compared with scrambled faces, suggesting that the motivational salience of the target can affect the allocation of attention, even under conditions in which attention is already being guided to the target stimuli in a top-down manner. Jannati et al. (2013) similarly found that the N2pc was larger (and earlier) when participants searched for targets with greater salience (color as opposed to shape singletons) within an array. Our finding also supports existing behavioural evidence that increasing target salience, for example, by increasing the dissimilarity between targets and distractors, leads to faster search (Duncan & Humphreys, 1989; Nagy & Sanchez, 1990; for a review, see Wolfe & Horowitz, 2004). The present findings, however, reinforce the notion that salience can be defined not only by the interrelationships among items within a display, but also by the inherent motivational properties of stimuli, and reveal that effects of salience on the allocation of attention can be observed within sparse search arrays containing just one target and one distractor.

As predicted, the N_T to scrambled and intact faces was reliably followed by a target positivity (P_T), which was greater for intact than scrambled faces. The P_T was analysed within a window of 200-270 ms, but informal observations of the waveforms suggest that it may have extended beyond this to around 400 ms. Active suppression of distractor stimuli (P_D) in Experiment 1 may also have extended up to around 400 ms as a contralateral positivity was present in the waveforms beyond the late N_D. The emergence of a P_T component is consistent with findings of Sawaki et al. (2012), who demonstrated that targets eliciting an N2pc were followed by a contralateral positivity. They suggested that active suppression might be a general purpose mechanism that can both prevent and terminate the allocation of attention. Our results provide further support for the conclusion that active suppression follows attentional facilitation at a target location, with the added confidence afforded by our experimental approach (cf. Hickey et al., 2009) that the P_D and P_T are uncontaminated by processes involved in attentional enhancement of a stimulus in the opposite hemifield. Notably, a similar pattern of target suppression was evident in Hickey et al. (2009), with waveforms indicating active suppression following attention to a salient lateral target (bright square; Experiment 4, figure 4b), but not evident when the target was less salient (i.e. was isoluminant with the background; Experiment 4, figure 5c). However, these effects were not formally analysed. Greater active suppression of more salient targets was similarly observed in the current experiment with a larger P_T to intact than to scrambled face targets. This general pattern of attention termination can also be seen in the waveforms of many previous studies that have focused on the N2pc component (e.g., Brisson & Jolicioeur, 2007; Carlisle & Woodman, 2011; Lien et al., 2008), although, again, the target positivity was not formally analysed in these studies.

Finally, in line with the findings of Experiment 1, the observed contralateral components (N_T, P_T) were not modulated by face valence (angry versus neutral). The absence of valence effects during these relatively undemanding low load tasks — particularly Experiment 1 — argues against perceptual capacity accounts' (e.g., Lavie, 2005, 2010) predictions that threat-related faces will attract attention preferentially under low perceptual load conditions. One of the aims of the last experiment (Experiment 3) was therefore to examine whether having a higher perceptual load would reveal modulatory influences of emotional face content (angry versus happy) on attentional orienting (N_D) mechanisms (see, e.g., Soares et al., 2015). We hypothesised that with a more demanding perceptual task, angry face distractors might evoke a stronger draw on attention (N_D) than neutral face distractors.

A further aim of Experiment 3 was to examine whether a higher perceptual load would lead to either the augmentation or the attenuation of processes of active suppression of distractor face stimuli. Hickey et al. (2009) found that increased task difficulty led to the appearance of a P_D, as compared with a simple detection task in which the P_D was effectively absent. Conversely, Sawaki and Luck (2010) found that increases in task difficulty had led to the opposite effect, with an elimination of the P_D under these conditions.

Experiment 3 examined a) whether a higher perceptual load than that used in Experiments 1 and 2 would lead to the greater involuntary capture of attention (N_D) by angry as compared with neutral face distractors; b) whether this higher perceptual load would lead to an enhancement or an attenuation of the active suppression (P_D) of irrelevant face distractors. As before, we also anticipated the presence of a Ppc. The design was the same as that used in Experiment 1, with the exception that a) only intact, but not scrambled, face stimuli were employed, and b) the target task differed. For the target task, participants were instructed to report the colour (red or green) of a pre-specified letter indicated at the beginning of a block. In the easy discrimination (low perceptual load) condition, the uppercase letters 'O' and 'I' appeared, one above the other, with one letter in red and the other in green. Participants were instructed to report as quickly and as accurately as possible, the colour that the pre-specified 'O' or 'I' appeared in on each trial. In the difficult discrimination (high perceptual load) condition, the uppercase letters 'E' and 'F' were used.

6. Experiment 3

6.1. Participants

Twenty healthy volunteers from the University of Roehampton received course credit for participation (fifteen female; 18–27 years old; mean: 21.30 years; SD: 2.6). All participants had normal or corrected-to-normal vision and all were right-handed.

6.2. Stimuli and Apparatus

All stimuli and equipment were the same as those used in Experiment 1, except as follows. Target stimuli (appearing on the vertical meridian) for the low perceptual load condition consisted of the easily distinguishable capitalised Ariel type font letters 'O' and 'I', placed one above the other, whereas the target stimuli for the high load condition were the less easily distinguishable letters 'E' and 'F'. Within each pair, one letter would appear in green (RGB = 0, 206, 0) and the other in red (RGB = 237, 0, 0). The combinations of letter position (top/bottom) and colour (red/green) resulted in the construction of four target stimuli for each of the low and high load conditions. Each letter measured 0.9 x 0.9 cm and the spacing between the letters was 0.2 cm. Each target stimulus was therefore 2.0 x 0.9 cm (subtending ~1.4^o x 0.6^o of visual angle). Only intact face stimuli appeared as distractors (presented laterally).

6.3. Procedure

See Figure 4 for the sequence of events within a trial. Participants were instructed to report the colour of the target letter that was indicated at the beginning of a block (e.g., in the 'O' instructed block, if the 'O' was displayed in red, then a button press corresponding to 'red' was required), and to ignore the face. Half of the participants reported 'red' with a right button press and 'green' with a left button press, and the other half used the opposite response mapping.

Each target letter (high load, letter ‘E’; high load, letter ‘F’; low load, letter ‘O’; low load, letter ‘I’) was assigned to a group of three consecutive blocks. Half of the participants performed six blocks of low load trials followed by six blocks of high load trials, with the opposite order for the other half of participants. Within the sequence of low load blocks, half of participants were assigned the letter ‘O’ as the target for the first three blocks and ‘I’ as the target for the following three blocks, with the reverse order for the other half of participants. Similarly, within the sequence of high load blocks, half of the participants were assigned the letter ‘E’ as the target for the first three blocks and ‘F’ as the target for the following three blocks, with the reverse order for the other half of participants. Participants were assigned these orders on a random basis. Within each block, each letter was presented an equal number of times either above or below its counterpart and also an equal number of times in the colours green or red. All other details were as in Experiment 1, except that only intact and not scrambled faces were presented as distractors.

Figure 4 about here

6.4. Electrophysiological recording and analysis

EEG recording and analysis procedures were as in Experiment 1, except that EEG was recorded from 64 Ag/AgCl electrodes placed according to the international 10-20 system. In Experiment 3, four participants were replaced for exceeding the EEG/EOG artefact threshold. Among the final twenty participants, artifacts led to the rejection of an average of 15.13% of trials (range 2.8 – 24.9%).

Additionally, separate means were computed for all combinations of perceptual load (high load vs. low load), distractor valence (angry face vs. neutral face), and laterality (electrodes contralateral vs. ipsilateral to the location of the face distractor). The Ppc, N_D and P_D were quantified on the basis of ERP mean amplitudes within four successive time windows (Ppc: 60-110 ms; N_D: 130-170 ms; P_D: 190-250 ms; late P_D: 250-400 ms). These time windows were determined on the basis of inspection of individual participant waveforms and of prior research involving contralateral attentional components (e.g., Eimer & Kiss, 2008; Holmes et al., 2009; Hickey et al., 2009; Sawaki & Luck, 2010, 2011, 2013; Sawaki et al., 2012; Mazza et al., 2009).

6.5. Results

Non-responses and trials with errors were discarded, as were those with reaction times (RTs) less than 200 ms (7.3% of all responses). For all analyses, Greenhouse–Geisser adjustments to the degrees of freedom were performed where appropriate.

6.5.1. Behavioural measures

Mean RTs and mean percentages of correct responses for each condition (see Figure 5) were entered into two separate 2 x 2 repeated measures analyses of variance (ANOVA), with factors of perceptual load (low, high) and distractor valence (angry, neutral). For the RT analysis, there was a significant main effect of load, $F(1, 19) = 13.31$, $p < .01$ ($\eta^2_p = .41$), as responses were faster for low perceptual load (994 ms) compared to high (1073 ms), indicating the effectiveness of the load manipulation. There were no other significant main effects or interactions for either RT (all *F*s < 1) or accuracy (all *F*s < 1.6).

Figure 5 about here

6.5.2. ERP measures

Mean amplitude values for each component (see Figure 6) were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of perceptual load (low load, high load), distractor face valence (angry, neutral), and laterality (electrodes contralateral to the distractor face, electrodes ipsilateral to the distractor face).

Figure 6 about here

6.5.2.1. Ppc: 60-110 ms

There was a main effect of laterality, $F(1, 19) = 47.18$, $p < .001$ ($\eta^2_p = .71$), as mean amplitudes were more positive for contralateral electrodes (0.12 μV) compared with ipsilateral (-0.32 μV); and a main effect of load, $F(1, 19) = 6.15$, $p < .05$ ($\eta^2_p = .24$), as mean amplitudes were more positive for high load (0.05 μV) compared with low (-0.25 μV). There was also a load x valence interaction, $F(1, 19) = 8.94$, $p < .01$ ($\eta^2_p = .32$), as the enhanced positivity for neutral compared with angry faces was greater for high load (means of 0.34 μV and -0.24 μV for neutral and angry faces, respectively, $t(19) = 3.74$, $p = .001$) than for low load conditions ($t < 1.3$). There was also a load x laterality interaction, $F(1, 19) = 11.15$, $p < .01$ ($\eta^2_p = .37$). The laterality effect was present for both high load (means of 0.34 μV and -0.23 μV for contralateral and ipsilateral electrodes, respectively; $t(19) = 8.18$, $p < .001$) and low load conditions (means of -0.09 μV and -0.40 μV for contralateral and ipsilateral electrodes, respectively; $t(19) = 3.93$, $p = .001$). The effect size, however, was larger for high than low load (*d*s of .56 and .33, respectively). There were no other significant main effects or interactions (all *F*s < 3.3).

6.5.2.2. N_D: 130-170 ms

There was a main effect of laterality, $F(1, 19) = 6.08$, $p < .05$ ($\eta^2_p = .24$), as mean amplitudes were more negative for electrodes contralateral to the distractor (0.53 μV) compared to ipsilateral (0.91 μV). There was also a main effect of load, $F(1, 19) = 11.55$, $p < .01$ ($\eta^2_p = .37$), as mean amplitudes were more negative for low (0.37 μV) than high (1.07 μV) load conditions; and a main effect of valence, $F(1, 19) = 18.14$, $p < .001$ ($\eta^2_p = .48$), as mean amplitudes were more negative for angry distractors (0.53 μV) compared with neutral (0.91 μV). Finally, there was a significant load x valence x laterality interaction, $F(1, 19) = 7.25$, $p < .05$ ($\eta^2_p = .28$). A valence x laterality ANOVA was performed for each level of perceptual load, where results for low perceptual load revealed a main effect of laterality (means of 0.15 μV and 0.59 μV for contralateral and ipsilateral electrodes, respectively; $F(1, 19) = 6.38$, $p < .05$, $\eta^2_p = .25$). Results for high perceptual load, however, showed a main effect of valence, $F(1, 19) = 31.58$, $p < .001$ ($\eta^2_p = .62$), as mean amplitudes were more negative for angry

(0.82 µV) than neutral (1.32 µV) distractors and a valence x laterality interaction, $F(1, 19) = 5.11$, $p < .05$ ($\eta^2_p = .21$), as the laterality effect appeared greater for angry (means of 0.57 µV and 1.07 µV for contralateral and ipsilateral face distractors, respectively; $t(19) = 2.44$, $p < .05$) compared to neutral distractors ($t = 1.99$, $p = .061$). There were no other significant main effects or interactions (all *F*s < 1.5).

6.5.2.3. P_D: 190-250 ms

There was a main effect of laterality, $F(1, 19) = 35.80$, $p < .001$ ($\eta^2_p = .65$), as mean amplitudes were more positive for electrodes contralateral to distractors (3.49 µV) compared to ipsilateral (1.76 µV); a load x valence interaction, $F(1, 19) = 6.58$, $p < .05$ ($\eta^2_p = .26$), as the valence effect was significant for the high load task (means of 2.90 µV and 2.52 µV for neutral and angry faces, respectively, $t(19) = 3.13$, $p = .006$) but not for the low ($t < 1$); and a load x laterality interaction, $F(1, 19) = 11.01$, $p < .01$ ($\eta^2_p = .36$). The laterality effect was present for both high (means of 3.72 µV and 1.70 µV for contralateral and ipsilateral, respectively, $t(19) = 6.18$, $p < .001$) and low (means of 3.25 µV and 1.81 µV for contralateral and ipsilateral, respectively, $t(19) = 5.26$, $p < .001$) perceptual load, but the effect size was larger for high than low load (*d*s of .49 and .42, respectively). There were no other significant main effects or interactions (all *F*s < 3.1).

6.5.2.4. Late P_D: 250-400 ms

There was a main effect of laterality, $F(1, 19) = 52.24$, $p < .001$ ($\eta^2_p = .73$), where mean amplitudes were more positive for electrodes contralateral to distractors (4.92 µV) compared to ipsilateral (3.93 µV); a load x valence interaction, $F(1, 19) = 5.60$, $p < .05$ ($\eta^2_p = .23$), where the valence effect was significant for the high load task (means of 4.17 µV and 4.53 µV for angry and neutral faces, respectively, $t(19) = 2.73$, $p = .013$) but not for the low ($t < 1$); and a significant load x laterality interaction, $F(1, 19) = 18.22$, $p < .001$ ($\eta^2_p = .49$). Paired comparisons *t*-tests on the load x laterality interaction reveal a significant effect of laterality for high perceptual load, $t(19) = 8.16$, $p < .001$, where electrodes contralateral to the distractor were more positive (4.98 µV) compared to ipsilateral (3.71 µV); and, a significant effect of laterality for low perceptual load, $t(19) = 4.88$, $p < .001$, where electrodes contralateral to the ignored distractor (4.86 µV) were more positive compared to ipsilateral (4.14 µV). The effect size, however, was larger for high than low load (*d*s of .56 and .31, respectively). These results indicate that the Late P_D shows an identical pattern of results as the P_D and likely reflects a continuation of the P_D. There were no other significant main effects or interactions (all *F*s < 3.0).

6.6. Discussion

Behavioural responses were faster for low compared to high perceptual load conditions, indicating the effectiveness of the load manipulation. Responses were not, however, sensitive to effects of valence, despite the influence of valence on the N_D component (see below). This is consistent with the findings of Experiments 1 and 2, in which RTs did not appear to reflect any of the electrophysiological effects that were observable within the early (~120-180 ms) time window. Notably, effects of perceptual load were present within the later P_D component (between 190 and 400 ms) suggesting that manual responses may be influenced to a greater extent by effects occurring later within the information processing stream.

The Ppc appeared greater for the high compared with the low perceptual load condition. Although a cross-hemispheric sensory energy imbalance is likely to be the main contributing factor to the Ppc, these differential 'load' effects are unlikely to reflect sensory differences between the lateral distractors across conditions, as the distractors were identical for low and high load visual arrays. One possible explanation for the differential load effects is that the Ppc is sensitive to early spatial selection of the lateral face distractor, with enhanced attention under conditions of high perceptual load. A further possibility is that these early differential load effects are partially a result of top-down suppression. The high and low load trials were grouped by means of the presentation of six consecutive low load blocks and six consecutive high load blocks. Participants may therefore have exerted strategically and continuously the level of top-down inhibition necessary for optimal performance in either high or low load conditions, which may have manifested in top-down inhibitory effects being apparent very early in the trial sequence. A similar conclusion regarding active suppression was put forward by Sawaki and Luck (2010) who found an early positivity to salient distractor stimuli starting at around 115 ms. Sawaki and Luck proposed that what was being observed was in fact early active suppression of an 'attend-to-me' signal. The suggestion that the Ppc may reflect similar properties to the P_D and late P_D is further supported by the fact that in our study a larger overall effect of distractor valence was observed in high as compared with low load conditions across all positive component time windows. A final possible explanation for the differential load effects relates to the suggestion that the Ppc may reflect item salience within a pre-attentive salience map (Fortier-Gauthier et al., 2012; Jannati et al., 2013). In other words, it may reflect an initial processing of a display based on locations of interest (e.g., due to local feature discontinuities), which may guide the later controlled allocation of visual spatial attention. Local competitive interactions between targets and nearby distractors in visual cortex, the magnitude of which may be affected by factors such as target-distractor similarity or simply the nature of the target, have been suggested to influence the representation of items within a salience map (Desimone & Duncan, 1995; Roper & Vecera, 2013; Torralbo & Beck, 2008). Minor differences between the targets in the current experiment (low load: 'OI'; high load: 'EF') may have been sufficient to have altered the competitive interactions between target and distractor items, producing differences in distractor saliency. Although such a strong modulatory influence on the Ppc would seem unlikely to arise from such minor differences in the midline stimuli, it should be noted that such an explanation cannot be ruled out entirely for either the Ppc or for the later P_D component.

Our N_D results indicate that angry face distractors elicited greater attentional capture than neutral ones, but only under conditions of high perceptual load. This finding leads to the tentative conclusion that the effects of emotion on attention are more likely to be revealed when resources are limited. Under low load conditions, the spill over of resources means that the saliency of distractor stimuli is enhanced to a level that would be insensitive to a further boost from emotion influences. Under high load conditions, the scarcity of resources for the processing of distractor items means that effects of emotion-related attentional enhancement become evident. Our results are consistent with a view of emotion processing as strongly automatic (Pourtois, et al., 2010; Vuilleumier, 2005; Williams et al., 2005) but with attentional enhancement effects becoming manifest when perceptual representations can benefit from such neural augmentation (i.e. under high perceptual load), consistent with a biased competition view of attention (Desimone & Duncan, 1995; Beck & Kastner, 2009). As an example of this, Williams et al. (2005) showed greater amygdala activation to fearful faces only when the faces were ignored and attention was directed towards superimposed houses. They concluded that the amygdala gives preference to potentially threatening stimuli under conditions of inattention. It should be noted, however, that a finding of emotion-specific attentional modulation under conditions of high load and thus with reduced attention to the distractors is not altogether consistent within the literature (e.g., see Bishop et al., 2007; Lim et al., 2008; Pessoa et al., 2002, 2005). One possible explanation, proposed by Palermo and Rhodes (2002), is that studies indicating obligatory and automatic processing of facial threat (e.g., greater amygdala activation to threat faces under both high and low perceptual load conditions), the faces have typically been presented in peripheral locations (e.g., Soares et al., 2015; Vuilleumier et al., 2001; Williams et al., 2005). Conversely, in studies indicating non-obligatory processing of threat (e.g., greater amygdala activation to threat faces under low but not high perceptual load conditions), the faces have been presented in central locations (e.g., Anderson et al., 2003; Pessoa et al., 2002). Thus, peripheral, but not central, threat faces may be processed automatically, irrespective of the availability of perceptual resources. This may be considered compatible with an evolutionary account of threat detection in which perception is tuned for the detection of environmental dangers that may appear outside of our central vision.

A further example of attentional enhancement of distractor stimuli under conditions in which resources had been depleted by a perceptually demanding task was provided by Biggs et al. (2015). They found that guided search was effective under high, but not low, load conditions. They suggested that under low load, automatic processing of the display occurs in parallel and in its entirety, before the observer can utilise any top-down information. However, under high load, guided search could be highly effective because observers could not process the display in parallel, which then provided the opportunity to guide attention towards the relevant information. Our results are also consistent with recent findings of greater effects of emotion-specific attentional enhancement under conditions of high ‘cognitive’ load. For example, Holmes et al. (2013) found that the depletion of cognitive control resources, using a working memory manipulation, increased the capacity of task irrelevant threat cues to capture and hold attention (but see Berggren et al., 2012).

It should be noted that no late N_D was present here, despite being observed to intact face distractors in Experiment 1. This effect was previously explained in terms of a reorienting of attention to the distractor following the preparation of a target response. The target tasks that were used here, however, were harder than the task employed in Experiment 1, as indicated by the longer RTs. This greater target difficulty may have made the release of attention to the distractor face less likely as task-focused attention would have been required for a longer period for the correct identification of the target.

As with Experiment 1, the N_D was followed by a P_D. The P_D, reflecting active suppression, was greater for the high relative to the low perceptual load condition. Thus, making the task harder increased the need for suppression of potentially interfering distractors. These findings are consistent with those of Hickey et al. (2009; see Kiss et al., 2012, for similar findings). They demonstrated that by changing the experimental task from discrimination to detection of a midline target, thereby reducing the attentional demands, the P_D to a lateral distractor was effectively eliminated. Our results are not, however, consistent with those of Sawaki and Luck (2010; see also Lavie & Fox, 2000). They found that when attention was focused toward a central region of a visual array for a perceptually demanding task, the P_D to an irrelevant salient singleton was eliminated, compared with conditions in which the target was less perceptually demanding. Sawaki and Luck argued that when perceptual load is sufficiently high, salient stimuli may be less likely to attract attention as perceptual resources are exhausted by the ongoing task (Lavie, 1995, 2005) and so active suppression of salient distractors may not be necessary. A difference between Hickey et al.'s (2009) and our experiments with those of Sawaki and Luck (2010) is that the former had displays of only two stimuli whereas the latter had displays of eight items. In addition, Sawaki and Luck's load manipulation involved a broad allocation of attention during the low load task compared with a narrow focus towards a central target stimulus during the perceptually demanding high load task. By contrast, there was no requirement to alter the window of attention across the two load conditions in our and Hickey et al.'s experiments. The narrowing of attention during the high load condition in Sawaki and Luck's study could arguably have lowered the relative competitive value and salience of the distractor stimuli, and thus there would have been no requirement to actively suppress the distractor stimuli. A final possible explanation for our results, which may preserve a 'perceptual load' account, entails a view of active inhibition as non-monotonic, taking a U shaped function. Yeshurun and Marciano (2013) suggested that if a task is very easy, participants do not need to invest resources in inhibiting a distractor because a reasonable level of performance can be attained without such inhibition. When the task is moderately hard, distractor inhibition may occur to counteract any detrimental effects of distractor processing on performance. If the task is particularly hard, however, the participants may not have the spare resources to invest in inhibition. It is possible that the 'hard' discrimination in our experiment may not have been taxing enough to have depleted attentional resources. We consider this unlikely, however, as the RTs for this experiment suggest that the task was extremely perceptually demanding.

7. General Discussion

The main results of the study are summarised as follows. The N2pc is likely an aggregate measure of at least two distinct processes: a P_D and an N_T, thereby replicating Hickey et al.'s (2009) findings and providing further support for the notion that these discrete components may have been confounded in earlier ERP studies. We also found evidence that human faces draw attention rapidly and involuntarily, as indexed by an early negativity (N_D) prior to their active suppression (P_D). By contrast, neural representations of stimuli that are not inherently salient (scrambled faces) can be directly inhibited (P_D), indicative of rapid suppression of attentional orienting (see Hickey et al., 2009; Sawaki & Luck, 2010). The results also showed that the magnitude of the P_D was associated with the perceptual load of the task, revealing that as task difficulty increased so did the requirement to inhibit potentially interfering stimuli (see also Hickey et al., 2009). In addition, attentional capture (N_D) by distractor faces was greater for angry as compared with neutral faces but only under conditions of high perceptual load (see also Soares et al., 2015).

7.1. P_D

A P_D component was elicited in Experiments 1 and 3. It was maximal at around 180-250 ms, extending to 400 ms, and arose at posterior scalp sites contralateral to the distractor position. The P_D is considered to reflect the active attentional suppression of a distractor stimulus (Hickey et al., 2009; Sawaki & Luck, 2010). In this study, it was found to be insensitive to the nature of the distractors, with neither the intrinsic salience (intact vs. scrambled faces) nor the emotional expression (angry vs. neutral) of the distractor stimuli having any influence on the size of the component. It was, however, sensitive to the perceptual demands of the target task, with a greater P_D under conditions of high relative to low perceptual load. Active inhibition may therefore be needed to protect against the detrimental impact of task-irrelevant distractor processing on performance when the target task is particularly demanding. This conflicts with predictions of perceptual load theory (Lavie, 1995, 2005). We propose that it is active inhibition, rather than the absorption of perceptual resources by the difficult target task (Lavie, 2005), that leads to reduced distractor interference under high load conditions (see also Benoni & Tsal, 2013).

7.2. N_T

An N_T (target negativity; Hickey et al., 2009) was observed within Experiment 2 where participants were required to attend to the lateral stimulus that had been previously ignored in Experiment 1. It appeared at lateral posterior electrode sites within a time frame of around 120-180 ms. This finding provides support for the suggestion that the N_T reflects the enhancement of target processing, providing one of two mechanisms of attentional selection (the other being distractor suppression) that summate to form the N2pc (Hickey et al., 2009). Notably, it was enhanced to intact as compared with scrambled faces that had been matched for overall luminance and contrast energy, indicating that the motivational relevance of attended material can affect the allocation of visual attention, even under conditions in which attention is already being guided to the target in a top-down manner.

7.3. N_D

Sawaki and Luck (2010) argued in their signal suppression hypothesis that signals generated by salient singletons (‘attend-to-me’ signals) can be overridden by an active suppression process (P_D) preventing the actual capture of attention. We provide further support for this hypothesis. In Experiment 1, we showed that active suppression (P_D) was used to prevent the capture of attention by a physically salient distractor (scrambled face). We also showed in Experiments 1 and 3 that when the distractor was intrinsically salient (intact face), the allocation of attention towards it could not be prevented. In this case, active suppression (P_D)

followed a negativity appearing at lateral posterior scalp sites at around 120-180 ms post-stimulus, similar in morphology to the N_T and N2pc components. It suggests that stimuli with socio-biological significance may capture attention automatically, before their ‘attend-to-me’ signals can be suppressed. In sum, distractors that either have overlapping physical attributes with a target stimulus (Sawaki & Luck, 2013) or are inherently salient by virtue of their motivational relevance, would appear to draw attention in an obligatory manner.

Crucially, the emotional valence of distractor stimuli (angry versus neutral facial expression) affected the N_D under conditions of high perceptual load (Experiment 3) but not under conditions of low perceptual load (Experiments 1 and 3). It is possible that under low load conditions, the neural representation of distractor stimuli is enhanced to a level that would be insensitive to any further boost from emotion processing systems, whereas this is not the case under high load conditions. It is, however, conceivable that a more affectively intense stimulus would have produced evidence of an emotional valence effect even under low load conditions. The enhanced neural activation of distractor items under conditions of low perceptual load can be explained either in terms of the increased availability of perceptual resources, consistent with Load Theory (Lavie, 2005, 2010), or in terms of reduced active suppression of distractor stimuli owing to the ease of the target task (see section on P_D above). Either way, our results are consistent with neurocognitive perspectives that stress the automaticity of emotion processing (Pourtois et al., 2004; Vuilleumier, 2005; Williams et al., 2005). Feedback from amygdala-mediated emotion systems is conceivably present regardless of task difficulty, but only becomes manifest when perceptual representations can actually benefit from such neural augmentation, in line with a biased competition view of attention (Desimone & Duncan, 1995; Beck & Kastner, 2009).

A late N_D was also observed to intact, but not scrambled, face distractors within a time range of between 250 and 300 ms in Experiment 1. This may reflect the sustained allocation of attention towards motivationally significant distractor stimuli when a target task is no longer competing for attentional resources.

7.4. P_T

In Experiment 2, a P_T (target positivity; Jannati et al., 2013) was observed within a window of 200-270 ms at lateral posterior scalp sites following the N_T component, although informal observations of the waveforms suggest that it may have extended up to around 400 ms. The P_T is almost identical in morphology to the P_D and has been argued to reflect the active suppression of attention following the completion of perception (Sawaki et al., 2012). Our results provide further support for this suggestion and indicate that active suppression may be a general purpose mechanism that can both prevent and terminate the allocation of attention (Sawaki et al., 2012). This conclusion is strengthened by our use of the experimental approach devised by Hickey et al. (2009) in which the P_D and P_T should not be confounded by other attentional operations. Future work should clarify the characteristics of the P_T and also its relevance to the work on attentional disengagement (e.g., Blakely et al., 2012; Boot & Brockmole, 2010; Georgiou et al., 2005; Posner, 1984).

7.5. Ppc

Evidence of a Ppc (Positivity, posterior contralateral; Fortier-Gauthier et al., 2012; Leblanc et al., 2008; Jannati et al., 2013) was revealed at lateral posterior scalp sites between approximately 50 and 110 ms, across all three experiments. Similar early contralateral positivities have been reported in a number of visual search studies. They have been attributed both to low-level sensory processes (Luck & Hillyard, 1994a) and also to preattentive identification of salient featural discontinuities, which may help guide the later controlled deployment of visual attention (Fortier-Gauthier et al., 2012; Leblanc et al., 2008). These views are not necessarily incompatible as both posit a central role for early sensory activity. In the present study, the Ppc was found to be equivalent across two experiments (1 and 2) in which the stimulus arrays were identical and the only difference related to the attentional requirements of the task. This may support an early sensory account of the Ppc, but this conclusion is tentative as the Ppc observed in Experiment 2 may have been confounded by latency differences in the activity observed in the contralateral and ipsilateral hemispheres (see Figure 3). In Experiment 3 the Ppc was augmented under conditions of high relative to low perceptual load. A sensory account may therefore not be the only explanation for this early positivity, as the lateral distractor stimuli were identical under both high and low load conditions. One possible explanation is that under some circumstances, active suppression of distractor stimuli may arise early within the information processing stream and summate with pre-existing sensory activity. In Experiment 3, participants may have exerted greater inhibitory control on each trial within the high load condition, starting early post-stimulus onset and being maintained through to the P_D measurement interval and beyond (possibly up to around 400 ms), in order to achieve optimum performance on each trial.

To conclude, the findings provide support for the suggestion that the N2pc reflects the contribution of at least two distinct processes of target enhancement and distractor suppression. They further reveal that the modulation of these component processes can occur as a function of the intrinsic salience of distractor or target stimuli and also the level of difficulty of the target task.

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