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The neural mechanisms of attention: Exploring threat-related suppression and enhancement using ERPs

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The neural mechanisms of attention: Exploring threat-related suppression and enhancement using ERPs

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By

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Declaration of Originality

I, Paul Michael Bretherton, hereby declare that this work was carried out in accordance with the Regulations of the University of Roehampton. I declare that this submission is my own work, and to the best of my knowledge does not represent the work of others, published or unpublished, except where duly acknowledged in the text. No part of this thesis has been submitted for a higher degree at another university or institution.

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Abstract

The capacity of the visual system to process information about multiple objects at any given moment in time is limited. This is because not all information can be processed equally or in parallel and subsequently reach consciousness. Previous research has utilized behavioural experiments to explore visual attention. More recently research, however, has used electroencephalography (EEG) to measuring the electrical brain activity in the posterior scalp. By time locking visual stimulus events to fluctuations in scalp activity researchers have been able to estimate the time course of attentional changes by measuring changes in these event-related potentials (ERP). One component in particular (N2pc) has been a reliable tool in measuring either the suppression of, or the shift of attentional to, both ignored and attended items in the visual scene. The N2pc is measured by comparing the ERP activity contralateral and ipsilateral to the visual field of interest.

More recently, evidence has been presented that the mechanisms of attention thought to be represented by the N2pc (suppression and attentional selection) could be separated into different ERP components (Pd: indexing attentional suppression of an ignored item; and Nt: indexing attentional selection of the target) and measured independently. In six experiments, using ERPs, this thesis employs these components to explore the mechanisms and strategies of the human attentional system. Additionally, this thesis focuses on the impact of different types of simultaneous processing load on the attentional system and how the mechanisms of this system are influenced.

Experiment 1 explores the idea that the type or valence of information to be ignored may influence the ability to suppress it. Results of this experiment

show that neither the type nor valence of the irrelevant information modulated the amplitude of the distractor positivity (Pd), indicating suppression of the irrelevant distractor was not altered. Noted in experiment 1 was also the presence of an early negativity (Ne) that appeared to represent attentional capture of the ignored lateral stimulus. Experiment 2 demonstrated that the valence of the lateral target did not alter the target negativity (Nt), indicating a different pattern of results between the Nt and the N2pc reported in previous studies (e.g. Eimer & Kiss, 2007; Feldmann-Wüstefeld et al., 2010). Experiment 2 also showed a similarity of the target negativity (Nt) to the early negativity (Ne; the N2pc like component observed in exp 1) toward face and non-face stimuli. This comparison supported the idea that the early negativity (Ne) reflected attentional capture of the ignored lateral distractor and as a result was relabelled the distractor negativity (Nd) in subsequent experiments.

Experiment 3 showed that the salience of the lateral image did not modulate the Pd as should be the case if the Pd reflected sensory-level processing. An early contralateral negativity (similar to the Nd observed in exp 1) was altered by the salience of the distractor which added support to the hypothesis that this reflects attentional capture of the lateral ignored image. Experiment 4 attempted to manipulate working memory (WM) to assess the effect of WM load on attentional capture and suppression. While the results did indicate modulation of suppression under WM load, the limitations of the design of experiment 4 made any definitive interpretation of the results unreliable. The results of experiment 5 showed that suppression, as indexed by the Pd, was not altered by cognitive load. However, reductions in attentional capture under high cognitive load, as indexed by the distractor negativity (Nd), were observed and contradict the results of previous experiments (c.f. Lavie & De Fockert, 2005) where cognitive load resulted in an increase in attentional capture. Although, there appears to be some issue in the authors interpretation of the results of these experiments (see chapter 6 for discussion). The results of Experiment 6 show the opposite effect with a significant increase in the laterality of the Pd under high perceptual load. A similar increase in the laterality of the Pd was not reflected in terms of valence though, where suppression of threat related distractors was not altered under high perceptual load. The hypothesis that an increase in perceptual load will result in a decrease in attentional capture was generally supported by the results of experiment 6. Under high perceptual load angry face distractors captured attention, as indexed by the laterality of the Nd, with neutral face distractors showing a reduction in attentional capture. While under low perceptual load, both angry and neutral face distractors resulted in a significant (and similar) laterality of the Nd.

The thesis concludes by discussing issues concerning Lavie's Load Theory of attention and outlines some potential misinterpretations of previous data that have led to the proposal that cognitive load results in a decrease in attentional resources and therefore a decrease in attentional capture of ignored stimuli. It is argued in this thesis that the results of Lavie and de Fockert (2005), which concluded that the increase in cognitive load resulted in a decrease in attentional capture, are more likely to be due to changes in attentional capture (i.e. a reduction) and changes in RT (i.e. an increase), under cognitive load being separate responses to the availability of resources, one that focusses attention on the goal directed task and the other that results in extended processing time to carry out the more difficult task. In this case both 'changes' appear to work to prioritise resources in favour of the goal directed task.

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Abbreviations

Ag/AgCl	Silver/Silver Chloride
ANOVA	Analysis of Variance
EEG	Electroencephalography
ERP	Event-related potential
fMRI	Functional magnetic resonance imaging
HEOG	Horizontal electro-occulography
IOR	Inhibition of return
ISI	Inter-stimulus interval
LDAP	Late directing attentional positivity
N2pc	Negative posterior contralateral ERP potential
NTI	Non-target inhibition view
Pd	Distractor positivity
PET	Positron emission tomography
Pl	Late positivity
Pt	Target positivity
ANOVA	Repeated measures analysis of variance
RMS	Root mean square
RGB	Red, Green, Blue

RT	Reaction time
STAI	State trait anxiety inventory
VEOG	Vertical electro-occulography
WM	Working memory

Chapter 1: Selective and emotional driven attention

The human brain is known for its staggering complexity and processing capacity; with its hundred billion (10^{11}) neurons and several hundred trillion synaptic connections it can process and exchange vast amounts of information over a distributed neural network in milliseconds. Such massive parallel processing capacity was thought to permit our visual system to successfully decode complex images in as little as 100 ms (Rousselet, Thorpe, & Fabre-Thorpe, 2004), but more recent evidence suggests this processing can happen in just 13 ms (Potter, Wyble, Hagmann, & McCourt, 2013). Despite the speed of processing ability of the human visual system, its capacity to process information about multiple visual objects at any given moment in time is limited (e.g. Cowan, 2000; Irwin, 1992; Pylyshyn & Storm, 1987). The visual system has evolved two solutions to this problem. The first is different levels of raw detail capture as the image on the retina is processed in its full detail only at the fovea, while at the periphery, where receptors are more widely spaced, the area of processing representative of the visual periphery on the cortex is smaller (White, Levi, & Aitsebaomo, 1992; Wilson, Levi, Maffei, Rovamo, & DeValois, 1990) and information is subsequently much more coarsely sampled (Wolfe, 1994). The second is to process incoming information selectively (Wolfe, 1994).

This limited processing capacity can be demonstrated with a simple experiment. If participants are asked to identify two different attributes of two different objects simultaneously (e.g. the colour of one and shape of another), the participants' performance is worse than if asked to identify two attributes within only a single object (Duncan, 1980; 1984; Treisman, 1969). This difference in processing is due to the speed and range of information processing in visual perceptual pathways being inherently limited, in that, not all captured sensory information can be equally processed in parallel and subsequently reach consciousness (Posner, Snyder, & Davidson, 1980; Marois & Ivanoff, 2005) and is the basis of the *Filter Theory* of attention (Broadbent, 1958). Filter theory posits that information processing is restricted by the capacity of any specific ‘channel’ being stimulated (Solso, 1998). In Broadbent’s model, several nerve fibres (channels) could be stimulated simultaneously and further processing would only occur after a particular signal was attended and passed on to be processed (Broadbent, 1958). As a typical scene may contain many objects that are all in competition for neural resources, and as awareness has a limited capacity for holding and manipulating multiple object representations at any given time, items in the visual scene must therefore be prioritised. The selective attention system and the emotion system are two neural systems that mediate such prioritization (Goolsby et al., 2009).

1.0.1 Summary

Given the above reviewed evidence the mechanism of the first stage of visual processing can be summarised as follows. Despite the complexity of the human brain the processing of visual information in real time is restricted by a limit to the amount of information the can be processed at any given time. Many theories have attempted to explain how a visual system that is limited by resources can manage to process more information than would be possible if all incoming visual information were attended simultaneously. Early theories of attention were inspired more by the biological nature of the visual system where their understanding of the cells in the retina and neurons in the visual cortex were used to explain the limits of visual processing and the subsequent cognitive organisation of attention and attentional processing. Theories since have incorporated a more ‘cognitive’ explanation of attentional organisation and attentional resource management.

1.1 The Selective Attention System

The way visual search is conducted depends on whether the target sought is distinguishable with a single glance at the whole scene (i.e. the target pops out of the display) or demands a shift of attention, or series of shifts, in order to be identified/located (Neisser, 1967). Neisser (1967) identified two processes by which this could be accomplished: a) a *parallel* type search that operates over large portions of the visual field at one time, and b) a *serial* type search where limited-capacity processes are restricted in their operation to a smaller portion of the visual field at any one time, so that in order to cover all of the visual field, attention must be deployed from location to location in a serial fashion.

Treisman (1969) postulated that a target pops out when it has a single unique feature (e.g. it is the only red item in the display), which can be detected with a parallel search of the whole display, and that unattended stimuli were ‘attenuated’ rather than completely filtered out. Therefore, the pop-out effect results when attention receives inputs from both attended and unattended stimuli. Treisman and Gelade (1980) later showed that this kind of search could be conducted pre-attentively without the need for focal attention as visio-spatial features such as the motion, colour, and orientation of objects in the visual field are registered early, automatically, and rapidly. On the other hand, searches for targets identified by the combination of two or more features (e.g. a colour and a shape) were characterized by directly increasing RTs as a function of the number of items in the visual scene, indicating a serial type search (Treisman &

Gelade, 1980). Consequently, these authors concluded that focal attention on individual items is necessary in order to combine separate features and assign them to a single object. The central tenet of the Guided Search model of attentional deployment is that limited resources of attention are guided by the output of earlier parallel processes (Wolfe, 1994). By contrast, the difference between a serial, parallel, feature, and combination search form the core of Feature Integration Theory (FIT; Treisman, 1969). FIT suggests that attention must be directed serially to each stimulus in a display whenever combinations of more than one separable feature are needed to characterize or distinguish the possible objects presented (Treisman & Gelade, 1980). FIT has since been contradicted on the basis that results have indicated combination type searches can be performed more efficiently than would be predicted by a strictly serial search (e.g. Nakayama & Silverman, 1986).

1.1.1 Bottom-up vs. Top-down attentional control

Attention has evolved in order to deal with the dilemma of limited processing resources and subsumes multiple neural processes contributing to select the most relevant or useful information (Driver & Vuilleumier, 2001; Kastner & Ungerleider, 2000). When there is more information than can be processed at any one time the information to be processed competes for representation. While competition for neural resources is biased towards behaviourally relevant information (Desimone & Duncan, 1995), a behaviourally-irrelevant stimulus may pop out due to its salience, in that, it will be processed preferentially or involuntarily because it distinctively deviates in terms of its physical features or is novel or unexpected relative to other competing stimuli (c.f. Ranganath & Rainer, 2003; Theeuwes, 1994; Wolfe & Horowitz, 2004), while other simultaneous but irrelevant events will fail to capture attention (as illustrated by change blindness; c.f. Pourtois et al., 2006a; Simons & Levin, 1997). Conversely, the prioritisation of information may also be done by attending to, or narrowing attention on, a specific region of the visual-perceptual field enabling selective processing of stimuli appearing in that position only (LaBerge, 1995). Desimone and Duncan (1995) outline the four guidelines of attentional competition bias as: a) dividing attention between two objects almost always results in poorer performance than focusing attention on one; b) the major performance limitation appears to occur at stimulus input rather than subsequent short-term storage and response if the stimuli exposures are brief; c) interference is independent of eye movements; and d) interference is also independent of the spatial separation between two objects.

Within the attentional selection system, attention is controlled either voluntarily in a goal-directed (i.e. top-down/endogenous) manner or by the properties of the stimulus features in an automatic stimulus-driven (i.e. bottom-up/exogenous) manner (c.f. Pourtois, Schettino, & Vuilleumier, 2013; Theeuwes, 2010). For example, if a person in a crowded room wants to follow a conversation, they can pay attention to the person speaking directly, subsequently filtering out the irrelevant noise. This process is what James (1980) referred to as ‘active attention’, also known as endogenous attention, in which attentional control is exerted in a top-down manner. For simplicity, from here active and endogenous attention will be referred to as ‘top-down’ attentional control. Conversely, elements in the environment can attract our attention independent of our intentions. For example, if we are startled by a loud noise, we will almost certainly turn abruptly in the direction of the sound. Attention to these elements is what James (1980) referred to as ‘the passive side of attentional deployment', also known as exogenous attention, in which the control is exerted in a bottom-up or stimulus driven manner. For simplicity, from here passive and exogenous attention will be referred to as 'bottom-up' attentional control.

Some of the first extended discussions of the distinction between top-down and bottom-up control of attention are provided by Jonides (1981). According to this author, top-down orienting is easily suppressed, is affected by subject's expectancies and by simultaneous memory load, is resource-limited, and requires conscious awareness. On the other hand, bottom-up orienting appears to be its antithesis as it cannot be suppressed, is resource-free, is unaffected by the person's expectations or by concurrent memory load, and does not require conscious awareness (Jonides, 1981). Top-down and bottom-up control processes interact to determine the location in the visual field that will be attended, where bottom-up subsequently compete with top-down control processes (Theeuwes, 2010). For example, when instructed to search for a green item among red items, it cannot be determined if the selection of the green item is the result of top–down or bottom–up control as the salient feature that pops-out from the display is also the element being sought and selected. To demonstrate true bottom–up selection, one must show that the green item is selected even though observers are actively trying to select some other element of the visual scene, for example a red stimulus (c.f. Theeuwes, 1992). This type of filtering, or a *spatial filtering,* is a simple mechanism that attenuates information from irrelevant locations allowing information from the unfiltered region of the visual field to be processing with minimal interference from irrelevant locations in the visual scene. Research has provided evidence for the existence of a spatial filtering mechanism such as this. As an example, Sagi and

Julesz (1986) had participants discriminate the orientation of a figure and found that as the distance between the target dot and the figure to be discriminated was increased, participants' detection accuracy subsequently decreased. Filtering will be discussed more in the section on the *N2pc*.

One of the main tools in the study of top-down and bottom-up orienting is Posner's costs and benefits paradigm (Posner, 1980). When the cue is presented before target onset the time taken to respond to a target in the cued location is compared to the time taken to respond to a target in an un-cued location. By comparing performance for neutral, valid, and invalid trials, attentional orienting benefits (valid cue trials minus neutral trials) and costs (invalid cue trials minus neutral trials) can be estimated with both central and peripheral cues (Posner, 1980). Bottom-up control processes bias selection toward visually prominent/salient items and top-down control processes bias attentional selection toward behaviourally relevant objects of interest (Pourtois et al., 2013; Theeuwes, 2010). Two main perspectives have emerged regarding the role of each of these processes in attentional selection. According to the *Salience Driven Selection H*ypothesis, it is the salience of an object in its entirety that determines the initial visual selection. *Salience* is computed on the basis of the detection of stimuli whose local visual attributes significantly differ from the surrounding image attributes, along a singular dimension or some combination of dimensions (Itti & Koch, 2001). *Selection*, on the other hand, is based on the idea that the cognitive system is flooded with information from multiple inputs simultaneously and that certain types of information are selected as being relevant or appropriate for processing, while other information is rejected (Yiend, 2010) and is defined as the transfer of information from an early, 'pre-attentive’ stage of processing to a later ‘attentive’ stage of processing (Jannati, Gaspar, & McDonald, 2013).

According to the *salience driven selection hypothesis*, attention is deployed in a stimulus-driven (i.e. bottom-up) manner initially to the most salient item, regardless of its behavioural relevance, a process that is referred to as attentional capture (Theeuwes, 1991, 1992, 1994, 2010). Therefore automatic selection of a non-target stimulus will result in a delay as it must be determined to be irrelevant before attention can then select the target of interest (McDonald, Green, Jannati, & Di Lollo, 2013). This type of orientation toward the most salient item, or toward a target of interest (as noted in Posner, 1980), can itself be divided into three mechanisms: shifting of attention, engaging the target, and disengaging from the target (e.g., Posner, Walker, Friedrich, & Rafal, 1984). *Shifting* can be defined as the relocation of attention spatially across the visual field, while *Engagement* is the evidence of the selection and facilitation of a given stimulus or location; and finally, *Disengagement* is the process of withdrawing or inhibiting the selection or facilitation of a given stimulus or location for its relocation elsewhere in the visual scene (Yiend, 2010). It is presumed that low level visual features are processed in parallel and that stimulus salience is calculated during the pre-attentive stage of processing. According to the *salience driven selection hypothesis*, after pre-attentive analyses has been carried out sensory information coming from the location with the highest salience is then transferred to the attentive stage of processing with no overriding top-down control (Jannati et al., 2013).

While there may be general agreement that the salience of an object in early visual processing can drive selection in a bottom-up fashion, the idea that salience-driven selection is an essential component of visual processing has met firm opposition. The *Contingent-capture* hypothesis is one of the main competing viewpoints and predicts that an irrelevant stimulus will capture attention only when its features are relevant to the task being undertaken (Folk, Remington, & Johnston, 1992). The modified spatial cueing paradigm has provided evidence for contingent capture where the typical abrupt-onset stimuli are replaced by a cue and target type search display. The cue is an irrelevant distractor whose location is independent of the location of the following target singleton. The results of experiments with this type of cue paradigm show that invalid cues slow RT more when the cue shares some defining feature with the target (i.e. when it is the same colour) than when it does not share a similar feature (Folk & Remington, 1998, 1999; Folk et al., 1992; Folk, Remington, & Wright, 1994). For example, in a series of experiments Folk et al. (1992) tested the hypothesis that involuntary shifts of attention are dependent on the relationship between the properties required for task performance and the properties of the stimulated event. Results indicate that although bottom-up shifts of attention are modulated by top-down factors, they are still driven by external stimuli and pre-established control settings. More recently, Hopfinger and Ries (2005) presented participants with a discrimination task where targets were preceded by a non-predictive cue set. Results of this study show that a visual cue would prolong visual processing of the target when the cue was congruent with top-down control settings. This indicates that when an irrelevant stimulus shares some defining feature or element with the task, its processing interferes with task processing more than when it does not share a defining feature or element.

The slowing of RT to invalid cues when they share some defining feature with the target suggests that salience-driven attentional capture can be contingent on whether the features of the most salient item match attentional control settings induced by the demands of the task. However, some research has also indicated that when an observer knows what to look for, such salience-driven attentional capture can be prevented, so that attention can be deployed directly to a behaviourally relevant, but less salient, stimulus (i.e. top-down control process; Anderson & Folk, 2010; Bacon & Egeth, 1994; Folk & Remington, 1998, 2006; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; Müller, Reimann, & Krummenacher, 2003; Wolfe, 1994; Wolfe, Butcher, Lee, & Hyle, 2003). Bacon and Egeth (1994) argued that in a task where participants searched multi-element displays for a salient target, participants may have adopted the strategy of searching for an odd form even though the specific target form was known. However, when participants were forced to search for the target feature there was no distracting effect of a salient singleton, demonstrating that top-down selection is possible during a visual search. This demonstrates that top-down (goal-directed) selection of a specific known feature may override bottom-up (stimulus-driven) capture by salient singletons (Bacon & Egeth, 1994).

Several mechanisms have been suggested to explain top-down dependent attentional capture. However, these theories have assumed that top-down mechanisms alter attentional selection by activating or inhibiting specific feature templates (e.g. red, green) or altering the output of target specific neurons (e.g. Duncan & Humphreys, 1989; Folk & Remington, 1998; Folk et al., 1992; Koch & Ullman, 1985; Maunsell & Treue, 2006; Navalpakkam & Itti, 2007; Treisman & Gelade, 1980; Treisman & Sato, 1990; Wolfe, 1994). For example, according to the *feature-similarity* view, attention will be focussed on the features of the target being sought which will increase the response to features that are similar to those target features (e.g. Martinez-Trujillo & Treue, 2004; see also Folk & Remington, 1998). Alternatively the *non-target inhibition view* proposes that observers can bias attention against the features of irrelevant non-targets. *Attentional-engagement theory* (Duncan & Humphreys, 1989) predicts that attention is most strongly attracted to items that are similar to the target and, at the same time, dissimilar to the non-targets in that both the target and the non-target features are important for top-down processing. The *optimal tuning account*, on the other hand, posits that attention will be focussed on the feature that most distinguishes the target from the non-targets (Navalpakkam & Itti, 2007). According to the *optimal tuning* model, when the target and non-targets are very similar it can be more advantageous to focus attention on a more extreme feature difference that is more different from the non-targets as this will reduce the overlap between the target and non-target features and subsequently increase the difference between targets and non-targets (e.g. Lee, Itti, Koch, & Braun, 1999; Navalpakkam & Itti, 2007; Scolari & Serences, 2009, 2010). It is clear that explanations of top-down selection differ with respect to the feature that will be prioritized in a given instance, in that, once attention is set to a particular feature, the item that is most similar to this feature should attract attention more strongly.

1.1.2 Summary

Early theories of attention have identified that different aspects, or features, of the items in the visual scene can also play a role in how attention is deployed. Feature integration theory (Treisman, 1969) suggested that it is the features of the items in the scene that determine how attention will be deployed, although this theory has since lost support. Further work has allowed for the development of guidelines of attentional competition, which has stemmed from understanding that attention can also be biased toward behaviourally relevant information. In sum these guidelines are: multiple objects require more processing with the resulting limitations in performance occurring at the stage of input; and the interference of the increase in processing is independent of both eye movement and how far apart both objects are in the visual scene (Desimone & Duncan, 1995). The behavioural intention of the observer can also influence how attention is deployed.

Two distinct influences of attention are identifiable as bottom-up and top down processing, where bottom-up processes influence selection to the physical properties of the items in the scene and top-down control processes influence attention toward objects of behavioural interest. While the research reviewed in this section gives an insight into how attention is deployed to physical features of the visual scene, with and without behavioural relevance, it does not cover how attention is altered by other types of information such as emotion.

1.2 The Emotion System

Even though salience plays an important role in bottom–up selection, it is also considered that selection is bottom–up when it is driven by other factors, against the intentions of the observers, such as the emotional content of stimuli (e.g. angry faces) or previous experience (Theeuwes, 2010). For example, Pinto, Olivers, and Theeuwes (2005) investigated why, in a visual search, when the target identity is uncertain a singleton distractor has a stronger interfering effect. When participants searched for a shape in a mixed block, in which the target shape could change from trial to trial, a colour singleton distractor had a larger slowing effect on RT, compared to a 'pure block' in which the target shape remained the same. Since the increased costs occurred only on trials in which either the target and the singleton distractor swapped identity or on trials in which the target alone changed identity while the singleton distractor remained constant, the increased singleton distractor effect could be traced back entirely to inter-trial priming. This suggested that target uncertainty itself did not lead to a strategic change in the attentional selection of singletons and that selection is affected by bottom-up (i.e. 'automatic') priming mechanisms that are enhanced by the competition for attention. Similarly, while top-down attention has typically been associated with voluntary and effortful control (Kastner & Ungerleider, 2000; Posner, Snyder, & Davidson, 1980), there is evidence it can also be influenced by automatic and unconscious activation of goals (Dijksterhuis & Aarts, 2010; Moskowitz, 2002). Evidence has been collected that suggests emotional information, especially threatening information, can be encoded automatically (i.e., involuntarily and independently of attentional resources; see Compton, 2003, for a review). Moskowitz (2002) demonstrated that when goals were self-relevant, attention was drawn toward behaviourally-relevant items even when these items were to be ignored and when responses occurred too fast for conscious control. Bias toward emotional information is likely to be stronger with 'biologically relevant' stimuli (e.g. faces), and with threat-related or negative emotions (e.g. fear or anger; Lang, Davis, & Öhman, 2000), although it has been noted that pleasant and arousing stimuli sometimes have a similar effect, which suggests arousal value, rather than just valence (negative vs positive), play an important role in bias toward emotional information (Anderson, 2005).

1.2.1 Neurophysiology and emotional processing

A number of neuroimaging studies have demonstrated the importance of the amygdala both, in playing a critical role in the detection of threat related stimuli, and in mediating responses to those stimuli. Studies of the monkey brain activity have revealed extensive projections from the amygdala back to the occipital cortex (Amaral, Price, Pitkanen, & Carmichael, 1992). It is through these projections that early visual processing of emotionally salient stimuli may be enhanced, leading to the selection of motivationally relevant stimuli. Both Functional Magnetic Resonance Imaging (fMRI; Armony & Dolan, 2001; Lang, Bradley, & Cuthbert, 1998) and Positron Emission Tomography (PET; Morris, Öhman, & Dolan, 1998) studies in humans have provided evidence supporting these findings. These results suggest that connections between the amygdala and perceptual regions serve as processes by which emotionally significant stimuli receive high processing priority through enhanced amygdala activation that may give rise to greater neural activity in modality-specific sensory cortical areas (Armony & Dolan, 2001; Lang et al., 1998; Morris et al., 1998; Pessoa & Ungerleider, 2004), while other studies have produced conflicting findings. A study by McKenna, Gutierrez, Ungerleider, and Pessoa (2001) found that amygdala responses to both fearful and happy facial expressions were increased under focal attention indicating that the processing of some emotional stimuli are modulated by attentional processes.

Thanks to work in recent years, the neural substrates of emotion processing have been investigated allowing for the pinpointing of the specific brain circuits that execute specialized mechanisms for ‘emotional attention’ (Vuilleumier, 2005). The two attention mechanisms, top-down and bottom-up, involve partly distinct brain circuits at the neuro-anatomical level, including frontal and parietal cortex (top-down) as well as subcortical structures, such as pulvinar and superior colliculus (bottom-up; Posner & Dehaene, 1994), but also show substantial overlap and functional interactions (e.g. Corbetta & Shulman, 2002). Emotional type processing presents obvious adaptive advantages, in that it allows for emotional information to quickly draw attention, which would therefore receive priority processing as a consequence (Silvert et al., 2007). Playing an essential role in this phenomenon is the amygdala (e.g., Öhman, 2005; Vuilleumier, 2005), which is a subcortical structure that is strongly involved in the emotional processing of sensory stimuli (see Phelps & Ledoux, 2005; Zald, 2003 for reviews). Based on inputs from low-level sensory cortices, as well as from sub-cortical sites, the amygdala can perform a rapid evaluation of the emotional value of incoming information (Adolphs, 2002), while altering the representation of emotional stimuli by supplying direct and indirect top–down signals to sensory pathways (c.f., Anderson & Phelps, 2001; Pessoa & Ungerleider, 2004; Phelps, Ling, & Carrasco, 2006).

The amygdala-*fear* hypothesis was popularized by research demonstrating that the amygdala, a small almond shaped structure of the limbic system, supports changes in cardiovascular function that occur when rats are startled in response to fear learning (i.e. tones previously paired with an electric shock; LeDoux, Thompson, Iadecola, Tucker, & Reis 1983; LeDoux, Cicchetti, Xagoraris, & Romanski, 1990; LeDoux, Ruggiero, & Reis, 1985; for reviews see Fanselow & Poulous, 2005; Fendt & Fanselow, 1999; LeDoux, 2007; and “fear potentiated startle”, Davis, 1992; Hitchcock & Davis, 1986, 1987; also see Fendt & Fanselow, 1999). In rats, defensive retreat behaviour is elicited by electrically stimulating the amygdala (e.g., Maskati & Zbrozyna, 1989) and also results in enhanced startle reflex to acoustic stimuli (Rosen & Davis, 1988). In humans, the amygdala-*fear* hypothesis has been strengthened further by similar evidence of increased amygdala activity to fear learning where neutral tones have been paired with unpleasant blasts of noise (e.g., LaBar, Gatenby, Gore, LeDoux, & Phelps, 1998).

The role of the amygdala in the processing of emotion comes from research where individuals with atrophy of the amygdala (Bechara, Tranel, Damasio, Adolphs, Rockland, & Damasio, 1995) or amygdala lesions (LaBar, LeDoux, Spencer, & Phelps, 1995) have shown difficulty perceiving instances of *fear* in voices (see Adolphs & Tranel 1999; Anderson & Phelps 1998), and startled faces with wide eyes (e.g., Adolphs, Gosselin, Buchanan, Tranel, Schyns, & Damasio, 2005; Tsuchiya, Moradi, Felsen, Yamazaki, & Adolphs, 2009). Anderson and Phelps (2002) describe deficits of an individual with bilateral amygdala lesions who, when placed in close contact with snakes, spiders, or were startled, failed to report fearful experiences. In psychopathology, the amygdala has also been implicated in the experience of anxiety in humans (for a review see Damsa, Kosel, & Moussally, 2009; for a meta-analytic review, see Etkin & Wager, 2007).

The processing of emotional information not only serves to elicit adaptive responses and modify perception but it also serves as a record of the value of sensory events (Vuilleumier, 2005). Several neuroimaging studies have shown that enhanced responses to emotional stimuli in visual cortex correlate with increased amygdala activity (Morris et al., 1998; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Sabatinelli, Bradley, Fitzsimmons, & Lang, 2005). For example, using fMRI, Sabatinelli et al. (2005) measured the functional activity in the amygdala and visual cortex of fearful and control participants while they viewed a range of emotionally arousing, fear-relevant, and neutral pictures. Activity closely covaried in the amygdala and inferior temporal visual cortex during viewing of emotional pictures which showed systematic increases as the rated arousal of each picture increased. Additionally, Sabatinelli et al. (2005) found that participants who rated high on a fear scale showed parallel, heightened activation, to specific fear cues, in these two structures compared with non-fearful controls. Earlier studies have provided evidence that amygdala responses to emotional stimuli predict neural activity in the extrastriate cortex (Morris et al, 1998) and primary visual cortex (Pessoa et al., 2002) when seeing fearful versus neutral faces. Using fMRI, Vuilleumier, Richardson, Armony, Driver, and Dolan (2004) provide direct evidence for a modulatory role where the enhanced visual activation for fearful faces relative to neutral faces is eliminated by amygdala lesions, despite visual areas remaining functionally and structurally intact. Patients with amygdala damage show no increases activity for fearful faces in the visual cortex, while patients with hippocampal damage, but an intact amygdala, show normal increases in activity to fearful faces (see Vuilleumier, 2005).

In line with this, several studies have shown that when threatening stimuli (mainly fearful faces) are presented outside the focus of attention, responses to these stimuli coincide with changes in amygdala activity. Vuilleumier, Armony, Driver, and Dolan (2001) presented participants with brief visual displays containing two faces and two houses arranged in vertical and horizontal pairs. In order to perform a same/different matching judgment for these two stimuli and while maintaining central fixation, participants were asked to attend to either the vertical or the horizontal pair of stimuli. Regardless of the initial allocation of spatial attention, results showed larger amygdala activation for fearful faces than for neutral faces (see also Vuilleumier et al., 2004). Likewise, Anderson, Christoff, Panitz, De Rosa, and Gabrieli (2003), using semi-transparent pictures of either fearful or neutral faces superimposed on pictures of places, reported variant amygdala activity when participants made a male/female judgment (i.e., attended to the faces), but also when they made an inside/outside judgment (i.e., attended to the places and ignored the faces). Similar results have been reported by Williams, McGlone, Abbott, and Mattingley (2005) with pairs of composite face/place stimuli (the same as used by Anderson et al., 2003, but a more difficult task), that were presented simultaneously on either side of a central fixation point.

1.2.2 Emotional processing and attention

Threat related stimuli have been found to elicit strong attentional biases in behavioural studies using dot probe detection (e.g., Mogg & Bradley, 1999) and attentional blink (e.g., Anderson & Phelps, 2001; Keil & Ihssen, 2004) paradigms. Visual search experiments have provided further evidence for the capture of attention by threat related stimuli. Hansen and Hansen (1988) found that angry faces presented among happy faces were detected faster than happy faces presented among angry. Similar results have also been obtained for line drawn angry faces (Öhman & Mineka, 2001; see also Eastwood et al., 2001), and for fear-related non-face stimuli (snakes and spiders) presented among fear irrelevant stimuli (Öhman, Lundqvist, & Esteves, 2001), suggesting that the emotional valence of a stimulus is processed outside the focus of attention and can guide attention to its location. Of particular importance in the Hansen and Hansen (1998) study was the use of a diagnostic from the visual search literature that is considered to be a good indicator of `pre-attentive' or automatic processing. In a typical visual search task the participant is instructed to detect the presence or absence of a specified target (e.g. a green circle) among irrelevant distractors (e.g. red circles). In this type of paradigm if search times do not increase substantially with increasing numbers of distractors in the display, the search is considered to be automatic as the target is thought to `pop-out' of the array (e.g. Treisman & Gelade, 1980; Treisman & Souther, 1985). Hansen and Hansen (1988) required participants to determine whether one face was different from the rest or whether displays of four and nine faces were all the same. It was noted that a happy face took longer to locate among eight angry faces than among three angry faces, whereas an angry face was detected as rapidly among three happy faces as among eight happy faces. These results indicated that facial displays of threat (angry faces) were detected automatically and that the consequence of this automatic analysis of threat was a shift of attention to a pre-attentively determined location. In contrast, detection of a discrepant happy face required a serial and linear search. According to Öhman and Mineka (2001), fear responses can be explained in terms of activation of a fear type module, which is described as a self-contained system that directs attention and information processing to threat independent of the current attentional focus, and then rapidly links them with appropriate reactions. This module is argued to be activated automatically, without consciousness, where it is not influenced by top-down processes, selectively activated and implemented by a specialized neural network, with the amygdala playing a crucial role (Öhman & Mineka, 2001, 2003).

The visual search paradigm may be one of the most widely used paradigms for studying the deployment of attention in which the participant searches for a target item among a set of distractor items. It simulates the everyday task of searching for a target among non-targets (i.e. distractors). For example, when paying for an item in a shop we might search for a specific coin in a handful of coins, or try to find a pen on a cluttered desk. Similarly, in a typical visual search task, participants are asked to find a target item among a varying number of non-target items on a computer screen, and indicate presence/absence or location of a target via a button press. Two methods may be used. Firstly, in a forced-choice experiment an array of coloured (green or red) letters (T’s & L’s) are presented, then an inter-stimulus interval (ISI), followed by a mask, with the total number of items (set size) being varied on different trials (Wolfe, Cave, & Franzel, 1989). By varying the set size the difficulty in detecting the target is increased or decreased. In the colour choice task, the participant responds either target-present or target-absent and the percentage correct is calculated as a function of the ISI. If a task is performed with high accuracy, even with short ISIs, and if the ISI x percentage correct calculation does not change with set size, all items must have been processed in ‘parallel’ to a degree sufficient to do the task. However, if larger set sizes result in longer ISIs to achieve the same accuracy compared to smaller set sizes, a process with limited capacity (i.e. ‘serial’ processing) was therefore required to complete the search task (Bergen & Julesz, 1983). The second method is a measure of reaction time (RT) as a function of set size. In this case, if the amount of time to respond "yes" or "no" to the presence or absence of the target (e.g. T in a field of L’s) is independent of set size, it suggests all items are being processed in parallel. Alternatively, if RTs increase roughly linearly with an increase in set size, this pattern of results is consistent with a serial self-terminating search in which the participant deploys attention at random from item to item until the target is found or until all items have been checked (Treisman & Gelade, 1980). Although, as pointed out by Townsend (1971, 1976, 1990), RT x set size functions are not definitive diagnostics for parallel versus serial processes by themselves. The original face-in-the-crowd task has been criticized on its methodology. Particularly, it was argued, that a detection advantage may have been caused by threat-irrelevant features for angry faces rather than their emotional content (Purcell, Stewart, & Skov, 1996). It is crucial to control for basic physical features that are emotion irrelevant and that might cause differences in attention allocation in order to conclude a threat detection advantage from a visual search task using targets of different emotional contents (Frischen, Eastwood, & Smilek, 2008). A detection advantage was also found for schematic faces (Eastwood et al., 2005; Fox, Russo, Bowles, Pichler, & Dutton, 2000; Öhman, Lundquist, & Esteves, 2001; Schubö, Gendolla, Meinecke, & Abele, 2006) and carefully controlled photographic faces (Horstmann & Bauland, 2006).

As mentioned, attentional selection has been shown to be the result of the brain’s limitations in its natural capacity to process all the information it is presented with, which has resulted in the extraction of relevant features via selective processing at the expense of non-relevant features (also see Allport, 1989; Johnston & Dark, 1986). Variants of the e*motional stroop* paradigm have been used to investigate the notion that affective events have a special effect on attentional capture (Algom et al., 2004; Mathews & MacLeod, 1985; Pratto & John, 1991). To investigate if threat-related information disrupts selective attention specifically or if it has a more general effect on processing, Algom et al. (2004) presented fearful and neutral words in two Stroop type tasks, one a colour naming task and the other a word reading task. Results show the emotional content of the words appeared to disrupt all ongoing activity rather than activity specific to selective attention, indicating that the emotional Stroop effect was not sustained by the same mechanism which produces the classic Stroop effect. Algom et al. (2004) noted that rather than a selective attentional mechanism, a threat-driven generic slowdown of activity may be implicated. Similarly, in research investigating the effect of emotional stimuli on attention using the *dot probe* paradigm, where the task is to detect a simple lateralized target stimulus (the dot probe), results have shown latencies are shorter when the probe follows a negatively valenced event, compared to a neutral event, suggesting attentional bias toward the location that corresponds to the position where the negative affective prime was presented (e.g., Mogg, Bradley, & Hallowell, 1994; for a review see Fox, 1995). Taken together these findings suggest that emotionally significant events elicit attentional bias toward that event, whereby after initial encoding, the emotional event receives more attentional resources toward its processing compared to neutral valenced events.

One interpretation of the capacity of emotional events to grab attention is that of ‘automaticity’ or attentional independence, during encoding (e.g., Pratto & John, 1991; Williams, Mathews, & MacLeod, 1996; also see Harris & Pashler, 2004, for a related viewpoint). In comparison to neutral, emotionally significant stimuli (particularly those with a negative valence; Pratto & John, 1991), appear to be processed somewhat automatically (e.g., Schneider & Shiffrin, 1977). Whereby in the competition toward selective processing, emotionally significant stimuli appear to be more effective in securing attentional resources, which may or may not, result in behavioural interference. One focus of debate has been the definition of the term ‘*automatic’* (see Moors & De-Houwer, 2006, for an analysis). Many appear to agree that at its core a definition of automaticity should include features such as minimal resource requirements, operation in parallel, speed of processing, subliminal processing (i.e. occurring below the threshold of conscious awareness), being unaffected by intentional control, and being essential (Bargh, 1994). Unfortunately, these features do not always appear to co-occur. The feature of automaticity that appears to be most often the subject of investigation is whether biased attention to emotional stimuli occurs subliminally (i.e. beneath awareness; Pratto & John, 1991; Yiend, 2010). Pratto and John (1991) investigated the interference effects of socially significant stimuli on colour naming in a stroop task. The subsequent interference was interpreted as an indication of an 'automatic vigilance' to the undesirability of the stimuli. The evidence for reduced search time of threat stimuli in visual search tasks is consistent with a reduced reliance on capacity-limited encoding processes (see Öhman, Flykt, & Esteves, 2001; Öhman et al., 2001). From the earliest perceptually driven encoding processes, to the post-encoding maintenance and response selection processes, the emotional significance of stimuli appears to influence information processing at each level (Anderson, 2005). Many studies have suggested that during encoding, emotional stimuli hold a special status in attention (e.g. De Houwer, 2003; Chen & Bargh, 1999; Öhman et al., 2001; Pratto & John, 1991; Wentura, Rothermund, & Bak, 2000). However, the evidence supporting this claim would require that attention is manipulated during the encoding stage of stimuli, a condition that does not appear to be met often (Anderson, 2005). For example, emotional stimuli influencing attention either by increasing suppression or altering facilitation of target processing alone cannot determine if emotional processing itself is altering attentional mechanisms at encoding or at later stages of processing.

Demonstrating that emotional stimuli hold a special status in attention during encoding stages of processing requires the direct manipulation of available attentional resources at the encoding stage.

What is also unclear is how the mechanisms of emotional processing could be related to the hypothesis that emotionally significant stimuli hold a special status in attention. Emotion itself is not necessarily unidimensional where it is as clear cut as emotion versus non-emotion, or high emotion versus low. However, it does appear to be easily separated into the dimensions of valence (i.e. positive, negative, and neutral) where arousal or intensity of experience is often strongly associated (Feldman-Barrett & Russell, 1999; Watson, Clark, & Tellegen, 1988). Some research has suggested there is 'bias' in the processing of valence information; where negative stimuli are attended to differently to non-negative stimuli (e.g., Mogg & Bradley, 2002; Öhman, Flykt, & Esteves, 2001; Pratto & John, 1991; Williams et al., 1996); as well as being processed earlier (Smith, Cacioppo, Larsen, & Chartrand, 2003). For example, in a series of experiments, Öhman et al. (2001) presented fear relevant stimuli (images of snakes and spiders) in a stimulus matrix along with fear non-relevant stimuli (images of flowers and mushrooms) in differing set sizes. Results show that despite increases in the number of distractors, RT to targets were not significantly longer for threat images in larger set sizes compared to smaller, indicating a default type attentional setting which manifests as a general bias for directing attention toward threat laden stimuli. In a dot probe paradigm using masked threat faces, Mogg and Bradley (2002) found similar results in anxious participants compared to non-anxious, where participants responded faster to probes that appeared in the special location of a masked threat cue compared to a neutral cue.

1.2.3 Summary

It seems clear that factors other than the physical salience of objects, or the behavioural intention of the observer, influence attention and attentional deployment. Research has shown that threatening or negative emotional information can impact both bottom-up and top-down attentional control. It is also has been demonstrated that positive information can have a similar effect (c.f. Holmes, Bradley, Nielsen, & Mogg, 2009) suggesting that arousal may play a role in the bias toward emotional information. Both positive and negative images result in changes in activity in the amygdala, via neural projections back to the visual cortex despite having partly distinct brain circuits. These projections support early visual processing and subsequently result in the selection of motivationally relevant information. Despite its function in processing positive information, the amygdala appears to play a particularly crucial role in the processing of threat related or negative information with some studies demonstrating a relationship with enhanced activity to negative information in the visual cortex correlating with activity in the amygdala, even when this information is presented outside the focus of attention.

The pattern of activation in the amygdala to negative stimuli has been reflected in the results of behavioural experiments, where threat related information impedes or interferes with attentional or other types of processing. One of the relevant questions surrounding the effect of negative emotional information on attention is whether this process happens automatically. Some studies have shown a processing bias toward negative information where attention to this information occurs happens during information encoding. Given the evidence outlined in the above section, it appears clear that negative, or threat related, information is prioritised in a different way to other information, even positive emotional information and that this aligns with an evolutionary advantage to perceive and identify a potential threat.

1.3 N2pc: Attentional selection of threat-related information

A large number of studies investigating the deployment of attention to emotion-relevant stimuli (c.f. MacLeod et al., 1986; Bradley, Mogg, Falla, & Hamilton, 1998; Mogg & Bradley, 1999; Wilson & MacLeod, 2003) to date have employed behavioural measures (i.e. reaction time, accuracy, eye-movement etc.). Unfortunately, behavioural data only provide a snapshot of the allocation of attention at any one point in time. A continuous measure of attentional allocation and processing is better suited to provide a more detailed account of the mechanisms and timings of attentional deployment. One such technique comes from the field of electrophysiology using electroencephalography (EEG). Sophisticated monitoring of scalp recorded electrical brain activity, which reflects the intermittent synchronous activation of small populations of cortical neurons, allows for the measurement of cognitive processes associated with mental calculations, working memory and selective attention (Nunez & Srinivasan 2006). The validity of these measurements is increased when such activity is time locked to specific perceptual, motor or cognitive events resulting in an event-related potential (ERP; Handy, 2004). ERPs provide precise information about the time course of information processing and can help reveal the timing and organization of stimulus selection processes in the brain’s attentional network. ERP studies provide support for a mechanism of early sensory facilitation, at the level of extrastriate visual cortex, during the spatial cueing of attention (Carrasco, 2011).

Previous research has demonstrated that the ‘N2pc’ ERP component reflects the spatial attentional selection of cued stimuli that appear in either the left or right visual field. This component is labelled “N2pc” to denote its latency (200-300 ms) from beginning of stimulus presentation and its occurrence at posterior contralateral scalp sites (see Heinze, Luck, Mangun, & Hillyard, 1990; Luck, Fan, & Hillyard, 1993; Luck, Heinze, Mangun, & Hillyard, 1990; Luck & Hillyard, 1994a; 1994b). The N2pc component has been observed when target items are embedded within displays of non-target items, which need to be ignored in order to allow correct discrimination of the target (Luck & Hillyard, 1994a). This has led to the hypothesis that the N2pc component also reflects a cognitive process of suppressing information arising from many non-relevant items.

One study in particular (i.e. Luck & Hillyard, 1994b) has provided several key pieces of evidence in support of this hypothesis. These authors have demonstrated that targets eliciting the N2pc in the presence of distractors subsequently failed to elicit the N2pc under at least three specific conditions: a) when distractors were absent (experiment 3), therefore no suppression was required; b) when distractors provided essential information about the presence or absence of the target, and thus, cued the selection task meaning the distractors were a part of the task itself, and therefore could not be suppressed (experiment 2); and c) when distractors shared task-relevant features with the target, also making them a part of the selection task and therefore not needing to be suppressed (experiment 4). These results indicate that the N2pc does not appear, or is reduced, when suppression of irrelevant information is not required, indicating that at least one mechanism indexed by the N2pc is the suppression of behaviourally irrelevant information or stimuli.

Ambiguity resolution theory (Luck et al., 1997) attempts to explain the apparent relationship between the N2pc and distractor-suppression in visual attention. This theory proposes that during the discrimination of fine details of objects in the visual field, when multiple objects are presented, attention acts to resolve the 'ambiguity' created when these objects are visually proximal and share similar features. According to this theory, attention employs suppressive mechanisms to reduce the influence of information not stemming from attended stimuli. In terms of ambiguity resolution theory, the N2pc is thought to be an index of the action of this suppressive mechanism. Other studies, however, have shown that when targets and distractors are spatially separate, target selection can also result in the direct suppression of distractor stimuli (Ruff & Driver, 2006; Cepeda et al., 1998). However, the proximal distance of the target to the distractor does not appear to be a determining factor in the amount of suppression required when indexed by the N2pc (Mazza, Turatto, & Caramazza, 2009).

Several experiments have shown that the N2pc component is related to the covert orienting of visual attention before the completion of object recognition (Luck & Hilliard, 1994a, 1994b) and more recent experiments have shown that it reflects a spatial filtering process that closely resembles attention-related modulations of activity measured from cortical neurons in monkeys (Luck et al., 1997). Therefore, if visual search involves rapid, serial shifts of attention, the N2pc component should shift rapidly between the left and right hemispheres as attention shifts rapidly between the right and left visual fields. This idea was explored in an experiment by Woodman and Luck (1999) where participants viewed stimulus arrays where the target and distractor were in either the same or different visual fields. Results showed that when target and distractor were in different visual fields an N2pc was initially observed contralateral to the distractor and then later contralateral to the target, indicating that the N2pc may reflect rapid shifts of attention. This indicates that as participants shift attention from one side of the display to another, the N2pc shifts from one hemisphere to the other. In addition, the timing of the N2pc can be used to track how long it takes an individual to find a task relevant object and shift attention to it (Luck, 2012). Additionally, an estimation of the point in time where attention shifts from one location of the display to another can be made by assessing whether the N2pc component emerges at an early (i.e. between 200 and 300 ms) or late (i.e. after 300 ms) temporal stage (Holmes et al., 2009). The N2pc is ideal for clarifying the direction and timings of processes that underlie attentional biases in visual spatial attention.

Additionally, the N2pc has been used to measure attentional bias toward negative emotional faces. Eimer and Kiss (2007) asked participants to detect infrequent luminance changes to the left or right of a fixation point while ignoring stimulus arrays containing a fearful face among neutral faces, or neutral face among fearful faces. Results showed that on trials without a target luminance change, an N2pc was elicited by fearful faces presented next to fixation, irrespective of whether the other faces in the array were mostly fearful faces or not. The finding that the N2pc to fearful faces was reduced when face arrays were presented concurrently with a target luminance change indicates simultaneous target processing can reduce available attentional resources by emotionally relevant events. In similar paradigms Holmes et al. (2009) and Feldmann-Wüstefeld, Schmidt-Daffy, and Schubö (2011) both observed enhanced N2pc activity to angry face distractors compared to happy face distractors, indicating the detection of threat related information compared to neutral. A more detailed review of the influence of emotional information processing on attention, as indexed by the N2pc, is outlined in the introduction section of chapter 2. Chapter 2 also outlines the independent measurement of the constituent components of the N2pc, namely suppression (i.e. Pd) and facilitation (i.e. Nt).

1.3.1 Summary

While behavioural studies have contributed greatly to our understanding of attention and the influence emotional information, particularly threat related information, has on attention they can only provide a coarse image of the timings of attentional deployment. A more accurate and complete measure of attentional processing involves the use of EEG. When stimuli are time locked to the resulting neural electrical activity a microsecond by microsecond analysis of the time course of cognitive processes, specifically attentional processes, are possible. One of the components of interest in attentional research is the N2pc that appears to comprise both the mechanisms of the suppression of irrelevant information and the attentional facilitation of target information. Additionally, the N2pc has been demonstrated to be sensitive to biases in attention toward emotional information, making it a valuable tool in investigating the influence that emotional processing has on attentional processes and resources.

1.4 Load theory of attention

The last four decades of attention research has investigated, and debated, the extent to which perception of irrelevant distractors can be prevented. Despite there being substantial evidence supporting both viewpoints, some theorists hold views that early perceptual processing of irrelevant distractors can be prevented by focussing attention (e.g., Neisser, 1967; Treisman, 1969; Treisman & Riley, 1969; Von Wright, 1970). For example, Von Wright (1970) showed, in a series of experiments, that as the number of distinctive features of a stimuli to be taken into account increases and as the differences between the categories of the stimuli to be distinguished become greater, selection became more difficult. Whereas others contend a later selection view where focussed attention can prevent distractors from controlling behaviour and memory (e.g., Eriksen & Eriksen, 1974).

The debate on early vs. late selection was centred around both negative priming effects and in relation to unattended processing measured indirectly with reaction-time manipulations (Driver, 2001). This longstanding debate between early and late-selection views of attention, as stated above, has been fuelled by mixed results as to whether focusing attention on task-relevant information can exclude irrelevant information from early perceptual processing or if focussing attention on task-relevant information can only prevent distractors from controlling behaviour and memory (Lavie, 2005). A possible solution for this debate has been provided by research investigating the role of load in the processing of task-relevant information (e.g., Lavie, 1995, 2005, 2006). This research has indicated that, under high perceptual load, distractor perception can be prevented during the processing of task-relevant stimuli (early selection), and that the impact of distractors, under low perceptual load, on behaviour depends on other types of load such as working memory (late selection) and has been labelled the *Hybrid selection model* (Lavie, 1995; Lavie et al., 2004; Lavie, 2006).

The hybrid selection model relies on the idea that, until perceptual capacity has been exhausted, perception proceeds automatically and in parallel (Lavie, 2006; Lavie, Hirst, de Fockert, & Viding, 2004; Biggs, Kreager, & Davoli, 2015). It is based on the idea that when an observer is able to process an entire display, or a scenario requiring low perceptual load, the resources they have in surplus resources will “spill over” and be available to process additional irrelevant information (i.e. distractors). In a classic response competition paradigm (e.g., Eriksen & Eriksen, 1974), processing the whole display is possible due to the small display sizes which results in parallel processing of both the relevant targets and the irrelevant distractors. Therefore, considerable distractor processing (or interference as the case may be) is a feature of low perceptual load, and suggests that low load induces late selection (Biggs et al., 2015). According to the model, if the target display is greater than the perceptual capacity of the observer, or a high perceptual load task, the available resources are then unavailable to process information other than that relevant to the relevant target. Additionally surplus resources are also unavailable to process the identity of irrelevant information, and therefore irrelevant distractors are never fully identified. According to Lavie and Cox (1997) the low versus high perceptual load distinction is a strict cut-off where perceptual resources are either available for processing or they are not. This point where selection shifts from late selection to early selection provides a defining line on the locus of selection. The origins of load theory and the relationship of early versus late selection are discussed in greater detail in chapters 4 and 5.

1.4.1 Attention and emotion: relevance of Load theory

Previous research has shown that attention can be altered by the type and difficulty of the task being undertaken. Bishop, Jenkins, & Lawrence (2007) examined the effects of perceptual load on emotion processing. These authors recorded fMRI while high and low anxious participants performed a letter search task with similar (high perceptual load) and non-similar (low perceptual load) letters that were superimposed over images of fearful and neutral face images. Results showed that when under high perceptual load, neither high nor low anxious participants showed an increased amygdala activity to fearful images. However, under low perceptual load, increased anxiety was associated with a heightened response to fearful faces in the amygdala and superior temporal sulcus, whereas participants high in trait anxiety showed a reduced prefrontal response to fearful face images, consistent with diminished recruitment of control mechanisms used to prevent the further processing of salient distractors.

Other studies using neuroimaging have demonstrated that when perceptual demands are high, by the directing of focal attention towards an unrelated task amygdala activity is suppressed in response to unattended fearful faces (Lim, Padmala, & Pessoa, 2008; Pessoa, Kastner, & Ungerleider, 2002; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Pessoa, Padmala, & Morland, 2005). This suggests that when additional attentional resources are unavailable, processing of emotional information unrelated to the task is reduced or extinguished completely. For example, Pessoa et al. (2005) investigated if emotional information being processed from outside of awareness would be reflected in amygdala activity. Participants performed the centralised task *without* the presence of emotional distractor stimuli. Their findings revealed that the focus of attention modulated amygdala responses. Stronger responses were evoked when faces were attended during a gender identification task relative to when faces were unattended in a bar-orientation task. Importantly, in the right amygdala, a valence effect was observed during low attentional demand conditions, but not during medium or high attentional demand conditions (Pessoa et al., 2005). It should also be noted that when participants performed a difficult non-emotional task alone, a decrease in amygdala activity were noted. These effects demonstrate that the modulation of perceptual load comprises a factor in predicting amygdala responses. Taken together these results show that both attentional resources and attentional load govern processing, of unattended emotional information, in the amygdala. The effect of load and the relationship of early versus late selection in the processing of emotional information are discussed in greater detail in chapters 4 and 5.

1.4.2 Summary and conclusions

The above review outlines some of the research investigating the effect of load, particularly perceptual load, on attention, and emotional processing and attention. A solution has been proposed to the on-going debate between those who favour the view that focusing attention can prevent the early perceptual processing of irrelevant information compared to those who have shown that focussing attention instead can prevent irrelevant information from influencing later stages of processing like behaviour and memory. The hybrid selection model predicts that if the target to be attended requires a large amount of attention, then the lack of spare attention results in irrelevant stimuli going unattended. Conversely, when attentional resources are not overwhelmed, any spare attention will be available to process irrelevant information, which will subsequently capture attention. A similar pattern of results has been reported in studies measuring amygdala activity in response to the processing of negative emotional information. In these studies irrelevant negative emotional information produced reduced amygdala activation when perceptual demands on an unrelated task were high compared to low.

The aim of this thesis is to examine further the effect that emotional information, particularly threat related information, has on attentional processing. Moreover, it is my intention to separate the primary mechanisms of attention indexed by the N2pc (namely suppression and facilitation) into separate measurable components to investigate the effect emotional processing has on the deployment of attention. I will forgo here the rationale and justification for each of these experiments as these will be provided in greater detail in the introductory text for each experiment separately.

Chapter 2: Is suppression modulated by the processing of higher level distractor information?

2.1 Experiment 1

It is understood that the capacity of the visual system to process information about multiple objects at any given moment in time is limited (e.g., Cowan, 2000; Irwin, 1992; Pylyshyn, & Storm, 1987). As a typical scene may contain many objects that are all in competition for neural resources, and as awareness has a limited capacity for holding and manipulating multiple object representations at any given time, items in the visual scene must therefore be prioritised. The selective attention system and the emotion system are two neural systems that mediate such prioritization (Goolsby et al., 2009).

The selective attention system facilitates the processing of task-relevant information and the suppression of task-irrelevant information in order to prioritise objects in the visual scene (Goolsby et al., 2009). When there is more information than can be processed at any one time the 'surplus' of information competes for representation. While competition for neural resources is biased towards behaviourally relevant information (Desimone & Duncan, 1995), as noted, the prioritisation of information may be done by attending to, or narrowing attention on, a specific region of the visual-perceptual field enabling selective processing of stimuli appearing in that position only (LaBerge, 1995). The result is an increase in neural activity in brain regions that are representative of the selected stimulus, or features of the particular stimulus being attended, thus excluding other information or other stimuli (Pourtois et al., 2013). This mechanism has been demonstrated repeatedly using imaging techniques (i.e. EEG, PET, fMRI) and shows the involvement of lower-level sensory areas (Posner & Dehaene, 1994; Corbetta & Shulman, 2002) that enhance the attended/relevant stimulus representation and suppress the unattended/irrelevant stimulus information (Pourtois et al., 2013).

Top-down and bottom-up control processes interact to determine the object and/or location in the visual field that will be attended. The stimulus-driven control processes bias selection toward visually salient items and the goal-directed control processes bias selection toward behaviourally relevant objects of interest (Theeuwes, 2010). Salience is computed on the basis of the detection of stimuli whose local visual attributes significantly differ from the surrounding image attributes, along a singular dimension or some combination of dimensions (Itti & Koch, 2001). According to the stimulus driven perspective, attention is deployed in a stimulus-driven manner initially to the most salient item, regardless of its behavioural relevance (Theeuwes, 1991, 1992, 1994, 2010). That attention can be automatically attracted by salient items with a high feature contrast, independent of top-down goals, has been widely accepted (e.g., Beck & Kastner, 2005; Itti & Koch, 2000; Navalpakkam & Itti, 2007; Reynolds & Desimone, 2003; Theeuwes, 2010; Zhang, Zhaoping, Zhou, & Fang, 2012). However, knowledge about features of an object to be ignored (i.e. top-down information) can modulate attention in order that items that are task-relevant are selected and those that are perceptually salient but task-irrelevant are ignored (Becker, Folk, & Remington, 2013).

Additionally, results show that when features of an irrelevant distractor are varied, target-similar distractors can attract attention more strongly than target-dissimilar distractors (e.g., Anderson & Folk, 2010; Ansorge & Heumann, 2003; Eimer, Kiss, Press, & Sauter, 2009; Folk & Remington, 1998; Ludwig &

Gilchrist, 2002). This effect of similarity shows that top-down attentional control settings are critical for the capture of attention by an irrelevant distractor (e.g., Folk et al., 1992). In accounting for top-down attentional capture, several different mechanisms have been proposed. However, most theories assume that top-down mechanisms influence selection by modulating the output of neurons that respond to specific feature values or by activating or inhibiting specific feature maps (Duncan & Humphreys, 1989; Folk & Remington, 1998; Folk et al., 1992; Koch & Ullman, 1985; Maunsell & Treue, 2006; Navalpakkam & Itti, 2007; Treisman & Gelade, 1980; Treisman & Sato, 1990; Wolfe, 1994).

Eimer (1996) observed the N2pc contralateral to a target, indicating attentional prioritisation of the target, when the target and distractors were presented in opposite hemi-fields; and Holmes et al. (2009) have shown similar results with bilaterally presented faces where attention, as measured by the N2pc, was biased to threatening faces compared to neutral as indexed by an increase in the N2pc contralateral to the angry face. However, in both of these studies the change in the N2pc could also be due to suppression of the opposing stimuli, rather than attentional facilitation of the target alone. Previously, single-unit studies in animals have also shown that when attention is deployed to the stimulus location, neural activity associated with that stimulus is enhanced (Treue & Maunsell, 1999; Roelfsema, Lamme, & Spekreijse, 1998; Motter, 1993; Spitzer, Desimone, & Moran, 1988). The types of enhancement identified in these studies have ranged from mechanisms such as the modulation of single-neuron response selectivity of target characteristics (Spitzer et al., 1988; although see McAdams & Maunsell, 1999) to simpler modulations such as increases in baseline rates of neural firing (Treue & Maunsell, 1999; Roelfsema, Lamme, & Spekreijse, 1998; Motter, 1993; Spitzer et al., 1988). The evidence of spatial attention being represented through the action of multiple mechanisms (i.e. attentional facilitation of behaviourally relevant information and suppression of behaviourally irrelevant information) provides a clear indication that the N2pc may represent both the facilitation of attentional selection and the suppression of irrelevant information.

This ‘multiple mechanism’ hypothesis was explored in a series of experiments carried out by Hickey, Di Lollo, and McDonald (2009) where they attempted to separately measure the mechanisms of suppression of behaviourally irrelevant stimuli and attentional facilitation of target specific stimuli by presenting only two stimuli, one on the vertical meridian and the other laterally in one visual field. By arranging the stimuli in this way, when the ERP waveforms are averaged contralateral and ipsilateral to the lateralised stimulus, the activity related to stimuli presented on the vertical meridian should be represented equally in both lateral (contralateral & ipsilateral) sites. However, the activity related to the processing of the laterally presented stimulus should be represented only in the site contralateral to that stimulus. Therefore, by altering the target (either vertical or lateral), in successive experiments, these authors have demonstrated separate ERP components for the suppression of behaviourally irrelevant stimuli (Pd; when the target is the stimulus on the vertical meridian and the lateral stimulus is to-be-ignored) and attentional facilitation of target relevant stimuli (Nt; when the target is the lateral stimulus and the stimulus on the vertical meridian is to-be-ignored).

In sum, the evidence of spatial attention being represented through the action of multiple mechanisms provides a clear indication that the N2pc may represent both the facilitation of attentional selection and the suppression of irrelevant information. According to the stimulus driven perspective attention is deployed in a stimulus driven manner initially to the most salient item, regardless of its behavioural relevance. But knowledge about features of an object to be ignored can lead to a modulation of attention in order to ignore task-irrelevant salient items and select task relevant items. ERP research to date has investigated the influence of low-level stimulus attributes like physical similarities between distractors and targets (Anderson & Folk, 2010; Eimer et al., 2009) and the spatial distance between distractors and targets either behaviourally (Cepeda, Cave, Bichot, & Kim, 1998) or on the time course and magnitude of the N2pc (Geng et al., 2006). However, in the competition for attentional resources, threat-related stimuli yield a stronger representation within the sensory pathways, compared to non-threatening stimuli and subsequently can modulate attentional selection toward the threat (i.e. attentional bias), particularly in high trait-anxious individuals (e.g. Beaver, Mogg, & Bradley, 2005; Fox, Derakshan, & Shoker, 2008; Mogg & Bradley, 2005). If the N2pc is a measure of both the suppression of irrelevant information and the facilitation of attentional selection, does the presence of behaviourally irrelevant threat-related information also modulate suppression of that information? The present experiment will utilise the Hickey et al. (2009) paradigm to investigate the suppression of socially relevant vs. socially non-relevant and threatening vs. non-threatening distractor stimuli. The primary aim of the study (experiment 1) is to investigate if the suppression of behaviourally irrelevant information (as indexed by the Pd) is modulated by intrinsic features of a distractor. This will be investigated in two ways. Firstly, by comparing the suppression of (via modulation of the Pd component) perceived socially relevant and non-socially relevant distractor information (i.e. intact faces vs. scrambled faces [matched for luminance and contrast energy]); and secondly, by comparing the suppression of (again via modulation of the Pd component) threat-related and non-threat-related distractor information (i.e., angry vs. neutral face distractors). Additionally, due to attentional bias toward threat varying with anxiety, supplementary analysis of trait anxiety and suppression measures will be included. In experiment 2, the lateralised stimuli, which appeared as distractors in experiment 1, will instead be targets to control for lateralised ERP effects that may arise simply from the imbalance of sensory information in one visual hemifield relative to the other.

2.1.1 Method

2.1.1.1 Participants

Forty one healthy volunteers from the University of Roehampton received course credit for participation. Two participants were excluded because of excessive eye blinks or eye movements, which resulted in <50% trials remaining. Therefore, 39 participants (5 male, 34 female; 18–28 years old; M: 19.95 years; SD: 2.08) remained in the sample. To allow comparison of sample characteristics across studies, participants' anxiety levels were assessed on the State Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). This inventory was selected as attentional responses to socio-emotional stimuli are particularly susceptible to the influence of anxiety (e.g., Bar-Haim, 2007). Their mean trait anxiety score was 37.7 (SD = 8.5; range = 21-60) and mean state anxiety score was 35.5 (SD = 8.8; range = 24-59), which are comparable with normative data for young adult samples (Spielberger et al., 1983). All participants had normal or corrected-to-normal vision and all were right-handed. The experiment was performed in compliance with The

University of Roehampton ethical and research guidelines and was approved by the University ethics committee.

2.1.1.2 Questionnaire

The *State-Trait Anxiety Inventory (STAI;* Spielberger et al., 1983*)* was used to measure the degree of anxiety. The scale comprises 20 questions relating to state and 20 questions relating to trait anxiety and uses a 4-point Likert scale for responses. The scale has a high internal consistency (Cronbach's alpha .87) and a test-retest reliability with a three-month interval (r = .80). (see Appendix B)

2.1.1.3 Stimuli and Apparatus

All stimuli appeared against a black background (0.19 cd/m^2). Participants were seated in a darkened cubicle and stimuli were presented 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, Eschman, & Zuccolotto, 2002). Following the appearance of a white central fixation cross (6 mm; subtending approximately 0.4^0 of visual angle), the stimulus array for each trial contained 2 stimuli, a green outline of a square (shape-stimulus; RGB = 0, 161, 0) that could be rotated 45% to a diamond form (both 12 mm x 12 mm; subtending approximately 0.9^0 x 0.9^0 of visual angle) and a face stimulus (see Appendix C for examples of each stimuli type used). The green square (1.5 cd/m2) was more luminous than the background. Face stimuli were the same as those used in Holmes et al. (2009). Half of the face stimuli consisted of grey scale photographs of 32 different individuals (8 angry female facial expressions; 8 neutral female facial expressions of the same identities as angry; 8 angry male facial expressions; 8 neutral male facial expressions of the same identities as angry) taken from the NimStim Set of Facial Expressions (Tottenham et al., 2009). The remaining half of the stimuli were the same images, except that each image was divided into a 4 x 5 array and randomly scrambled using VLC media player (c.f. http://www.videolan.org/vlc). Therefore, all configural information relating to the face was removed (see Appendix C). An additional set of neutral face pairs using photographs of sixteen different individuals (8 female) from the NimStim set was used for practice items. Each face stimulus measured 46 mm high x 35 mm wide (subtending approximately 3.3^0 x 2.5^0 of visual angle respectively). The original colour images of the faces were grey scaled and corrected for centre by aligning the bridge of the nose of each face with the diagonal centre of the image. The faces were then equated for mean luminance and root mean square (RMS) contrast energy. The mean luminance energy was calculated for each image and equated across all images, then the total RMS energy of each luminance-equated picture was 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/m2 (Michelson contrast 0.934).

Individual stimuli could be presented in one of six screen locations. These locations were equidistant from a central fixation point (55 mm; subtending 3.9^0 of visual angle) measured from the centre of the image to the centre of fixation. To ensure that the position of the target was not primed at the beginning of the trial, the shape-stimulus was presented on the vertical meridian (i.e., either directly above or directly below fixation) randomly an equal number of times. In the remaining four positions face stimuli were presented at locations 60%, 120%, 240% and 300% off vertical (c.f. Hickey, Di Lollo, & McDonald, 2009). Therefore, face-stimuli were presented in two lateralized positions located above the horizontal meridian and two lateralized positions located below the horizontal meridian.

2.1.1.4 Procedure

At the beginning of each session, after informed consent was given, participants completed the state and trait sections of the STAI (see Appendix B). The experiment itself consisted of 12 blocks of 96 trials for a total of 1152 trials per participant. Before each experiment, a practice block consisting of 32-trials was administered for participant training. Shape stimuli locations were varied randomly such that each shape was presented in each position in one half of the trials. Similarly for face stimuli, but as there were four possible positions each individual stimuli were presented in each position in one quarter of the trials. Each trial presentation consisted of two stimuli; one face stimulus and one shape stimulus (and fixation cross). Both were presented simultaneously either above or below fixation, in random combinations (e.g., intact angry face with diamond shape, scrambled neutral face with square, etc.), so that all combinations were presented an equal number of times across the experiment. While Hickey et al. (2009) presented targets and distractors in both the same and different hemi-fields (upper/lower); they reported no significant interaction between target position (upper/lower) and distractor position (upper/lower) on the magnitude of the Pd. This meant that the target and distractor being in the same or different hemi-fields (upper/lower) did not affect the magnitude of the Pd, and did not alter suppression of the ignored distractor. Hence, for simplicity, the present experiment presented targets and distractors together in the same hemi-field only.

To minimise the influence of any systematic ERPs that might relate to the prediction of trial onset and to ensure attention was located on fixation at the onset of each trial, fixation was randomly presented for either 1000, 1100, 1200, 1300, 1400, 1500, 1600, or 1700 ms (see figure 2.1 for stimuli presentation sequence). The array remained on the screen until either a participant’s response was detected or 1000 ms passed, following either of which a new trial began after an inter-trial interval of 500 ms. The stimulus arrays and timings of the practice blocks were identical to the trials in the experimental conditions except only neutral faces and their scrambled versions were presented as lateral stimuli. Participants were required to achieve 80% accuracy before they could proceed to the experimental conditions. If participants failed to achieve 80%, the practice block was repeated until 80% was achieved.

While maintaining focus on the central fixation point, participants indicated the form of the shape stimulus (square or diamond) with the right hand via a response box. Half the participants pressed the left button with their index finger when the target was presented as a diamond and the right button with their middle finger when it was presented as a square, with the remaining half of participants using the opposite response map. Participants were instructed to respond as quickly and as accurately as possible with equal importance on both accuracy and speed. For the experimental section, if the participants’ accuracy dropped below 80%, a message at the end of the block reminded them of the instructions (i.e., REMEMBER! Respond with a RIGHT button press when the square appears and a LEFT button press when the diamond appears). If the participants’ accuracy reached above 80%, participants were presented with the message “Well done!”.

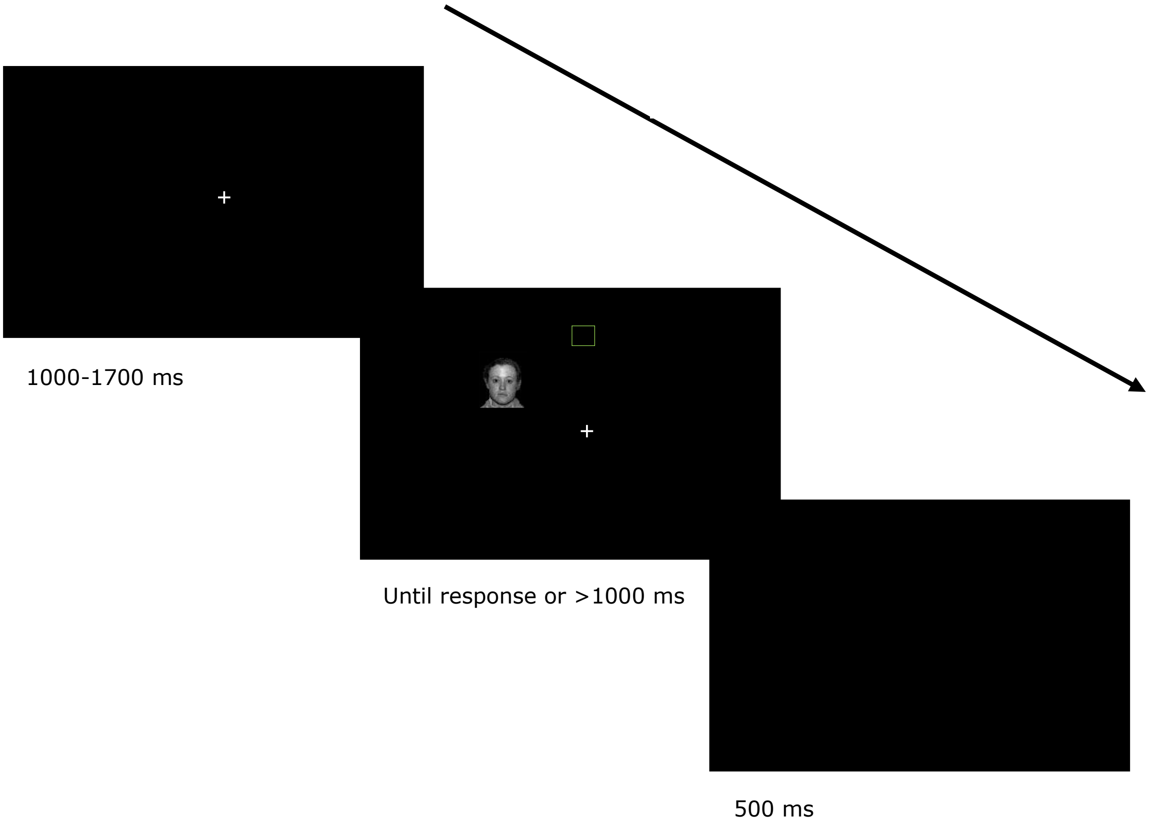


Figure 2.1: Presentation sequence containing fixation screen, sample trial and inter-trial interval.

2.1.1.5 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 d.c. to 100 Hz with vertex (CZ) serving as the online reference. Following EEG recording, 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 ms to 500 ms after stimulus array onset. A baseline adjustment was performed on the pre-stimulus interval and trials with lateral eye movements (HEOG ± 30 μV) as well as trials with vertical eye movements, eye-blinks (VEOG ± 80 μV), or other artefacts (a voltage ± 80 μV at any electrode) measured in the entire epoch were excluded from analysis. Epoched data were then re-referenced to the average of A1 and A2 (ear lobe) electrodes.

For analyses, trials were collapsed across shape types (square or diamond) and presentation locations (upper, lower; left, right), to eliminate extraneous sensory effects unrelated to the aims of the study (c.f. Sawaki & Luck, 2010). Therefore, separate means were computed for all combinations of distractor type (intact face vs. scrambled face), distractor valence (angry face vs. neutral face), and laterality (electrodes contralateral vs. ipsilateral to location of distractor). Visual inspection of the waveforms resulted in the identification of five main contralateral (to the distractor) ERP components in the lateral posterior area. These were assessed for the current study with reference to the distractor location; namely, a positivity beginning around 56 ms (as the specific process it represents is uncertain, and for ease of identification, it will be described as the early positivity; Pe); an early contralateral negativity beginning at around 120 ms (while it resembles an early N2pc, this is yet to be confirmed, therefore at present, and for ease of identification, it will be described as the early negativity: Ne); a distractor positivity (Pd; cf., Hickey et al., 2009) beginning around 180 ms; a contralateral negativity beginning at around 250 ms (as this appears as a later negativity contralateral to distractor presentation it will be labelled as Nl); and a positivity beginning around 310 ms (as the specific process it represents is uncertain, and for ease of identification, it will be described as a late positivity: Pl). Previous research has primarily focussed analysis of the N2pc (c.f. Eimer & Kiss, 2008; Holmes et al., 2009; Mazza et al., 2009) and Pd (c.f. Hickey et al., 2009) components at PO7/PO8 electrode sites. To reduce the risk of capitalising on chance with a single electrode analysis, electrodes for the present study were selected on the basis of previous N2pc and Pd studies and also of where the components presented as maximal. Therefore, components were individually measured and automatically extracted at their respective time windows from the mean of the five left posterior parieto-temporal electrodes; P3, P7, PO3, PO7 and O1 and five right posterior parieto-temporal electrodes; P4, P8, PO4, PO8 and O2 (see figure 2.2 for electrode cluster positioning). Figure 2.5 shows intact and scrambled face distractor laterality difference activity for each time interval.

The Pe was defined as the mean amplitude between 56-106 ms post-stimulus presentation, overlapping the P1 time window (c.f. Luck & Hillyard, 1994a; Batty & Taylor, 2003). The Ne was defined as the mean amplitude between 120-180 ms post-stimulus presentation, overlapping the N170 time window (c.f. Eimer, 1998; Williams et al., 2006). The Pd was defined as the mean amplitude between 180-250 ms post-stimulus presentation (c.f. Hickey et al., 2009). The Nl was defined as the mean amplitude between 250-300 ms post-stimulus presentation. And finally, the Pl was defined as the mean amplitude between 310-370 ms post-stimulus presentation, overlapping with the P300 time window (Polich, 2007). As can be seen in figure 2.7, a clear divergence of the contralateral and ipsilateral waveforms is in evidence in the latencies between 56-106; 120-180; 180-250; 250-300; and 310-370 ms post-stimulus indicating the presence of activity that is contralateral to the visual field in which the distractor appeared. Residual lateral eye movement were calculated as the difference for distractor-left minus distractor-right presented trials of HEOG to allow direct comparison with each component of analysis for the same trials, in the same time interval. Any values for any participant greater than ± 4 μV resulted in additional analyses within each component of interest.

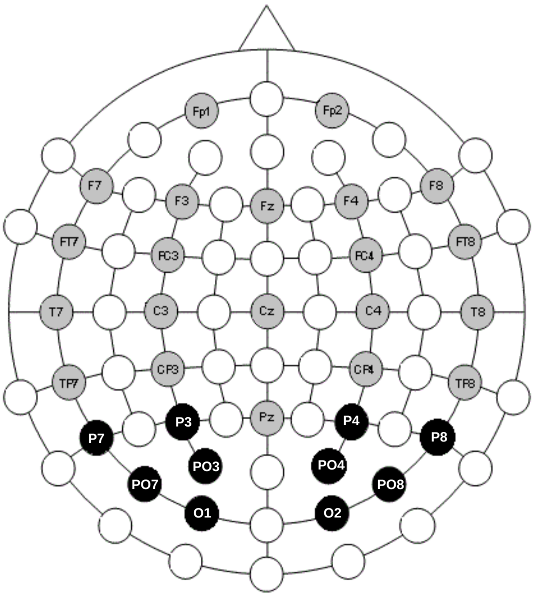


Figure 2.2: Taken and adapted from EASYCAP GmbH: www.easycap.de. Cluster of 5 electrodes for posterior left and posterior right used for statistical analysis.

2.1.2 Results

Figure 2.3 and 2.4 show intact and scrambled face grand average ERPs for electrodes contralateral and ipsilateral to ignored distractor across all conditions and across valence respectively. Non-responses and trials with errors were discarded, as were any with reaction times (RT) less than 200 ms (6.8% of all responses). When using ANOVAs to determine statistical effects, partial eta-squared (η^2_p) are reported as an estimate of effect size for every significant effect found.

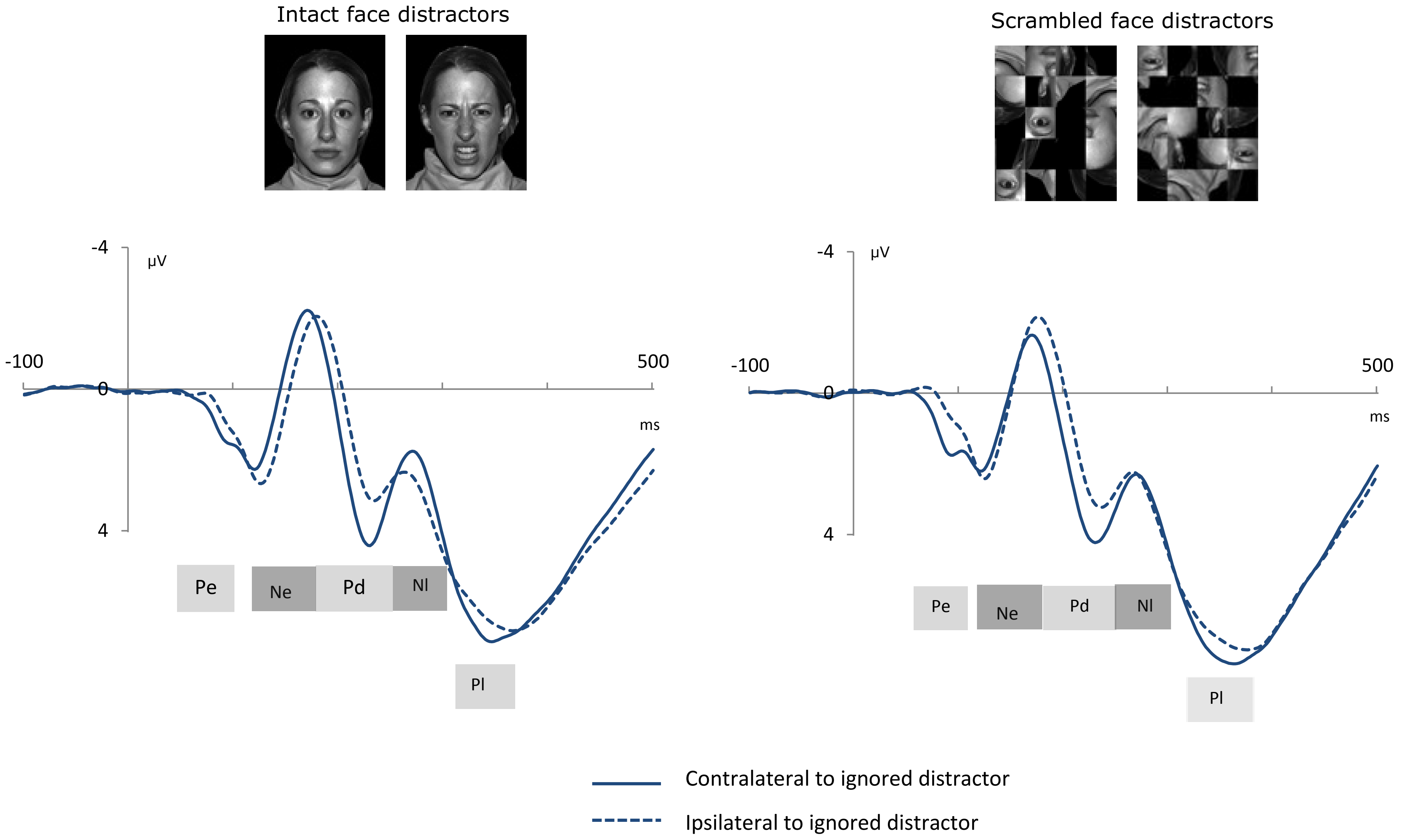


Figure 2.3. Intact and scrambled face grand average ERPs for electrodes contralateral and ipsilateral to ignored distractor across all conditions. The 56-106 ms (Pe); 120-180 ms (Ne); 180-250 ms (Pd); 250-300 ms (Nl); and 310-370 ms (Pl) time intervals are depicted.

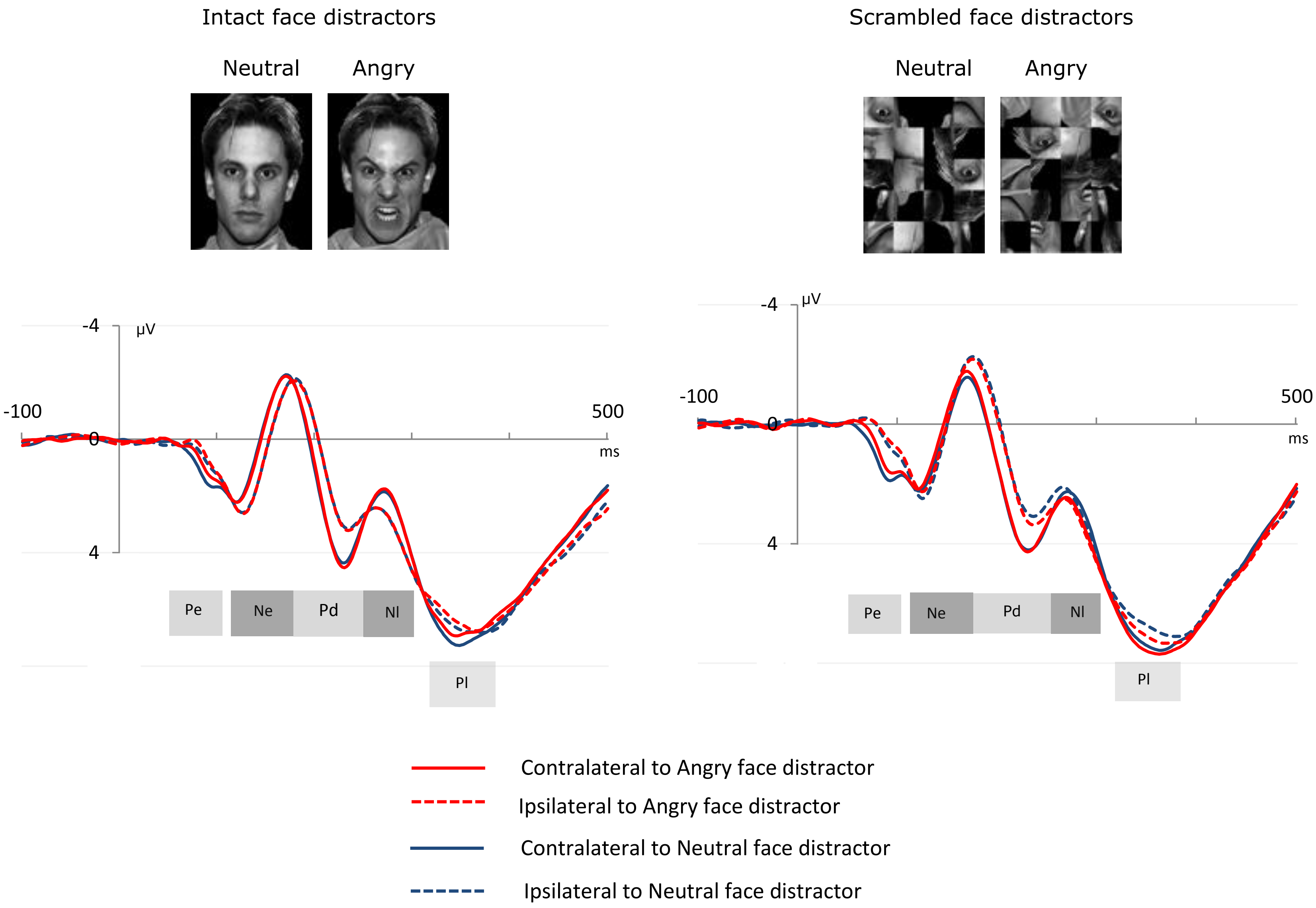


Figure 2.4. Intact and scrambled face grand average ERPs for electrodes contralateral and ipsilateral to ignored angry or neutral distractor. The 56-106 ms (Pe); 120-180 ms (Ne); 180-250 ms (Pd); 250-300 ms (Nl); and 310-370 ms (Pl) time intervals are depicted.

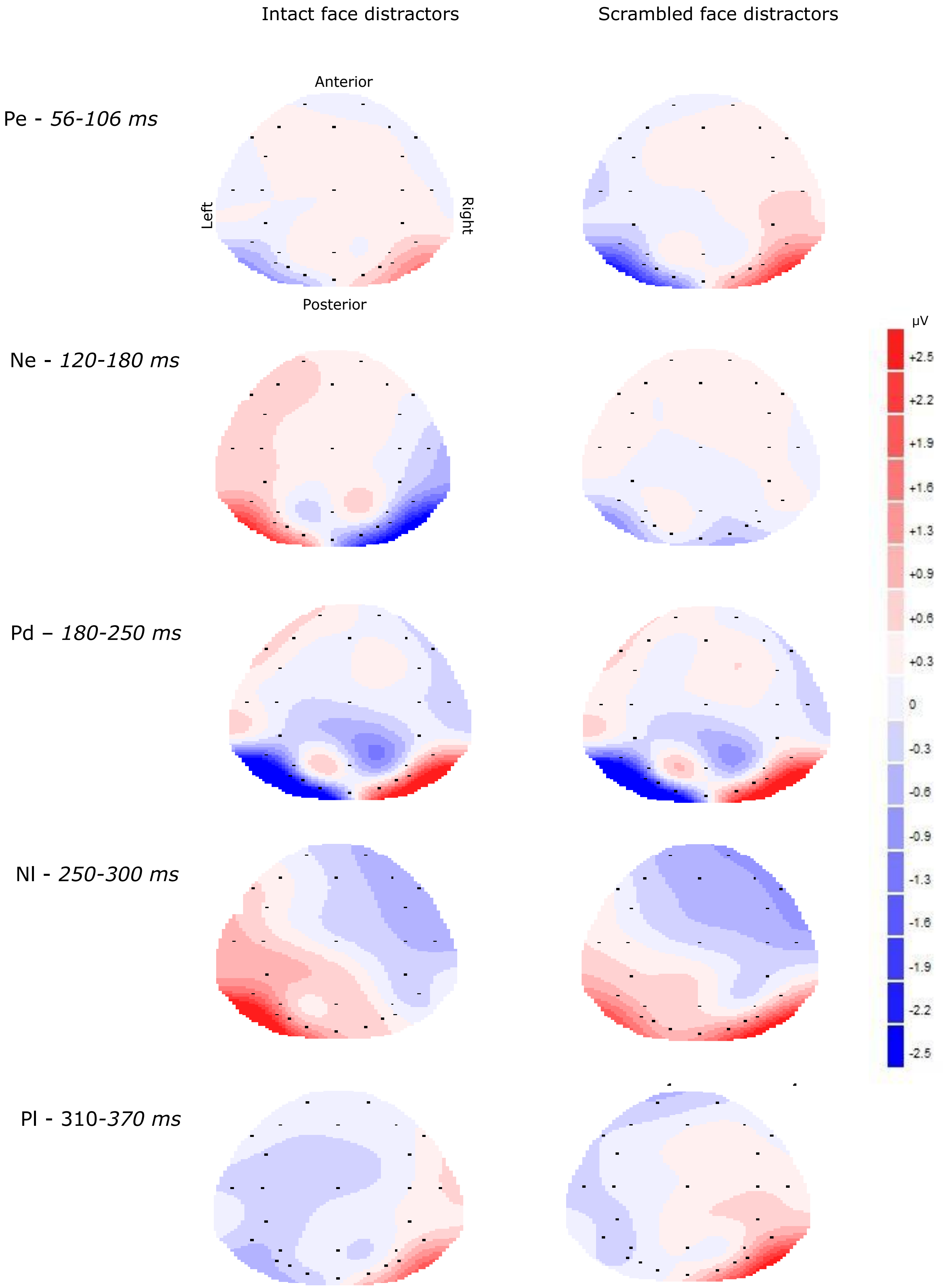


Figure 2.5. Intact face (left) and scrambled face (right) face distractor laterality difference activity (activity of electrodes contralateral to ignored distractor minus activity ipsilateral to ignored distractor) for each time interval.

2.1.2.1 Behavioural measures

2.1.2.1.1 Reaction Time (RT)

Mean correct reaction times (RTs) are shown in table 2.1. Mean RTs for each condition were entered into a 2 x 2 repeated measures analysis 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 (all *F*s < 1.5).

Table 2.1. *Means (and standard deviations), for correct reaction times to targets (ms) for each condition of experiment 1*

	Intact face distractor	Scrambled face distractor
Neutral	534 (47.6)	536 (48.3)
Angry	534 (48.8)	539 (48.0)

2.1.2.1.2 Accuracy

Table 2.2 shows the mean correct responses to targets for each condition. Planned comparisons of total correct responses for each condition were entered into a 2 x 2 repeated measures analysis 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 (all *F*s < 2.1).

Table 2.2. *Mean (SD) number of correct responses to targets for each condition. Scores are total out of 72.*

	Intact face distractor	Scrambled face distractor
Neutral	67.3 (4.15)	66.51 (5.0)
Angry	67.6 (4.35)	68.3 (5.0)

2.1.2.2 ERP measures

To ensure lateral eye-movement does not contaminate the ERPs being measured, residual lateral eye-movement was calculated as the difference for distractor-left minus distractor-right presented trials of the HEOG channel. This will allow for direct comparison with each component of analysis for the same trials, in the same time interval. Any values for any participant greater than ± 4 μV resulted in re-analysis, minus those participants, within each component of interest. Figure 2.8 shows intact and scrambled face distractor grand averaged ERPs for electrodes contralateral and ipsilateral to distractor presentation and figure 2.9 shows angry vs. neutral face distractor grand average ERPs for both intact and scrambled face images, for electrodes contralateral and ipsilateral to distractor presentation. Figure 2.6 shows the grand average waveforms of HEOG for left and right presentations.

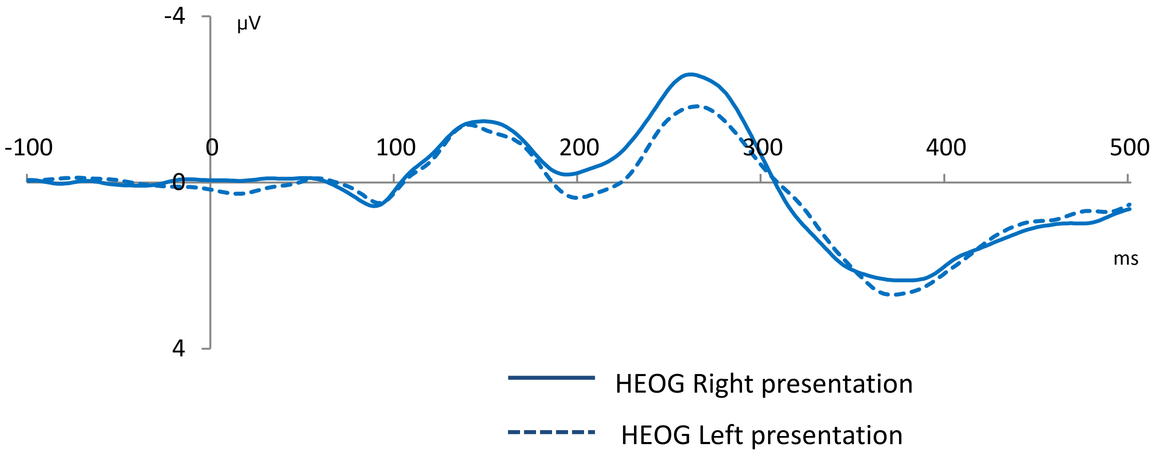


Figure 2.6 Grand average lateral eye-movement (HEOG) for right (solid line) and left (dashed line) stimulus presentation across all conditions.

2.1.2.2.1 Pe: 56-106 ms

Residual lateral eye-movement for the 56-106 ms time interval ranged between -2.13 and 2.61 µV. Mean amplitude values for the Pe were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of distractor type (intact face, scrambled face), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality $F(1,38) = 47.41$, $p < .001$ ($\eta^2_p = .56$), where mean amplitudes where more positive for contralateral electrodes (0.97 µV) compared to ipsilateral (0.46 µV); and a significant main effect of valence $F(1,38) = 4.51$, $p < .05$ ($\eta^2_p = .11$), where mean amplitudes where more positive for neutral face distractors (0.80 µV) compared to angry (0.60 µV). Also revealed was a significant type x laterality interaction, $F(1,38) = 31.92$, $p < .001$ ($\eta^2_p = .46$), as the laterality effect was greater for scrambled as compared with intact faces; and a trend toward a valence x laterality interaction, ($F = 4.02$; $p = .052$), as the laterality effect was greater for neutral than for angry faces.

Paired comparisons *t*-test on the type x laterality interaction reveal a significant effect of laterality (contralateral vs. ipsilateral) for intact face distractors, $t(38) = 4.04$, $p < .001$ (2-tailed), where electrodes contralateral (0.90 μV) to the ignored distractor were more positive compared to electrodes ipsilateral (0.57 μV); and, a significant effect of laterality for scrambled face distractors, $t(38) = 8.81$, $p < .001$ (2-tailed), where electrodes contralateral to the ignored distractor (1.01 μV) were more positive compared to electrodes ipsilateral (0.32 μV). There were no other significant main effects or interactions (all *F*s < 1). The significance of the type x laterality interaction and the observation that the laterality effect appears in a position where it overlaps with the P1 ERP component could possibly be explained by an imbalance in sensory energy between the intact and scrambled faces. Although, this is unlikely given that the distractor images were equated for low-level surface characteristics. The result that contralateral means were greater for scrambled face distractors compared to that of their intact counterparts (see figure 2.7) is evidence that the Pe fits into the description of 'pre-attentive processing' outlined in the salient-signal suppression hypothesis (c.f. Jannati, Gasper, & McDonald, 2013) and is likely related to the processing of basic features of the stimuli array and possibly also the subsequent generation of a salience map (Jannati et al., 2013).

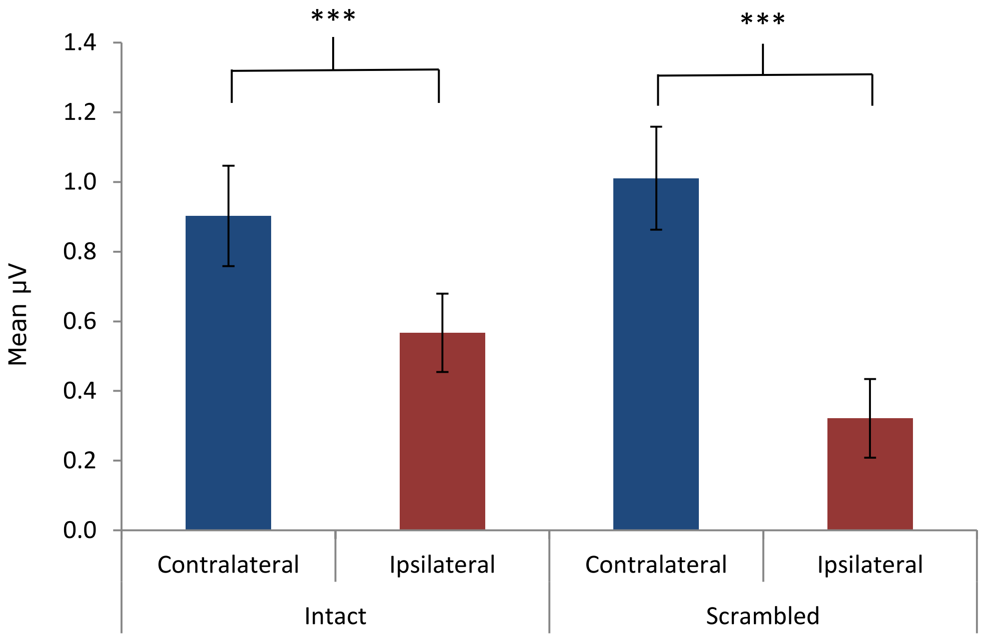


Figure 2.7. Mean amplitudes (µV) of the 56-106 ms (Pe) interval for contralateral vs. ipsilateral of intact and scrambled face distractors (error bars represent 95% CI), *** p<.001.

2.1.2.2.2 Ne: 120-180 ms

Residual lateral eye-movement for the 120-180 ms time interval ranged between -2.48 and 3.69 µV. Mean amplitude values for the early negativity (Ne) were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of distractor type (intact face, scrambled face), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality, *F*(1,38) = 10.52, *p* < .01 (η^2_p = .22), where mean amplitudes were more negative for electrodes contralateral to the ignored distractor (-0.23 µV) compared to electrodes ipsilateral (0.15 µV). Also revealed was a significant type x laterality interaction, *F*(1,38) = 47.29, *p* < .001 (η^2_p = .55), as the laterality effect was greater for intact than for scrambled faces (see figure 2.8).

Paired comparison *t*-tests on the type x laterality interaction showed a significant effect of laterality (contralateral vs. ipsilateral) for intact face distractors, *t*(38) = 5.37, *p* < .001 (2-tailed), where electrodes contralateral to the ignored distractor (-0.43 µV) were more negative compared to ipsilateral (-0.34 µV); but similar results were not evident for scrambled face distractors (*t* < 1). There were no other significant main effects or interactions (all *F*s < 1). The finding that intact face distractors resulted in a significant laterality effect, but scrambled did not, could potentially be explained by the sensory differences between intact and scrambled face distractors themselves, although it has been suggested by Hickey et al. (2009; p764) that differences in this time range could also reflect attentional processes. In this case the presence of face information could be altering attentional deployment resulting in activity overlapping with the face processing N170.

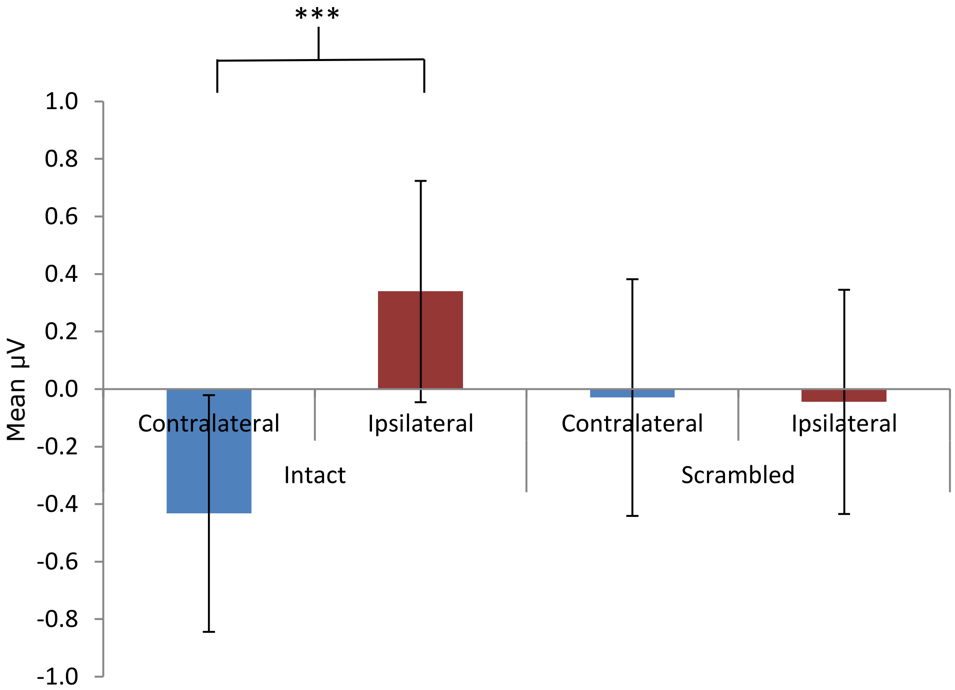


Figure 2.8. Mean amplitudes (µV) of the 120-180 ms (Ne) interval for contralateral vs. ipsilateral of intact and scrambled face distractors (error bars represent 95% CI), *** p<.001.

It should be noted, however, that the waveforms indicate the presence of a latency shift in the Ne component (i.e., earlier for contralateral vs. ipsilateral for intact faces; see figure 2.8), which may account for the significant laterality effect (see figure 2.4). This type of latency shift is not typically characteristic of shifts of attention as indexed by contralateral components such as the N2pc (c.f. Kiss & Eimer, 2008) or Nt (c.f. Hickey et al., 2009). It could be explained by the fact that the structural encoding of faces (as indexed by the N170; c.f. Eimer & Holmes, 2007) is carried out more rapidly by the hemisphere contralateral to the visual field in which the intact face stimulus is displayed.

To investigate this potential latency shift, peak latency values for the N170 time window (100-200 ms) were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of distractor type (intact face, scrambled face), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). Results show a significant main effect of type, $F(1,38) = 4.79$, $p < .05$ ($\eta^2_p = .11$), where the peak of intact face distractors (163 ms) were delayed compared to that of scrambled face distractors (160 ms). Also revealed was a significant main effect of laterality, $F(1,38) = 12.45$, $p < .01$ ($\eta^2_p = .25$), where electrodes contralateral to ignored distractor (159 ms) showed an earlier peak than electrodes ipsilateral (164 ms). There were no other significant main effects or interactions (all *F*s < 1.6). As the laterality x type interaction was non-significant ($F = 0.89$, $p = .35$), the previous laterality x type interaction for mean amplitudes would seem most likely to be explicable in terms of the rapid preferential allocation of attention towards intact as compared with scrambled faces, as opposed to a contralateral effect for the structural encoding of faces. However, it should be noted that a rapid deployment of attention to the intact face does not entirely fit with the conclusion arising from the behavioural data that intact and scrambled face distractors show no significant difference in reaction time.

To investigate the potential effect of anxiety on attentional capture, correlations of the difference waveforms (contralateral minus ipsilateral) were conducted on both STAI state and trait scores. There were non-significant correlations between trait anxiety scores and .14 (p = n.s) intact neutral faces distractors; .12 (p = n.s) intact angry face distractors; -.02 (p = n.s) scrambled neutral face distractors; and -.02 (p = n.s) scrambled angry face distractors. Similarly there were non-significant correlations between state anxiety scores .09 (p = n.s) intact neutral faces distractors; .18 (p = n.s) intact angry face distractors; .02 (p = n.s) scrambled neutral face distractors; and -.07 (p = n.s) scrambled angry face distractors.

2.1.2.2.3 Pd: 180-250 ms

Residual lateral eye-movement for the 180-250 ms time interval ranged between -3.47 and 3.06 μV. To investigate the Pd (c.f. Hickey et al., 2009) as an index of the suppression of attention to an ignored distractor and whether it is modulated by the type and/or valence of the distractor, mean amplitude values of the 180-250 ms time interval were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of distractor type (intact face, scrambled face), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality, $F(1,38) = 67.90$, $p < .001$ ($\eta^2_p = .64$), where mean amplitudes where more positive for contralateral electrodes sites (2.39 μV) than ipsilateral (1.18 μV; see figure 2.9), potentially indicating neural activity involved in the suppression of distractor stimuli (c.f. Hickey et al., 2009). Also, a trend toward a valence x laterality interaction (*F* = 3.58; *p* = .066) was revealed as the laterality effect appeared to be greater for neutral than for angry faces. Mean amplitudes of the Pd for contralateral vs. ipsilateral and for neutral vs. angry faces are displayed in figure 2.4. There were no other significant main effects or interactions (all *F*s < 2). Notably, the Pd was not affected by distractor type (i.e., whether faces were intact or scrambled), *F* = 1.34, p = .25, suggesting that the social relevance of stimuli did not modulate the mechanism of distractor suppression.

To investigate the potential effect of anxiety on suppression correlations of the difference waveforms (contralateral minus ipsilateral) were conducted on both STAI state and trait scores for the 180 – 250 ms time interval. There were non-significant correlations between trait anxiety scores and .03 (*p* = n.s) intact neutral faces distractors; .002 (*p* = n.s) intact angry face distractors; .02 (*p* = n.s) scrambled neutral face distractors; and .01 (*p* = n.s) scrambled angry face distractors. Similarly there were non-significant correlations between state anxiety scores -.03 (*p* = n.s) intact neutral faces distractors; .06 (*p* = n.s) intact angry face distractors; .06 (*p* = n.s) scrambled neutral face distractors; and -.03 (*p* = n.s) scrambled angry face distractors.

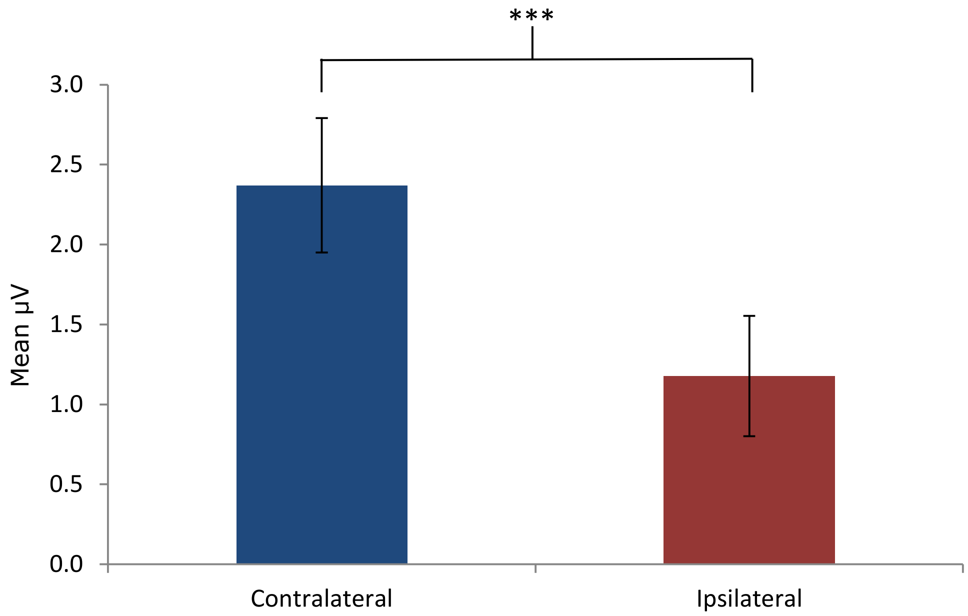


Figure 2.9. Mean amplitudes (µV) for the 180-250 ms (Pd) time interval for contralateral vs. ipsilateral of intact and scrambled face distractors (error bars represent 95% CI), *** p<.001.

2.1.2.2.4 Nl: 250-300 ms

Residual lateral eye-movement for the 250-300 ms time interval ranged between -3.40 and 3.49 µV. Mean amplitude values for the Nl were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of distractor type (intact face, scrambled face), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant type x laterality interaction, $F(1,38) = 20.40$, $p < .001$ ($\eta^2_p = .34$), as the laterality effect was greater for intact than for scrambled faces (figure 2.10), and a trend toward a main effect of laterality ($F = 3.66$; $p = .063$), where electrodes contralateral to the ignored distractor were more negative.

Paired comparison *t*-tests on the type x laterality interaction showed a significant effect of laterality (contralateral vs. ipsilateral) for intact face distractors, $t(38) = 3.35$, $p < .01$ (2-tailed), where electrodes contralateral to the ignored distractor (2.54 µV) were more negative compared to ipsilateral (3.11 µV); but similar results were not evident for scrambled face distractors (*t* < 1). This indicates that the Nl may reflect attentional selection of the ignored distractor after the stage of stimulus selection and/or response preparation and the subsequent termination of suppression, with intact faces capturing more attention compared to scrambled faces. These results are very similar to those of the early negativity (Ne). Therefore, if the Nl does reflect attentional selection of the lateral distractor after target selection, it is possible the Ne reflects unintended attentional capture of the distractor. There were no other significant main effects or interactions (all *F*s < 1.8).

As the Nl could possibly represent attentional selection of the lateral distractor and to investigate the potential effect of anxiety on attentional selection correlations of the difference waveforms (contralateral minus ipsilateral) were conducted on both STAI state and trait scores. There were non-significant correlations between trait anxiety scores and -.01 (*p* = n.s) intact neutral faces distractors; .09 (*p* = n.s) intact angry face distractors; .22 (*p* = n.s) scrambled neutral face distractors; and .23 (*p* = n.s) scrambled angry face distractors. Similarly there were non-significant correlations between state anxiety scores .14 (*p* = n.s) intact neutral faces distractors; .26 (*p* = n.s) intact angry face distractors; .10 (*p* = n.s) scrambled neutral face distractors; and .11 (*p* = n.s) scrambled angry face distractors.

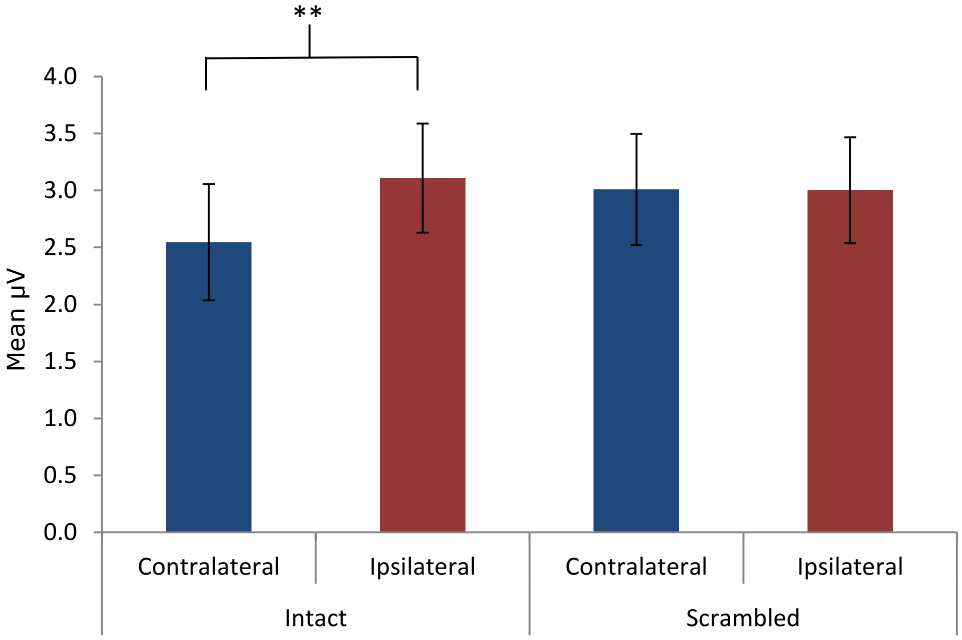


Figure 2.10. Mean amplitudes (µV) for the 250-300 ms (Nl) time interval for contralateral vs. ipsilateral of intact and scrambled face distractors (error bars represent 95% CI), ** p < .01.

2.1.2.2.5 Pl: 310-370 ms

Residual lateral eye-movement for the 310-370 ms time interval ranged between -2.78 and 3.69 µV. Figure 2.11 shows the means for laterality of the Pl. Mean amplitude values for the Pl were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of distractor type (intact face, scrambled face), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality *F*(1,38) = 15.80, *p*<.001 (η^2_p = .29), where mean amplitudes where more positive for contralateral electrodes (6.86 µV) compared to ipsilateral (6.46 µV); and a main effect of type (intact face, scrambled face) almost reaching significance *F*(1,38) = 3.78, *p* = .059 (η^2_p = .09) in the direction of an increased positivity for scrambled faces distractors. There were no other significant main effects or interactions (all *F*s < 2.1).

The presenece of a late positivity contralateral to the distractor indicate it may reflect processes related to late directing attentional positivity (LDAP). The LDAP is thought to reflect the control of attention in visually mediated external space (Van Velzen, Forster, Eardley, & Eimer, 2006) and has previously been shown to be an index of attentional orientation to a lateralised stimulus (Kiss, Van Velzen, & Eimer, 2008). Alternatively, a main effect (almost reaching statistical significance) of distractor type and the significant delay in reaction time indicates the Pl may reflect similar processes to the P300 ERP component and may subsequently represent decision making and memory processes (Polich, 2007) as is suggested by its appearance in this time range and as it’s localised in parieto-occipital areas. As this component does not appear to reflect attentional processes anxiety correlations are not reported here.

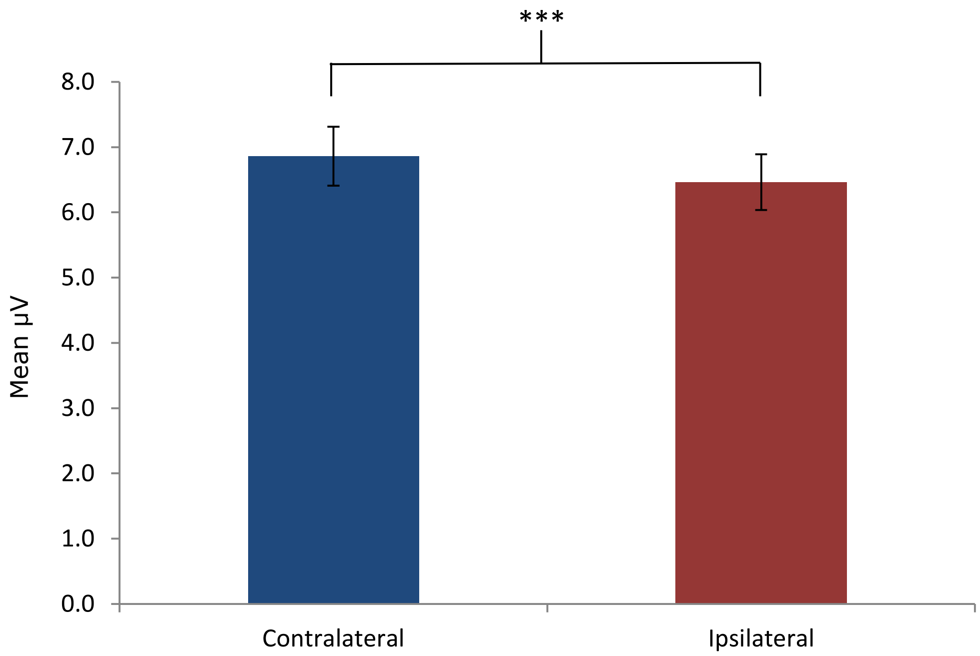


Figure 2.11. Mean amplitudes (μV) for the 310-370 ms (Pl) time interval for contralateral vs. ipsilateral of intact and scrambled face distractors (error bars represent 95% CI), *** p < .001.

2.1.3 Discussion

2.1.3.1 Distractor Positivity (Pd)

The primary aim of experiment 1 was to investigate if the Pd, as an index of the suppression of behaviourally irrelevant information, is modulated by the processing of distractor stimuli that vary in terms of intrinsic features, including social relevance (i.e. intact faces vs. scrambled faces) and emotional valence (i.e. angry vs. neutral face distractors). In addressing the primary aim of the experiment it was important to firstly determine if the results of Hickey et al. (2009) would be replicable; thus, does the Pd demonstrate as an index of the suppression of irrelevant information? The principal finding of experiment 1 is illustrated in Figure 2.8 and 2.9. Consistent with the results of Hickey et al. (2009), the ERP waveforms over the posterior scalp within the 180-250 ms time window were more positive contralateral to the ignored distractor compared to ipsilateral, indicative of activity related to the lateral ignored stimulus and not the midline target stimulus.

In addressing the primary aim, results indicate that whether the distractor was an intact face image (that contains social and identity information) or a scrambled face image (where this information has been removed, whilst equating for surface physical characteristics) did not significantly modulate the extent of distractor suppression, as measured by the Pd. It is noteworthy that both RT and accuracy results also show no effect of distractor interference. This indicates that the amount of suppression required is not being influenced by intrinsic features when that information is socially relevant compared to non-socially relevant. However, it is very likely that ERPs are considerably more sensitive to changes in either stimuli or task demands than are behavioural measurements. Additionally, the present experiment also investigated if suppression, as measured by the Pd, is modulated by threat-related (i.e. angry vs. neutral faces) distractor information. The results do indicate a trend toward neutral face content eliciting a greater Pd than threat-related face content, despite there being no difference in the RT or accuracy scores. This may be an indication that emotional content is modulating, on some level, the mechanism of suppression as measured by the Pd. However, closer inspection of the waveforms (figure 2.9) indicate, on the measure of threat, a greater numerical difference between contralateral and ipsilateral waveforms as a function of face emotion for scrambled face distractors compared to intact, which show almost no divergence (although this was not reflected statistically by means of a 3-way interaction). If the threat (compared to non-threat) of the distractor were altering the mechanism of suppression, then it would seem logical that this would be evident for intact face distractors rather than scrambled as all facial, and consequently threat-related, information had been removed from the scrambled face distractors. The present findings contrast with previous research that has demonstrated the modulation of suppression by low level characteristics. Subsequently, as this effect was not statistically significant, it would appear likely that these effects are anomalous, although, subsequent experiments should clarify this more definitively.

Interestingly, previous research has provided tantalising indications that suppression can be influenced by the demands on the task. Results of a study by Jannati et al. (2013) indicate that observers were able to actively suppress a salient distractor on fast-response trials, but not slow, and that the distractor-interference effect was smaller on fast-response trials as measured by the Pd, indicating that distractor suppression may increase the efficiency of fixed-feature search. This could also perhaps indicate that when the task is easy and not taxing of attentional (or other cognitive) demands (c.f. Hickey et al., 2009: Exp 2), suppression is less required and therefore only partially initiated or not at all. It should be noted that, while the Hickey et al. (2009) results indicate an absence of suppression under very low task demands, it is possible that suppressive effort was present but simply reduced to a level undetectable to the manipulation or subsequent analysis. Correlations of the difference waves show no effect of either state or trait anxiety on suppression as indexed by the Pd.

2.1.3.2 Early Negativity (Ne) & Late Negativity (Nl)

Two negative components were observed in the waveform. These were temporarily labelled the early negativity (Ne; 120-180 ms post-stimulus) and the late negativity (Nl; 250-300 ms post-stimulus) and were both larger contralaterally than ipsilaterally to the distractor. Additionally, both appear more negative contralateral to the intact face distractors whereas a similar effect was not evident for scrambled face distractors, indicating that both components may represent a similar process.

The increase in activity contralateral to the ignored distractor, shown in both the Ne and Nl components, to the distractor when it is displayed as an intact face, and not when it is displayed as a scrambled face, indicate that these components represent attention capture by socially relevant information before target processing and response. According to the salience-driven selection hypothesis, the location of the most salient item in the display may be detected pre-attentively, after which attention is deployed automatically to that location (Theeuwes, 2010). The presence of a salient distractor, by this account, could delay search for a less-salient target because attention is deployed initially to the distractor location and then to the target location, but only after the distractor has been identified and dismissed (Theeuwes, 2010). While, in the present experiment the distractor is singular and in one visual field, the 'N2pc-like' attentional preference appears to be for socially relevant over non-socially relevant information. The singular distractor is also the likely reason for the early temporal position of the Ne; the salience of a single face distractor is greater compared to previous attentional bias experiments where faces were bilaterally presented. In these latter experiments it stands to reason that the difference between the faces must first be determined before the salient features of one face over other can influence attention. While it occupies a very early temporal position, in the present study, the observation that the laterality of the Ne is present for intact face distractors and not scrambled indicates that it possibly represents attentional capture similar to that of the N2pc. In previous studies the onset of the N2pc has been observed between 180 ms and 225 ms post stimuli presentation (Eimer & Kiss, 2008; Holmes et al., 2009; Holmes et al., 2014; Jannati, Gasper, & McDonald, 2008; Kiss, Van Velzen, & Eimer, 2008; Kiss, JolicŒur, DellAqua, & Eimer, 2008; McDonald et al., 2013). An explanation could be that the distractor being singular, and in the same hemi-field as the target, may have placed the distractor in the vicinity of the attentional trajectory, thus resulting in capture being based more on proximity rather than any salient feature of the distractor and subsequently displaying as a negative deflection in the earlier position of the ERP. Consequently, once attention had been 'captured' the reduction in the laterality of the negativity for scrambled face distractors may result from non-face information not needing to be processed to a high level before attention could be redeployed, although, if this is the case, it was not evident in the lateral components following the Ne, or in the behavioural data (which shows no effect of distractor type or valence). It is noted that ERP’s themselves are more sensitive to attentional demands than are revealed by RT methodologies. Another possible explanation of the early temporal divergence is that the distractors in the present experiment are directly competing with the target for attentional resources, whereas in paradigms incorporating bilateral distractors competition is between the salient features of the distractors.

An alternative explanation is that the increased negativity may be the result of an imbalance in sensory energy between intact and scrambled faces, although this is unlikely given that the images were equated for low-level surface characteristics. A further possibility is that the structural encoding of faces (as indexed by the N170; c.f., Eimer & Holmes, 2007) is carried out more rapidly by the hemisphere contralateral to the visual field in which the intact face stimulus is displayed, although peak latency results of the present experiment indicate this is unlikely. Interestingly, a similar early contralateral negativity is apparent in Hickey et al. (2009; attend to square experiment 4b) waveforms for a manipulation that does not include faces as distractor stimuli. Evidently the distractor shape presented in the lateral position of the Hickey et al. (2009) experiment appears to produce a contralateral negativity, as would be expected if attention was deployed laterally before vertical target selection. This may be an indication that the early negativity (Ne), in both the present experiment and Hickey et al. (2009; attend to line 4b), are possibly a result of salience driven attentional capture of the laterally presented stimulus. However, in the present experiment the attentional capture appears to be elicited by the presence of socially relevant vs. non-socially relevant information rather than the appearance of the bright shape in the lateral position vs. a line stimulus in the vertical.

The presence of a salient distractor delaying the search for a less-salient target would presumably slow reaction time compared to when the target was the most salient item. However, the behavioural results of the present experiment demonstrate this is not the case and indicate no additional interference from distractor type or distractor valence. However, the ERP results suggest that attention was deployed to intact faces more than scrambled, indicative of salience driven attentional capture. Müller et al. (2003) identify at least two sources of variability that could interfere with successful application of attentional control as: 1) changes in target and distractor locations from trial to trial; and 2) a random intermixing of distractor present and distractor absent trials. A third source of interference may potentially be the random intermixing of trials where the distractor either shares task relevant features or does not share task relevant features, as is evident in the present experiment with intact faces and scrambled faces. For example, the target location may have been selected initially but more time may have been required for the subsequent filtering when the distractor was a scrambled face (that contained square like patterns therefore sharing task relevant features), compared to when it was an intact face (that showed smooth features and not square like patterns). Although, this attentional ‘sharing’ between the target and the distractor for scrambled faces should have been evident if the Ne indicates attentional capture. Subsequent experiments without the intermixing of trials should help to clarify this.

That the Ne component is also showing increased activity contralateral to the ignored distractor when it is displayed as an intact face, and not when it is a scrambled face, indicates that attention is being diverted to, perhaps social relevance of, the face information after the termination of suppression and stimulus selection but before motor preparation or response initiation (given its position in the waveform after the Pd, but before response). However, even at this late stage of attentional deployment there appears to be no influence of distractor threat-related information on attentional selection as has been seen in previous experiments (e.g. Eimer & Kiss, 2007; Holmes et al., 2009; Holmes et al., 2014).

2.1.3.3 Late Positivity (Pl)

A contralateral positivity between 310 and 370 ms was also observed. Mean amplitudes were more positive for contralateral compared to ipsilateral locations, which indicates positive activity related to the distractor. One possibility is the lateralised activity may be the result of attentional orienting to the distractor after target evaluation and before response preparation. The Late Directing Attention Positivity (LDAP) has been observed where a cue informed the location of a target (c.f. Kiss et al., 2008) and when those cued locations were close to the central fixation (c.f. Van Velzen, Eardley, Forster, & Eimer, 2006). The Pl (observed here) reflecting an LDAP is perhaps unlikely given the preceding negativity likely represents that very process or at least one related to face processing which would require attentional orientation. Alternatively, that the Pl is also showing increased overall activity (although not reaching significance) when it is displayed as a scrambled face, compared to an intact face, indicates it may have a similar function to the P3b component which facilitates context maintenance and represents task related memory operations (c.f. Polich, 2007). It may be that the squared features of the scrambled face distractors caused interference in the stages of processing after suppression but before response. As Pritchard (1981) has noted, the P300 component (for which the P3b is a sub component) does not appear to be a real-time index of target selection; it does however, appear to index stimulus evaluation time. This conclusion would be consistent with the indication that the presentation of scrambled faces resulted in an overall increased positivity followed by a subsequent delay in reaction time for scrambled face distractors, as these shared task relevant features with the target stimuli.

2.2 Experiment 2

To control for lateralised ERP effects that may arise simply from the imbalance of sensory information in one visual hemifield relative to the other, these lateralised stimuli were also presented as ‘targets’ (in the following experiment) as well as distractors (in the previous experiment). Here a target negativity (Nt) representing attention to the lateral target should be present thereby allowing for the conclusion that the Pd is an index of suppression as opposed to a lateralised stimulus-driven effect. The following experiment was therefore conducted to test for this. Additionally, if the Nt is present as a result of attention directed to the lateral stimulus will allow for the comparison to the early negativity observed in experiment 1.

2.2.1 Method

2.2.1.1 Participants

The participants were 38 healthy volunteers from The University of Roehampton. One participant was excluded because of misplaced data (i.e. STAI questionnaire). Therefore 37 participants (28 female; 18–29 years; M: 20.22; SD: 2.41) remained in the sample. All participants had normal or corrected-to-normal vision and all were right-handed. The experiment was performed in compliance with The University of Roehampton guidelines and was approved by the University ethics committee.

2.2.1.2 Stimuli and Apparatus

All stimuli, timings and equipment were identical to those used in experiment 1.

2.2.2 Procedure

As in experiment 1, at the beginning of the session, after informed consent was given, participants completed the state and trait sections of the STAI. In experiment 1 participant’s had indicated the form of the shape stimulus (square or diamond) with the right hand via a response box. In experiment 2, participants were instructed to indicate the form of the lateral face stimulus (intact or scrambled face). Half the participants pressed the left button with their index finger when the lateral target was an intact face image 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 map. As in experiment 1, participants were instructed to respond as quickly and as accurately as possible with equal importance on both accuracy and speed. Competence was monitored identically to experiment 1.

2.2.2.1 EEG Data Acquisition

EEG data acquisition was identical to that of experiment 1.

Separate means were computed for all combinations of target type (intact face vs. scrambled face), target valence (angry face vs. neutral face), and laterality (electrodes contralateral vs. ipsilateral to location of target). Visual inspection of the waveforms resulted in the identification of three main ERP components in the lateral posterior area. These were assessed for the current study; namely, an positive posterior contralateral (Pe) beginning around 56 ms, a target negativity (Nt) beginning around 120 ms, and a positivity contralateral to the target (Pt) beginning around 200 ms. The Pe was defined as the mean amplitude from 56-106 ms post-stimulus presentation, the Nt was defined as the mean amplitude from 120-180 ms post-stimulus presentation, and the Pt defined as the mean amplitude from 200-270 ms post-stimulus presentation (c.f. Dennis & Chao-Chen, 2007; Eldar & Bar-Haim, 2009). These components were individually measured at their respective time windows from the mean of the left five posterior parieto-temporal electrodes (P3, P7, PO3, PO7 and O1) and right five posterior parieto-temporal electrodes (P4, P8, PO4, PO8 and O2), identical to experiment 1. These time windows and electrode sites were chosen as they coincide with latencies of components in Experiment 1 and are where maximal activity was apparent for each component. As can be seen in figure 2.12, a clear divergence of the contralateral and ipsilateral waveforms is in evidence in the latency between 56 and 106 ms (Pe); 120 and 180 ms post-stimulus indicating the presence of a lateralised negativity that has been suggested to be related to the attentional selection of the target (Nt; c.f. Hickey et al., 2009); and a later positivity between 200 and 270 ms contralateral to the target (Pt). Figure 2.13 shows the ERPs for electrodes contralateral and ipsilateral to angry and neutral targets at posterior parietal electrode sites. Additionally, residual lateral eye movement were calculated as the difference for distractor-left minus distractor-right presented trials of HEOG to allow direct comparison with each component of analysis for the same trials, in the same time interval. Mean amplitudes were automatically extracted for all components.

2.2.3 Results

Figure 2.14 shows intact and scrambled face target laterality difference activity for each time interval. As in experiment 1, non-responses and trials with errors were discarded, as were any with reaction times (RT) less than 200 ms (9.5% of all responses). Analyses were collapsed across shape types and presentation locations, to eliminate sensory confounds related to these factors (c.f. Sawaki & Luck, 2010). When using ANOVAs to determine statistical effects,

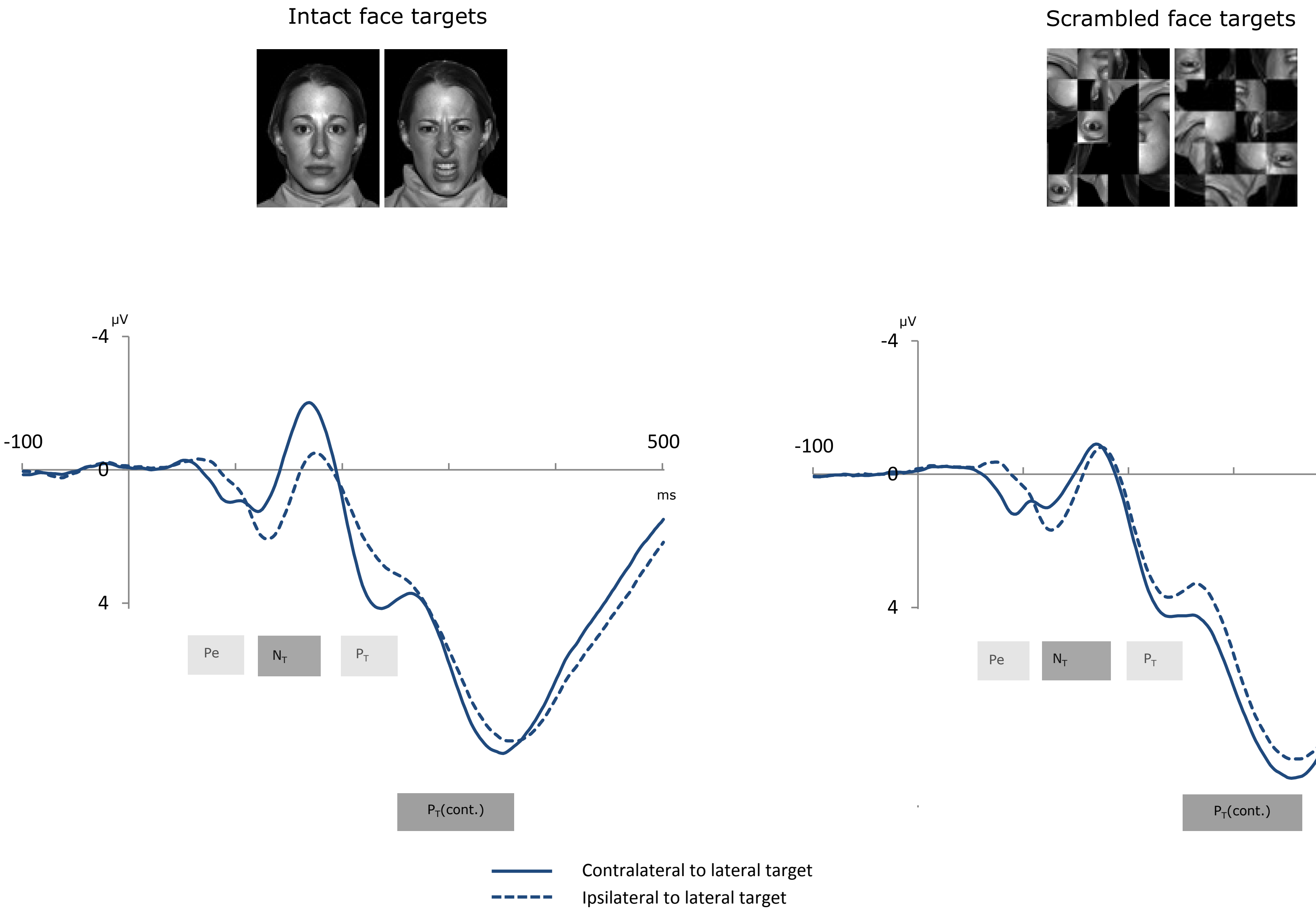


Figure 2.12. Grand average ERPs for contralateral (solid lines) and ipsilateral (dashed lines) electrodes to lateral target, for both intact (left) and scrambled (right) faces. The 56-106 ms (Pe); 120-180 ms (Nt); 200-250 ms (Pt); and 250-360 ms (Pt$_{(\text{cont.})}$) are depicted.

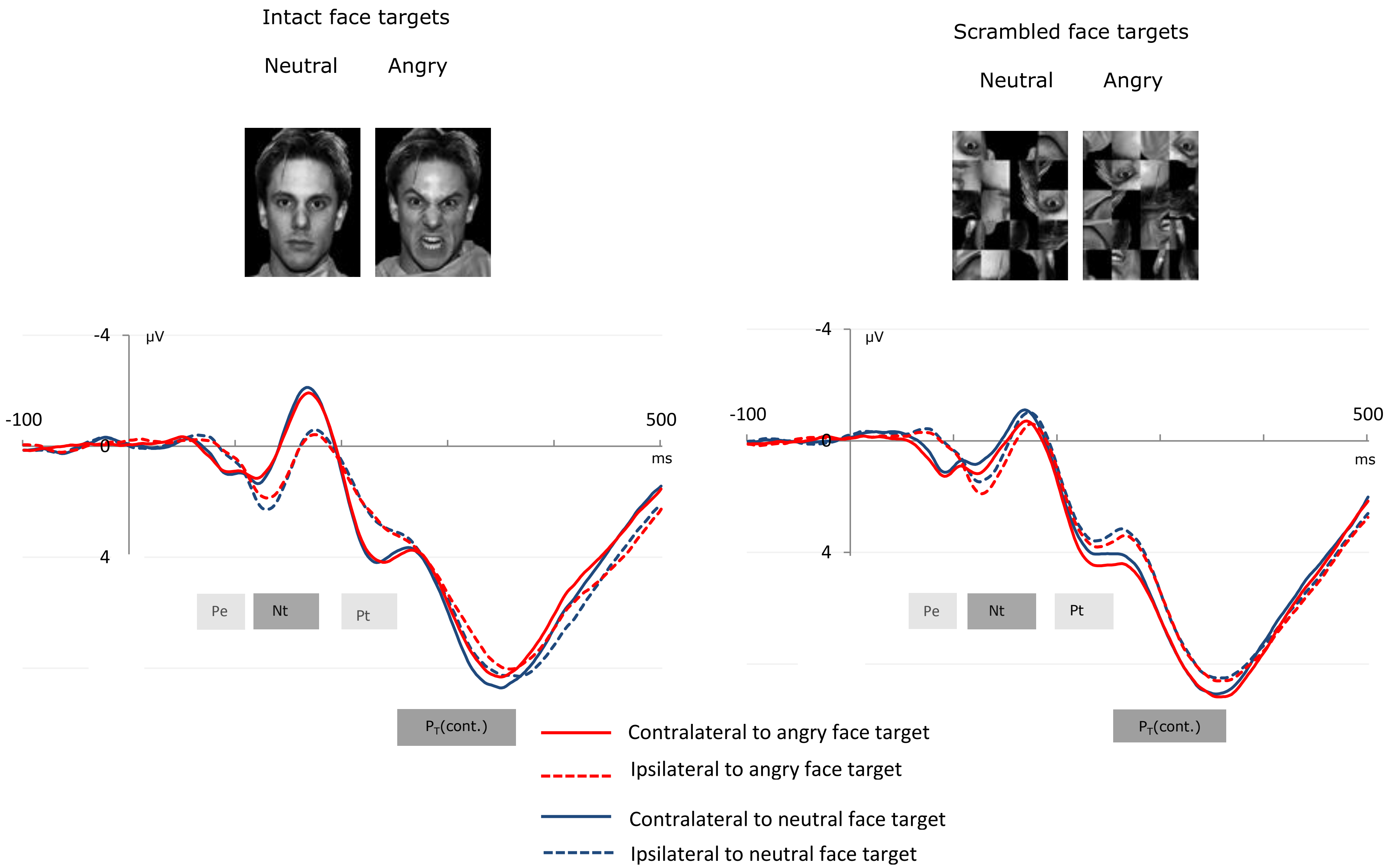


Figure 2.13. Grand average ERPs for contralateral (solid lines) and ipsilateral (dashed lines) electrodes to lateral target, for both neutral (blue) and angry (red) face targets. The 56-106 ms (Pe); 120-180 ms (Nt); 200-250 ms (Pt); and 250-360 ms ($Pt_{(cont.)}$) are depicted.

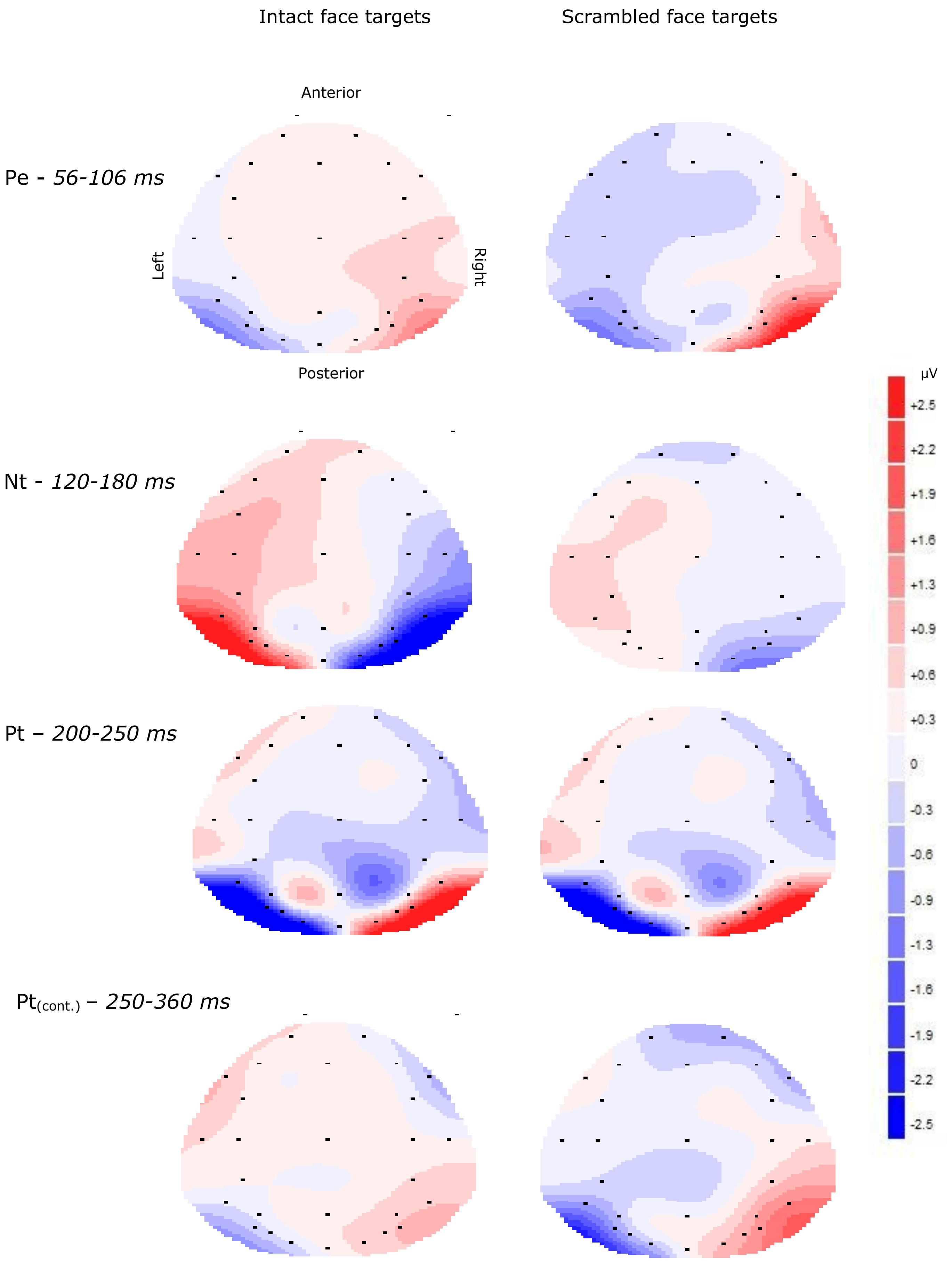


Figure 2.14. Intact face (left) and scrambled face (right) face target laterality difference activity (activity of electrodes contralateral to lateral target minus activity ipsilateral to lateral target) for each time interval.

partial eta-squared (η^2_p) are reported as an estimate of effect size for every significant effect found.

2.2.3.1 Behavioural measures

2.2.3.1.1 Reaction time (RT)

Mean correct RTs are shown in table 2.3. Mean RTs for each condition were entered into a 2 x 2 repeated measures analysis 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 (all *F*s < 2.1).

Table 2.3. *Means (SD) for correct reaction times to targets (ms) for each condition.*

	Intact target	Scrambled target
Neutral	517 (56.0)	513 (50.1)
Angry	519 (55.9)	514 (50.0)

2.2.3.1.2 Accuracy

Table 2.4 shows the mean correct responses to target for each condition. Planned comparisons of total correct responses for each condition were entered into a 2 x 2 repeated measures analysis of variance (ANOVA), with factors of target type (intact, scrambled), and lateral image valence (neutral, angry). There were no significant main effects or interactions (all *F*s < 2.1).

Table 2.4. *Means (SD) for correct responses to targets (out of 72) for each condition.*

	Intact target	Scrambled target
Neutral	62.4 (3.5)	64.8 (4.1)
Angry	61.1 (3.9)	63.7 (5.0)

2.2.3.2 ERP measures

To ensure lateral eye-movement does not contaminate the ERPs being measured, residual lateral eye-movement was calculated as the difference for distractor-left minus distractor-right presented trials of the HEOG channel. This will allow for direct comparison with each component of analysis for the same trials, in the same time interval. Any values for any participant greater than ± 4 μV resulted in additional analyses, minus those participants, within each component of interest. As many of the following results reveal this interaction, figure 2.13 shows angry vs. neutral face distractor grand average ERPs for both intact and scrambled face images, for electrodes contralateral and ipsilateral to distractor presentation. Figure 2.15 shows the grand average waveforms of HEOG for left and right presentation of stimuli.

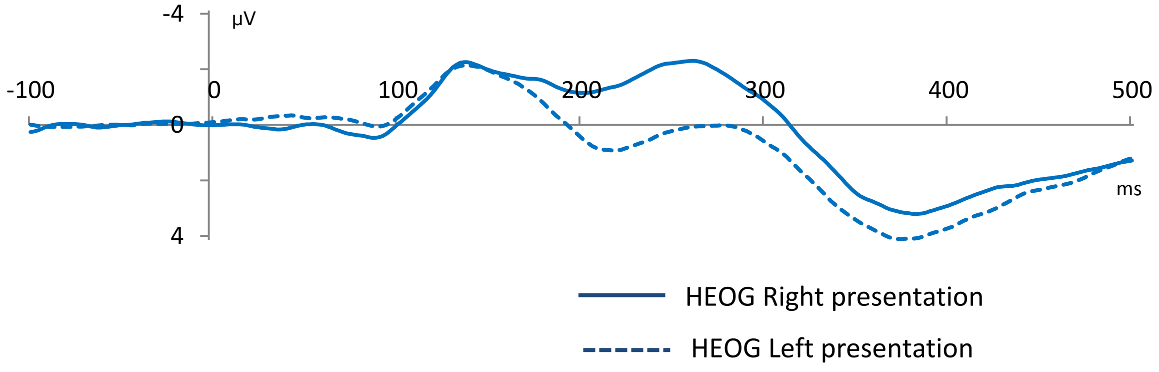


Figure 2.15. Grand average lateral eye-movement (HEOG) for right (solid line) and left (dashed line) stimulus presentation across all conditions.

2.2.3.2.1 Pe: 56-106 ms

Residual lateral eye-movement for the 56-106 ms time interval ranged between -6.46 and 2.15 μV. Mean amplitude values for the Pe were submitted to a 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 attended target, electrodes ipsilateral to attended target). There was a significant main effect of laterality $F(1,36) = 36.19$, $p < .001$ ($\eta^2_p = .50$), where mean amplitudes where more positive for electrodes contralateral to face target (0.61 μV) compared to ipsilateral (-0.07 μV). Analysis also revealed a significant type x laterality interaction, $F(1,36) = 4.18$, $p < .05$ ($\eta^2_p = .10$), as the laterality effect was greater for scrambled compared to intact faces. Paired comparisons *t*-tests revealed a significant effect of laterality (contralateral vs. ipsilateral) for intact face distractors, $t(36) = 4.93$, $p < .001$ (2-tailed), where electrodes contralateral (0.52 μV) to the ignored distractor were more positive compared to electrodes ipsilateral (0.08 μV); and, a significant effect of laterality for scrambled face distractors, $t(36) = 4.32$, $p < .001$ (2-tailed), where electrodes contralateral to the ignored distractor (0.70 μV) were more positive compared to electrodes ipsilateral (-0.22 μV). These results appear very similar to the results reported in experiment 1 for this time range and support the conclusion that the Pe likely reflects pre-attentive processing akin to basic feature and salience map processing as outlined in Jannati et al. (2013).

The independence of this component from attentional manipulation can be assessed by comparing the laterality effects across experiments 1 and 2 statistically. Thus to investigate the Pe as an index of feature processes separate from attention, mean amplitudes of the Pe from experiment 1 were labelled component Pe1 and mean amplitudes of the Pe from experiment 2 were labelled component Pe2 and entered into a 2 x 2 x 2 x 2 mixed analysis of variance (ANOVA) with between group factors of component (Pe1, Pe2) and within group factors of lateral image type (intact face, scrambled face), lateral image valence (angry, neutral), and laterality (electrodes contralateral to lateral face image, electrodes ipsilateral to lateral face image). Results show a significant main effect of component, $F(1,74) = 7.97$, $p < .01$ ($\eta^2_p = .10$), where mean amplitudes were more positive for the Pe1 component (0.72 μV) compared to the Pe2 component (0.27 μV); a main effect of laterality $F(1,74) = 79.29$, $p < .001$ ($\eta^2_p = .52$), were mean amplitudes where more positive for electrodes contralateral to lateral face image (0.79 μV) compared to ipsilateral (0.20 μV); and a significant type x laterality interaction, $F(1,74) = 12.31$, $p < .01$ ($\eta^2_p = .14$), as the laterality effect was greater for intact than for scrambled face images. Paired comparisons *t*-tests show a significant effect of laterality (contralateral vs. ipsilateral) for intact lateral face images, $t(75) = 6.35$, $p < .001$ (2-tailed), where electrodes contralateral to the lateral image (0.72 μV) were more positive compared to ipsilateral (0.33 μV) and a significant effect of laterality (contralateral vs. ipsilateral) for scrambled lateral face images, $t(75) = 7.22$, $p < .001$ (2-tailed), where electrodes contralateral to the lateral face image (0.86 μV) were more positive compared to ipsilateral (0.06 μV). There were no other significant main effects or interactions (all *F*s < 2.2). A lack of a laterality x component ($F = 1.50$; $p = .23$) or a type x laterality x component ($F = 0.28$; $p = .60$) interaction indicate that neither the Pe1 nor Pe2 appear to be influenced by attentional selection, but instead given their very early position in the waveform they appear to reflect pre-attentive processing and likely comprise basic feature and salience map processing similar to that outlined in the Salient-signal selection hypothesis (c.f. Jannati et al., 2013).

Inspection of the residual lateral eye-movement values shows one participant to have a value greater than ± 4 μV. This participant was excluded in a follow up analysis. Results show an identical pattern of results were evident where a significant main effect of laterality, $F(1,35) = 33.65$, $p < .001$ ($\eta^2_p = .49$), and a significant type x laterality interaction, $F(1,35) = 3.87$, $p < .05$ ($\eta^2_p = .10$). This additional analysis demonstrates that lateral eye-movement is not contributing to the effects reported for the 56-106 ms time interval.

2.2.3.2.2 Nt: 120-180 ms

Residual lateral eye-movement for the 120-180 ms time interval ranged between -3.45 and 3.31 μV. Mean amplitude values for the Nt were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of target type (intact, scrambled), target valence (angry, neutral), and laterality (electrodes contralateral to lateral face image, electrodes ipsilateral to lateral face image). There was a significant main effect of laterality $F(1,36) = 29.59$, $p < .001$ ($\eta^2_p = .45$) were mean amplitudes where more negative for contralateral electrodes (-0.42 μV) compared to ipsilateral (0.62 μV; see figure 2.16), and also showing a significant type x laterality, $F(1,36) = 33.39$, $p < .001$ ($\eta^2_p = .48$) interaction, as the laterality effect appeared greater for intact than for scrambled faces.

Paired comparisons *t*-tests on the type x laterality interaction reveal a significant effect of laterality (contralateral vs. ipsilateral) for intact face targets, $t(36) = 6.54$, $p < .001$ (2-tailed), were mean amplitudes for contralateral were more negative (-0.73 μV) than ipsilateral (0.77 μV); and for scrambled face targets, *t*(36) = 3.17, *p* < .01 (2-tailed), were mean amplitudes for electrodes contralateral to targets (-0.12 μV) where more negative than ipsilateral (0.46 μV); a significant effect for contralateral, *t*(36) = 3.50, *p* < .001 (2-tailed) where intact face targets were more negative than scrambled; and a significant effect for ipsilateral, *t*(36) = 2.15, *p* < .05 (2-tailed), where scrambled face targets were more negative than intact (see figure 2.11). There were no other significant main effects or interactions (all *F*s < 1.3).

The finding that the pattern of results for the attentional selection of the target (Nt) appears similar to the Ne in experiment 1 raises the possibility that the Ne is the result of attentional capture of the ignored lateral distractor stimuli. To investigate the Ne as an index of attentional processes similar to that of the Nt, mean amplitudes of the Ne from experiment 1 and mean amplitudes of the Nt from experiment 2 were entered into a 2 x 2 x 2 x 2 mixed analysis of variance (ANOVA) with between group factors of component (Ne, Nt) and within group factors of lateral image type (intact face, scrambled face), lateral image valence (angry, neutral), and laterality (electrodes contralateral to lateral face image, electrodes ipsilateral to lateral face image).

Results show a significant main effect of laterality, *F*(1,74) = 41.05, *p* < .001 (η^2_p = .36), where mean amplitudes were more negative for electrodes contralateral (-0.33 μV) to lateral face images compared to ipsilateral (0.38 μV); a significant type x laterality interaction, *F*(1,74) = 76.95, *p* < .001 (η^2_p = .51), as the laterality effect was greater for intact than for scrambled face images; and a significant laterality x component interaction, *F*(1,74) = 8.93, *p* < .01 (η^2_p = .11), as the laterality effect appeared greater for the Nt compared to the Ne component. While independent samples test show no significant effects of component (Ne, Nt) for electrodes contralateral (*F* = < 1) or electrodes ipsilateral (*F* = < 1.5). The absence of an effect of component on either contralateral or ipsilateral electrodes indicates the Ne and Nt reflect similar processes. Paired comparisons *t*-tests reveal a significant effect of laterality (contralateral vs. ipsilateral) for the Ne component, $t(38) = 3.24$, $p < .01$ (2-tailed), where mean amplitudes where more negative for contralateral electrodes sites (-0.23 μV) than ipsilateral (0.15 μV) and a significant effect of laterality for the Nt component, $t(38) = 5.44$, $p < .001$ (2-tailed), where mean amplitudes where more negative for contralateral electrodes sites (-0.42 μV) than ipsilateral (0.62 μV). Paired comparisons *t*-tests on the type x laterality interaction show a significant effect of laterality (contralateral vs. ipsilateral) for intact lateral face images, $t(75) = 8.08$, $p < .001$ (2-tailed), where electrodes contralateral to the lateral image (-0.58 μV) were more negative compared to ipsilateral (0.55 μV) and a significant effect of laterality (contralateral vs. ipsilateral) for scrambled lateral face images, $t(75) = 2.46$, $p < .05$ (2-tailed), where electrodes contralateral to the lateral face image (-0.07 μV) were more negative compared to ipsilateral (0.20 μV).

To investigate the potential effect of anxiety on attentional capture correlations of the difference waveforms (contralateral minus ipsilateral) were conducted on both STAI state and trait scores for the 180 – 250 ms time interval. There were non-significant correlations between trait anxiety scores and .03 (*p* = n.s) intact neutral faces distractors; .002 (*p* = n.s) intact angry face distractors; .02 (*p* = n.s) scrambled neutral face distractors; and .01 (*p* = n.s) scrambled angry face distractors. Similarly there were non-significant correlations between state anxiety scores -.03 (*p* = n.s) intact neutral faces distractors; .06 (*p* = n.s) intact angry face distractors; .06 (*p* = n.s) scrambled neutral face distractors; and -.03 (*p* = n.s) scrambled angry face distractors.

That the Nt is showing a laterality effect is in line with the conclusion that it reflects goal directed effortful attentional selection of the lateral face image. Furthermore, the results also show that, in comparison, the Ne demonstrates a very similar pattern of effects to the Nt meaning that, as the negativity was relative to the ignored lateral distractor-face stimulus, the Ne reflects unintended attentional capture of that stimulus. Therefore, from here on the early negativity in the 120–180 ms time interval (Ne) will be referred to as the distractor negativity (Nd) as it appears to reflect the process of unintended attentional capture of an ignored lateral distractor and that this is separate from both goal directed attentional selection (Nt) and suppression of the lateral image (Pd). To this authors knowledge this is the first time an ERP component specific to the unintended attentional capture of an ignored stimulus, that does not also include goal driven facilitation (i.e., Nt), suppression (i.e., Pd) or a combination (i.e., N2pc), has been described.

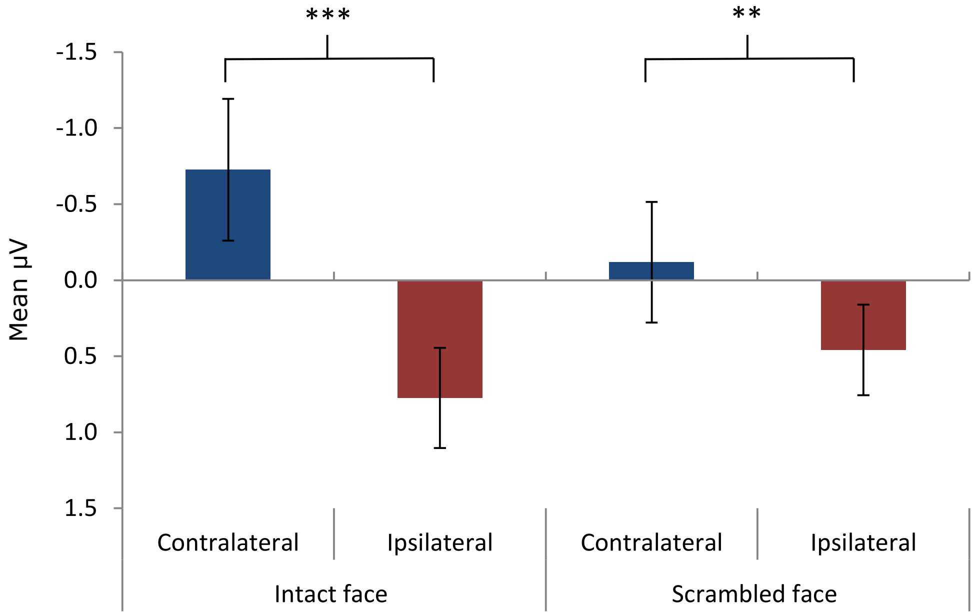


Figure 2.16. Mean amplitudes (µV) in the 120-180 ms (Nt) time interval for the contralateral vs. ipsilateral of intact and scrambled face targets (error bars represent 95% CI), ** *p* < .01; *** *p* < .001 when comparing contralateral and ipsilateral amplitudes across type.

2.2.3.2.3 Pt: 200-250 ms

Residual lateral eye-movement for the 200-250 ms time interval ranged between -1.39 and 17.37 µV. To investigate the positivity contralateral to the target, mean amplitude values for the Pt were submitted to a 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 lateral face image, electrodes ipsilateral to lateral face image). There was a significant main effect of laterality (see figure 2.19), *F*(1,36) = 8.59, *p* < .01 (η^2_p = .20), where mean amplitudes were more positive for contralateral electrodes sites (2.85 µV) than ipsilateral (2.34 µV); and a trend toward a type x valence x laterality interaction, *F*(1,36) = 3.77, *p* = .061. There were no other significant main effects or interactions (all *F*s < 2.6). It may be that the Pt is a contralateral target positivity which represents termination of target processing through suppression (c.f. Sawaki, Geng, & Luck, 2012). That the results of the Pt show a similar pattern to that of the Pd indicates these components may represent similar processes relating to suppression (see also Hickey et al., 2009), however, as attention previous to this point was presumably focused on the lateral target stimulus (as indexed by the Nt), it could be argued that a suppressive mechanism could be used here to disengage attention from a selected item for redeployment (c.f. Sawaki et al., 2012).

Therefore to investigate the Pt as an index of suppression similar to that of the Pd, mean amplitudes of the Pd from experiment 1 and mean amplitudes of the Pt from experiment 2 were entered into a 2 x 2 x 2 x 2 mixed analysis of variance (ANOVA) with between group factors of component (Pd, Pt) and within group factors of lateral image type (intact face, scrambled face), lateral image valence (angry, neutral), and laterality (electrodes contralateral to lateral face image, electrodes ipsilateral to lateral face image). There was a significant type x valence x laterality x component interaction, $F(1,74) = 5.98$, $p < .05$ ($\eta^2_p = .08$); a significant valence x laterality x component interaction, $F(1,74) = 7.26$, $p < .01$ ($\eta^2_p = .09$); and a significant laterality x component interaction, $F(1,74) = 9.29$, $p < .01$ ($\eta^2_p = .11$) where the laterality effect appears larger for the Pd compared to the Pt. See figure 2.17 for grand average difference ERPs (contralateral minus ipsilateral) for experiment 1 and 2 to lateral stimuli.

To investigate the type x valence x laterality x component interaction, a valence (angry, neutral) x laterality (contralateral, ipsilateral) x component (Pd, Pt) ANOVA was conducted for each level of type (intact, scrambled). Results for intact face lateral images do not show a component interaction (all Fs < 1.6).

However, results for scrambled face lateral images revealed a significant valence x laterality x component interaction $F(1,74) = 8.27$, $p < .01$ ($\eta^2_p = .10$); and a significant laterality x component interaction $F(1,74) = 13.58$, $p < .001$ ($\eta^2_p = .35$). The valence x laterality x component interaction was explored with two laterality x component ANOVAs, one for each level of each level of valence (angry, neutral). For neutral face images results indicate a significant laterality x component interaction $F(1,74) = 13.51$, $p < .001$ ($\eta^2_p = .15$). Paired comparisons t-tests on the laterality x component interaction for neutral face images show a significant effect of laterality (contralateral vs. ipsilateral) for the Pd component, $t(38) = 8.24$, $p < .001$ (2-tailed), where electrodes contralateral to the lateral image (2.39 μV) were more positive compared to ipsilateral (1.18 μV) and a significant effect of laterality (contralateral vs. ipsilateral) for the Pt component, $t(36) = 3.20$, $p < .01$ (2-tailed), where electrodes contralateral to the lateral face image (2.85 μV) were more positive compared to ipsilateral (2.32 μV). There were no other significant main effects or interactions (all Fs < 2.6). The laterality effect being greater for the Pd compared to the Pt indicates that the amplitude for the Pd is greater than that of the Pt, however, that the components do not differ on measures of lateral image type or valence indicate they likely reflect similar processes (see Figure 2.18 for Pd and Pt laterality difference activity). If such a process was driven by an imbalance of sensory energy it would seem likely the laterality effect be much more similar. That the effect is greater in experiment 1 where the lateral image was ignored than in experiment 2 where the lateral image was attended indicates these are perhaps similar, but separate processes unrelated to sensory effects.

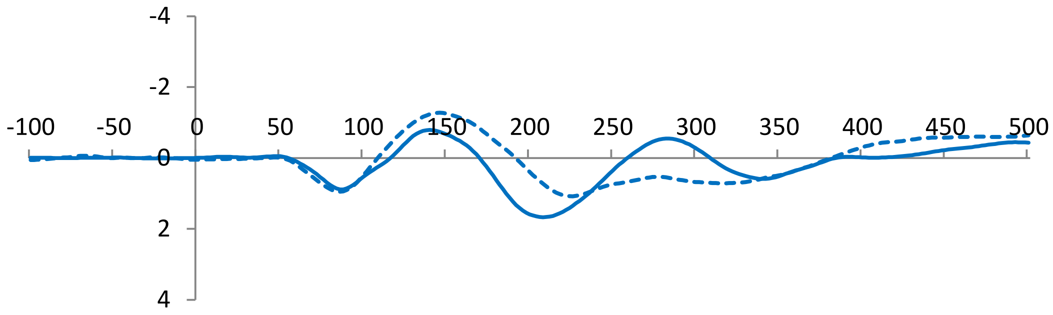


Figure 2.17. Grand average difference ERPs (contralateral minus ipsilateral) for experiment 1 (solid line) and experiment 2 (dashed line) to lateral stimuli.

Inspection of the residual lateral eye-movement values shows one participant to have a value greater than ± 4 μV. This participant was excluded in a follow up analysis. Results show an similar pattern of results were evident where a significant main effect of laterality $F(1,35) = 11.60$, $p < .001$ ($\eta^2_p = .25$). However, the type x valence x laterality interaction did not reach significance ($F = 2.26$, $p = .13$). It is apparent that the removal of this participant did not alter the presence of the component itself, it does; however, appear to reduce the interaction effects below significance. It should be noted here though that despite the significant interaction there was no evidence of the Pt differing on measures of lateral image type or valence with the inclusion of the participant. With this in mind, we should however interpret these results with caution.

To investigate the potential effect of anxiety on Pt component, correlations of the difference waveforms (contralateral minus ipsilateral) were conducted on both STAI state and trait scores. There were non-significant correlations between trait anxiety scores and -.11 (p = n.s) intact neutral faces distractors; .12 (p = n.s) intact angry face distractors; .05 (p = n.s) scrambled neutral face distractors; and -.05 (p = n.s) scrambled angry face distractors.

Similarly there were non-significant correlations between state anxiety scores -.07 (*p* = n.s) intact neutral faces distractors; -.09 (*p* = n.s) intact angry face distractors; .20 (*p* = n.s) scrambled neutral face distractors; and -.14 (*p* = n.s) scrambled angry face distractors.

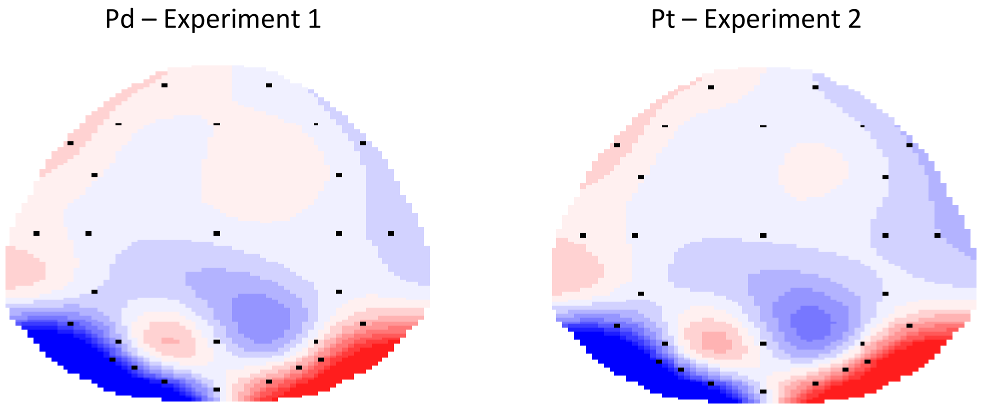


Figure 2.18. Pd (lateral distractor; left) and Pt (lateral target; right) laterality difference activity (activity of electrodes contralateral to lateral stimulus minus activity ipsilateral to lateral stimulus) show a strikingly similar distribution of activity, supporting the idea that suppression is used to terminate attention from the selected lateral stimuli.

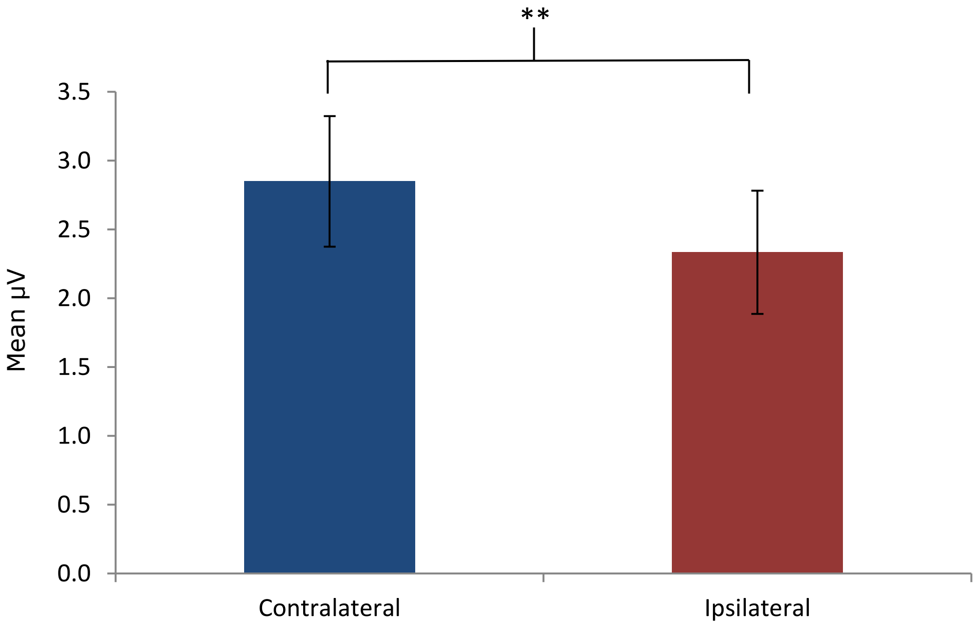


Figure 2.19. Mean amplitudes (μV) for the Pt in the 200-250 ms time interval for the contralateral vs. ipsilateral lateral targets (error bars represent 95% CI), ** *p* < .01; when comparing contralateral and ipsilateral amplitudes across type.

2.2.3.2.4 $Pt_{(cont.)}$: 250-360 ms

Residual lateral eye-movement for the 250-360 ms time interval ranged between -4.05 and 13.09 μV. To investigate the positivity contralateral to the target, mean amplitude values for the 250-360 ms time interval ($Pt_{(cont.)}$) were submitted to a 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 lateral face image, electrodes ipsilateral to lateral face image). There was a significant main effect of laterality (see figure 2.20), $F(1,36) = 16.44$, $p < .001$ ($\eta^2_p = .31$), where mean amplitudes were more positive for electrodes contralateral to target (6.58 μV) than ipsilateral (6.0 μV); and a significant type x laterality interaction, $F(1,36) = 26.84$, $p < .001$ ($\eta^2_p = .43$), where the laterality effect appears greater for scrambled face targets. There were no other significant main effects or interactions (all *F*s < 1.2).

Paired comparisons *t*-tests on the type x laterality interaction for intact face images show a significant effect of laterality (contralateral vs. ipsilateral), $t(36) = 2.31$, $p < .05$ (2-tailed), where electrodes contralateral to the lateral image (6.37 μV) were more positive compared to ipsilateral (6.0 μV) and a significant effect of laterality (contralateral vs. ipsilateral) for scrambled face images, $t(36) = 5.53$, $p < .001$ (2-tailed), where electrodes contralateral to the lateral image (6.78 μV) were more positive compared to ipsilateral (5.90 μV).

Inspection of the residual lateral eye-movement values shows one participant to have a value greater than ± 4 μV. This participant was excluded in a follow up analysis. Results show an identical pattern of results were evident where a significant main effect of laterality, $F(1,35) = 15.40$, $p < .001$ (η^2_p =

.31), and a significant type x laterality interaction, *F*(1,35) = 25.63, $p < .001$ ($\eta^2_p = .42$). Demonstrating that lateral eye movement is not contributing to the effects reported in the 250-360 ms time interval.

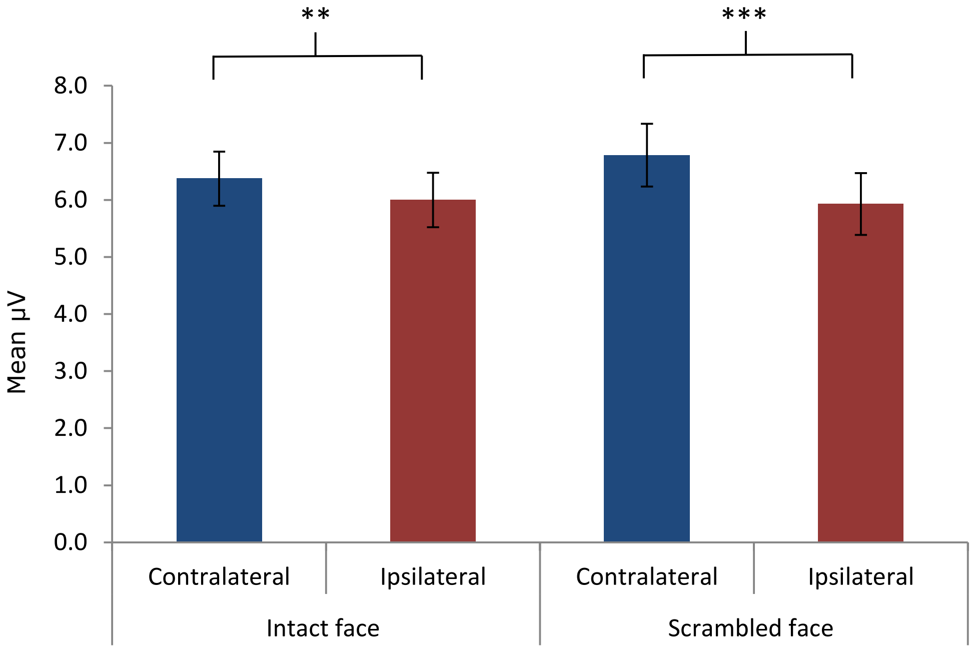


Figure 2.20. Mean amplitudes (µV) in the 250-360 ms ($Pt_{(cont.)}$) time interval for the contralateral vs. ipsilateral of intact and scrambled face targets (error bars represent 95% CI), ** $p < .01$; *** $p <$ 001 when comparing contralateral and ipsilateral amplitudes across type.

2.2.4 Discussion

The design of experiment 2 was nearly identical to that of experiment 1 except that the instructions for the target and distractor were reversed. Whereas participants discriminated a shape stimulus on the vertical meridian in experiment 1, in experiment 2, participants discriminated the face stimulus (intact or scrambled) presented in the lateral position. The aims of this approach of presenting lateralised stimuli as targets (experiment 2) as well as distractors (experiment 1) were to control for lateralised ERP effects that may arise simply from the imbalance of sensory information in one visual hemifield relative to the other.

2.2.4.1 Target Negativity (Nt)

The principal finding of Experiment 2 is illustrated in figure 2.12. Consistent with the results of Hickey et al. (2009), the ERP waveforms over the posterior scalp were more negative contralateral to the target stimulus compared to ipsilateral, indicating the contralateral negativity reflects activity related the attentional selection of the lateral stimuli. However, the position in the waveform in the present experiment is earlier than reported by Hickey et al. (2009) ‘attend to lateral line and ignore midline square’ experiment 4c, where the Nt is reported to begin around 175 ms. In the Hickey et al. (2009) ‘attend to lateral square and ignore midline line’ experiment 4b, the negative deflection appears to begin approx. 50-60 ms earlier, consistent with the present results, and as would be expected if attentional selection were not delayed by the salience of the vertical stimuli over the lateral (c.f. Hickey et al., 2009; ‘attend to lateral line and ignore midline square’ experiment 4c). That the laterality effect was greater for intact than for scrambled face targets indicates the structural encoding of faces results in a sustained negativity. That there was no effect of valence on the Nt indicates that, despite the structural encoding of faces being evident in the ERP, attentional selection of the lateral stimuli appears to not be modulated by the presence of threat-related (angry) faces over non-threat (neutral), although this may simply be a ceiling type effect where attentional selection can only be speeded up to a point. If the salience of a target is sufficient, then attentional selection could likely be close to or at its maximum, therefore feature differences on attentional selection may not be apparent.

The comparison of the Nd (experiment 1) with the Nt indicated that, while they show a similar effect, in that both are a negative contralateral deflection, they also differ in their intensity. That the Nd shows a laterality effect similar to that of the Nt demonstrates it to be a similar process to the Nt. If the negative deflection in the 120-180 ms time range were due to a sensory processes it would be expected that the Nd and Nt show similar intensities. That the Nt shows a greater lateral effect compared to the Nd supports the conclusion that the Nt is an index of effortful attentional selection, thus resulting in a greater negative effect, and the Nd as attentional capture of the lateral face image. Subsequent experiments should support this conclusion.

2.2.4.2 Early Positivity (Pe)

The results of experiment 1 indicated the Pe to be due to early pre-attentive sensory processes showing primarily contralateral to the lateral stimuli and do not represent attentional processes. The results of experiment 2 and the subsequent comparison of experiment 1 and 2 support this conclusion. As this component in evidently not attentional it is of no direct interest to the focus of this thesis.

2.2.4.3 Target Positivity (Pt and Pt$_{(cont.)}$)

As is illustrated in figure 2.15 and 2.16, a deflection in the ERP waveforms over the posterior scalp indicate a greater positivity contralateral to the lateral target compared to ipsilateral, indicating that this contralateral positivity reflects activity related to the processing of the lateral target. Sawaki et al. (2012) described a late (i.e., post-N2pc) positivity contralateral to task-relevant targets and interpreted this target positivity (or Pt) as a suppression-based termination of target processing. Five aspects of the present results support this possibility. Firstly, its' position in the waveform relative to the Pd, that it shares the same latency window; secondly, that it appears after attentional selection; thirdly, like the Pd, it is not altered by features of the lateral stimuli (socially relevant, non-socially relevant; angry, neutral), fourthly, while it shares these similarities, it does differ in its intensity, thus indicating that while it is similar, it is not identical; and finally, and perhaps less quantitatively, it shares a very similar topographical distribution of activity with the Pd (see figure 2.12). While there was a trend toward a type x valence x laterality interaction, visual inspection of the numerical mean show very little difference in this time range. It may be speculated that Pt is merely a positive going overshoot, perhaps reflecting ion equilibration, as much as a separate action potential (c.f. Sawaki et al., 2012; Sawaki & Luck, 2013). However, much evidence already exists that the N2pc is not followed by a positive deflection in a number of manipulations, such as when the task requires attention to be maintained after the initial deployment (c.f. Woodman, Arita, & Luck, 2009). Therefore, a plausible functional role for the Pt in this experiment is the termination of target processing via suppression (c.f. Sawaki et al., 2012; Sawaki & Luck, 2013), with the $\mathrm{Pt}_{(\mathrm{cont.})}$ appearing to represent a continuation of this process. This is supportive evidence that suppression also acts to terminate the allocation of attention for redistribution. Evolutionarily the most efficient use of resources would be having the same mechanism applied to two separate functions (i.e., preventing irrelevant information from entering attention for task related processes and disengaging attention so that attention could be relocated to other items in the scene or to a new task) as opposed to two mechanisms, one for each function.

Chapter 3: Are the observed similar laterality effects of the Nd and Nt, and the Pd and Pt due to low level sensory processing?

3.1 Experiment 3

The results of experiments 1 and 2 have revealed a number of interesting effects that remain to be definitively explained. It was noted that the Pd (experiment 1) and the Pt (experiment 2) showed three striking similarities despite being generated using different manipulations: a) they appear in the same time-interval (180-250 ms and 200-250 ms respectively); b) neither were modulated by semantic differences in the lateral images (intact face, scrambled face; angry, neutral); and c) they shared a similar topographical (lateral posterior) distribution of activity. However, they did differ in their laterality effect (contralateral minus ipsilateral) with the Pd showing a greater laterality effect compared to the Pt. Taken together, these results may provide evidence that the Pd and Pt are more reflective of imbalances in lower level sensory processing rather than either the suppression of irrelevant information (c.f. Hickey et al., 2009) or suppression for the purpose of disengagement of attention (c.f. Sawaki et al., 2012, Sawaki & Luck, 2013).

Since the Pd was first described in detail by Hickey et al. (2009) as an index of the process of attentional suppression, it has been used to investigate the active suppression of irrelevant information (Sawaki & luck, 2010, 2011) and more recently the termination of attentional selection (Sawaki et al., 2012; Sawaki & Luck, 2013). How top-down control mechanisms interact with bottom-up sensory factors to determine whether a salient non-target stimulus will capture attention has been a longstanding debate in the attention literature (e.g. Theeuwes, 1990; Theeuwes, 1991; Folk et al., 1992; Yantis, 1993; Yantis & Hillstrom, 1994). The findings of these studies have led to alternate hypotheses of attentional capture. The *bottom-up saliency hypothesis* predicts that attentional capture by salient distractors can be purely stimulus-driven (e.g. Theeuwes, 1991; Theeuwes & Burger, 1998), and the *contingent involuntary orienting hypothesis* outlines that attentional capture depends entirely on the attentional set that is induced by task demands (e.g. Folk et al., 1992; Folk, Remington, & Joseph, 1994). The s*ignal suppression hypothesis* was proposed as an alternative that attempts to resolve the conflicting results of the two and was created by combining elements of each with the addition of attentional suppression (c.f. Sawaki & Luck, 2010).

Like the bottom-up saliency hypothesis, the signal suppression hypothesis proposes that salient singletons are always detected and generate an 'attend-to-me' signal (Sawaki & Luck, 2014). While the priority signal can be suppressed by top-down control before attention has shifted, in the absence of attentional control, this signal causes a shift in attention toward a salient object (Sawaki & Luck, 2010). This process was tested in a series of experiments (c.f. Sawaki & Luck, 2010) using ERPs where participants searched for a specific letter that was sometimes presented with a salient distractor. The bottom up saliency hypothesis would predict that attention will be automatically captured by the distractor, leading to an increase in the N2pc to its presentation (Luck & Hillyard, 1994a, 1994b), whereas the contingent involuntary orienting hypothesis would predict that the salient distractor would not generate attentional priority and thus no subsequent increase in the N2pc would be observed. The results of Sawaki and Luck (2010) supported the predictions of the signal suppression hypothesis, where the targets were attended eliciting an N2pc and the distractors were suppressed, eliciting a Pd. As the lateral ignored stimulus of experiment 1 (in the present series of studies) would generate an attend-to-me signal, it may be that the observed Nd (observed in exp 1) represents stimulus driven attentional capture similar to that of the N2pc, minus generalised suppression, and could also explain why its latency is earlier than that of the Pd (as an index of suppression of the ignored distractor). However, the presence of the Pt (exp 2) in the same time interval as the Pd (exp 1), instead of an Nt (as was demonstrated by Hickey et al., 2009; experiment 4c) and the fact that the Pt similarly was not altered by semantic features of the lateral image, leaves the possibility that the Pd is instead the result of an imbalance in lower level sensory processing. If the Pd is representative of lower level sensory processes related to the lateral presented stimuli, then it would be reasonable to expect it to modulate in response to changes in lower level attributes. A replication of the original Hickey et al. (2009) experiment, using simple line and shape stimuli, and a modulation of the target stimuli (vertical vs. lateral) in the same participant set, should provide the clearest evidence of the Pd being due to attention processes by allowing for a direct comparison with the Nt, as this appeared in the same time interval as the Pd in Hickey et al. (2009). Alternatively, a sensory account would be supported by the presence of a lateralised positivity under both vertical and lateral target conditions. Furthermore, a manipulation of the perceptual salience of the lateral stimuli should lead to a modulation of the Pd if this component is elicited by factors such as an imbalance in sensory energy. If the Pd were due to lower level sensory processes it would be expected that it would be modulated in a similar manner to components that are thought to index lower level sensory processes (e.g., P1

& Pe). Both components (Pd, Pt) appearing in the same time interval will provide further support for the sensory account that was provided by the results of experiment 1 and 2.

In experiment 1 an early lateralized negativity appeared between 120 and 180 ms (Nd; and again after the Pd between 250-300 ms – Nl), which appears to represent unintended attentional capture of the ignored stimuli. However, some uncertainty still remains regarding the validity of the distractor negativity (Nd) in representing attentional processes related to attentional capture (or attentional selection) rather than being the result of imbalances in lower level sensory processing caused by stimuli appearing in one visual-field only. The indication that the distractor negativity (Nd; exp 1) and the target negativity (Nt; exp 2) show a similar laterality effect for lateral intact face images demonstrates the possibility that these two components also represent similar processes. They do, however, differ in that the Nt shows a greater overall difference in the numerical means of the laterality effect (although this was not significant) compared to the Nd, which may be explained by the former representing effortful goal-directed attentional selection of the attended lateral stimuli and the latter representing bottom-up attentional capture by the ignored lateral distractor stimuli. However, this is not sufficient to rule out the sensory account. If the Nd is representative of stimulus driven attentional capture, as can be seen with results from other studies with the N2pc (e.g. Eimer & Kiss, 2007; Holmes et al., 2009) then it would be reasonable to expect the Nd of experiment 1 to be modulated similarly by threat-related information similar to other studies (e.g. Eimer & Holmes, 2002, 2007; Holmes et al., 2009; Holmes et al., 2014). Results of experiment 1 indicate that whether the distractors were threat-related or non-threat related images did not affect the laterality of either the Nd or Nl (late negativity) components. However, the same result was also true for the Nt (exp 2) component, which is thought to represent attentional selection similar to that of the N2pc (Hickey et al., 2009; Sawaki & Luck, 2013, 2014). The absence of emotional valence effects will be considered further in the Discussion and conclusions chapter (chapter 6).

It should be noted that a contralateral negativity, similar in appearance to the Nd, is apparent in the waveforms displayed in Hickey et al. (2009; figure 5b), with a line as vertical target and a square as lateral distractor. However, the same lateralised negativity (Hickey et al., 2009; figure 4c) is not apparent when the square (as a target) is in the vertical position and a line (as a distractor) in the lateral. It must be stated here that these observations are derived only from the figures presented by Hickey et al. (2009) and were not described by statistical analysis. If these observations are accurate, it can be presumed that the attend-to-me signal was triggered only when the square, and not the line, was the ignored lateral stimulus. It may be that the salience of the square was greater in relation to the top-down task set (discriminate length of line) resulting in the attend-to-me signal capturing attention. A similar negative deflection is not evident, however, when these stimuli were reversed and the line, with arguably lesser salience, was the lateral distractor. While these observations are based only on the numerical properties of the grand averaged waveforms, one explanation may be that in relation to the top-down task set (discriminate square from diamond), the attend-to-me signal is weaker for the lateral line (compared to the lateral square) and therefore fails to capture attention. Alternatively, this pattern may simply be a representation of lower level sensory processing of the larger lateral square vs. the smaller lateral line. It could be argued that the salience of the distractor faces in experiment 1, presumably having substantially greater salience than either of the distractors presented in Hickey et al. (2009), were also greater compared to the top-down task set (discriminate square and diamond), subsequently resulting in the attend-to-me signal being sufficiently greater and therefore capturing attention. However, from a low level sensory perspective, it is possible that the physical salience of the lateral image may have resulted in the negative lateral component. A replication of the original Hickey et al. (2009) experiment with an alteration of the target stimuli in the same participant set (vertical stimuli target vs. lateral stimuli target) should highlight if the Nd (distractor negativity present in the vertical target task) is due to attention processes by allowing for a direct comparison with the early components (Nt) of the lateral target task. Additionally, by manipulating the salience of the lateral stimuli, if the Nd were due to lower level sensory processes, it would be expected that it would be modulated similarly to components that are thought to index lower level sensory processes.

In sum, the results from experiments 1 and 2 have left the small possibility that the Pd and, Nd (exp 1); and Nt and Pt (exp 2) are representative of an imbalance in lower level sensory processes (as they are present for different attentional conditions with the same stimulus presentations), rather than processes related to attention. Therefore, the first aim of the study is to investigate, this time using simple shape stimuli akin to those employed by Hickey et al. (2009), if the Pd under these conditions can be modulated by changes in the target task (lateral vs. vertical) as would be expected if the Pd were due to processes related to attention. The second aim of the study is to investigate if the Pd is instead modulated by lower level attributes of the lateral stimuli (i.e., perceptual salience; specifically 1 line vs 3 lines) as would be expected if it represented lower level sensory processes. If the Pd is an index of lower level sensory processes then a modulation of the Pd by attention should not be apparent. However, when lower level sensory attributes of the distractor are altered a change in the Pd should be evident as a result of this sensory alteration, similar to components that are known to show modulations in response to changes in lower level sensory features (e.g., P1 & Pe; c.f. Luck & Hillyard, 1994a; Batty & Taylor, 2003). The third aim of the study is to investigate if the Nt is modulated by changes in the target task (lateral vs. vertical) as would be expected if the Nt were due to processes related to attention. The fourth aim of the study is to investigate if the Nt is instead modulated by lower level attributes of the lateral stimuli (i.e. distractor salience) as would be expected if it represented lower level sensory processes. The fifth aim of the study is to investigate if the Nd is modulated by changes in the target task (lateral vs. vertical) as would be expected if the Nd were due to processes related to attention. The sixth and final aim of the study is to investigate if the Nd is instead modulated by lower level attributes of the lateral stimuli (i.e. distractor salience) as would be expected if it represented lower level sensory processes.

3.1.1 Method

3.1.1.1 Participants

Nineteen healthy volunteers from the University of Roehampton received course credit for participation (9 male and 10 female; 18–28 years old; M: 20.53 years; SD: 2.34). All participants had normal or corrected-to-normal vision and all were right-handed. The experiment was performed in compliance with The University of Roehampton ethical and research guidelines and was approved by the University ethics committee.

3.1.1.2 Stimuli and Apparatus

The stimuli and procedure were identical to that of experiment 1, except as follows (see figure 3.1 for trial sequence). The lateral stimulus consisted of either a single red line (1.84 cd/m2) or three red lines (3.10 cd/m2) that were both substantially more luminous than the background. All lines were 2 x 17 mm (approx. 0.1° x 1.2°) for short and 2 x 22 mm (approx. 0.1° x 1.6°) for long versions. For the 3-line lateral stimulus each line was placed one atop another 3 mm (approx. 0.2°) apart, forming a distractor that was 12 x 17 mm (approx. 0.9° x 1.2°) for short and 12 x 22 mm (approx. 0.9° x 1.6°) for long (see Appendix C for stimuli).

3.1.2 Procedure

At the beginning of each session, after informed consent was given, participants completed the state and trait sections of the STAI (see Appendix B). As in all other experiments, each trial presentation consisted of two stimuli; one target stimulus and one distractor stimulus (plus one fixation). However, for half of the trials, participants were instructed to distinguish the form of the shape stimulus (either square or diamond) and for the other half to distinguish the length of the line stimulus (either short or long) irrespective of the number of lines. The experiment itself consisted of 24 blocks of 64 trials for a total of 1536 trials. As in Experiment 1, participants were instructed to respond as quickly and as accurately as possible with equal importance on both accuracy and speed. Training was administered, and competence monitored, identically to experiment 1.

3.1.2.1 EEG Data Acquisition

EEG acquisition was identical to experiment 1 with the exception of the use of a 64 channel array with placement according to the international 10-20 system. As in experiments 1 and 2, to eliminate extraneous variables unrelated to the aims of the study, trials were collapsed across vertical shape types (square or diamond) and presentation hemi-field (upper, lower, left, right). Separate means were computed for all combinations of target location (vertical vs. lateral), lateral stimulus salience (1-line vs. 3-lines), and laterality (electrodes contralateral vs. ipsilateral to location of lateral stimulus). Similar to previous experiments, visual inspection of the waveforms resulted in the identification of 4 main contralateral (to the lateral stimulus) ERP components in the lateral posterior area. These were assessed for the current study with reference to the side of the lateral stimulus; namely, a positive posterior contralateral (Pe) beginning around 86 ms; an early negativity for both the lateral distractor and lateral target conditions (Nd/Nt) beginning around 140 ms (and continuing to 260 ms in the case of the Nt); a positivity relating to the

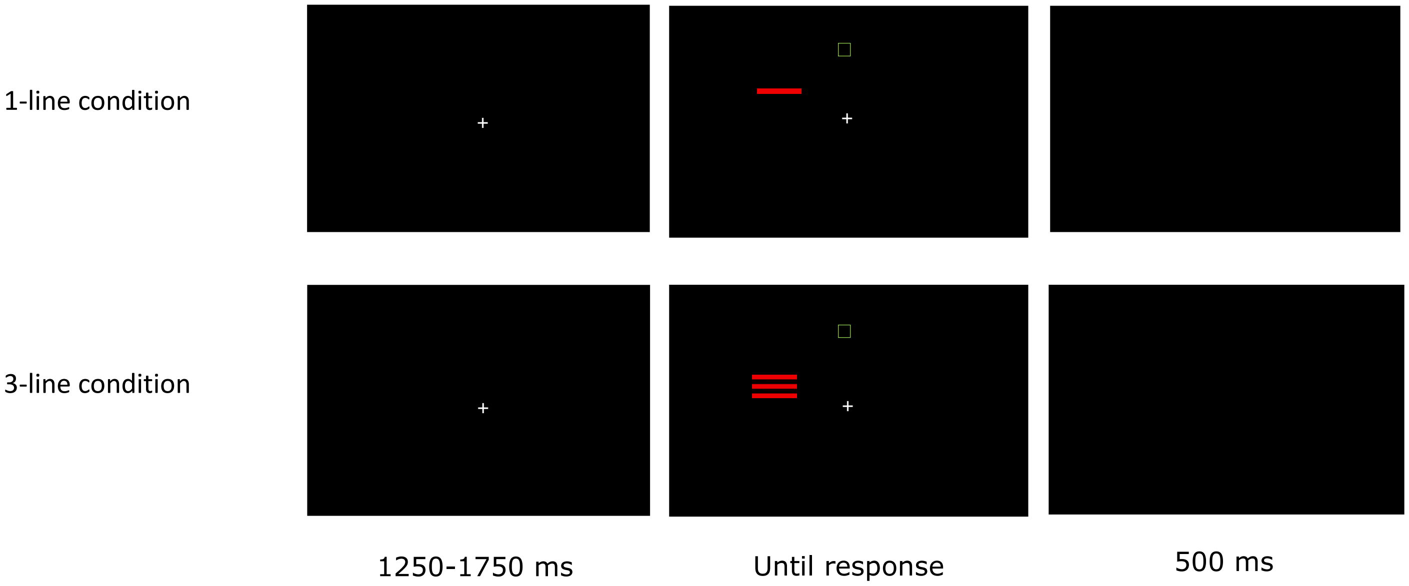


Figure 3.1. Presentation sequence containing fixation screen, sample trial for both levels of salience and inter-trial interval.

lateral distractor condition (Pd; c.f. Hickey et al., 2009) beginning around 180 ms, (overlapping with the time course of the continued negativity relating to the lateral target condition (Nt; c.f. Hickey et al., 2009)); and a positivity relating to both the lateral distractor (Pd continued) and lateral target conditions (Pt) (Sawaki et al., 2012; Sawaki & Luck, 2013) beginning around 260 ms. As in previous experiments these components were individually measured at their respective time windows from the mean of the five left posterior parieto-temporal electrodes and five right posterior parieto-temporal electrodes (see figure 3.2 for electrode positioning), as this is where maximal activity was apparent for each component (see figure 3.7).

The Pe was defined as the mean amplitude between 86-130 ms post-stimulus presentation (c.f. Luck & Hillyard, 1994a; Batty & Taylor, 2003). The Nd/Nt was defined as the mean amplitude between 140-180 ms post-stimulus presentation (Hickey et al., 2009). The Pd/Nt$_{\text{(cont.)}}$ was defined as the mean amplitude between 180-260 ms post-stimulus presentation (c.f. Hickey et al., 2009) and the Pd$_{\text{(cont.)}}$/Pt was defined as the mean amplitude between 260-360 ms post-stimulus presentation. Figure 3.8 shows the contralateral and ipsilateral topographical difference activity. Mean amplitudes were automatically extracted for all components.

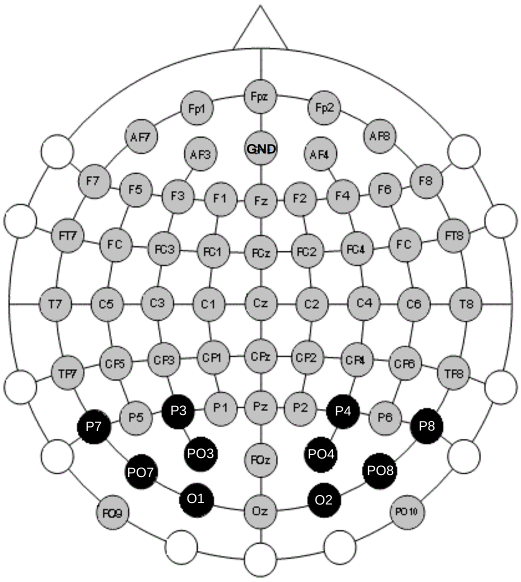


Figure 3.2. Taken and adapted from EASYCAP GmbH: www.easycap.de**.** Cluster of 5 electrodes for posterior left and posterior right used in statistical analysis.

3.1.3 Results

Figure 3.3 shows vertical lateral target grand average ERPs for electrodes contralateral and ipsilateral to lateral stimulus across all conditions and figures 3.4 and 3.5 show lateral difference activity for lateral and vertical targets respctively. Non-responses and trials with errors were discarded, as were any with reaction times (RT) less than 200 ms (5.0% of all responses). When using ANOVAs to determine statistical effects, partial eta-squared (η^2_p) are reported as an estimate of effect size for every significant effect found.

3.1.3.1 Behavioural measures

3.1.3.1.1 Reaction time (RT)

Mean correct reaction times (RT) are shown in table 3.1. Mean RTs for each condition were entered into a 2 x 2 repeated measures analysis of variance (ANOVA), with factors of target location (vertical, lateral), and lateral stimulus type (1-line, 3-lines). There was a significant main effect of location, $F(1,18)$ =

5.09, $p < .05$ ($\eta^2_p = .22$), where responses were faster for vertical (668 ms) targets compared to lateral (748 ms) indicating that distinguishing the length of

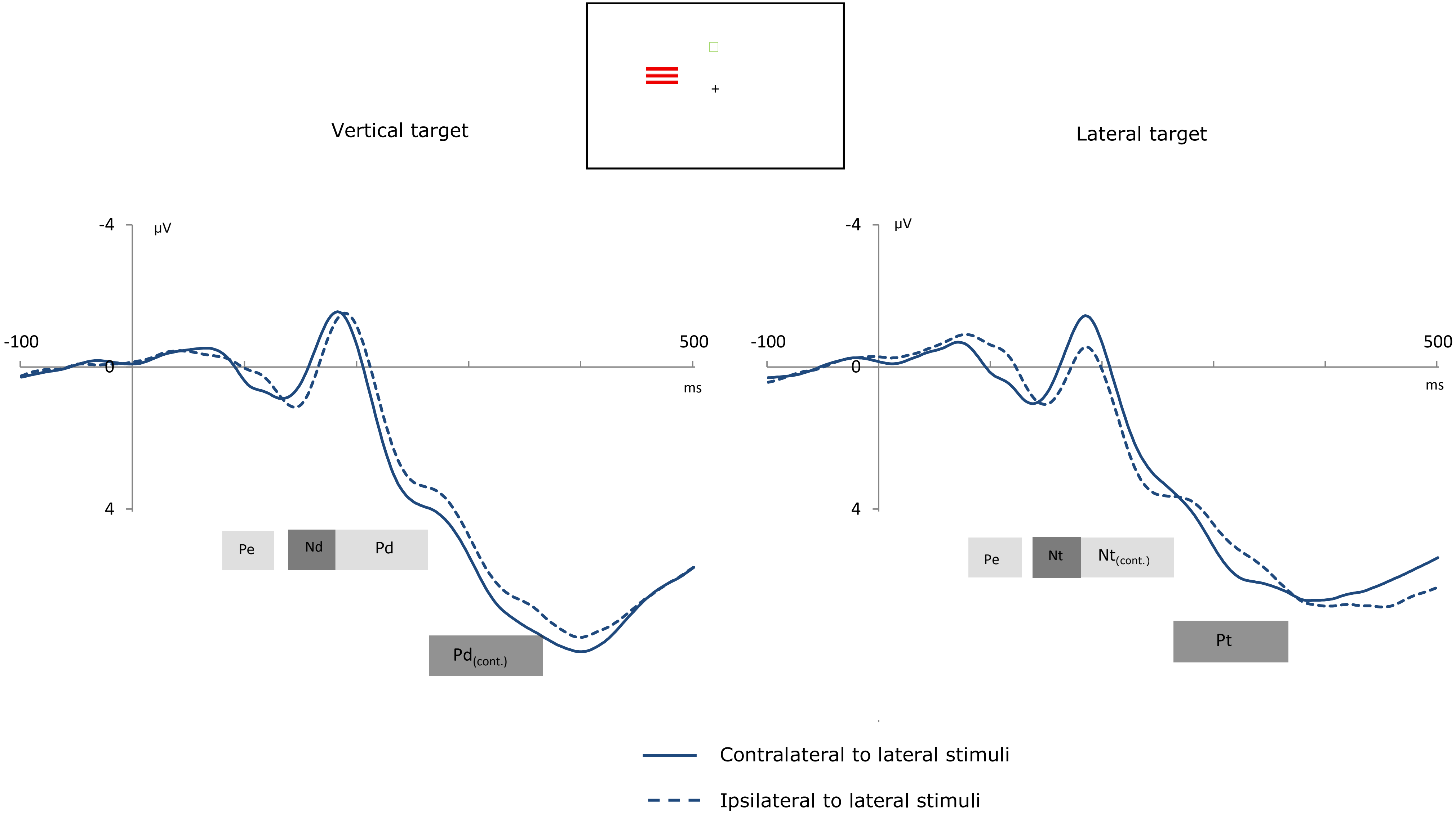


Figure 3.3. Vertical target (left) and lateral target (right) grand average ERPs for electrodes contralateral and ipsilateral to lateral stimulus across all conditions. The 86-130 ms (Pe); 140-180 ms (Nd/Nt); the 180-260 ms (Pd/$\text{Nt}_{(\text{cont.})}$); and 260-360 ms ($\text{Pd}_{(\text{cont.})}$/Pt) time intervals are depicted.

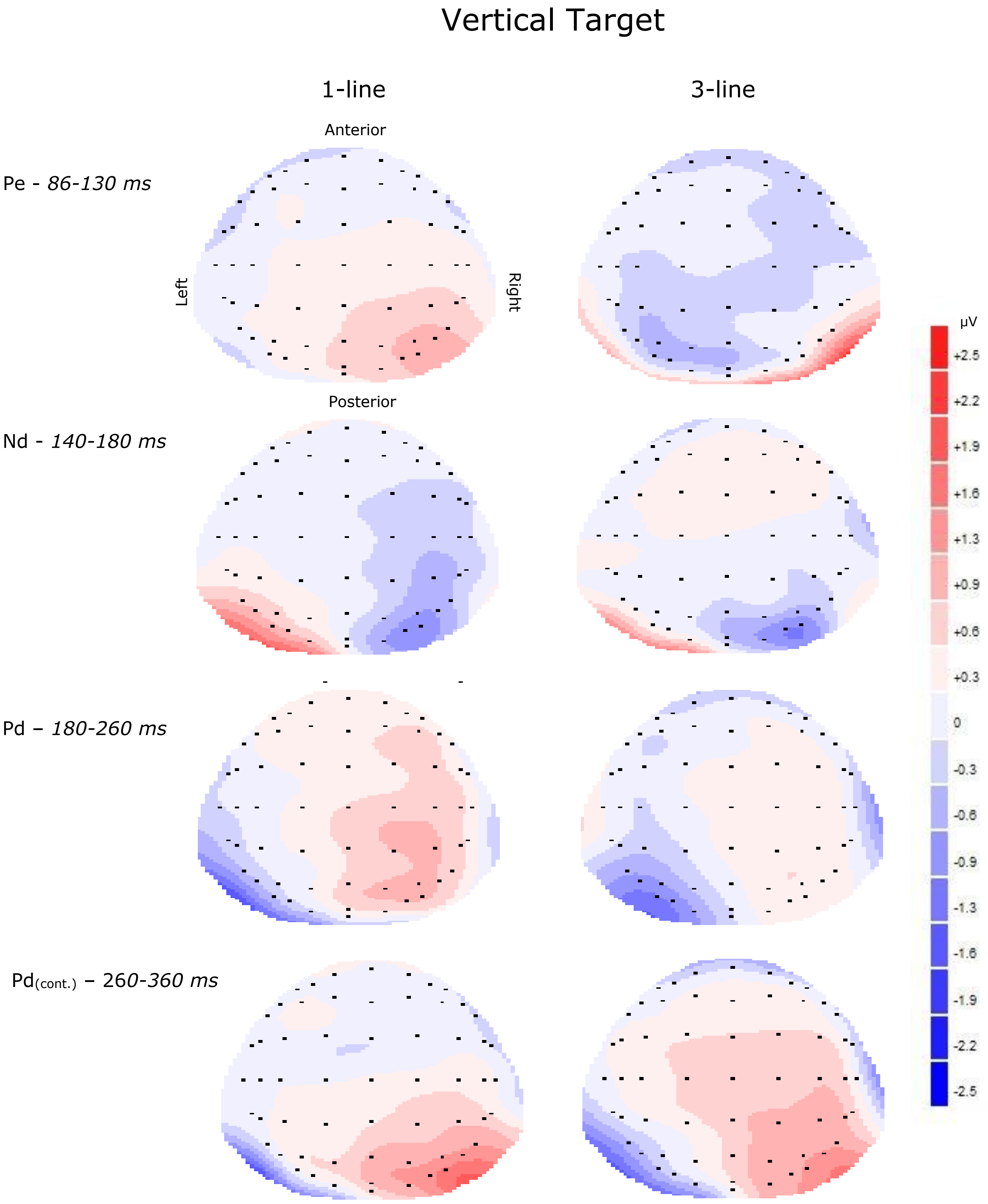


Figure 3.4. Vertical target 1-line distractor (left) and 3-line distractor (right) laterality difference activity (activity of left presented ignored distractor minus activity right presented ignored distractor) for each time interval in analysis.

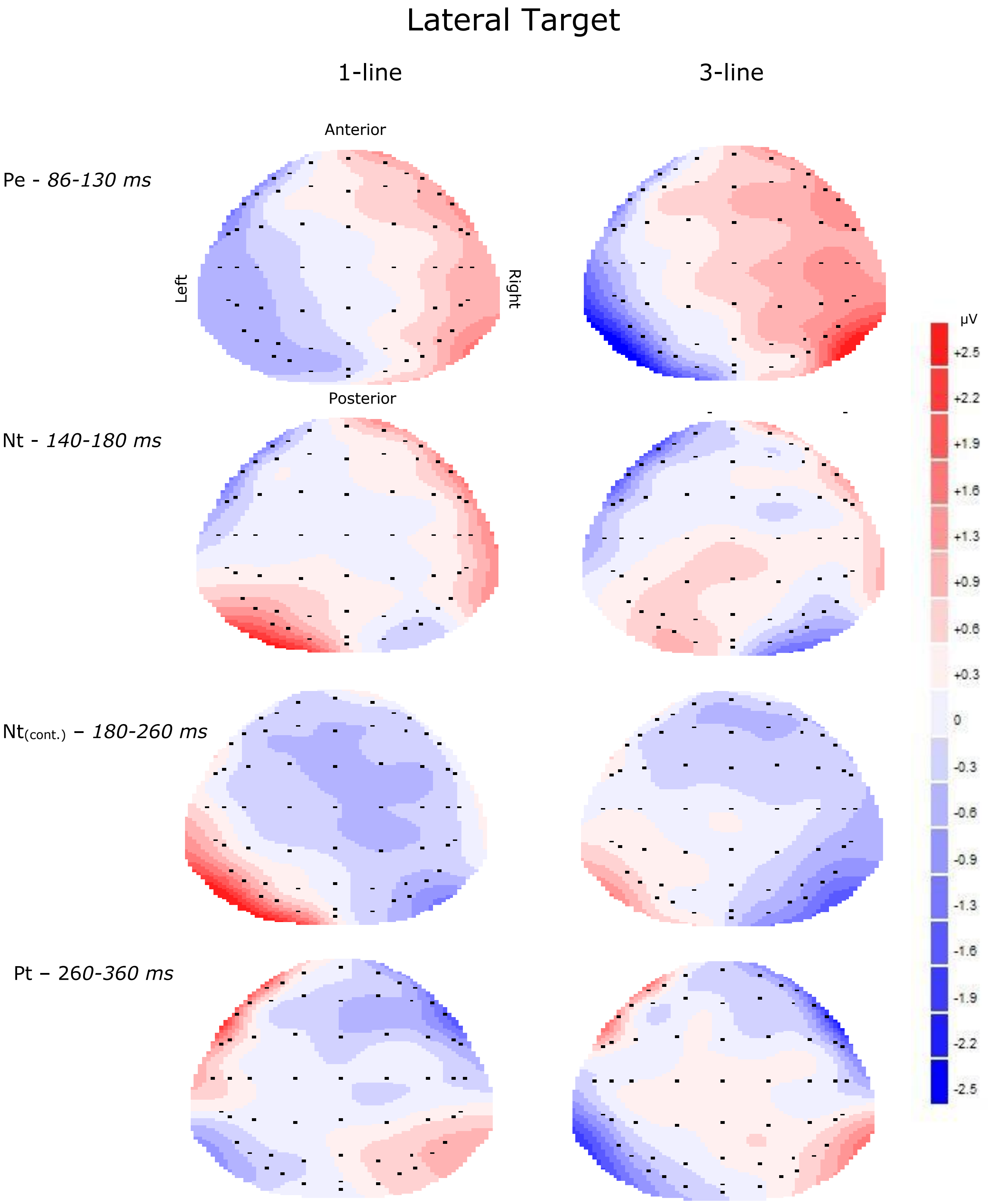


Figure 3.5. Lateral target 1-line distractor (left) and 3-line distractor (right) laterality difference activity (activity of left presented ignored distractor minus activity right presented ignored distractor) for each time interval in analysis.

the lines was more difficult than type of shape. Also, there was a significant main effect of salience, $F(1,18) = 8.85$, $p < .01$ ($\eta^2_p = .33$), where responses were faster for 3-line stimulus displays (701 ms) compared to 1-line stimulus displays (715 ms), and a location x salience interaction, $F(1,18) = 9.74$, $p < .01$ ($\eta^2_p = .35$), where the difference between 1-line and 3-line stimulus displays was greater when targets were lateral lines as compared with vertical squares/diamonds.

Paired comparisons *t*-test on the location x salience interaction revealed a significant effect of salience for lateral target location, $t(18) = 4.39$, $p < .001$ (2-tailed), where RTs to the 3-line stimulus displays were faster (736 ms) compared to the 1-line stimulus displays (760 ms); but no similar effect for the vertical target location, ($t < 1$), indicating that determining the length of the 3-line stimuli was easier (and subsequently faster) than the 1-line stimuli, but the salience of the ignored stimuli did not have a slowing effect on RTs for distinguishing a square from a diamond shape. This indicates that the to-be-ignored 3-line stimuli did not attract attention favourably over the 1-line stimuli when it was a distractor. However, when the target was a 3-line stimuli it appeared easier to determine its length compared to when it was a 1-line stimuli.

Table 3.1

Means (SD) for correct reaction times (ms) to vertical and lateral targets for each 1-line and 3-line lateral stimuli.

	Vertical target	Lateral target
1-line lateral stimulus	670 (178.0)	760 (140.7)
3-line lateral stimulus	666 (159.4)	736 (134.4)

3.1.3.1.2 Accuracy

Table 3.2 shows the mean correct responses to target for each condition. Planned comparisons of total correct responses for each condition were entered into a 2 x 2 repeated measures analysis of variance (ANOVA), with factors of target location (vertical, lateral), and lateral stimulus type (1-line, 3-lines). There were no significant main effects or interactions (all *F*s < 1.1).

Table 3.2

Mean (SD) correct responses (out of 64) to vertical and lateral targets for each 1-line and 3-line lateral stimuli.

	Vertical target	Lateral target
1-line lateral stimulus	45.8 (2.2)	45.3 (3.2)
3-line lateral stimulus	45.9 (2.2)	45.2 (1.9)

3.1.3.2 EEG measures

To ensure lateral eye-movement does not contaminate the ERPs being measured, residual lateral eye-movement was calculated as the difference for distractor-left minus distractor-right presented trials of the HEOG channel. This will allow for direct comparison with each component of analysis for the same trials, in the same time interval. Any values for any participant greater than ± 4 μV resulted in additional analyses, minus those participants, within each component of interest. Figure 3.5 shows the grand mean HEOG waveforms for left (dashed line) and right (solid line) waveforms. Figure 3.7 shows vertical and lateral target grand average ERPs for electrodes contralateral and ipsilateral to lateral stimulus presentation, averaged across all conditions.

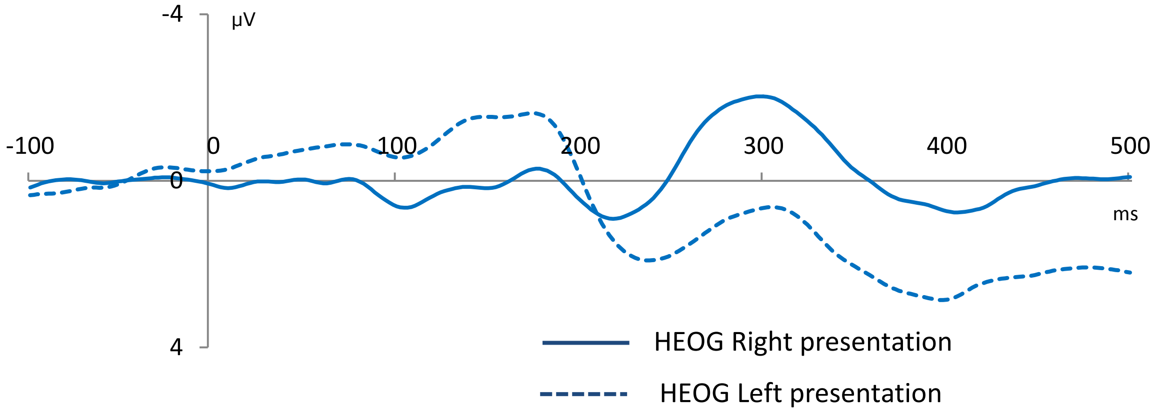


Figure 3.5. Grand average lateral eye-movement (HEOG) for right (solid line) and left (dashed line) stimulus presentation across all conditions.

3.1.3.2.1 Pe: 86-130 ms

Residual lateral eye-movement for the 86-130 ms time interval ranged between -5.60 and 2.27 μV. Mean amplitude values for the Pe were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of target location (vertical, lateral), lateral stimulus salience (1-line, 3-line), and laterality (electrodes contralateral to lateral stimulus, electrodes ipsilateral to lateral stimulus). There was a significant main effect of laterality *F*(1,18) = 22.72, *p* < .001 (η^2_p = .56), where mean amplitudes were more positive for contralateral electrodes (0.43 μV) compared to ipsilateral (-0.08 μV) indicating activity related to the lateral stimulus; a significant main effect of location, *F*(1,18) = 8.66, *p* < .01 (η^2_p = .33), where mean amplitudes were more positive for vertical targets (0.38 μV) compared to lateral (-0.03 μV); and a significant salience x laterality interaction, *F*(1,18) = 4.20, *p* < .05 (η^2_p = .19), where the laterality effect appears greater for the 3-line stimuli, than the 1-line. Also revealed was a trend toward a location x laterality interaction, (*F* = 3.91; *p* = .064).

Paired comparison *t*-tests on the salience x laterality interaction show a significant effect of laterality (contralateral vs. ipsilateral) for the 1-line lateral stimuli, $t(18) = 4.33$, $p < .001$ (2-tailed), where contralateral electrodes (0.26 μV) were more positive compared to ipsilateral (-0.15 μV); and a significant effect of laterality (contralateral vs. ipsilateral) for the 3-line lateral stimuli, $t(18) = 4.55$, $p < .001$ (2-tailed), where contralateral electrodes (0.59 μV) were more positive compared to ipsilateral (-0.01 μV). This indicates that the 3-line lateral stimuli show a greater laterality effect (difference between contralateral and ipsilateral) than the 1-line lateral stimuli (see figure 3.6). There were no other significant main effects or interactions (all *Fs* < 2.9).

Inspection of the residual lateral eye-movement values shows two participants to have values greater than ± 4 μV. These participants were excluded in a follow up analysis. Results are almost identical where a significant main effect of laterality, $F(1,16) = 17.28$, $p < .001$ ($\eta^2_p = .52$), a main effect of target, $F(1,16) = 5.32$, $p < .05$ ($\eta^2_p = .25$), and a significant location x laterality interaction, $F(1,16) = 12.44$, $p < .01$ ($\eta^2_p = .44$) were evident. While the removal of two participants did results in the salience x laterality interaction not reaching significance, this could very well be due to the reduction of power resulting from a lower number of participants. Despite this, these results demonstrate that lateral eye movement is not contributing to the effects reported for the 86-130 ms time interval.

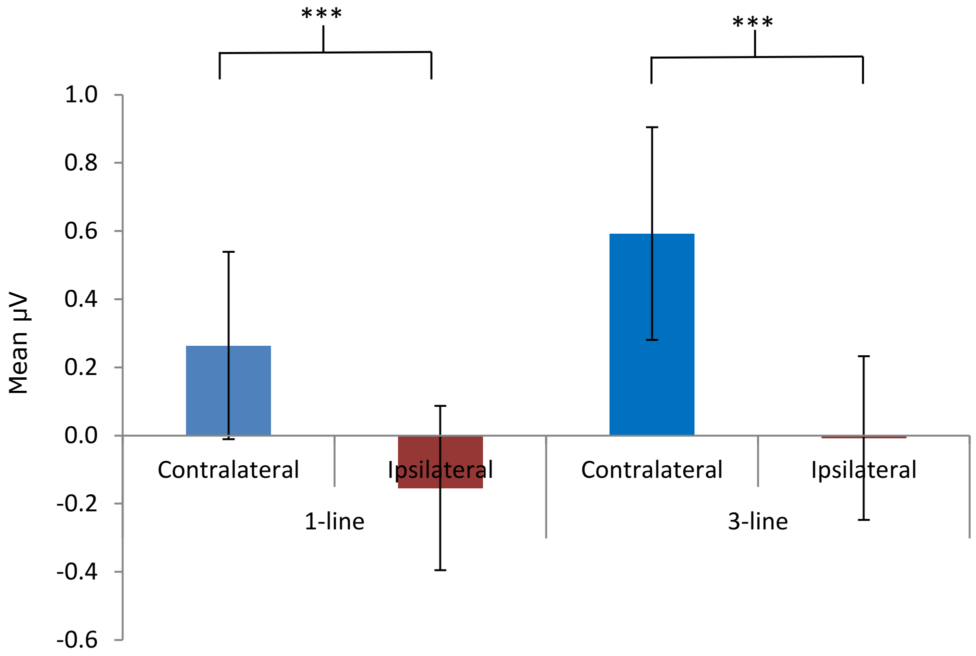


Figure 3.6. Mean amplitudes (µV) for the 86-130 ms (Pe) time interval for salience (1-line, 3-line) x laterality (contralateral, ipsilateral) of vertical and lateral target stimuli (error bars represent 95% CI), *** *p* < .001, indicating the increased laterality of the 3-line lateral stimuli compared to the 1-line. Note: positive is up.

3.1.3.2.2 Nd/Nt: 140-180 ms

Residual lateral eye-movement for the 140-180 ms time interval ranged between -6.88 and 2.27 µV. Figure 3.7 shows mean amplitudes for the Nd/Nt time interval for contralateral vs. ipsilateral of vertical and lateral target stimuli. Mean amplitude values for the Nd/Nt were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of target location (vertical lateral), lateral stimulus salience (1-line, 3-line), and laterality (electrodes contralateral to lateral stimulus, electrodes ipsilateral to lateral stimulus). There was a significant main effect of laterality, *F*(1,18) = 12.26, *p* < .01 (η^2_p = .41), where mean amplitudes where more negative for contralateral electrodes (-0.11 µV) compared to ipsilateral (0.43 µV), indicating activity related to the lateral stimulus. There were no other significant main effects or interactions (all *Fs* < 2.6). The lack of a location x laterality interaction indicates the negativity for the vertical target and the lateral target conditions reflect similar processes, similar to the results of experiments 1 (Nd) and 2 (Nt).

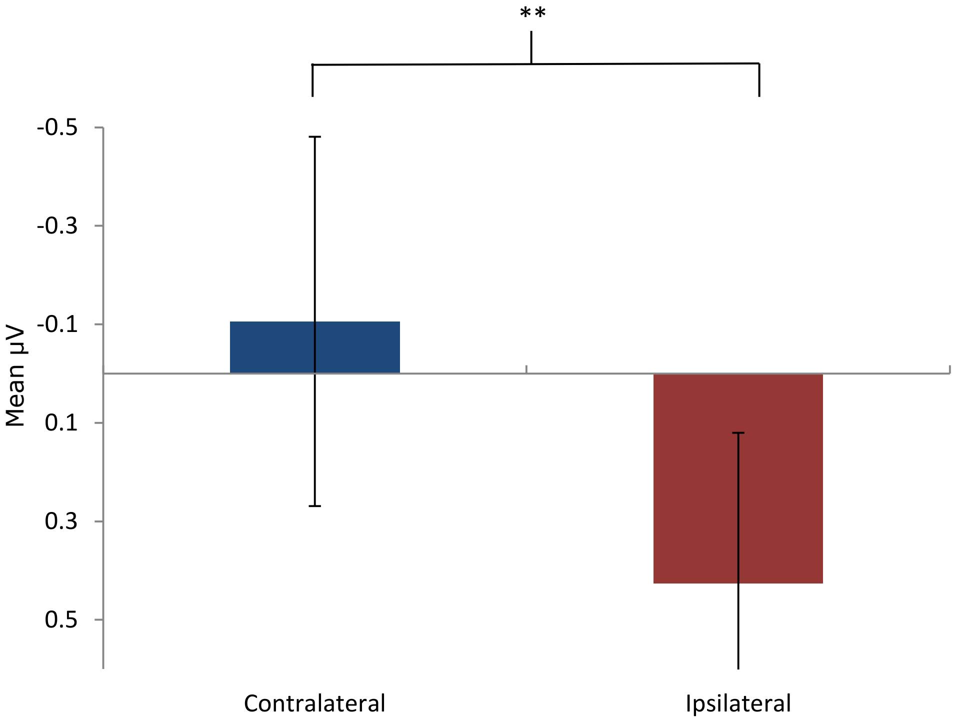


Figure 3.7. Mean amplitudes (µV) for the 140-180 ms (Nd/Nt) time interval for contralateral vs. ipsilateral of vertical and lateral target stimuli (error bars represent 95% CI), ** $p < .01$, indicating the increased contralateral negativity to the lateral stimuli. Note: negative is up.

Inspection of the residual lateral eye-movement values shows five participants to have values greater than ± 4 µV. These participants were excluded in a follow up analysis. Results are identical in that there was only a significant main effect of laterality, $F(1,13) = 9.48$, $p < .01$ ($\eta^2_p = .42$) was evident. These results demonstrate that lateral eye movement is not contributing to the effects reported for the 140-180 ms time interval.

3.1.3.2.3 Pd/Nt$_{(cont.)}$: 180-260 ms

Residual lateral eye-movement for the 180-260 ms time interval ranged between -2.73 and 7.38 µV. Figure 3.8 shows mean amplitudes for the Pd/Nt$_{(cont.)}$ for contralateral vs. ipsilateral of vertical and lateral target stimuli. To investigate the Pd (c.f. Hickey et al., 2009; experiment 1c) as an index of the suppression of attentional capture to an ignored distractor versus the Nt as an index of goal directed attentional selection (c.f. Hickey et al., 2009; experiment 4c), mean amplitude values were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of target location (vertical, lateral), lateral stimulus salience (1-line, 3-line), and laterality (electrodes contralateral to lateral stimulus, electrodes ipsilateral to lateral stimulus). There was a significant location x laterality interaction, $F(1,18) = 38.24$, $p < .001$ ($\eta^2_p = .68$) only, where the laterality effect was in a positive direction (Pd) when the target appeared in the vertical location and in a negative direction (Nt) when the target appeared in the lateral location.

Paired comparison *t*-tests on the location x laterality interaction for show a significant effect of laterality (contralateral vs. ipsilateral) for stimuli in the vertical location, $t(18) = 3.49$, $p < .01$ (2-tailed), where contralateral electrodes (1.50 µV) were more positive compared to ipsilateral (0.92 µV); and a significant effect of laterality (contralateral vs. ipsilateral) for stimuli in the lateral location, $t(18) = 2.93$, $p < .01$ (2-tailed), where contralateral electrodes (1.22 µV) were more negative compared to ipsilateral (1.85 µV), and is consistent with the results of Hickey et al. (2009) for both the Pd and Nt components respectively. There were no other significant main effects or interactions (all *Fs* < 3).

Inspection of the residual lateral eye-movement values shows two participants to have values greater than ± 4 µV. These participants were excluded in a follow up analysis. Results are almost identical where a significant main effect of location x laterality interaction, $F(1,16) = 35.56$, $p < .001$ (η^2_p = .69). These results demonstrate that lateral eye movement is not contributing to the effects reported in the 180-260 ms time interval.

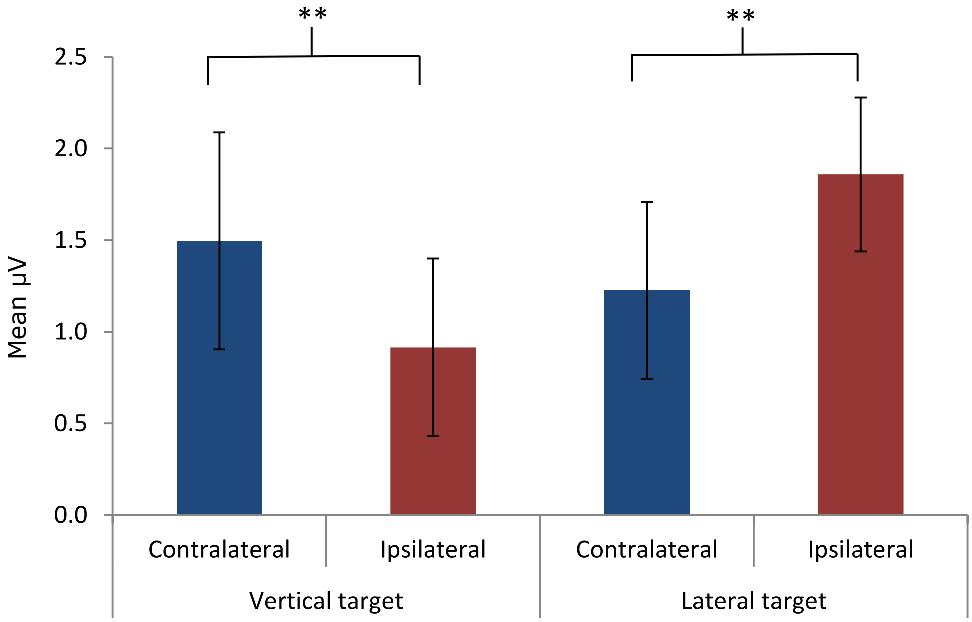


Figure 3.8. Mean amplitudes (µV) for the 180-260 ms (Pd/Nt$_{(cont.)}$) time interval for contralateral vs. ipsilateral of vertical and lateral target stimuli (error bars represent 95% CI), ** $p < .01$, indicating the increased contralateral positivity of the Pd in the vertical task with lateral stimuli as distractor and the increased contralateral negativity of the Nt in the lateral task with lateral stimuli as target.

3.1.3.2.4 Pd$_{(cont.)}$/Pt: 260-360 ms

Residual lateral eye-movement for the 260-360 ms time interval ranged between -4.05 and 13.09 µV. To investigate the Pd as an index of attentional suppression (c.f. Hickey et al., 2009; experiment 4c) vs. Pt as an index of the disengagement of attention via suppression, mean amplitude values were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of target location (vertical, lateral), lateral stimulus salience (1-line, 3-line), and laterality (electrodes contralateral to lateral stimulus, electrodes ipsilateral to lateral stimulus). There was a significant main effect of laterality, $F(1,18) = 19.82$, $p < .001$ ($\eta^2_p = .52$), where mean amplitudes where more positive for contralateral electrodes (5.40 μV) compared to ipsilateral (4.87 μV), indicating activity related to the lateral stimulus (see figure 3.9). There were no other significant main effects or interactions (all *F*s < 3.5). The lack of a location x laterality interaction (F < 1) indicates the positivity for the vertical target and the lateral target conditions likely reflect similar processes, similar to the results of experiments 1 (Pd) and 2 (Pt).

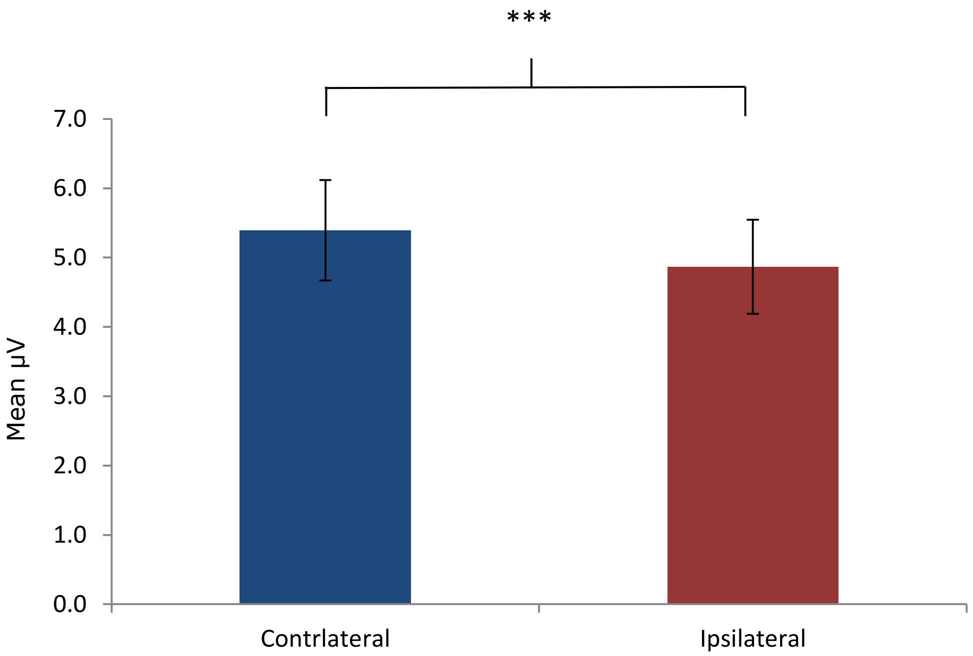


Figure 3.9. Mean amplitudes (μV) for the 260-360 ms ($Pd_{(cont.)}$/Pt) time interval for contralateral vs. ipsilateral of vertical and lateral target stimuli (error bars represent 95% CI), *** $p < .001$.

Inspection of the residual lateral eye-movement values shows seven participants to have values greater than ± 4 μV. These participants were excluded in a follow up analysis. Results are almost identical where a significant main effect of laterality $F(1,11) = 14.04$, $p < .01$ ($\eta^2_p = .56$), and a significant location x salience interaction, $F(1,11) = 6.96$, $p < .05$ ($\eta^2_p = .39$) were evident. While there is an additional location x salience interaction, as this is not lateralised these results demonstrate that lateral eye movement is not contributing to the effects reported in the 250-360 ms time interval.

3.1.4 Discussion

The experiment was designed with the intention that by replicating the original Hickey et al. (2009) experiment manipulation with the inclusion of the vertical target and lateral target tasks in the same participant set, as it would provide the clearest evidence of the Pd and Nt being explicable in terms of processes related to attention. A further aim of the study was to examine whether a manipulation of the perceptual salience of the lateral stimuli would lead to a modulation of the Pd and Nt. This would provide the clearest evidence that the Pd and Nt could be explicable in terms of lower level sensory processes. If these components were in fact the result of lower level sensory processes, it would also be expected that they would be modulated by perceptual salience similarly to components earlier in the waveform known to represent lower level sensory processes.

3.1.4.1 Distractor Positivity (Pd)/ Target Negativity (Nt)

The first aim of the study was to investigate if the Pd would be modulated by changes in the target task (lateral vs. vertical). Results show that in the 180-260 ms time interval there was a location x laterality interaction. For the vertical target task a greater positivity for electrodes contralateral to the ignored stimuli compared to ipsilateral was evident and is consistent with the distractor positivity described by Hickey et al. (2009). For the lateral target task, a greater negativity for electrodes contralateral to the attended stimuli compared to ipsilateral was evident and indicates negative activity related to target processing (Nt). If the Pd and Nt reported by Hickey et al. (2009) were the result of an imbalance of lower level sensory processing, it would reasonable to expect that presenting the same stimulus in each target location condition would result in components of the same polarity. That each condition generated components in the same time interval of different polarities is strong evidence that the Pd and Nt reported by Hickey et al. (2009) are the result of processes related to attention. That the contralateral positivity appeared to an ignored irrelevant lateral stimulus supports the conclusion that the Pd is an index of the attentional suppression of irrelevant information. Likewise, the contralateral negativity appearing in response to an attended relevant lateral stimulus supports the conclusion that the Nt is an index of attentional selection and enhanced target processing. These results subsequently address the first and third aims of the study respectively.

The second and forth aims of the study were to investigate if the Pd and Nt, respectively, would be modulated by lower level attributes of distractor stimuli (i.e. lateral stimuli salience; 1-line, 3-line). In the vertical target condition the Pd appeared at around 180 ms and was observed to extend up to 420 ms (180-260 ms for the Pd/$\text{Nt}_{(\text{cont.})}$ analysis and 260-360 ms for the $\text{Pd}_{(\text{cont.})}$/Pt analysis) and is consistent with the findings of Hickey et al. (2009). No difference was apparent for the 1-line lateral stimuli compared to the 3-line on the laterality of the Pd in either time interval (180-260 ms; 260-360 ms) indicating the Pd was not modulated by changes in the salience of the distractor. Likewise, no difference was apparent for the 1-line lateral stimuli compared to the 3-line on the laterality of the Nt in either time interval (140-180 ms; 180-260 ms) indicating the Nt was not modulated by changes in the perceptual salience of the distractor. Notably, a positive posterior contralateral (Pe) was again apparent in the P1 time range that appeared to show a very similar pattern of results as the positive posterior contralateral (Pe) observed in experiments 1 and 2. In the present experiment, the significant salience x laterality interaction of the Pe demonstrates that the laterality for the 3-line stimulus was greater compared to the 1-line stimulus, which would be expected for a component that reflects processes related to the lower level sensory features of stimuli that were presented in one visual field only. If the Pd or Nt were due to the same imbalance in sensory level processing it would be reasonable to expect that they would be similarly modulated by changes in the salience of the lateral stimulus. That one component is modulated by the salience of the lateral stimulus (Pe) and other components are not (Pd, Nt), indicates they represent different neural processes. These results and those of experiment 1 support the conclusions of Hickey et al. (2009); Sawaki et al. (2012); and, Sawaki and Luck, (2013) that the Pd represents attentional processes related to the suppression of the ignored lateral distractor and the Nt represents attentional selection of the lateral attended stimuli and neither represent a hemifield imbalance of lower level sensory energy.

3.1.4.2 Distractor Positivity (Pd) / Target Positivity (Pt)

As illustrated in figure 3.7 (vertical target condition), a Pd continues through to 420 ms which allowed for the comparison with a positivity observed in the lateral target condition (Pt) that appeared in the same time interval. Mean amplitudes for the 260-360 ms time interval were more positive for contralateral than ipsilateral locations, which indicates a positivity related to the distractor. The conclusion that the Pd is representative of suppression of the ignored distractor, and given the Pd and the Pt display the same polarity and are evident in the same time interval, leads to the conclusion that the Pt must also represent suppression of the lateral stimuli. Again, the Pt showing a different pattern of results to the earlier Pe suggests that the Pe and Pt likely represent different neural processes and that the co-occurrence of the Pd and Pt is unlikely to be due to an imbalance in sensory energy. In the vertical target condition, the positivity is most likely a continuation of the Pd; however, for the lateral target condition, the lateralised positivity begins after the Nt, which is thought to represent attentional selection similar to that of the N2pc (Sawaki & Luck, 2013, 2014). In the lateral target condition attention is directed from central fixation to the lateral image and is reflected in the Nt present between 140 and 260 ms. A lateral positivity (Pt) arising after the selection of the target indicates activity potentially related to the termination of target selection via suppression as has been described previously by Sawaki et al. (2012) and Sawaki and Luck (2013). It is possible to understand how this rapid reorienting occurred because ERPs provide a continuous measure of processing in the period between the onset of the stimulus array and the response to the target. Previous research has shown that shifts of attention may be followed by inhibition of return (IOR) to that location (Klein 1988, 2000; Posner & Cohen, 1984). IOR is typically observed beginning 300 ms after a transient shift of attention and is signified by a slowing of RTs for targets appearing at a previously attended location. While IOR is typically observed only after exogenously driven shifts of attention (Müller & Findlay, 1988), the present study investigated the termination of both exogenous and endogenous shifts of attention. Additional research is needed to determine whether the Pd and Pt (i.e. suppression & disengagement via suppression) reflect similar neural mechanisms that underlie the IOR.

3.1.4.3 Distractor Negativity (Nd) / Target Negativity (Nt)

Figure 3.7 also shows a negativity for the vertical target condition in the 140-180 ms time range, indicating that the Nd in the vertical target and Nt in the lateral target conditions do not differ significantly on either measure of location (lateral, vertical) or salience (1-line, 3-line). The Nt and Nd display a similar pattern of results, indicating that they likely represent very similar processes where the latter may represent stimulus driven attentional capture and the former goal directed attentional selection of the lateral stimuli. Given there was no effect of salience for either the vertical or lateral conditions in this time interval suggests that both reflect attentional processes; one stimulus driven attentional capture (Nd) by the lateral ignored stimulus and the other goal directed attentional selection (Nt) of the lateral attended stimulus. Presumably the salience of the lateral stimuli (in the vertical condition) generated an attend-to-me signal irrespective of whether it was a 1-line or 3-line stimulus and the signal was greater relative to the top-down task set, subsequently capturing attention. The 1-line distractor did not appear to capture attention in the Hickey et al. (2009) study, but did appear to capture attention in the present replication. The likely reason is that the 1-line and 3-line stimuli were not matched for luminance with the background as was carried out in the Hickey et al. (2009) series of studies, possibly resulting in overall greater attend-to-me signals than those generated by the stimuli in the Hickey et al. experiments. It is noteworthy that if the Nd seen here does represent attentional capture similar to that of the N2pc noted in previous studies (e.g. Eimer & Kiss, 2007; Holmes et al., 2009; Holmes et al., 2014), the following Pd must therefore represent both the disengagement of attention from the lateral stimuli (as attention was localised there due to capture) and its subsequent suppression, and may form part of the reason for the extended Pd (from 180 ms to approx. 420 ms) of the present experiment compared to Hickey et al. (2009; figure 4c), however this is also likely to be due to the absence of a behavioural response limit that was imposed in the Hickey et al. (2009) experiments, but was not imposed in the present experiment. The extended Pd was not observed in experiment 1, which consists of a very similar design, where a 1000 ms response limit was imposed.

It is difficult to be absolutely certain that the Pd effect observed following the Nd in Experiment 1 reflects a similar attentional effect to the Pt observed following the Nt in Experiment 2 (and for other types of salient distractors in previous studies; Hickey et al., 2009; Kiss et al., 2012; Sawaki & Luck, 2010, 2011). It is equally difficult to be absolutely certain that the Nd effect observed in Experiment 1 reflects a similar attentional effect as the Nt observed in Experiment 2. However, given that only a small fraction of neural processes will lead to a recordable scalp ERP effect, the identical polarity and similar scalp distributions of these effects make it very likely that they reflect very similar underlying neural processes (see Kappenman & Luck, 2012). That the Nt has been shown to represent attentional selection of a lateral attended target (Hickey et al., 2009) and given that the Nd is showing an identical pattern of results in the same within subjects experiment as the Nt, it is reasonable to conclude that the Nd reflects attentional facilitation of the lateral stimuli. That the stimuli in this instance are ignored leads to the conclusion that the Nd is stimulus driven attentional capture of the lateral irrelevant stimuli.

Chapter 4: The influence of reduced executive control resources on the allocation of attention to task-irrelevant threat

4.1 Experiment 4

The comparison of results from experiment 1 and 2 and the results of experiment 3 provided support for the conclusion that the distractor negativity (Nd) is similar to the target negativity (Nt) and very likely reflects activity related to stimulus driven attentional capture of the ignored lateral stimulus. However, some caution must still be taken with this interpretation as sensory factors, at this stage, cannot be completely ruled out. Additionally, for experiments 1 and 2, the negative results relating to the effects of valence (anger vs. neutral) on the components representing stimulus driven attentional capture and suppression contrast with some (e.g., Mogg & Bradley, 1999; experiment 2) but not all previous findings. Notably, Holmes et al. (2014) found evidence of an N2pc to threat faces under conditions of high WM load, but not low WM load. It could therefore be the case that the availability of cognitive resources for suppression of task irrelevant threat may be an important factor in determining the presence of threat related attentional bias. An overall aim of the present study is therefore to explore this possibility.

Mixed results in attentional selection research has fuelled a longstanding debate between early and late-selection views of attention over the extent to which selective attention can prevent the processing of task-irrelevant distractors (Lavie, 2000, 2005, 2006). On the one hand, focusing attention on task-relevant stimuli can exclude distractors from early perceptual processing (an 'early' selection effect); on the other, it can prevent distractors from controlling behaviour and memory (a 'late' selection effect; Lavie, 2005). The debate between early vs. late selection has recently been rekindled by claims of threat related distractors holding a *special* status in attentional selection (Bishop et al., 2007) compared to non-threat. Specifically, a number of neuroimaging studies investigating amygdala response have reported that the response to threat-related stimuli (i.e., fearful faces) is not modulated by attentional focus (c.f. Vuilleumier et al., 2001; Dolan & Vuilleumier, 2003) which has led to the suggestion that threat-related stimuli may be processed ''automatically'', irrespective of the availability of attentional resources (Bishop et al., 2007).

It has been suggested that the emotion system evaluates objects in order to prioritise them relative to current and future goals (e.g., Ortony, Clore, & Collins, 1988) and that it can operate in a stimulus driven bottom-up way (Vuilleumier & Huang, 2008), against the intention of the observer. The competition bias model argues that the representation of threat, over competing stimuli, is biased by the amygdala by means of feedback to sensory processing areas of the brain (Pessoa, 2009; Pourtois et al., 2013; Vuilleumier, 2005). It has been proposed that neural circuitry, centred on the amygdala, supports specialized emotion processing systems that mediate threat-related attentional capture, prioritizing the attentional selection of stimuli with a high level of importance (Vuilleumier & Huang, 2009). Some studies report that the amygdala is activated when participants view threat related faces (e.g., fearful), even when those faces are masked (Morris, DeGelder, Weiskrantz, & Dolan, 2001), demonstrating that the amygdala is specialized for the fast detection of emotionally relevant stimuli in the environment and that this can occur without attention or even without conscious awareness.

Enhanced perceptual representation of stimuli as a result of attention induced by emotion has been demonstrated by behavioural experiments (Phelps et al., 2006; Bocanegra & Zeelenberg, 2009, 2011; Brosch, Pourtois, & Sander, 2010). Visual search (Eastwood, Smilek, & Merikle, 2001; Öhman et al., 2001), attentional blink (Keil & Ihssen, 2004; Anderson, 2005), and spatial orienting paradigms (Armony & Dolan, 2002; Pourtois, Grandjean, Sander, & Vuilleumier, 2004) have shown faster and/or more accurate detection of threat-related compared to neutral stimuli, indicating threat-related stimuli capture attention more rapidly and/or easily than non-threat-related stimuli. Some research has suggested that when processing resources are fully engaged by another task, threat-related distractors do not capture attention more than do neutral distractors (Pessoa & Ungerleider, 2004). However, others have shown (c.f. Holmes et al., 2014) that the depletion of cognitive control resources, using a working memory manipulation, increases the capacity of task irrelevant threat-related cues to capture and hold attention.

It has been suggested that 'automaticity' in emotion processing should be more clearly defined (Moors & De Houwer, 2006). Some emotion processing effects may be automatic in that they can arise without, or even against, conscious control yet still require attentional resources (Okon-Singer, Tzelgov, & Henik, 2007). Conversely, perceptual processing can be unconscious but not automatic, as shown for effects of expectation on priming (Kiefer, 2007).

Enhanced perceptual processing by selective attention is thought to be the result of the top-down modulation of the sensory cortex by higher-level regions in parietal and frontal cortex (Kastner & Ungerleider, 2000). For example, enhanced perceptual representations of threat may arise due not only to amygdala feedback, but also to fronto-parietal modulation of top-down biasing signals. This enhancement may be driven by exogenous factors such as abrupt changes and sensory salience of external inputs (e.g. loudness, brightness, pop-out, etc.) or by endogenous factors related to current goals (Vuilleumier, 2005). Although this goal-driven selective attention clearly plays a key role in the control of perception and behaviour, it could also be harmful if significant events, particularly those of a threatening nature, occurring outside the current focus of voluntary attention, are totally ignored (Vuilleumier, 2005). Evolutionarily, it would be advantageous if unexpected events, especially those of a threatening emotional nature, could be monitored and detected to some extent independently of the current attentional goal driven top-down task set. A monitoring process such as this would also act to redirect processing resources and promote shifts of attention to a new focus of interest.

Selective attention usually allows for, with minimal intrusions from goal-irrelevant information, the efficient and focused processing of goal-relevant stimuli (Lavie, 2001). In situations where irrelevant as well as relevant stimuli are processed, a second, more active control function becomes prominent (Lavie, 2001). In such cases, active control of attention is crucial for suppressing response tendencies toward the irrelevant, yet processed distractors (Lavie, 2001; Hickey et al., 2009; Sawaki & Luck, 2010, 2011). Active control may be crucial not only for the suppression of response tendencies, but also for the suppression of perceptual and cognitive processes. Efficient ‘‘pre-attentive’’ processing of, and stimulus driven attentional capture by, threat-related stimuli may be reflective of a default type mode of processing, perhaps due to the high relevance of threat-related stimuli, but such readiness could be enhanced or suppressed depending on factors such as the context in which the threat is present or factors related to the individual (Vuilleumier & Huang, 2008).

Studies using behavioural measures (e.g., Mogg & Bradley, 1999; Nummenmaa, Hyönä, & Calvo, 2009; Öhman, Flykt, & Esteves, 2001) or the N2pc (e.g., Eimer & Kiss, 2007; Holmes et al., 2009) have indicated that attention is preferentially attracted by threat-related stimuli. In a series of studies using a modified version of the dot-probe task, Mogg and Bradley (1999) investigated whether individuals preferentially allocated attention to the spatial location of threatening faces presented outside awareness. Results showed that the pre-attentive processing of masked threat faces resulted in attentional orientation toward that location. More recently, in a study investigating attentional capture of task irrelevant threat faces, Eimer and Kiss (2007) had participants detect infrequent luminance changes of a fixation point while task irrelevant fearful and neutral faces were presented either singularly next to or to the left and right of fixation. Results show that the N2pc was elicited on trials where fearful faces were presented next to fixation irrespective of if the luminance of fixation was modulated or if the face were singletons or were presented along with a neutral counterpart. Additionally, results of this study show that the N2pc to fearful faces was modulated by a change in luminance of fixation, indicating that concurrent target processing reduces attentional capture by emotional salient stimuli (Eimer & Kiss, 2007).

Active control processes ensure that low-priority irrelevant items can be suppressed by relying on higher mental functions, such as working memory, which are required to maintain current priority of attention (Lavie, 2005). Conversely, task-irrelevant information may be less likely to be effectively inhibited if executive control resources are weak or depleted; that is, under high simultaneous WM load, threat-related (relative to neutral) distractors may be more likely to intrude into the focus of attention due to insufficient executive attention resources to suppress their processing (Holmes et al., 2014). While other research has shown in increase in inhibition to irrelevant distractors under high WM load (de Fockert, Rees, Frith, & Lavie, 2001). Other research has shown no effect of manipulating simultaneous WM load on the discrimination of emotional (vs. neutral) stimuli (e.g., Phillips, Channon, Tunstall, Hedenstrom, & Lyons, 2008), while others (e.g., Van Dillen, Heslenfeld, & Koole, 2009) have shown a reduced amygdala response to aversive stimuli that were viewed immediately before the cognitive load in an arithmetic task. Unfortunately, with the exception of de Fockert et al. (2001), these studies did not directly examine effects of working memory (WM) load on the allocation of attention to task-irrelevant threat or its effortful suppression.

In sum, focusing attention on task-relevant stimuli can prevent distractors from controlling behaviour and memory, but it may also exclude distractors from early perceptual processing. The debate between early vs. late selection has recently been rekindled by claims of threat-related distractors holding a special status with the suggestion that threat-related stimuli may be processed automatically, irrespective of the availability of attentional resources. Some have suggested that when processing resources are fully engaged by another task, threat-related distractors do not capture attention more than do neutral, while others have shown that the depletion of cognitive control resources increases the capacity of task irrelevant threat-related cues to capture and hold attention. Neuroimaging and behavioural data have indicated that emotional influences on attention are modified by processing strategies or task goals suggesting that emotional processing can be differentially modulated by the availability of attentional resources. This control can be driven by exogenous factors such as abrupt changes and sensory salience of external inputs or by endogenous factors related to current goals. It may be that under conditions of limited attention emotional information is prioritized in a way that it receives privileged access to attention and awareness. While some studies have shown no effect of manipulating simultaneous cognitive load on the discrimination of emotional (vs. neutral) stimuli, others have shown a reduced amygdala response to aversive stimuli that were viewed immediately before a cognitive load task. However, no study has thus far conducted a direct examination of the effects of WM load on the allocation of attention to task-irrelevant threat where the suppression of task irrelevant information can be studied independently of attentional selection.

The main aim of the present study is to examine the effects of WM load on the allocation of attention to task-irrelevant threat. If by increasing WM load on higher mental functions results in a drain on the capacity for active control of attention, it may be that the increased WM load results in less available resources to suppress irrelevant information while maintaining attentional task priority. Consequently, the first specific aim of the study is to investigate the effect of WM load on distractor suppression as measured by the Pd. The second aim of the study is to investigate whether the effect of WM load on suppression, as measured by the Pd, is affected by the emotional valence of the distractors (angry vs. neutral).

Additionally, results of experiments 1 and 3 indicate an early negativity (Nd) that is likely related to a process of unintended attentional capture of the ignored lateral stimuli and that appears similar to the Nt of experiment 2. If the

Nd is representative of stimulus driven attentional capture, and, if by increasing the load on higher mental functions results in a drain on the capacity for active control of attention (i.e., suppression) which subsequently results in more, rather than fewer, intrusions from irrelevant distractors, it would be evident that under high WM load, the ignored distractor would more readily capture attention compared to under low WM load. Therefore, the third aim of the study is to investigate the effect of WM load on attentional capture as indexed by the distractor negativity (Nd). Additionally, if the Nd is representative of attentional capture similar to that of the Nt (Hickey et al., 2009) or N2pc observed in other studies (c.f. Eimer & Kiss, 2007; Holmes et al., 2009; Holmes et al., 2014), then it would be reasonable to expect the Nd to be modulated similarly by threat-related information. Consequently, it would be expected that attentional capture by the threat-related distractor would be enhanced under high WM load (compared to low) which would be revealed by an increased Nd for angry faces compared to neutral. Therefore, the final aim of the study is to investigate the effect of WM load on the attentional capture of threat-related distractor information as indexed by the distractor negativity (Nd).

4.1.1 Method

4.1.1.1 Participants

Thirty healthy volunteers from the University of Roehampton received course credit for participation. Four participants were excluded, one because of excessive eye blinks/movements and three because of eye blinks/movements and low accuracy, either of which resulted in <50% trials remaining. Therefore, 26 participants (3 male and 23 female; 18–27 years old; M: 20.62 years; SD: 2.38) remained in the sample. All participants had normal or corrected-to-normal vision and all were right-handed. The experiment was performed in compliance with The University of Roehampton ethical and research guidelines and was approved by the University ethics committee.

4.1.1.2 Stimuli and Apparatus

The stimuli and procedure were identical to those of experiment 1, except as follows. To minimise the influence of any systematic ERPs that might relate to the prediction of trial onset and to ensure attention was located on fixation at the onset of each trial, fixation was randomly presented for either 1250, 1300, 1350, 1400, 1450, 1500, 1550, 1600, 1650, 1700, or 1750 ms (see figure 4.1 for stimuli presentation sequence). The shape stimuli (square or diamond) were presented in one of three colours, green, blue, or red. The specific hues used to define the shape-stimuli were green (RGB = 0, 206, 0; 1.5 cd/m2), blue (RGB = 0, 0, 255; 0.80 cd/m2) and red (RGB = 237, 0, 0; 1.12 cd/m2). All were substantially more luminous than the background (0.19 cd/m2). Only intact face stimuli were presented as distractors and were the same intact face stimuli (neutral, angry) used in experiments 1 and 2.

4.1.2 Procedure

At the beginning of each session, after informed consent was given, participants completed the state and trait sections of the STAI (see Appendix B). The experiment itself consisted of 12 blocks of 144 trials for a total of 1728 trials per participant. The entire session was comprised of two task conditions, each consisting of 6 successive experimental blocks with half the participants receiving the low load condition first and half the high load condition first. In the low WM load condition, a shape stimuli appeared 80% of the time along with the face stimulus and 20% of the time a face stimulus appeared alone without a shape stimulus. While maintaining focus on the central fixation point, participants were instructed to press, with their dominant hand via a response box, the left button with their index finger to indicate when the target (either square or diamond of any colour) appeared on the screen (target present) and the right button with their middle finger to indicate if no shape appeared (target absent), with the remaining half of participants using the opposite response map. In the high WM load condition, while focusing on the central fixation, participants were instructed to monitor the upper or lower presented shape and to respond, with their dominant hand via a response box, by pressing the left button with their index finger to indicate when the shape stimulus presented was identical (in terms of shape and colour) to the shape presented in the previous trial (shape repeat; 20% of trials) and the right button when the shape stimulus was different to that of the previous trial (shape non-repeat; 80% of trials). As in experiments 1 and 2, each trial presentation consisted of two stimuli presented in the same hemi-field; one face stimulus (presented with equal probability in one of the 4 lateral positions) and one shape stimulus (presented with equal probability in either upper or lower positions on the vertical meridian). The array remained on the screen until either a participant's response was detected or 1000 ms passed, following either of which a new trial began after an inter-trial interval of 500 ms. In the low WM load (detect) condition, each block consisted of 96 target-present and 24 target-absent trials, thus, there were 576 target present trials and 144 target-absent trials in total, with only target present trials included in the analysis. In the high WM load (repeat) condition, each block consisted of 96 non-repeat trials and 24 repeat trials, totalling 576 non-repeat trials and 144 repeat trials in total, only non-repeat trials were included in the analysis.

Before each condition, a practice block consisting of 32-trials was administered for participant training. The stimulus arrays and timings of the practice blocks were identical to the trials in each of the experimental conditions, except only neutral faces were presented as lateral stimuli. Participants were required to achieve 70% accuracy (was set to 80% in experiments 1, 2, & 3) before they could proceed to the experimental sections to allow for the increased difficulty (and expected reduced accuracy) of the high WM load task.

4.1.2.1 EEG Data Acquisition

EEG acquisition was identical to experiment 1 with the exception of the use of a 64 channel array with placement according to the international 10-20 system. Separate means were computed for all combinations of WM load (low vs. high), distractor valence (angry face vs. neutral face), and laterality (electrodes contralateral vs. ipsilateral to location of distractor). Visual inspection of the waveforms resulted in the identification of three main contralateral (to the distractor) ERP components in the lateral posterior area. These were assessed for the current study with reference to the side of the face distractor; namely, an positive posterior contralateral (Pe) beginning around 60 ms; a distractor negativity (Nd) beginning around 120 ms, and a distractor positivity (Pd; cf. Hickey et al., 2009) beginning around 180 ms. As in experiments 1 and 2, these components were individually measured at their respective time windows from the mean of the five left posterior parieto-temporal electrodes; P3, P7, PO3, PO7 and O1 and five right posterior parieto-temporal electrodes; P4, P8, PO4, PO8 and O2, as this is where maximal activity was apparent for each component (to match experiment 1 & 2; see figure 3.2 for electrode cluster positioning).

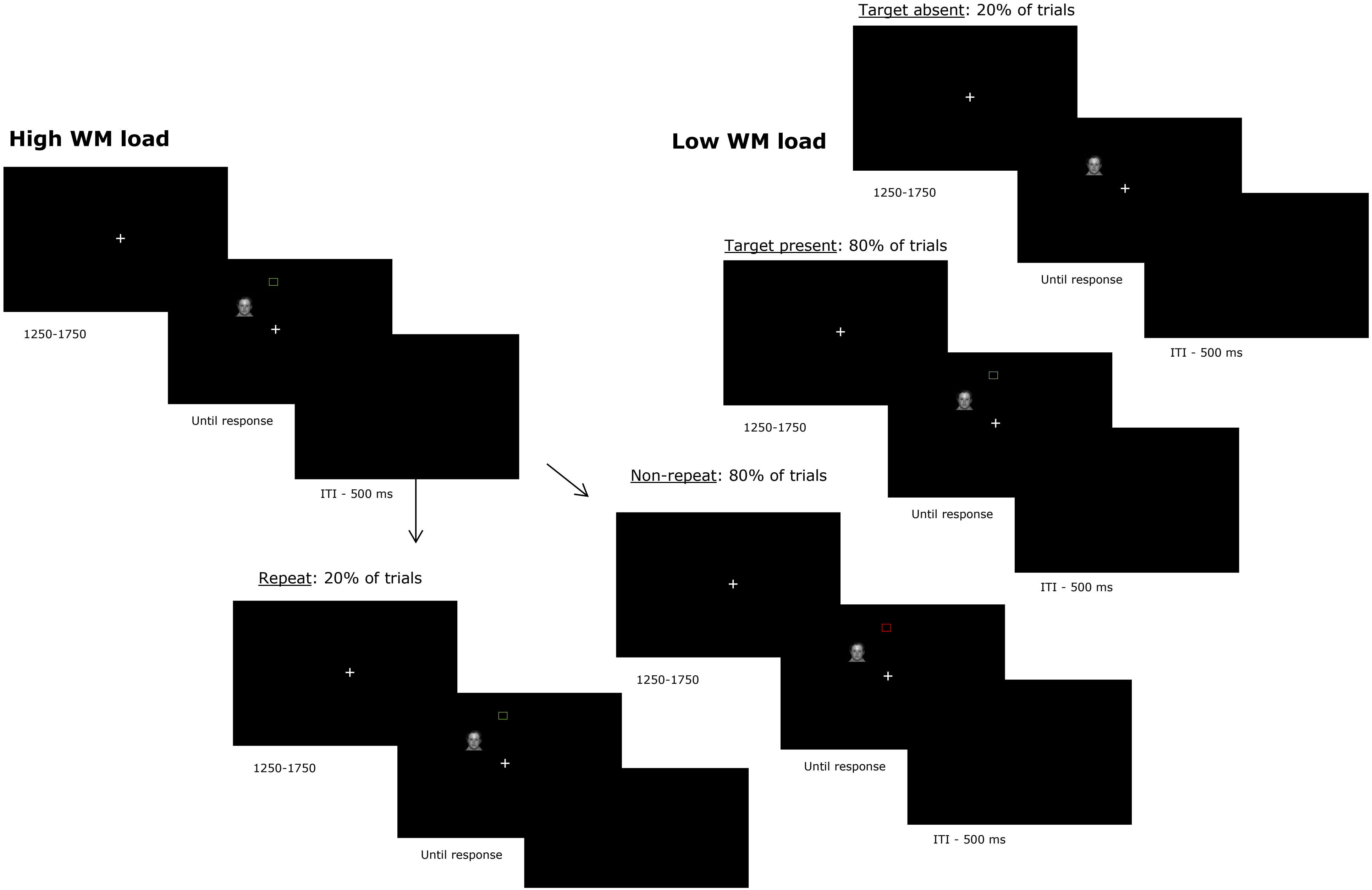


Figure 4.1. Presentation sequence containing low WM load and high WM load conditions.

The early contralateral positivity (Pe) was defined as the mean amplitude between 60-110 ms post-stimulus presentation, overlapping the P1 time window (c.f. Luck & Hillyard, 1994a; Batty & Taylor, 2003). The distractor negativity (Nd) was defined as the mean amplitude between 120-180 ms post-stimulus presentation. The distractor positivity (Pd) was defined as the mean amplitude between 180-250 ms post-stimulus presentation (c.f. Hickey et al., 2009). Figure 4.5 shows the contralateral and ipsilateral ERPs observed at the posterior parietal electrode sites. With respect to the low load condition, mean amplitudes were automatically extracted for trials where the target was present (80% of total) and for the high load task trials were extracted that were not repeats (80% of total) across all components.

4.1.3 Results

Non-responses and trials with errors were discarded, as were any with RTs less than 200 ms (18.4% of all responses). As with experiments 1, 2, and 3 analyses were collapsed across shape types and presentation locations, to eliminate sensory confounds related to these factors (c.f. Sawaki & Luck, 2010). When using ANOVAs to determine statistical effects, partial eta-squared (η^2_p) are reported as an estimate of effect size for every significant effect found.

4.1.3.1 Behavioural measures

4.1.3.1.1 Reaction time (RT)

Mean correct RTs are shown in table 4.1. Planned comparisons of mean RT for each condition were entered into a 2 x 2 repeated measures analysis of variance (ANOVA), with factors of WM load (low, high), and distractor valence (angry, neutral). There was a significant main effect of load, $F(1,25) = 46.30$, $p < .001$ ($\eta^2_p = .65$) where responses were faster for the low WM load (492 ms) compared to the high (567 ms), indicating the manipulation was effective and the increased effort required for the high WM load task resulted in a significant slowing of reaction time to compensate. There were no other significant effects or interactions (all *Fs* < 1.5).

Table 4.2 *Mean (SD) number of correct responses for each condition. Scores out of 72*

	Low WM load	High WM load
Neutral	68.1 (5.2)	61.9 (10.7)
Angry	68.2 (5.6)	58.1 (7.7)

4.1.3.2 EEG measures

Figure 4.2 shows low and high WM load grand average ERPs for electrodes contralateral and ipsilateral to distractor presentation, averaged across all conditions. To ensure lateral eye-movement does not contaminate the ERPs being measured, residual lateral eye movement were calculated as the difference for distractor-left minus distractor-right presented trials of the HEOG channel. This will allow for direct comparison with each component of analysis for the same trials, in the same time interval. Any values for any participant greater than ± 4 μV resulted in additional analyses, minus those participants, within each component of interest. Figure 4.3 low and high working memory load lateral difference activity for each time interval and figure 4.4 shows the grand average HEOG waveforms for left (color of line) and right (colour of line) waveforms.

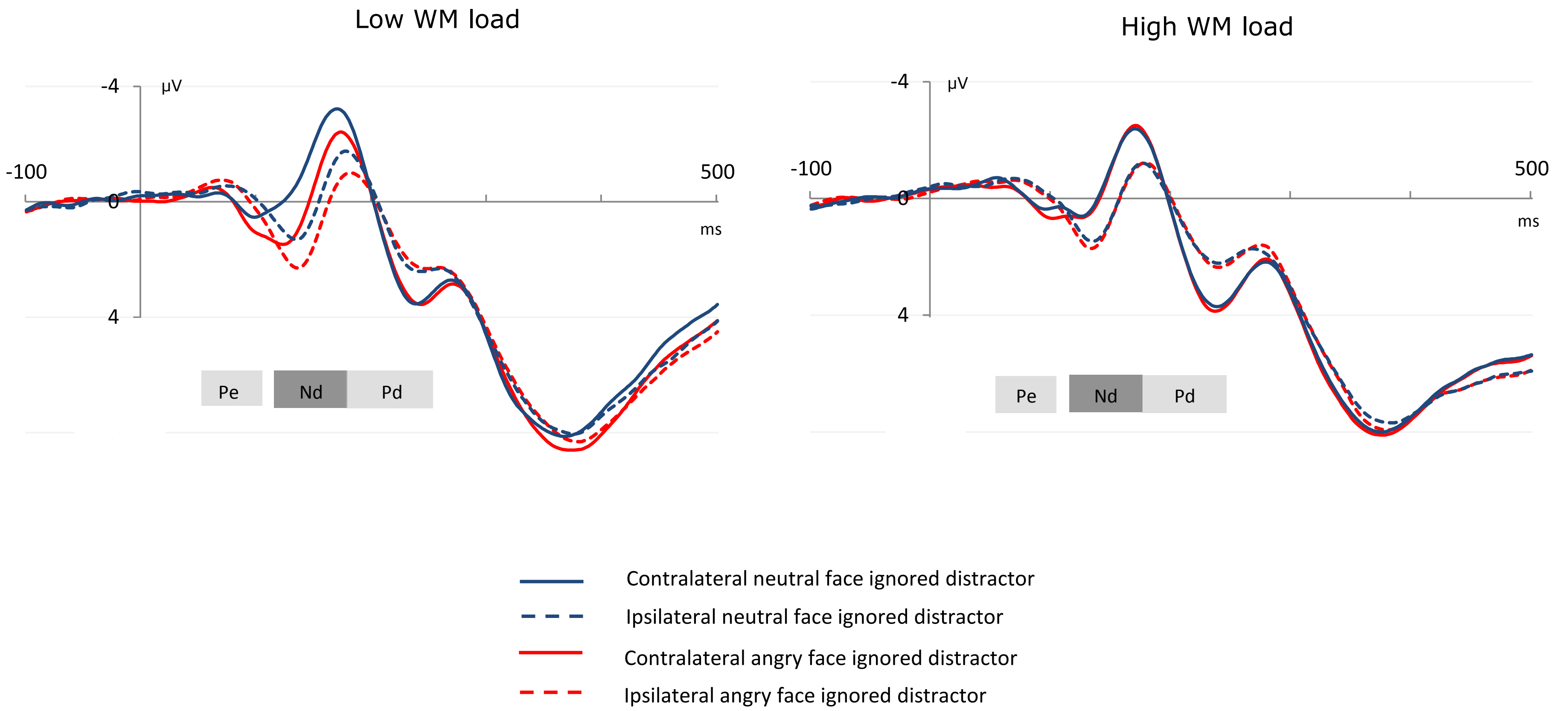


Figure 4.2. Low and high WM load task grand average ERPs for ignored neutral and angry face distractor. The 60-110 ms (Pe); 120-180 ms (Nd); and 180-250 ms (Pd) time intervals are depicted.

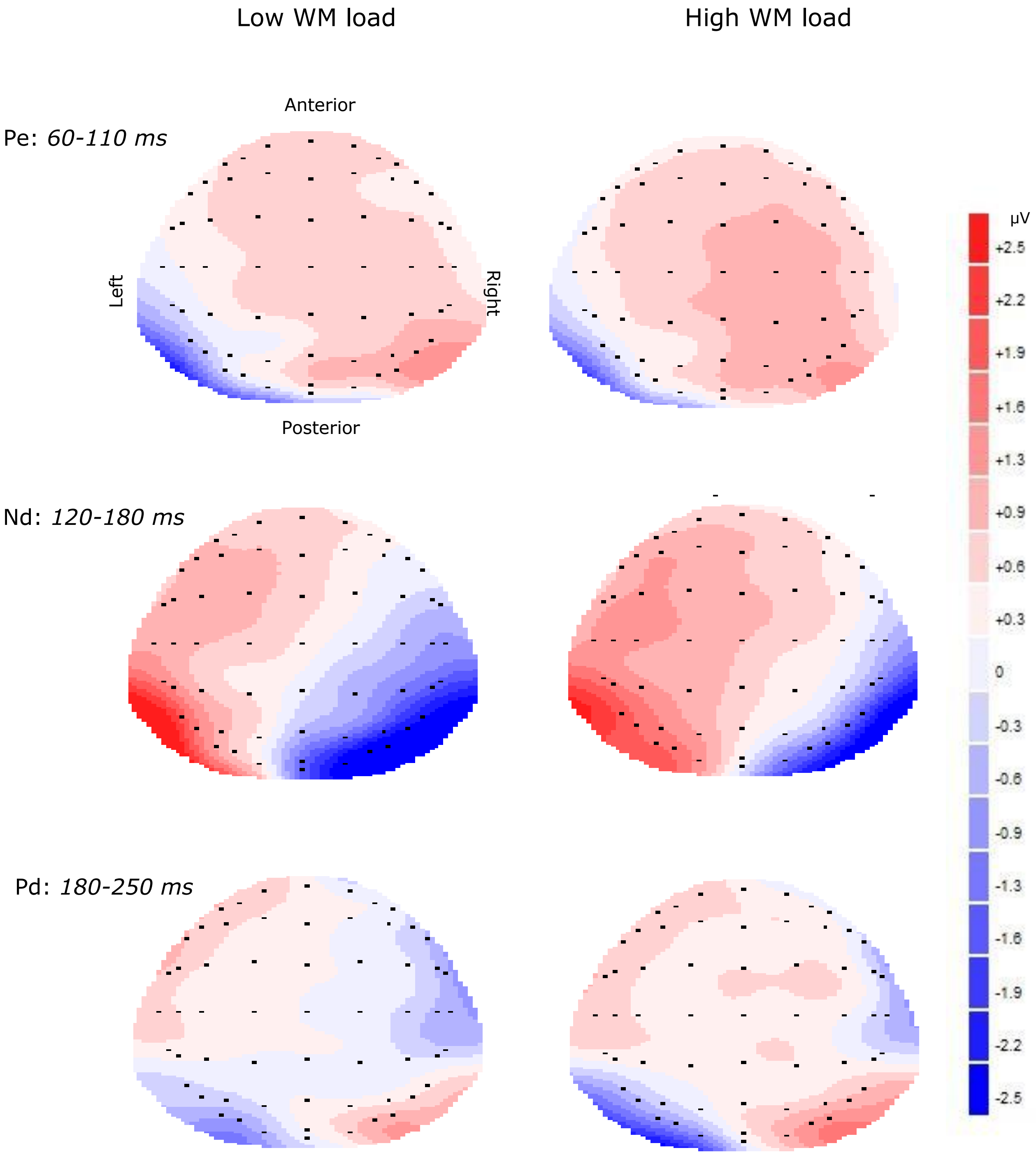


Figure 4.3. Low WM load (left) and high WM load (right) task laterality difference activity (activity of left presented ignored distractor minus activity right presented ignored distractor) for each time interval in analysis.

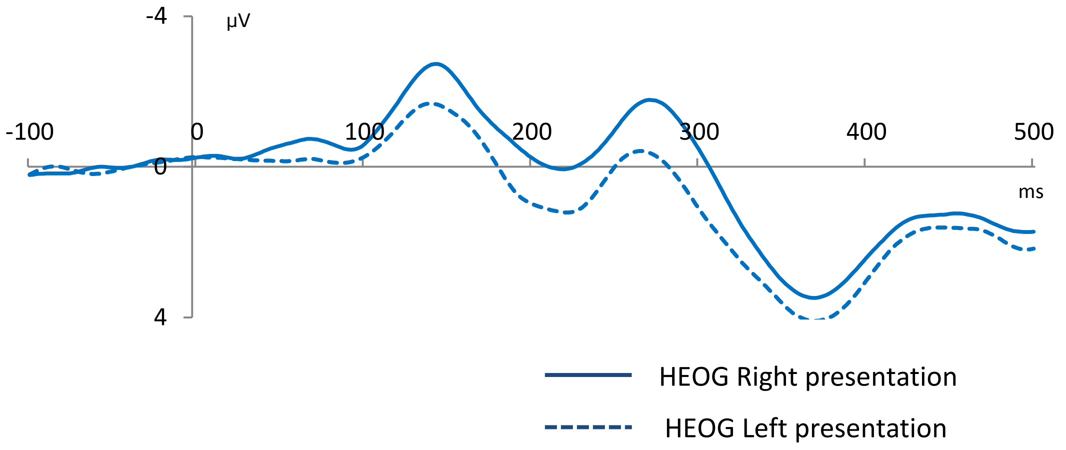


Figure 4.4. Grand average lateral eye-movement (HEOG) for right (solid line) and left (dashed line) stimulus presentation across all conditions.

4.1.3.2.1 Pe: 60-110 ms

Residual lateral eye-movement for the 60-110 ms time interval ranged between -1.62 and 2.54 μV. Mean amplitude values for the Pe were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of WM load (low, high), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality $F(1,25) = 16.98$, $p < .001$ ($\eta^2_p = .40$), where mean amplitudes where more positive for contralateral electrodes (0.17 μV) compared to ipsilateral (-0.30 μV) indicating activity related to the distractor. There were no other significant main effects or interactions (all *F*s < 3).

4.1.3.2.2 Nd: 120-180 ms

Residual lateral eye-movement for the 120-180 ms time interval ranged between -1.47 and 2.64 μV. Mean amplitude values for the Nd were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of WM load (low, high), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality *F*(1,25) = 32.88, $p < .001$ ($\eta^2_p = .57$) where mean amplitudes were more negative for contralateral electrodes (-1.07 μV) compared to ipsilateral (0.43 μV) indicating the presence of the Nd; a significant main effect of valence *F*(1,25) = 35.18, $p < .001$ ($\eta^2_p = .59$) were mean amplitudes where more negative for angry face distractors (-0.62 μV) compared to neutral (-0.02 μV); also revealed was a significant load x laterality interaction, *F*(1,25) = 8.26 $p < .01$ ($\eta^2_p = .25$), as the laterality effect was greater for the low load than for the high load task (see figure 4.2); a significant load x valence interaction, *F*(1,25) = 15.38, $p < .01$ ($\eta^2_p = .38$), as the valence effect was greater for the high load than for the low load task; and a significant load x valence x laterality interaction, *F*(1,25) = 4.87, $p < .05$ ($\eta^2_p = .16$).

The significant load x valence x laterality interaction was investigated by performing two valence x laterality ANOVAs for each level of WM load (low, high). Results show, for low WM load, a significant effect of laterality, *F*(1,25) = 31.76, $p < .001$ ($\eta^2_p = .61$), where electrodes contralateral to the ignored distractor were more negative (-0.90 μV) than ipsilateral (0.81 μV); and a significant valence x laterality interaction, *F*(1,25) = 4.93, $p < .05$ ($\eta^2_p = .17$), where the laterality effect appears greater for angry face distractors compared to neutral; however, an effect of laterality only, *F*(1,25) = 21.94, $p < .001$ ($\eta^2_p = .47$), for high WM load where electrodes contralateral to the ignored distractor were more negative (-0.48 μV) than ipsilateral (0.79 μV; see figure 4.3 for mean amplitudes of the Nd for contralateral vs. ipsilateral for angry and neutral face distractors across low and high WM load). Paired comparison *t*-tests on the valence x laterality interaction for low WM load show a significant effect of laterality (contralateral vs. ipsilateral) for neutral face distractors, *t*(25) = 5.68, *p* < .001 (2-tailed), where electrodes contralateral to the ignored distractor were more negative (-0.52 μV) than ipsilateral (0.96 μV); and a significant effect for angry face distractors, *t*(25) = 6.98, *p* < .001 (2-tailed), where electrodes contralateral to the ignored distractor were more negative (-1.82 μV) than ipsilateral (0.02 μV). There were no other significant main effects or interactions (all *F*s < 1.9).

4.1.3.2.3 Pd: 180-250 ms

Figure 4.5 shows low and high WM load grand average ERPs for electrodes contralateral and ipsilateral to ignored distractor across all conditions. Residual lateral eye-movement for the 180-250 ms time interval ranged between -2.59 and 3.36 μV. To investigate if the Pd (c.f. Hickey et al., 2009), as an index of the suppression of attention to threat-related (vs. non-threat-related) ignored distractors, is modulated by WM load, mean amplitude values were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of WM load (low, high), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality *F*(1,25) = 11.03, *p* < .01 (η^2_p = .31) where mean amplitudes were more positive for contralateral electrodes sites (1.52 μV) than ipsilateral (0.86 μV) indicating the presence of the Pd; and a significant load x laterality interaction, *F*(1,25) = 6.06, *p* < .05 (η^2_p = .20) as the laterality effect was greater for high WM load compared to low.

Paired comparison *t*-tests on the load x laterality interaction reveal, across load (low vs. high), a significant laterality effect for low WM load, *t*(25) = 2.53, *p* < .05 (2-tailed), where mean amplitudes were more positive for electrodes contralateral (1.30 μV) compared to ipsilateral (0.77 μV); and a significant laterality effect for high WM load, *t*(25) = 3.90, *p* < .01 (2-tailed), where mean amplitudes were more positive for electrodes contralateral (1.75 μV) compared to ipsilateral (0.96 μV; see figure 4.2 for mean amplitudes of the Pd for contralateral vs. ipsilateral for low and high WM load). The greater laterality effect for high WM load vs. low indicates an increase in the Pd under the high WM load and subsequently that suppression (as indexed by the Pd), is modulated by WM load. Also, these results indicate that suppression is present under low resource requirements of a detect task, which differs from the findings of Hickey et al. (2009; experiment 2) where under a detect task suppression was not evident. This was likely due to the salience of the lateral face image (compared to the faint red line of Hickey et al., 2009) generating an attend-to-me signal greater than the top-down task set that needed to be suppressed in order to prevent it from capturing attention and interfering in task performance. There were no other significant main effects or interactions (all *F*s < 2.4).

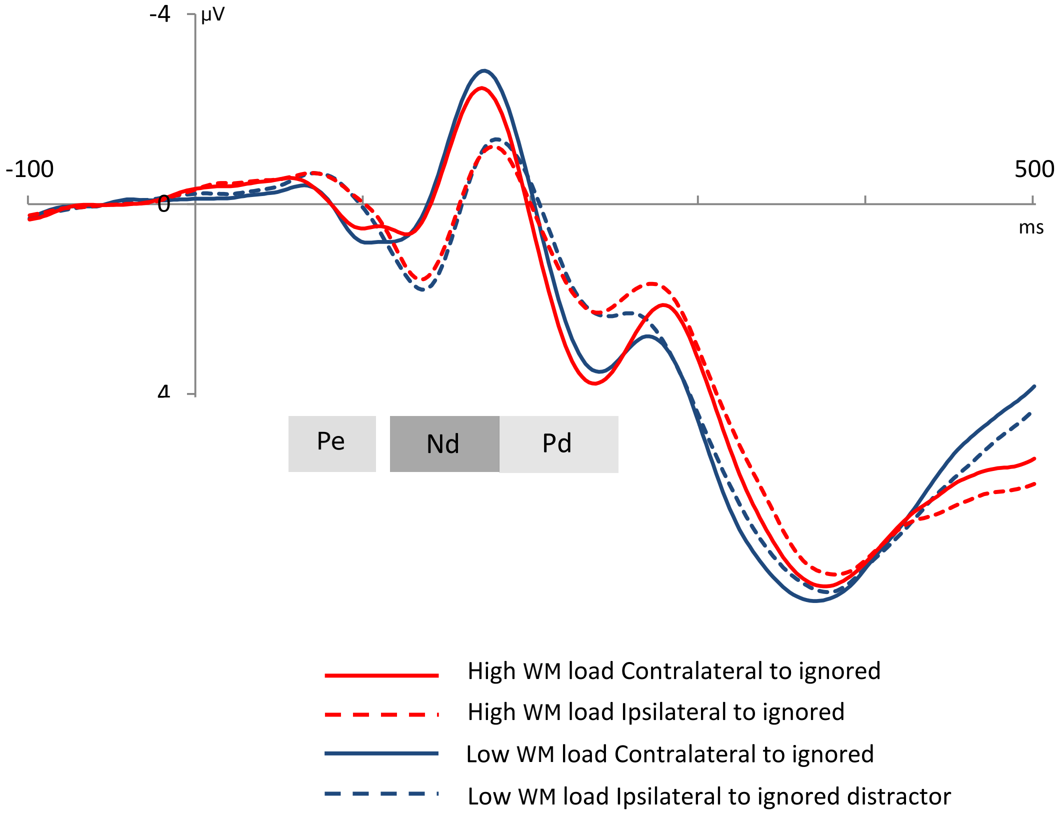


Figure 4.5. Low and high WM load grand average ERPs for electrodes contralateral and ipsilateral to ignored distractor across all conditions. The 60-110 ms (Pe) 120-180 ms (Nd); and 180-250 ms (Pd) time intervals are depicted.

4.1.4 Discussion

The primary aim of the study was to examine the effects of WM load on the allocation of attention to task-irrelevant threat. This was achieved by examining the effect of WM load on the suppression of the ignored distractor via the modulation of the Pd and also attentional capture as indexed by the modulation of the Nd.

4.1.4.1 Distractor Positivity (Pd)

The first aim of the study was to investigate the effect of WM load on suppression as indexed by the Pd. Results are consistent with experiments 1, 2, and 3 by confirming the presence of the Pd as demonstrated by the increased positivity contralateral to the ignored distractor (compared to ipsilateral) within the 180-250 ms time range. In addition, the laterality effect of the Pd was greater for the high WM load task compared to the low WM load task. Results show an increase in suppression, as indexed by an increase in the contralateral positivity for the high WM load task. It is unclear why suppression should be greater under the high WM load condition when presumably fewer cognitive resources are available for such suppression. One possibility is that a limitation in the present study (i.e. the comparison of a detection task (low WM load) with a discrimination task (high WM load)) resulted in perceptual/attentional rather than cognitive resources being varied.

In Hickey et al. (2009; experiment 2) the detection task resulted in a significant reduction in the Pd compared to the discrimination task (experiment 1) presumably because the perceptual task was easier to carry out and there was consequently little need for suppression of distractor stimuli. This was used to demonstrate the Pd as an index of attentional processes and not the result of an imbalance in sensory elements caused by a distractor being presented in one visual field only. In the present experiment the apparent 'increase' in the Pd for the high WM load task could therefore be the result of the greater perceptual/attentional demands for the discrimination task as compared with the low WM (detection) task. The use of a detection task (low WM load) and a discrimination task (high WM load) in the present experiment could therefore be the cause of the apparent 'increase' in the Pd under high WM load, as there was a conflating of attentional demands with cognitive. Therefore, the present experimental manipulation is inadequate in determining if an increase in cognitive load and subsequently an increase on higher mental functions, results in a drain on the capacity for active control of attention and if this would result in a decrease in suppression of an ignored irrelevant distractor. The present experiment did, however, support the results of Hickey et al. (2009; experiment 2) in demonstrating a decrease in the Pd as a result of reduced attentional demands and, along with experiments 1 and 2 of the present series of studies, support the conclusion that the Pd is an index of suppression of irrelevant distractor information and not the effect of an imbalance in sensory processing. It should be noted here that in the Hickey et al. (2009; experiment 2) study the laterality of the Pd was reduced below significance. The same level of attenuation of the Pd not being evident for the detection task in the present experiment is likely due to the salience of the ignored distractor (compared to the top-down task set) generating an attend-to-me signal that then required suppression. In the light of the problems associated with the current study design, a more valid measure of cognitive load would be one where both low and high load vary only on cognitive demands of the task and do not differ in the type of task that results in a concurrent modulation of attentional or perceptual demands.

The second aim of the study was to investigate the effect of WM load the suppression of threat-related distractors (angry vs. neutral), as measured by the Pd. Given the previous conclusion, the results showing that high WM load did not result in greater suppression for threat-related (vs. non-threat) distractors compared to low WM load is of little surprise. While previous studies have shown increases in the N2pc (which has been linked to the suppression of irrelevant/threat-related information) to threat faces as a result of high WM load (Holmes et al., 2014) the limitations of the present experiment make it difficult to reliably separate out attentional and cognitive processes which may have opposing effects on suppression, leaving the possibility that the Pd was influenced in different directions by each resulting in the cancelling out of the effect, therefore making the results unreliable.

4.1.4.2 Distractor Negativity (Nd)

The third aim of the study was to examine the effect of WM load on attentional capture as indexed by the Nd. Results are consistent with experiments 1, 2, and 3 and confirm the presence of the Nd as demonstrated by the increased negativity contralateral to the ignored distractor (compared to ipsilateral) within the 120-180 ms time range. Results also show a reduced laterality effect under high WM load compared to low indicating that the increase in demand on executive control resources results in a reduction in attentional capture by an ignored distractor. The final aim of the present experiment was to investigate if attentional capture of threat-related distractors (relative to non-threat) would be influenced by the availability of executive control resources.

Results show a reduced laterality effect under low WM load for angry face distractors compared to neutral, while the effect of threat distractors is reduced under the high WM load condition, indicating that the increase in demand on executive control resources results in a reduction in attentional bias toward the threat related information of an ignored distractor. One interpretation may be that in order to detect threat a template of threat-related information is used to compare with objects in the visual field, therefore when resources are available threat detection is high, but when resources are not available threat detection is reduced. However, as stated earlier, the limitations in the current manipulation makes it difficult to accurately interpret the current findings in light of previous work. A reduction in the Nd as a result of increased perceptual load is consistent with Lavie's (2005, 2010; Lavie et al., 2004) theory and previous findings showing that the N2pc is reduced under heightened perceptual load (Bishop, Jenkins, & Lawrence, 2007; Fenker et al., 2010; Okon-Singer et al., 2007) and may indicate that the present study manipulated perceptual load as well as cognitive WM load.

The finding that an irrelevant singleton captures attention, even when top-down control functions are not diminished (as in the low-load condition), points to a stimulus-driven component of attentional orientation. The features of the target and the singleton distractor meant the irrelevant distractor was more salient than the target shape, resulting in the irrelevant distractor generating an attend-to-me signal greater than the top-down task set. Under these conditions, the singleton intrudes into the task set, even when it is irrelevant and even when participants had resources available to control against interference from the irrelevant distractor. Unfortunately, the limitations of the manipulation in this experiment make it difficult to reliably separate out attentional and cognitive processes which may have opposing effects on suppression and/or attentional bias/capture.

4.2 Experiment 5

The issues in the methodology of experiment 4 make it difficult to determine if increasing WM load (as a measure of cognitive load) results in a decrease in suppression of an irrelevant distractor. Surprisingly, the results showed that under conditions where executive control resources were reduced, suppression of an irrelevant distractor was greater. However, as the experiment contained more than one manipulation (conflating attentional and cognitive demands) the results are difficult to interpret. Therefore, as it is not clear whether the results of experiment 4 are a consequence of a cognitive or perceptual/attentional load manipulation, a further study was undertaken in which perceptual factors were held constant and only cognitive factors were manipulated.

Recent studies have proposed that threat processing in attention tasks (that do not modulate WM load specifically) may be diminished under cognitive load, though studies investigating this topic are few in number. Van Dillen and Koole (2009) presented participants with a mathematics task as a measure of cognitive load, while they responded to the gender identity of happy or angry faces. Results showed RTs faster for angry faces than happy, indicating angry faces captured and held attention under low load, while under high load the difference was eliminated. Van Dillen and Koole (2009) found that high cognitive load reduced amygdala response to aversive stimuli that were passively viewed immediately before an attention-demanding arithmetic task. Results also showed that increasing task load led to increases in activation in cognitive regions, and exposure to negative stimuli led to increased activation in emotional regions. Additionally, increases in task load resulted in reductions in participants' subjective experience of negative emotions in response to negative stimuli.

Results from this study demonstrate that when executive control resources were available threat-related faces were processed favourably over non-threat-related, however under conditions where executive control resources were depleted threat-related faces were not processed favourably compared to non-threat (Van Dillen et al., 2009).

Other studies though have shown no impact of cognitive load on emotion processing. Pecchinenda and Heil (2007) investigated increases in response-competition under cognitive load where participants responded to the valence of a target word, either positive or negative, that was superimposed over angry, happy or neutral faces. An effect of cognitive load on responses to the valence of target words was not found in this experiment. Instead a compatibility effect was evident under both load conditions, suggesting that emotional distractors may be processed independently from working memory manipulations (see Berggren, Koster, & Derakshan, 2012) and indicating that automatic evaluation of incoming affectively negative emotional information occurs regardless of task priorities (i.e. working memory load). In this experiment, whether or not cognitive load could increase the effect of the distractor for non-emotional faces could not be determined.

In sum, the comparison of a detection task with a discrimination task in experiment 4 has led to a difficulty in separating the influence of attentional demands and cognitive load on executive control resources. The allocation of attention to task-irrelevant threat is thought to depend on an interaction between top-down resources and emotion-related processing. While few in number, recent studies have proposed that threat-related processing in attention tasks can be either diminished or enhanced under cognitive load (c.f. de Fockert et al., 2001). In an experiment using fMRI, de Fockert et al. (2001) demonstrated that increased memory load, associated with increased prefrontal activity, resulted in greater interference effects on behavioural performance from the distractor faces, as well as increased face-related activity in the visual cortex. While some have shown a reduced effect of negative emotion processing under high load as measured with a RT task, others have indicated a reduced activity in areas of the brain related to emotion processing under high task load. However, no study has thus far conducted a direct examination of the effects of cognitive load on the allocation of attention to task-irrelevant threat where the suppression of task irrelevant information can be studied independently of attentional selection or facilitation. The present experiment will utilise the Hickey et al. (2009) paradigm used in experiments 1, 2, 3 and 4 to examine the effects of cognitive load on the allocation of attention to task-irrelevant threat while correcting for limitations of experiment 4. This will be achieved by comparing two identical tasks that vary only in cognitive effort and examining the effect of cognitive load on the suppression of an ignored distractor via the modulation of the Pd and attentional capture of an ignored salient distractor as indexed by the modulation of the distractor negativity (Nd).

The main aim of the present study is to correct the limitations of experiment 4 and examine the effects of increased cognitive load (i.e. reduced executive control resources) on the allocation of attention to task-irrelevant threat by comparing tasks that differ in cognitive resource requirements while maintaining attentional demands constant. If increasing cognitive load on higher mental functions results in a drain on the capacity for active control of attention, it may be that the increased cognitive load results in less available resources to suppress irrelevant information while maintaining attentional task priority. This would be expected to result in a reduced Pd under high cognitive load. Consequently the first specific aim of the study is to investigate the effect of cognitive load on suppression as measured by the Pd. The second aim of the study is to investigate whether the effect of cognitive load on suppression, as measured by the Pd, is affected by the emotional valence of the distractors (angry vs. neutral).

While some doubt still remains, evidence is growing for the interpretation that the distractor negativity (Nd) is an index of unintended attentional capture to an ignored lateral stimulus and that it may share similar functions to those of the N2pc. Results of experiment 4 indicate the Nd is modulated by the demand on attentional/cognitive resources, in that, under low demand, angry face ignored distractors captured attention less than did neutral, indicating privileged access to attention for threatening information, whereas under high demand this difference was eliminated. The manipulation of experiment 4 did not allow for the direct examination of depleted executive control resources via increases in cognitive load. Therefore the third specific aim of the study is to investigate the effect of cognitive load, while keeping attentional demands constant, on attentional capture as indexed by the Nd. It would be expected that the Nd would be affected by the threatening content of distractors (relative to non-threatening) differently under conditions of high vs. low cognitive load. Therefore, the final specific aim of the study is to investigate the effect of cognitive load on the attentional capture of threat-related distractor information as indexed by the Nd.

4.2.1 Method

4.2.1.1 Participants

Twenty-four healthy volunteers from the University of Roehampton received course credit for participation. Three participants were excluded because of excessive eye blinks or eye movements, which resulted in < 50% trials remaining. Therefore, 21 participants (5 male & 16 female; 18–26 years old; M: 20.00 years; SD: 1.84) remained in the sample. All participants had normal or corrected-to-normal vision and all were right-handed. The experiment was performed in compliance with The University of Roehampton ethical and research guidelines and was approved by the University ethics committee.

4.2.1.2 Stimuli and Apparatus

The stimuli and procedure were identical to experiment 1, except as follows. The fixation cross was displayed for 500 ms in either green (RGB = 0, 206, 0) or red (RGB = 237, 0, 0), which then changed to white and was randomly presented for either 750, 800, 850, 900, 950, 1000, 1050, 1100, 1150, 1200, 1250 ms to minimise the influence of any systematic ERPs that might relate to the prediction of trial onset and to ensure attention was located on fixation at the start of each trial (see figure 4.6 for stimuli presentation sequence). The vertical stimulus (upper or lower) consisted of the letters ‘X’ and ‘O’, placed one atop another. Each letter was presented an equal number of times in the upper or lower positions and also an equal number of times in the colours green (RGB = 0, 206, 0) or red (RGB = 237, 0, 0), such that when one letter was displayed green, the other was displayed red. Each letter (9 x 9 mm) of the target stimulus was spaced 2 mm apart leaving a stimulus that was 20 x 9 mm (subtending approximately 1.4^{O} x 0.6^{O} of visual angle) and was substantially more luminous (3.55 cd/m^2) than the background (0.19 cd/m^2). The letters were presented in capitalised Arial type font. Only intact face stimuli were presented as distractors in this experiment and were the same intact face stimuli used in experiments 1, 2, and 4.

4.2.2 Procedure

The experiment itself consisted of 12 blocks of 96 trials for a total of 1152 trials per participant. As in Experiments 1, 2, 3, and 4, each trial presentation consisted of two stimuli; one target stimulus and one distractor stimulus, except that in the low cognitive load condition, for the first three blocks, the first fixation (500 ms) was presented in red, and for the second three blocks, was presented in green, with half of the participants receiving the opposite sequence. For the high cognitive load condition, the first fixation was randomly presented in either green or red for the entire 6 blocks. Half the participants received the low load condition first and half received the high load condition first in the sequence. Participants were instructed to report the letter indicated by the colour of the first fixation (e.g., red fixation then a red 'X' alongside a green 'O' required button press corresponding to 'X') with half of participants responding 'X' with a right button press and 'O' with a left button press, and the other half responding with the opposite response map.

Before each section, a practice block consisting of 32-trials was administered for participant training. The stimulus arrays and timings of the practice blocks were identical to the trials in the experimental sections except a different set of neutral face identities was presented as lateral stimuli. As in experiment 4, accuracy for the practice and experimental sessions was set at 70%.

4.2.2.1 EEG Data Acquisition

EEG data collection is identical to that of experiment 3 and 4. Separate means were computed for all combinations of cognitive load (low vs. high), distractor valence (angry face vs. neutral face), and laterality (electrodes contralateral vs. ipsilateral to location of distractor). Visual inspection of the waveforms resulted in the identification of three main contralateral (to the distractor) ERP components in the lateral posterior area. These were assessed for the current study with reference to the distractor location; namely, a positive posterior contralateral (Pe) beginning around 70 ms; a contralateral negativity (Nd) beginning around 120 ms, and a distractor positivity (Pd; cf. Hickey et al. 2009) beginning around 180 ms. As in experiments 1, 2, 3, and 4, these components were individually measured at their respective time windows from the mean of the five left posterior parieto-temporal electrodes and five right posterior parieto-temporal electrodes (see figure 3.2 for electrode positioning), as this is where maximal activity was apparent for each component.

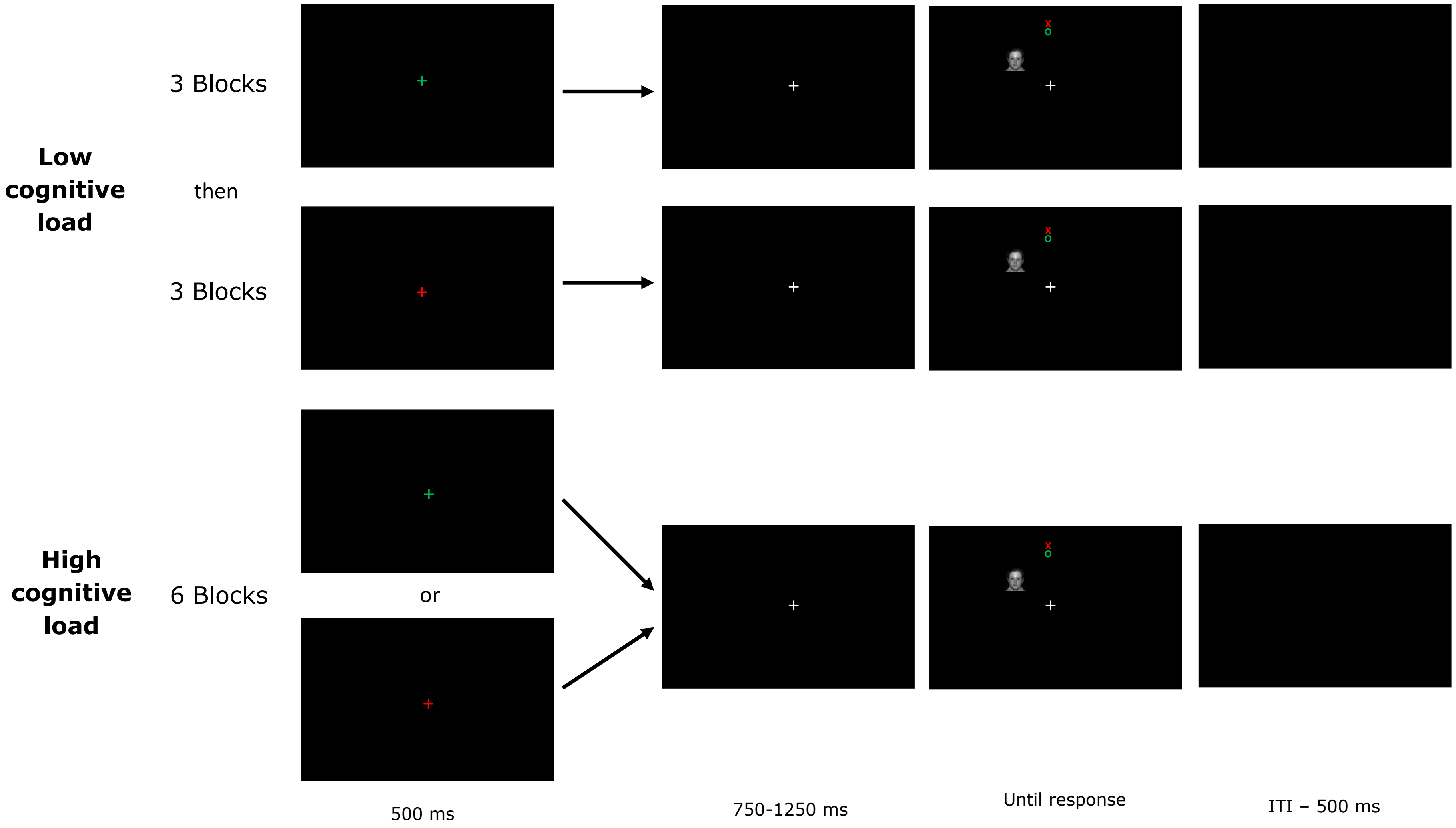


Figure 4.6. Presentation sequence containing fixation screen, sample trial and inter-trial interval.

The Pe was defined as the mean amplitude between 70-120 ms post-stimulus presentation, overlapping the P1 time window (c.f. Luck & Hillyard, 1994a; Batty & Taylor, 2003). The Nd was defined as the mean amplitude between 120-180 ms post-stimulus presentation, overlapping the N170 time window (c.f. Eimer, 1998; Williams et al., 2006). The Pd was defined as the mean amplitude between 180-250 ms post-stimulus presentation (c.f. Hickey et al., 2009). Figure 4.9 shows the contralateral and ipsilateral ERPs observed at the posterior parietal electrode sites. Mean amplitudes were automatically extracted for all components. Figure 4.10 shows low and high cognitive load task laterality difference activity for each time interval in analysis.

4.2.3 Results

Non-responses and trials with errors were discarded, as were any with RTs less than 200 ms (12.4% of all responses). As in previous experiments, to eliminate sensory confounds related to presentation locations, these factors were collapsed for analysis (c.f. Sawaki & Luck, 2010). When using ANOVAs to determine statistical effects, partial eta-squared (η^2_p) are reported as an estimate of effect size for every significant effect found.

4.2.3.1 Behavioural measures

4.2.3.1.1 Reaction time

Mean correct RTs are shown in table 4.3. Planned comparisons of mean RT for each condition were entered into a 2 x 2 repeated measures analysis of variance (ANOVA), with factors of cognitive load (low, high), and distractor valence (angry, neutral). There was a significant main effect of load, $F(1,20) = 18.55$, $p < .001$ ($\eta^2_p = .48$) where responses

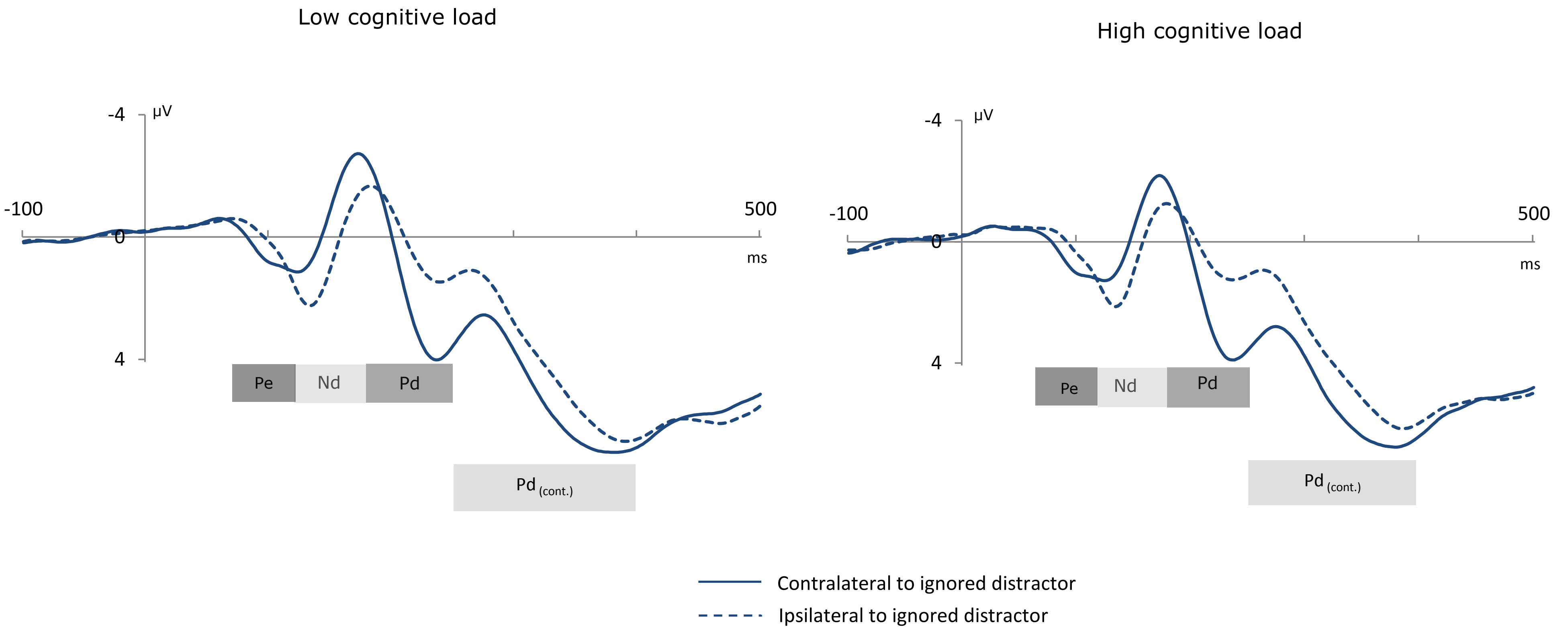


Figure 4.7. Grand average ERPs of low and high cognitive load tasks for electrodes contralateral and ipsilateral to ignored distractor across all conditions. The 70-120 (Pe); 120-180 ms (Nd); 180-250 ms (Pd); and 250-400 ms ($\text{Pd}_{(\text{cont.})}$) time intervals are depicted.

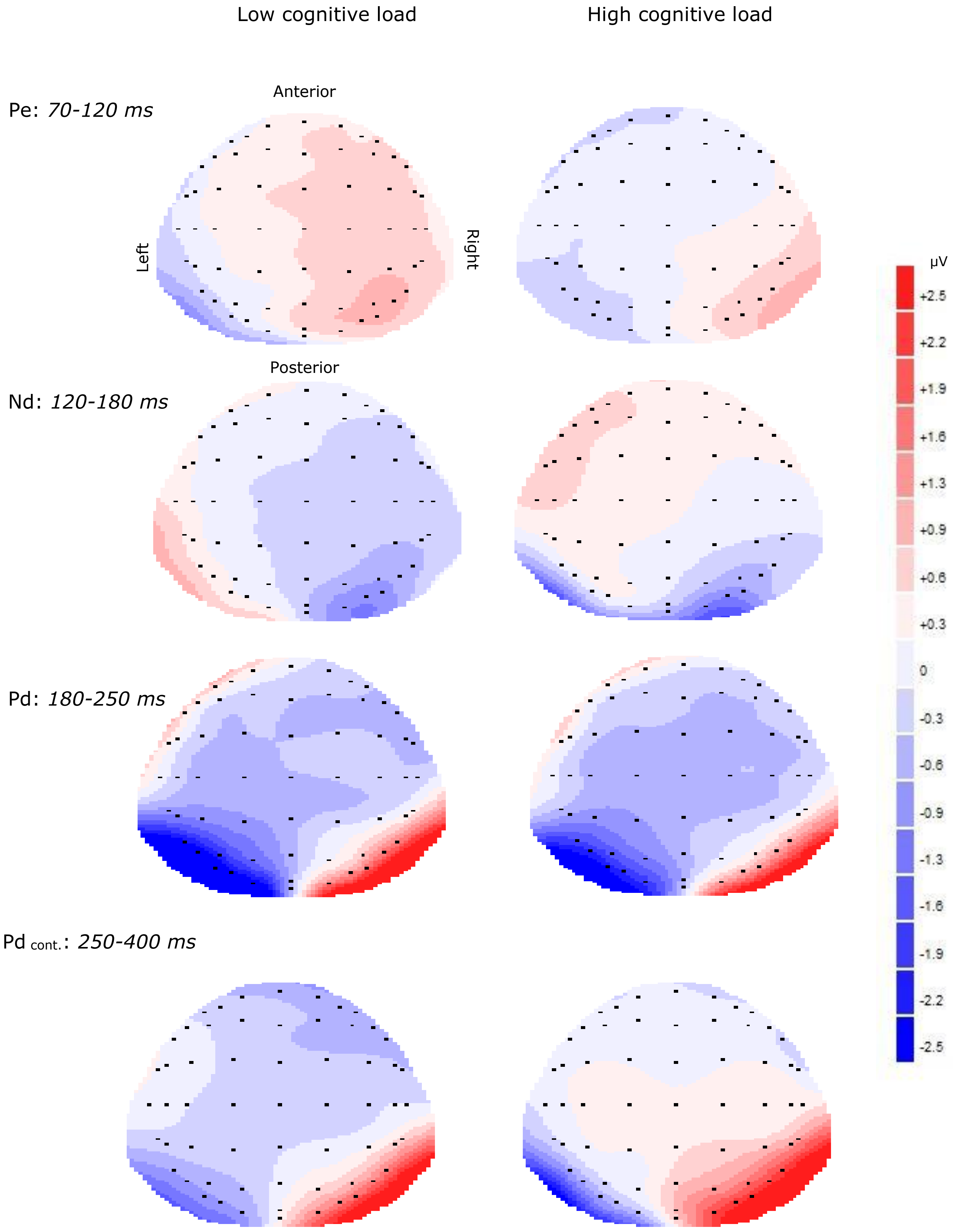


Figure 4.8. Low (left) and high (right) cognitive load task laterality difference activity (activity of left presented ignored distractor minus activity right presented ignored distractor) for each time interval in analysis.

were faster to the low load (647 ms) compared to the high (748 ms) task, indicating the manipulation was effective. There were no other significant effects or interactions (all *F*s < 1).

Table 4.3. *Means (and standard deviations), for correct reaction times to targets (ms) for each condition*

	Low load	High load
Neutral	649 (128.6)	761 (222.9)
Angry	653 (130.7)	778 (193.1)

4.2.3.1.2 Accuracy

Mean correct RTs are shown in table 4.4. Planned comparisons of total correct responses for each condition were entered into a 2 x 2 repeated measures analysis of variance (ANOVA), with factors of cognitive load (low, high), and distractor valence (angry, neutral). There was a significant main effect of load, $F(1,20) = 24.41$, $p < .01$ ($\eta^2_p = .55$) where responses were more accurate for low load (95%) compared to the high (83%), again, indicating the manipulation was effective. There was also a significant main effect of valence, $F(1,20) = 19.77$, $p < .001$ ($\eta^2_p = .50$) where responses were more accurate for neutral face distractors (91%) compared to angry (88%); and a significant load x valence interaction, $F(1,20) = 27.35$, $p < .001$ ($\eta^2_p = .58$), where the valence effect appears greater for the high task load.

Paired comparison *t*-tests on the load x valence interaction show a significant effect of valence for high load, $t(20) = 4.97$, $p < .001$ (2-tailed), where responses for neutral face distractors were more accurate (90%) than for angry face distractors (83%), but similar effects were not found for the low load task (*t* < 1), indicating that when executive control resources are diminished threat-related distractor processing reduces task accuracy.

Table 4.4. *Mean (SD) number of correct responses for each condition. Scores out of 72.*

	Low load	High load
Neutral	68.1 (5.2)	61.9 (10.7)
Angry	68.2 (5.6)	58.1 (7.7)

4.2.3.2 EEG measures

To ensure lateral eye-movement does not contaminate the ERPs being measured, residual lateral eye movement were calculated as the difference for distractor-left minus distractor-right presented trials of the HEOG channel. This will allow for direct comparison with each component of analysis for the same trials, in the same time interval. Any values for any participant greater than ± 4 μV resulted in additional analyses, minus those participants, within each component of interest. Figure 4.9 shows the grand mean HEOG waveforms for left (color of line) and right (colour of line) waveforms. Figure 4.8 displays grand average ERPs for electrodes contralateral and ipsilateral to distractor presentation, averaged across all conditions for low and high cognitive load tasks.

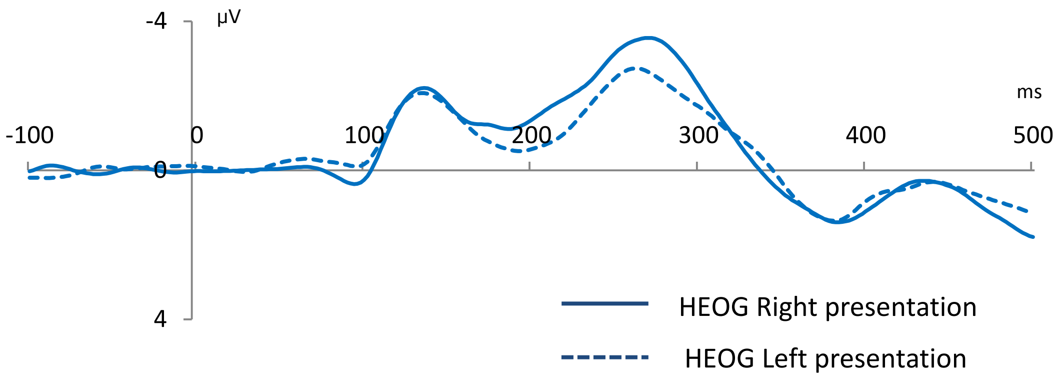


Figure 4.9. Grand average lateral eye-movement (HEOG) for right (solid line) and left (dashed line) stimulus presentation across all conditions.

4.2.3.2.1 Pe: 70-120 ms

Residual lateral eye-movement for the 70-120 ms time interval ranged between -1.82 and 1.22 μV. Mean amplitude values for the Pe were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of task load (low, high), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality $F(1,20) = 14.66$, $p < .01$ ($\eta^2_p = .42$), where mean amplitudes were more positive for contralateral electrodes (0.59 μV) compared to ipsilateral (-0.18 μV) indicating activity related to the distractor. There were no other significant main effects or interactions (all *F*s < 3).

4.2.3.2.2 Nd: 120-180 ms

Residual lateral eye-movement for the 120-180 ms time interval ranged between -3.05 and 2.34 μV. Figure 4.10 displays mean amplitudes of the Nd for contralateral vs. ipsilateral for low and high cognitive load tasks. To investigate the effect of load on attentional capture by threat-related ignored distractors, mean amplitude values for the Nd were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of cognitive load (low, high), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality $F(1,20) = 24.34$, $p < .001$ ($\eta^2_p = .55$) where mean amplitudes were more negative for contralateral electrodes (-0.66 μV) compared to ipsilateral (0.61 μV); a significant load x laterality interaction, $F(1,20) = 8.23$, $p < .01$ ($\eta^2_p = .29$), where the laterality effect appears greater for low cognitive load than for high.

Paired comparison *t*-tests on the load x laterality interaction show a significant effect of laterality, $t(20) = 5.60$, $p < .001$ (2-tailed), for the low load task, where electrodes contralateral (-0.86 μV) to the ignored distractor were more negative than ipsilateral (0.60 μV); and a significant effect of laterality, $t(20) = 3.96$, $p < .01$ (2-tailed), for the high load task, where electrodes contralateral (-0.46 μV) to the ignored distractor were more negative than ipsilateral (0.62 μV). There were no other significant main effects or interactions (all *F*s < 2.3).

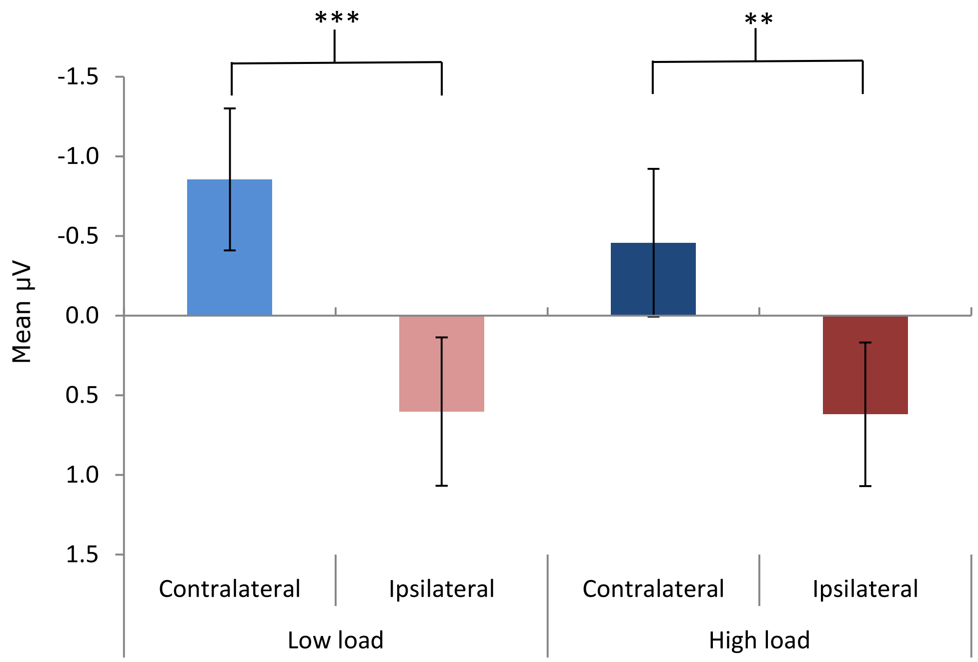


Figure 4.10. Mean amplitudes (µV) in the 120-180 ms (Nd) time interval for low and high cognitive task load (upper) and contralateral vs. ipsilateral (lower) conditions (error bars represent 95% CI), ***p* < .01, *** *p* < .001. Note negative is up.

4.2.3.2.3 Pd: 180-250 ms

Residual lateral eye-movement for the 180-250 ms time interval ranged between -0.79 and 2.15 µV. Figure 4.11 shows mean amplitudes of the Pd for contralateral vs. ipsilateral for low and high load conditions. To investigate if the Pd (c.f. Hickey et al., 2009), as an index of the suppression of attention to an ignored distractor, is altered by the load of a central task, mean amplitude values were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of task load (low, high), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of load, $F(1,20) = 5.87$, $p < .05$ ($\eta^2_p = .22$), where mean amplitudes were more positive for the high load condition (0.98 µV) compared to low (0.45 µV); and a significant main effect of laterality, *F*(1,20) = 46.79, $p < .001$ ($\eta^2_p = .70$), where mean amplitudes were more positive for contralateral electrodes sites (1.25 µV) than ipsilateral (0.17 µV). There were no other significant main effects or interactions (all *F*s < 2.9). The absence of a significant load x laterality interaction indicates that suppression of an irrelevant distractor, as indexed by the Pd, is not altered under conditions of high cognitive load.

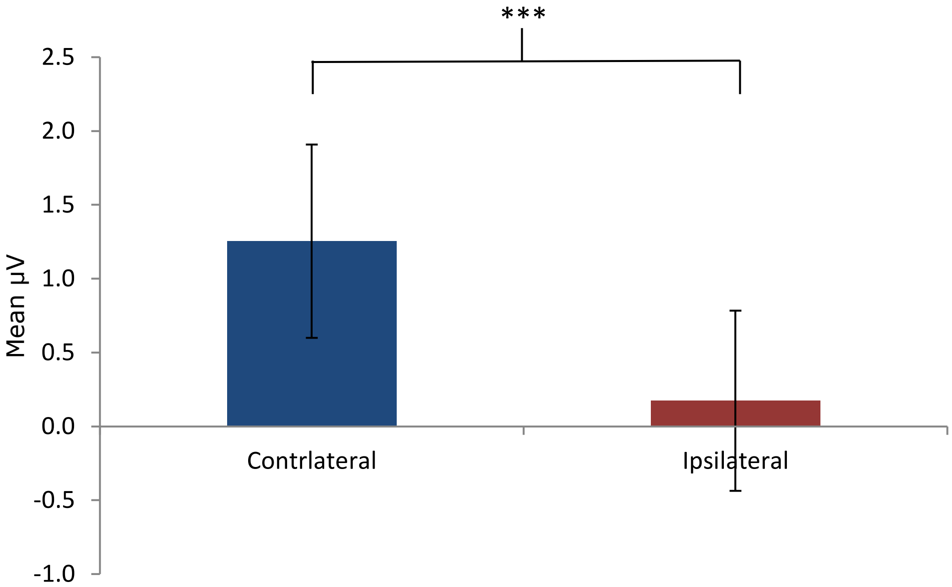


Figure 4.11. Mean amplitudes (µV) in the 180-250 ms (Pd) time interval for contralateral vs. ipsilateral (lower) conditions (error bars represent 95% CI), *** $p < .001$.

4.2.3.2.4 Pd $_{cont.}$: 250-400 ms

Residual lateral eye-movement for the 250-400 ms time interval ranged between -1.74 and 2.52 µV. Figure 4.12 shows mean amplitudes of the Pd $_{cont.}$ for contralateral vs. ipsilateral for low and high load conditions. Mean amplitude values were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of task load (low, high), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality, *F*(1,20) = 46.79, $p < .001$ ($\eta^2_p = .70$), where mean amplitudes were more positive for contralateral electrodes sites (1.25 µV) than ipsilateral (0.17 µV); and a significant load x laterality interaction, *F*(1,20) = 5.73, $p < .05$ ($\eta^2_p =$ .22), where the laterality effect appears greater for high cognitive load than for low.

Paired comparison *t*-tests on the load x laterality interaction show a significant effect of laterality, *t*(20) = 7.01, $p < .001$ (2-tailed), for the low load task, where electrodes contralateral (5.10 µV) to the ignored distractor were more negative than ipsilateral (4.05 µV); and a significant effect of laterality, *t*(20) = 9.95, $p < .001$ (2-tailed), for the high load task, where electrodes contralateral (5.04 µV) to the ignored distractor were more negative than ipsilateral (3.78 µV). There were no other significant main effects or interactions (all *F*s < 2.3).

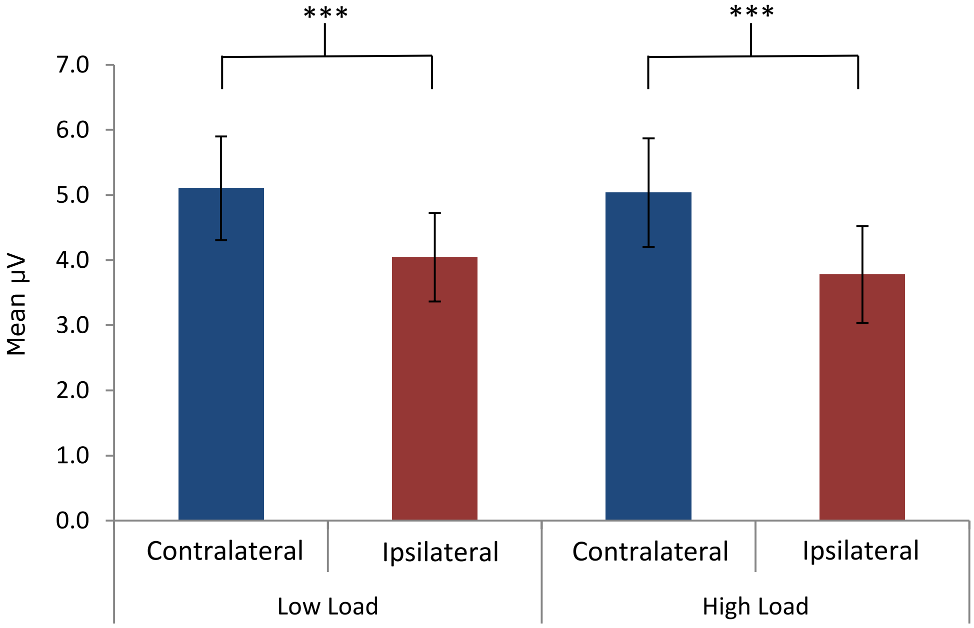


Figure 4.12. Mean amplitudes (µV) in the 250-400 ms ($Pd_{(cont.)}$) time interval for contralateral vs. ipsilateral (lower) conditions (error bars represent 95% CI), *** $p <$ .001.

4.2.4 Discussion

The main aim of the present study was to examine the effects of cognitive load on the allocation of attention to task-irrelevant threat while correcting for limitations of experiment 4. This was achieved by comparing two identical tasks that varied only in cognitive effort and examining the effect of cognitive load on the suppression of an ignored distractor via the modulation of the Pd and to a lesser extent attentional capture of an ignored salient distractor as indexed by the modulation of the N2pc.

4.2.4.1 Distractor Positivity (Pd & Pd $_{(cont.)}$)

The first aim of the study was to investigate the effect of cognitive load on suppression as measured by the Pd. If by increasing cognitive load on higher mental functions results in a drain on the capacity for active control of attention, it may be that the increased cognitive load results in less available resources to suppress irrelevant information. A contralateral (to the distractor) positivity was observed in the 180-250 ms time range (see figure 4.9) that signifies the presence of the Pd as an index of suppression of the ignored distractor (c.f. Hickey et al., 2009). The absence of a load x laterality interaction indicates that the increase in cognitive load, and subsequently reduced executive control resources, did not result in a decrease in suppression to the ignored distractor as previously reported by Lavie et al. (2004). The absence of a significant reduction in the Pd may be due to the task not reaching a level of difficulty sufficient to deplete cognitive control resources. However, this is unlikely given that the behavioural results indicate that the task was sufficiently difficult to result in a significant increase in both RT and accuracy for the high cognitive load task compared to low. Alternatively, it may be that the top-down suppression of irrelevant information is not being implemented in this task, or, more likely, that the Pd is insensitive to manipulations of top-down suppression and instead is sensitive to local suppression that arises at a perceptual level. Recent work however has indicated that spatial suppression may be influenced more by the perceptual elements in the visual field. Hopf et al. (2006) have proposed that the focus of attention contains an excitatory peak surrounded by a narrow inhibitory region, where suppression is maximal. By presenting participants with a probe stimulus at varying distances from a target, these authors have shown that suppression of irrelevant distractors appears to be maximal at a specified distance from the target meaning that distractors within the field of the centre-surround are suppressed while attended stimuli are enhanced. This would indicate that suppression of irrelevant stimuli is more a perceptually driven process and not influenced by cognitive demands. It is therefore possible that the magnitude of the Pd may be affected by manipulations of perceptual/attentional load (e.g., Hickey et al., 2009; see also experiment 4, this thesis) rather than cognitive load. This possibility will be followed up in experiment 6.

The second specific aim of the study was to investigate the effect of cognitive load on the suppression of threat-related distractors (angry vs. neutral), as measured by the Pd. Results show no effect of load on the valence of the distractor, indicating that whether executive control resources were depleted or not did not result in an increase in suppression despite diminished response accuracy in the high load task for threat-related faces, which suggests a greater intrusion of threat-related faces when executive control resources are diminished. The results are consistent with Pecchinenda and Heil (2007) who found concurrent WM load did not significantly alter the interference effect of emotional face distractors on valence judgements of emotional word targets that were used to index attention.

4.2.4.2 Distractor Negativity (Nd)

The final aim of the study was to investigate cognitive load on attentional capture of threat-related ignored distractor information as indexed by the Nd. Results are consistent with experiments 1, 3, and 4, and confirm the presence of the Nd as demonstrated by the increased negativity contralateral to the ignored distractor (compared to ipsilateral) within the 120-180 ms time range. Similar to experiment 4, results also show a reduced laterality effect under high load compared to low, indicating that the increase in demand on executive control resources resulted in a reduction in attentional capture to an ignored distractor as indexed by a reduction in the Nd. These results appear to contradict previous conclusions that increasing cognitive (WM) load results in an increase in attentional capture. Lavie and de Fockert (2005), tested participants under single and dual-task conditions with a singleton distractor both present and absent for each condition. In this series of experiments attentional capture was assessed by the extent to which target response times were slower in the presence of a singleton compared to when the singleton was not present in both a single and dual task condition. Results show that under high WM load RT in the distractor singleton present condition were significantly greater than for the single absent, but the same pattern of results is not evident for the low WM load condition indicating that a depletion of executive control resources (by increasing WM load) results in an increase in attentional capture of an irrelevant distractor singleton. While a reduction in the laterality effect for the high cognitive load condition in the present experiment indicates attentional capture was reduced as a result of the depletion in executive control resources, the absence of a 'no-distractor- condition makes it difficult to compare findings. It appears though that Lavie and de Fockert (2005) have concluded that an increase in attentional capture results from an increase RT. Lavie and de Fockert (2005) observed an increase in RT in the low perceptual load task for the distractor present condition, which must contain attentional capture, compared to distractor absent, which must not. From this they have concluded that an increase in RT results in an increase in attentional capture. However, the correct conclusion would be that an increase in attentional capture results in an increase in RT. When this incorrect interpretation is applied to the results of the high load condition these authors have concluded that the increase in RT, due to increase in load has resulted in an increase in attentional capture due to the increase in cognitive load. However, this interpretation leaves out the possibility that an increase in RT can coincide with a decrease in attentional capture, which is evident in the present experiment (see chapter 6 for a more detailed discussion). The laterality of the Nd being diminished in the high cognitive load task of the present experiment indicates that when executive control resources are depleted attentional capture of an irrelevant distractor is reduced due to reduced available resources along with an increase in the time it takes to carry out the task.

Accuracy results though, do indicate that when executive control resources are diminished threat-related distractor processing reduces task accuracy, although this effect is not reflected in the neither the RT data nor the Nd or Pd ERP components. This result would indicate that while threat-related distractor information may diminish task accuracy when executive control resources are diminished, these are not influencing attentional processes (as indicated by changes in the laterality of the Nd or Pd) as has been reported in previous fMRI (Van Dillen et al., 2009) and N2pc (Holmes et al., 2014) studies. Theeuwes (2010) has shown that pre-attentive analysis is limited to the attended area in that the occurrence of attentional capture is determined by the extent to which attention is spread. When attention is more diffuse, visual search may be conducted in parallel across all items in the visual field, therefore any singleton relevant or irrelevant can be selected; however when attention is narrowed, singletons that fall outside of the attentional focus will not capture attention (Theeuwes, 2010). It may be that the Nd is not reflective of attentional bias similar to that seen with the N2pc (Brosch et al., 2011; Holmes et al., 2009; Holmes et al., 2014) given its early position in the waveform and its subsequent early position in the sequence of processing. However, it seems the Nd does represent unintended attentional capture of the ignored lateral stimuli as the Nd demonstrates to be effected by the availability of executive control resources as seen in the present experiment. It should be noted though that the results of experiment 4 demonstrate threat bias toward angry face distractors under ‘low’ load. This indicates that threat having privileged access to attention is revealed only under very low attentional demands.

Chapter 5: Perceptual load and the allocation of attention to task-irrelevant threat

5.1 Experiment 6

The results of experiment 4 have shown that suppression of irrelevant distractor information is increased under high ‘attentional/cognitive’ demand indicating that when executive control resources are diminished suppression of an irrelevant distractor is increased. However, the limitation in the design of experiment 4 meant that the results could potentially be due to the reduction of perceptual/attentional requirements of the ‘low load task’ and not specifically the reduction of executive control resources of the high load task. In experiment 5 attentional demand was controlled across WM load conditions with results showing no difference for suppression of the irrelevant distractor when executive control resources were depleted (high cognitive load), despite the behavioural results showing significant reductions for both accuracy and speed of response for the high cognitive load task. These results indicate either that the suppression of irrelevant information is not being controlled by top-down cognitive processes or that the Pd is not sensitive to top-down suppression. Additionally, the results of experiment 1 showed that modulating high level semantic features of the distractor (intact faces vs. scrambled) did not result in a significant modulation of suppression as indexed by the Pd. Therefore, it may be that suppression of irrelevant information is more perceptually driven (bottom-up) rather than cognitively controlled (top-down).

By using the dichotic listening paradigm, many early studies of attention have demonstrated that unattended information typically goes unnoticed (e.g., Neisser & Becklen, 1975; Rock & Gutman, 1981; Treisman & Geffen, 1967), a result that supports the early selection view. Conversely, many other studies that used indirect measures of distractor perception, in Stroop-like tasks, provided support for the late selection view (e.g., the flanker task; Eriksen & Eriksen, 1974).

A response-competition paradigm was one of the first paradigms to investigate behavioural load on distractor perception (Eriksen & Eriksen, 1974), which was chosen because it has been widely accepted as a conventional measure of distractor perception within research of the early and late selection debate (Yantis & Johnston, 1990; for review see Lavie & Tsal, 1994). In a typical response-competition task, while attempting to ignore a peripheral distractor letter, participants make speeded responses indicating whether a central target is one of two pre-specified letters (e.g. 'X' or 'N'). Slower responses in the presence of an incongruent distractor (distractor 'X' for target 'N') compared with a congruent distractor (distractor 'X' for target 'X') indicate that the distractor identity was perceived. Lavie (1995) has suggested that perceptual load is a major determinant of the occurrence of early or late selection and that understanding the role of perceptual load on attention will offer a resolution to the apparent discrepancies between previous studies on the time course of attentional selection (i.e., early vs. late). Two studies investigated the ideal conditions under which early selection might occur. In a cueing paradigm Yantis and Johnston (1990a) had participants identify a target with both validly and invalidly cued positions. Early selection was only obtained when the target was validly cued. However, as load was not varied in this manipulation it is difficult to reach firm conclusions on the role of perceptual load in the time course of attentional processes. In an additional study however, Yantis and Johnston

(1990b) manipulated the perceptual load of the display in a similar cuing paradigm to the previous and demonstrated that cuing the position of a target eliminated compatibility effects for irrelevant letters under the condition of high load, while under low-load the cue was not effective in reducing the processing of the distractor. Unfortunately, these studies have manipulated perceptual load by increasing the size of the elements in the display resulting in substantial changes in their appearance which subsequently led to changes in lower level sensory elements of the target from one condition to another. This makes it difficult to draw definitive conclusions however they do appear to indicate that when resources are available unattended information is processed to a higher level than when resources are not available.

In a series of experiments, Lavie (2005) investigated the issue further by manipulating display set size of target items (experiment 1); colour of the target items (experiment 2a); and distance of distractor to the target (experiment 2b). Results of experiment 1 show that loading the perceptual system with more information (i.e. increasing target size) resulted in a decrease in the representation of the distractor and presumably in the amount of suppression required to prevent it from intruding into attention. While these results are in line with the more recent *signal suppression hypothesis* (c.f. Sawaki & Luck, 2010), in that, by varying the salience of the task stimuli, the attend-to-me signal generated by the distractor has a reduced effect on the capture of attention, the issue of increasing the size of the target and thus the sensory characteristics across conditions still remains. A similar issue is present for experiment 2a in that by altering the colour of the target results in a change in the lower level sensory elements. Therefore, separating these results from the attempted changes in perceptual processing load of the target stimulus is difficult. Experiment 2b controlled for lower level sensory changes and showed an increase in distractor processing when perceptual resources were available, demonstrating that by increasing perceptual load, distractor processing was eliminated (Lavie, 2005). Taken together, the different manipulations show that interference from irrelevant distractors was evident under conditions of low perceptual load (despite manipulating lower level sensory elements in experiments 1 & 2a) and eliminated under conditions of high perceptual load.

The experimental manipulations in studies that provided support for early selection may be generally characterized as carrying a higher level of load (e.g., with a greater number of stimuli present in the studies of Kahneman & Chajczyk, 1983; Yantis & Johnston, 1990) and those that provided support for late selection typically involved a low level of perceptual load (often with just one target and one distractor identity present; e.g., see Gatti & Egeth, 1978). A hybrid perceptual load model has been proposed as a possible resolution to the early/late selection debate (Lavie, 1995; Lavie et al., 2004). According to this model, focusing attention on a task can prevent perception of task-irrelevant stimuli (early selection) when the processing of task-relevant stimuli involves a high level of perceptual load that consumes all available capacity. By contrast, when processing of the task-relevant stimuli places lower demands on the perceptual system, any spare capacity from the task-relevant processing spills over involuntarily, resulting in the perception of irrelevant stimuli (late selection).

Increasing the load on cognitive control functions that serve to actively maintain processing priorities (e.g., working memory; Holmes et al., 2014) have been shown to increase distractor processing (in this case threat processing) rather than decrease distractor processing. These results contrast with those described thus far from studies in which perceptual load has been manipulated. Therefore, selective perception and active control of response selection (two functions of attention) may be distinguished from one another by contrasting the effects of different types of load on distractibility. Cartwright-Finch and Lavie (2006) used the *inattentional blindness* paradigm to evaluate perceptual load on conscious perception. As predicted by perceptual load theory, awareness of a task-irrelevant stimulus was significantly reduced by higher perceptual load (with increased numbers of search items, or a harder discrimination vs. detection task). These results demonstrate that conscious perception of task-irrelevant stimuli depend upon the level of task-relevant perceptual load rather than intentions or expectations, thus enhancing the resolution to the early vs. late selection debate offered by the perceptual load theory. However, it must be stated here that the comparison of a discrimination task and a detection task does mean that the manipulation for the discrimination task contains both a cognitive and an attentional/perceptual process and the manipulation for the detection task contains an attentional/perceptual process only.

Theeuwes, Kramer, and Belopolsky (2004) examined whether perceptual load is the primary factor in determining the efficiency of attentional selection. In these experiments participants were asked to perform a visual search task under high and low perceptual load conditions. In line with the perceptual load hypothesis, results show that presenting low load and high load in separate blocks of trials resulted in processing of the to-be-ignored stimuli in the low load condition only (experiment 1). However, when low and high load conditions were randomly mixed in blocks of trials, the results showed processing of to-be-ignored stimuli in both conditions, which suggests that high perceptual load alone is not necessarily sufficient to obtain perceptual selectivity (experiment 2). These results indicate that perceptual load is not the only factor determining attentional selectivity.

Several studies have also examined effects of perceptual load on emotion processing (e.g., Bishop et al., 2007; Richards, Hadwin, Benson, Wenger, & Donnelly, 2011). While these studies have also investigated the effect of anxiety on the perception of threat, they show that under conditions of low perceptual load, resources were available to attend more to threat-related distractor stimuli, compared to higher load conditions where resources were less available supporting Lavie's (1995) perceptual load theory of attention. As noted in chapter 4, the debate between early vs. late selection has recently been rekindled by claims of threat-related information holding a *special* status in attentional selection (Vuilleumier et al., 2001; Dolan & Vuilleumier, 2003). Specifically, a number of neuroimaging studies have reported that the response to threat-related stimuli is not modulated by attentional focus (c.f. Anderson et al., 2003; Vuilleumier et al., 2001) which has led to the suggestion that threat-related stimuli may be processed 'automatically', irrespective of the availability of attentional resources. Strong evidence also comes from research where patients with visual extinction can detect emotional expressions to a greater extent compared to neutral when they are presented in their neglected visual field (Lucas & Vuilleumier, 2008; Vuilleumier & Schwartz, 2001a; 2001b), which indicates that emotional stimuli are being processed in the absence of attention since they can be detected even in the 'extinguished' visual field. Similar results are noted with pictures of spiders when they are presented in the neglected field compared to pictures of flowers (Vuilleumier & Schwartz, 2001b).

Conversely, as the attention system is limited in its capacity, it has been argued that emotion processing requires attention (Pessoa, 2005). Support for this view comes from behavioural experiments that presented multiple levels of processing load (Erthal et al., 2005; Yates, Ashwin, & Fox, 2010). Erthal et al. (2005) instructed participants to indicate the orientation of a target bar under low, medium and high levels of processing load. Emotional distractors (i.e. photographs of mutilated bodies) produced interference under low and medium load conditions with these effects being eliminated under the high load condition. The emotional images did not produce distraction under the high load condition indicating they had not captured attention nor had been processed due to the lack of available resources. Furthermore Yates et al. (2010) presented neutral face distractors and angry face distractors with and without fear conditioning under low and high perceptual load. Results of this study show that unattended but highly salient face distractors do capture attention, but only under conditions where attentional resources are available to guide attention to the unattended face. Moreover, studies using the attentional blink paradigm have also shown that the processing of emotional faces was reduced under high perceptual load (Fox, Russo, & Georgiou, 2005). In the Fox et al. (2005) experiment for example, even though the fearful facial expressions were detected more frequently than happy expressions, demonstrating a level of automaticity, they still produced a significant “blink” effect suggesting that attention was required for their detection. Other neuroimaging studies have demonstrated, when perceptual demands are increased by focal attention to a cognitive task, the complete suppression of amygdala activity in response to unattended fearful faces (Lim et al., 2008; Pessoa et al., 2002; Pessoa et al., 2002; Pessoa et al.,

2005) suggesting that when attentional resources are unavailable, processing of emotional information is reduced or extinguished.

In sum, the results of experiment 5 have indicated that suppression of irrelevant distractor information may not be cognitively controlled, which leaves the possibility that it is instead perceptually driven. According to the hybrid selection model (Lavie, 1995; Lavie et al., 2004), focusing attention on a task can prevent perception of task-irrelevant stimuli when the processing of task-relevant stimuli involves a high level of perceptual load that consumes all available capacity (early selection). By contrast, when processing of the task-relevant stimuli places lower demands on the perceptual system, any spare capacity from the task-relevant processing spills over involuntarily, resulting in the perception of irrelevant stimuli (late selection). Previous research on perceptual load has indicated that under low perceptual load, resources for processing the distractor are available; however, when perceptual load is high, resources are not available (i.e. consumed by perceptual processes) and distractor processing is subsequently decreased.

Therefore the main aim of the present study is to examine the effects of perceptual load on the allocation of attention to task-irrelevant threat. If increasing perceptual load results in irrelevant information having a lesser influence on attentional demands, the same increase should result in a reduced requirement to suppress the ignored distractor as the high perceptual demand would consume all (or most) available attentional/perceptual capacity. The reduced requirement to suppress the ignored distractor should result in a reduction in the Pd as an index of suppression. Therefore, the first aim of the study is to investigate the effect of perceptual load on suppression as measured by the Pd. Specifically it is hypothesised that an increase in perceptual load will result in a decrease in the Pd as an index of suppression of an ignored distractor. The second aim of the study is to investigate the effect of perceptual load on the suppression of threat-related distractors (angry vs. neutral), as measured by the Pd. Similarly, if increasing perceptual load results in a decrease in resources to processes threat-related irrelevant information, the same increase should result in a reduced requirement to suppress the threat-related ignored distractor as the high perceptual demand would consume all (or most) available attentional/perceptual capacity.

Additionally, results of experiments 1, 3, 4, and 5 indicate an Nd (distractor negativity) that appears to be unintentional attentional capture of the ignored distractor. Therefore the third aim of the study is to investigate the effect of perceptual load on attentional capture as indexed by the Nd. If the Nd does reflect attentional capture, and, if increasing perceptual load results in fewer resources to process irrelevant information, the same increase should result in a reduced capacity for the ignored distractor to capture attention as high perceptual demand would consume all (or most) available attentional/perceptual resources. It is therefore hypothesised that an increase in perceptual load will result in a decrease in the laterality of the Nd as an index of attentional capture of the ignored distractor. Additionally, it is possible that the Nd is also sensitive to the presence of threatening information similar to what has been reported with the N2pc (c.f. Eimer & Kiss, 2007; Holmes et al., 2009; Holmes et al., 2014). Therefore, the final aim of the study is to investigate the effect of perceptual load on the attentional bias to threat-related distractor information as indexed by changes in the laterality of the Nd. If threat-related information is processed automatically, irrespective of attentional demands, it would be expected that under high perceptual load, attentional capture of threat-related distractors would be greater than neutral.

5.1.1 Method

5.1.1.1 Participants

Twenty-four healthy volunteers from the University of Roehampton received course credit for participation. Two participants were excluded because of excessive eye blinks or eye movements, which resulted in < 50% trials remaining. Therefore, 22 participants (6 male and 16 female; 18–27 years old; mean age: 21.22 years; SD: 2.45) remained in the sample. All participants had normal or corrected-to-normal vision and all were right-handed. The experiment was performed in compliance with The University of Roehampton ethical and research guidelines and was approved by the University ethics committee.

5.1.1.2 Stimuli and Apparatus

The stimuli and procedure were identical to experiment 5, except as follows. Two different vertical target stimuli consisted of the letters ‘O’ and ‘I’, placed one atop another for the first vertical target stimuli; and ‘E’ and ‘F’, placed one atop another for the second vertical target stimuli. As distinguishing the letters ‘I’ and ‘O’ require less perceptual effort than ‘E’ and ‘F’, these conditions were collapsed to form the ‘low’ perceptual load condition, while ‘E’ and ‘F’ were collapsed to form the ‘high’ perceptual load condition. For both stimuli sets, each letter was presented an equal number of times either above or below its counterpart and also an equal number of times in colours green (RGB = 0, 206, 0) or red (RGB = 237, 0, 0), such that when one letter of the target stimulus was displayed green, the other was displayed red, which resulted in 4 individual stimuli for the 'low' perceptual load condition and 4 individual stimuli for the 'high' perceptual load condition. Each letter (9 x 9 mm) of the target stimulus was spaced 2 mm apart leaving a stimulus that was 20 x 9 mm (subtending approximately 1.4^{O} x 0.6^{O} of visual angle) with both sets of stimuli ('I'-'O' & 'E'-'F') being substantially more luminous (3.52 & 3.67 cd/m^2 respectively) than the background (0.19 cd/m^2). The letters were presented in capitalised Arial type font (see Appendix C for stimuli). As with experiment 4 and 5, only intact face stimuli were presented as distractors in this experiment and were the same intact face stimuli used in all previous experiments, with the exception of experiment 3.

5.1.2 Procedure

At the beginning of each session, after informed consent was given, participants completed the state and trait sections of the STAI (see Appendix B). The experiment itself consisted of 12 blocks of 96 trials for a total of 1152 trials per participant that were divided into 4 task conditions, with one section for each letter presented as the target stimulus, each consisting of 3 successive experimental blocks (see figure 5.1). As in all other experiments each trial presentation consisted of two stimuli; one target stimulus (presented on the vertical meridian) and one distractor face stimulus (presented in one of four lateral positions). Participants were instructed to report the colour of the target letter that was indicated at the beginning of the section (i.e. in the 'O' instructed section, if the 'O' was presented red, then a button press corresponding to 'red' was required) with half of participants reporting 'red' with a right button press and 'green' with a left button press, and the other half reporting with the opposite response map. Each letter was presented an equal number of times in each position in the sequence (i.e. ‘O’ target letter was presented in the first, second, third, and fourth positions in the block sequence an equal number of times), with high load and low load conditions being kept together in the sequence (e.g., one sequence of conditions was ‘E’, ‘F’, ‘I’, then ‘O’; another was ‘O’, ‘I’, ‘F’, then ‘E’).

Before each of the four sections, a practice block consisting of 32-trials was administered for participant training. The stimulus arrays and timings of the practice blocks were identical to the trials in the experimental sections except a different set of neutral face identities was presented as lateral stimuli. As in experiments 4 and 5, participant competence was set at 70%.

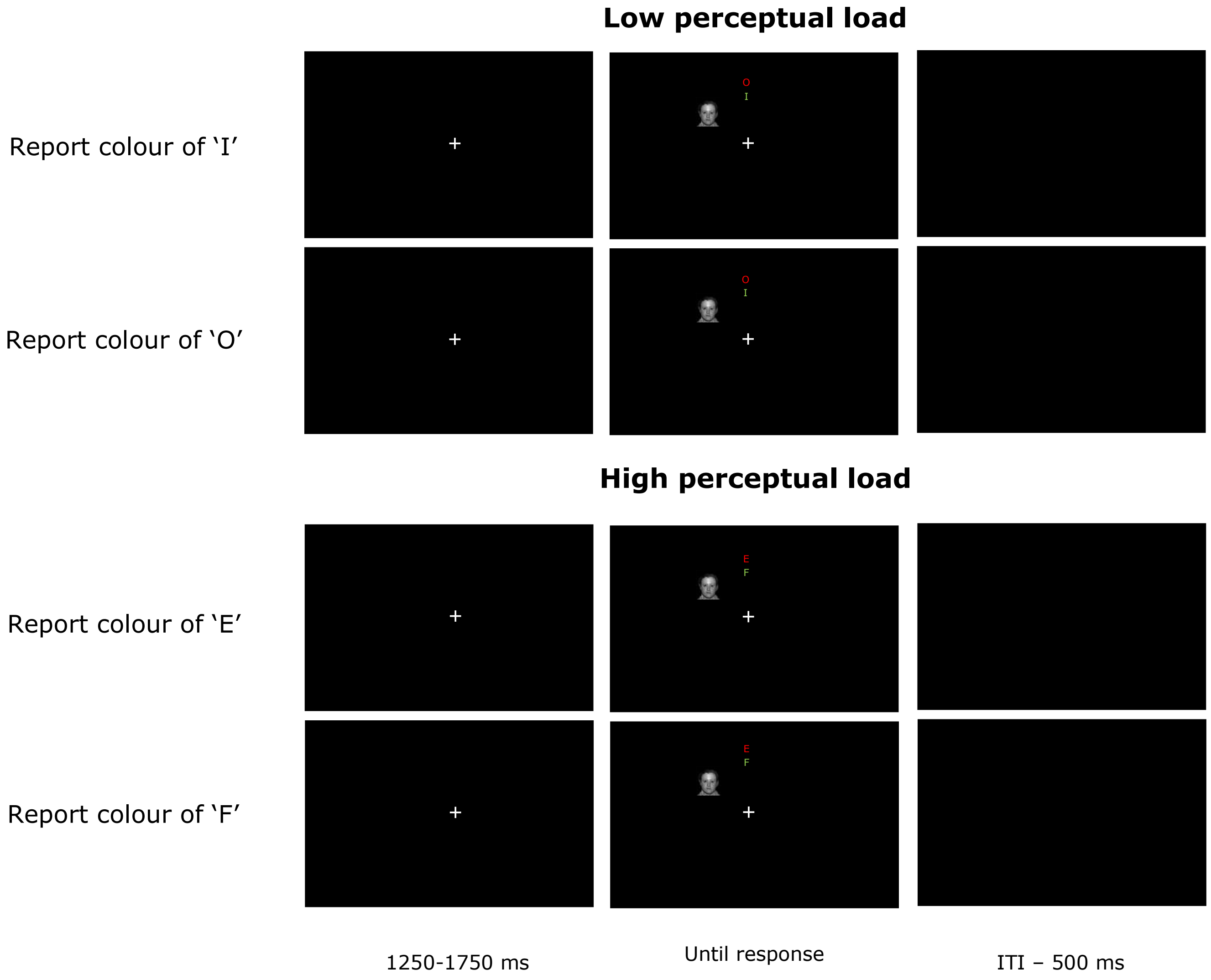


Figure 5.1. Presentation sequence containing fixation screen, sample trial and inter-trial interval.

5.1.2.1 EEG Data Acquisition

EEG data collection is identical to that of experiment 3 and 4. Separate means were computed for all combinations of perceptual load (low vs. high), distractor valence (angry face vs. neutral face), and laterality (electrodes contralateral vs. ipsilateral to location of distractor). Similar to previous experiments, visual inspection of the waveforms resulted in the identification of three main contralateral (to the distractor) ERP components in the lateral posterior area. These were assessed for the current study with reference to the side of the face distractor; namely, a positive posterior contralateral (Pe) beginning around 70 ms; a distractor negativity (Nd) beginning around 130 ms, and a contralateral positivity (Pd; cf. Hickey et al., 2009) beginning around 190 ms. As in previous experiments these components were individually measured at their respective time windows from the mean of the five left posterior parieto-temporal electrodes and five right posterior parieto-temporal electrodes (see figure 3.2 for electrode positioning), as this is where maximal activity was apparent for each component (see figure 5.2).

The Pe was defined as the mean amplitude between 70-110 ms post-stimulus presentation, overlapping the P1 time window (c.f. Luck & Hillyard, 1994a; Batty & Taylor, 2003; Jannati et al., 2013). The Nd was defined as the mean amplitude between 130-170 ms post-stimulus presentation, overlapping the N170 time window (c.f. Eimer, 1998; Williams et al., 2006). The Pd was defined as the mean amplitude between 190-250 ms post-stimulus presentation (c.f. Hickey et al., 2009). Figure 5.2 shows the contralateral and ipsilateral ERPs observed at the posterior parietal electrode sites. Mean amplitudes were automatically extracted for all components. Figure 5.3 shows low high perceptual load laterality difference activity for each time interval in analysis.

5.1.3 Results

Non-responses and trials with errors were discarded, as were any with RTs less than 200 ms (8.4% of all responses). When using ANOVAs to determine statistical effects, partial eta-squared (η^2_p) are reported as an estimate of effect size for every significant effect found.

5.1.3.1 Behavioural measures

Mean correct RTs and accuracy results are shown in tables 5.1 and 5.2 respectively.

5.1.3.1.1 Reaction time (RT)

Planned comparisons of mean RT for each condition were entered into a 2 x 2 repeated measures analysis of variance (ANOVA), and factors of task load (low, high), and distractor valence (angry, neutral). There was a significant main effect of load, $F(1,21) = 8.81$, $p < .01$ ($\eta^2_p = .30$) where responses were faster for low perceptual load (974 ms) compared to the high (1027 ms), indicating the manipulation was effective resulting in a significant slowing of reaction time to compensate for the difficulty of the high perceptual load task. There were no other significant effects or interactions (all *F*s < 1).

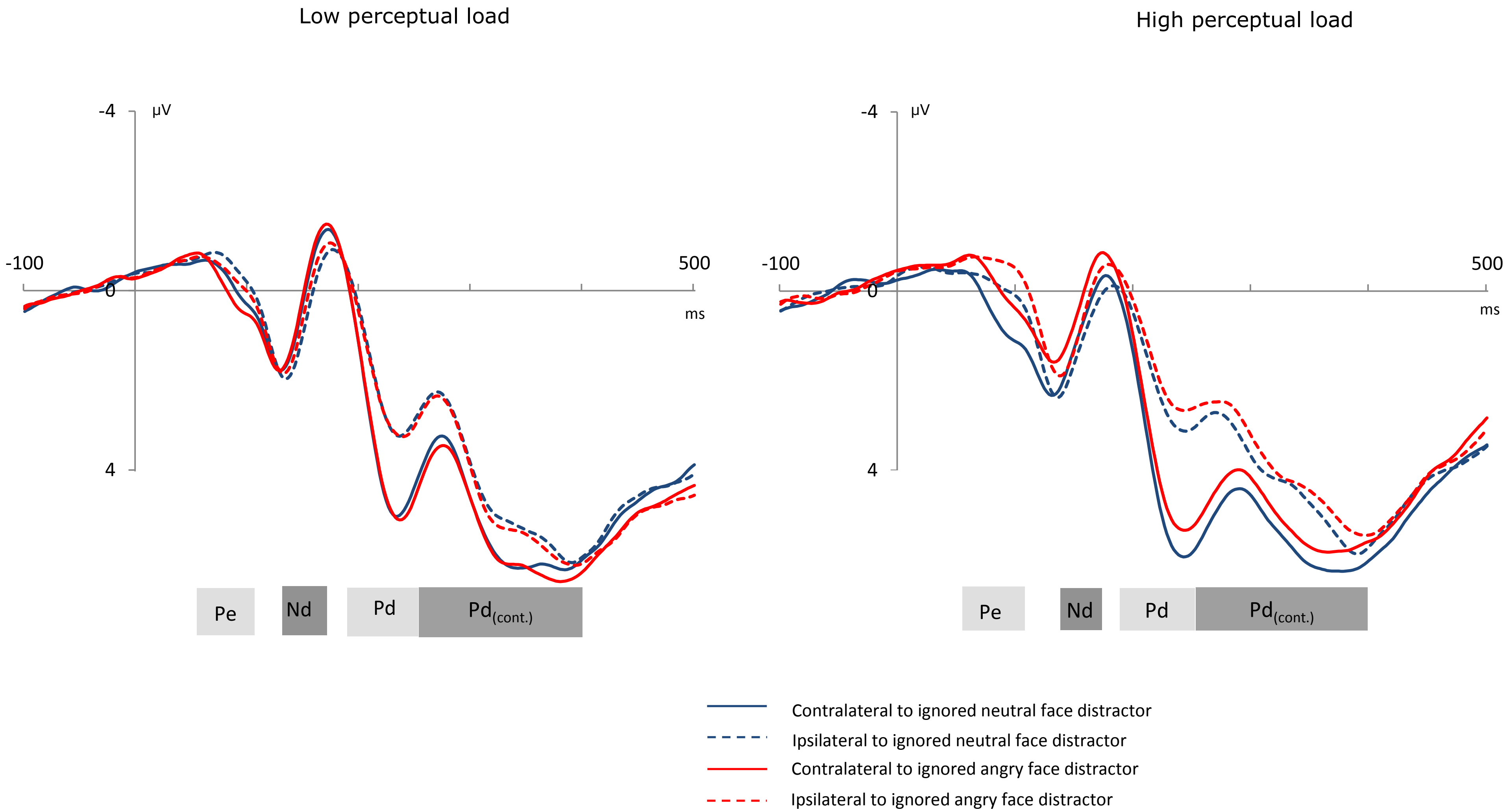


Figure 5.2. Low and high perceptual load grand average ERPs for electrodes contralateral and ipsilateral to ignored distractor across neutral and angry face distractors. The 60-110 ms (Pe) 130-170 ms (Nd); 190-250 ms (Pd); and 250-400 ms (Pd $_{\text{(cont.)}}$) time intervals are depicted.

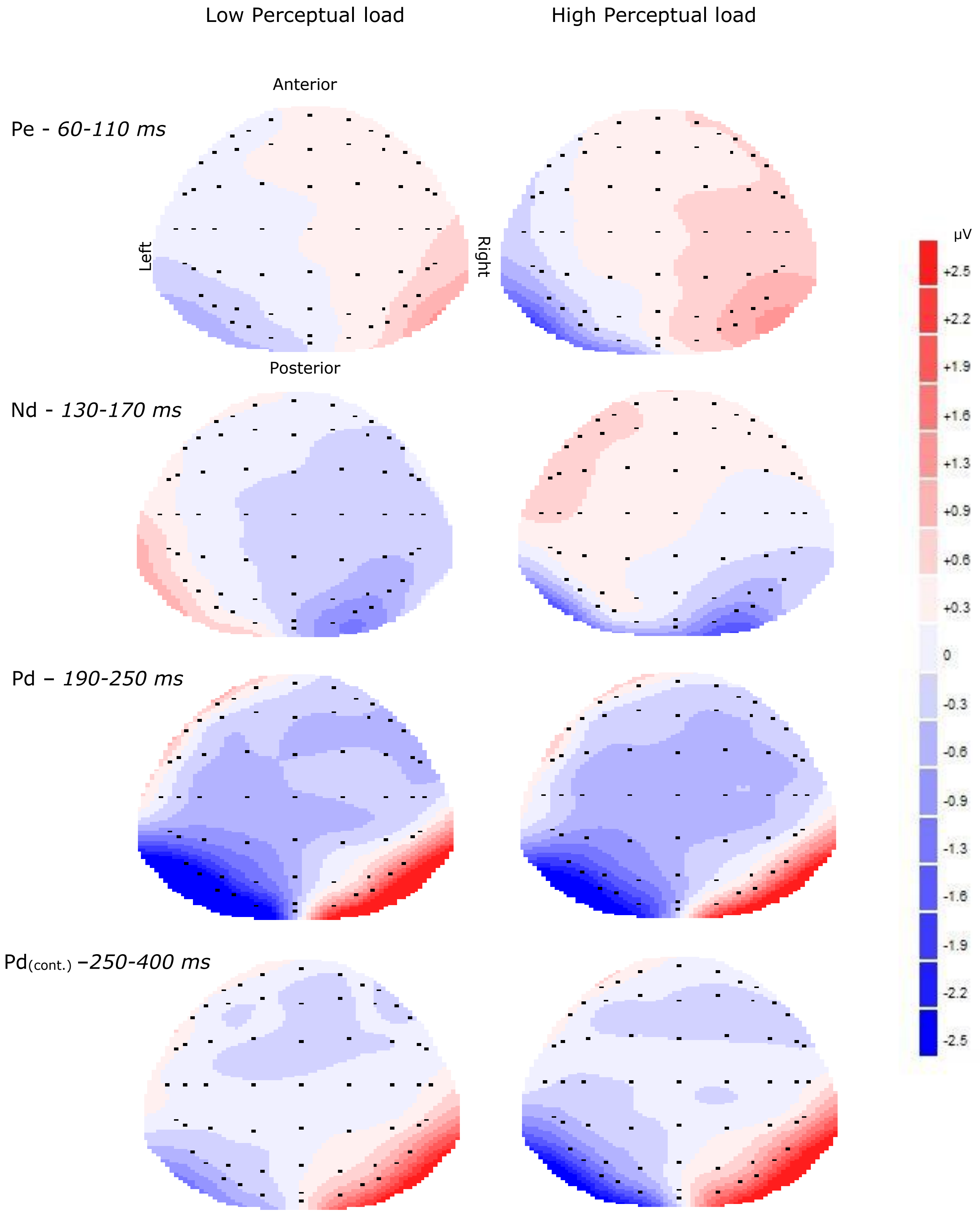


Figure 5.3. Low perceptual load (left) and high perceptual load (right) laterality difference activity (activity of left presented ignored distractor minus activity right presented ignored distractor) for each time interval in analysis.

Table 5.1. *Means (and standard deviations), for correct reaction times (ms) to targets for each condition*

	Low perceptual load	High perceptual load
Neutral	974 (199.3)	1021 (228.9)
Angry	974 (219.5)	1034 (241.2)

5.1.3.1.2 Accuracy

Planned comparisons of total correct responses for each condition were entered into a 2 x 2 repeated measures analysis of variance (ANOVA), with factors of task load (low, high), and distractor valence (angry, neutral). There were no significant main effects or interactions (all *F*s < 2.9), indicating the increase in perceptual load did not result in an increase in errors.

Table 5.2. *Mean (SD) number of correct responses for each condition. Scores are total out of 72.*

	Low load	High load
Neutral	66.7 (3.42)	64.9 (7.10)
Angry	67.6 (3.79)	64.8 (7.37)

5.1.3.2 ERP measures

To ensure lateral eye-movement does not contaminate the ERPs being measured, residual lateral eye movement were calculated as the difference for distractor-left minus distractor-right presented trials of the HEOG channel. This will allow for direct comparison with each component of analysis for the same trials, in the same time interval. Any values for any participant greater than ± 4 μV resulted in additional analyses, minus those participants, within each component of interest. Figure 5.4 shows grand average ERPs for electrodes contralateral and ipsilateral to distractor presentation of angry and neutral face distractors for low and high perceptual load.

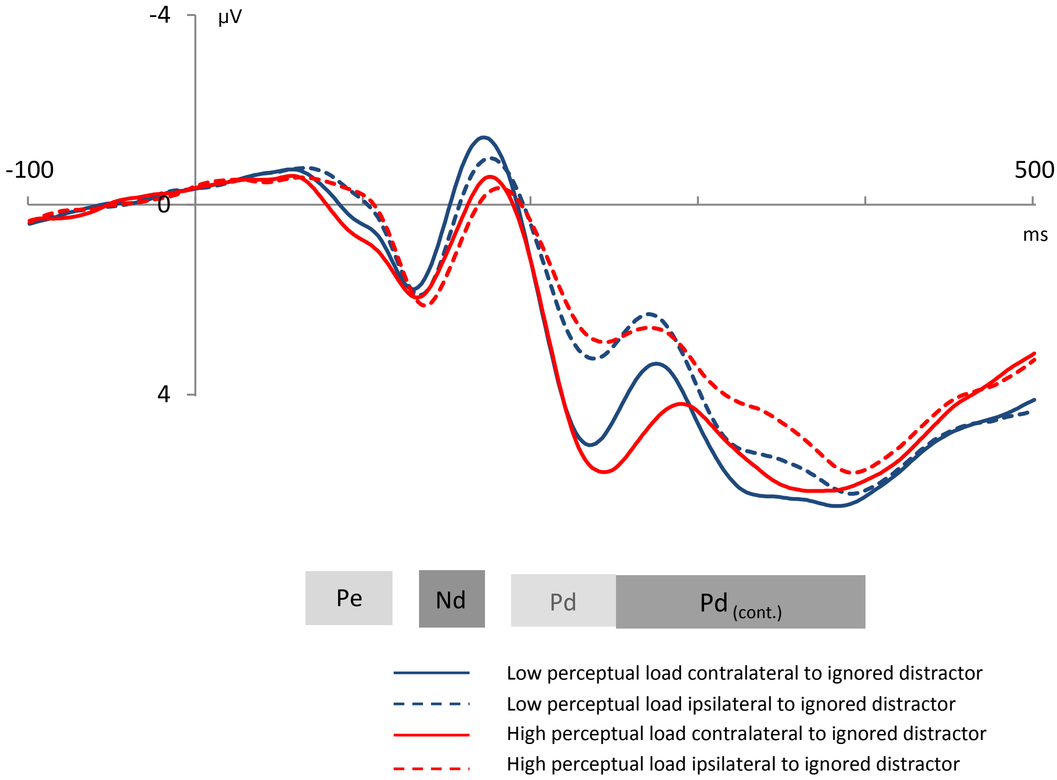


Figure 5.4. Low and high perceptual load grand average ERPs for electrodes contralateral and ipsilateral to ignored distractor across neutral and angry face distractors. The 60-110 ms (Pe); 130-170 ms (Nd); 190-250 ms (Pd); and 250-400 ms ($Pd_{(cont.)}$) time intervals are depicted.

5.1.3.2.1 Pe: 60-110 ms

Residual lateral eye-movement for the 60-110 ms time interval ranged between -1.71 and 0.91 μV (see figure 5.5). Mean amplitude values for the Pe were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of perceptual load (low, high), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality, $F(1,21) = 63.36$, $p < .001$ ($\eta^2_p = .75$), where mean amplitudes where more positive for contralateral electrodes (0.06 μV) compared to ipsilateral (-0.42 μV) indicating sensory activity related to the both the distractor and target. Also there was a significant main effect of valence, $F(1,21) = 4.31$, $p < .05$ ($\eta^2_p = .17$), where mean amplitudes were more positive for neutral distractors (-0.08 μV) compared to angry (-0.28 μV); a significant load x valence interaction, $F(1,21) = 12.47$, $p < .01$ ($\eta^2_p = .37$) where the valence effect appears greater for high load task compared to low; and a significant load x laterality interaction, $F(1,21) = 9.26$, $p < .01$ ($\eta^2_p = .31$), where the laterality effect appears greater for the high load task compared to the low.

Paired comparison *t*-tests on the load x valence interaction indicate a significant effect of valence for high load, $t(21) = 4.39$, $p < .001$ (2-tailed), where angry face distractors were more positive (0.29 μV) compared to neutral (-0.30 μV); but no similar effect for the low load task ($t < 1.2$). Paired comparison *t*-tests on the load x laterality interaction reveal a significant laterality effect for high perceptual load, $t(21) = 9.90$, $p < .001$ (2-tailed), where electrodes contralateral to the ignored distractor were more positive (0.29 μV) compared to ipsilateral (-0.30 μV); and a significant laterality effect for low perceptual load, $t(21) = 4.83$, $p < .001$ (2-tailed), where contralateral were more positive (-0.04 μV) compared to ipsilateral (-0.39 μV). There were no other significant main effects or interactions (all *F*s < 2).

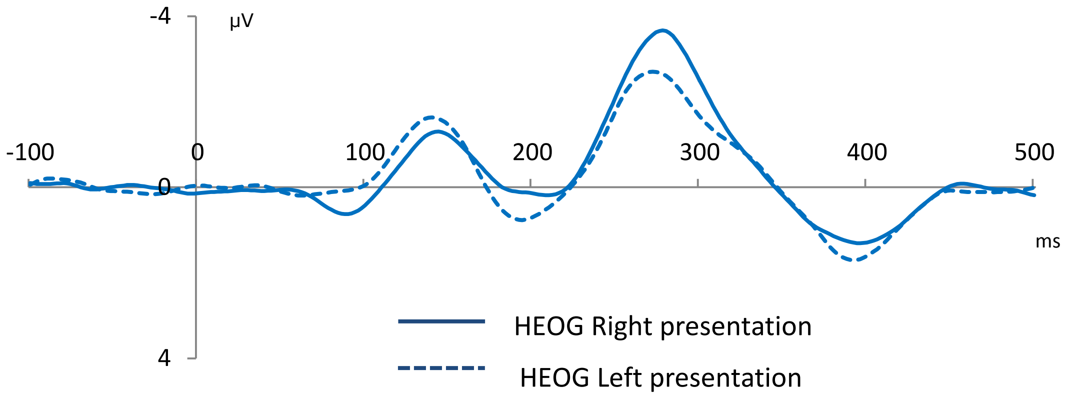
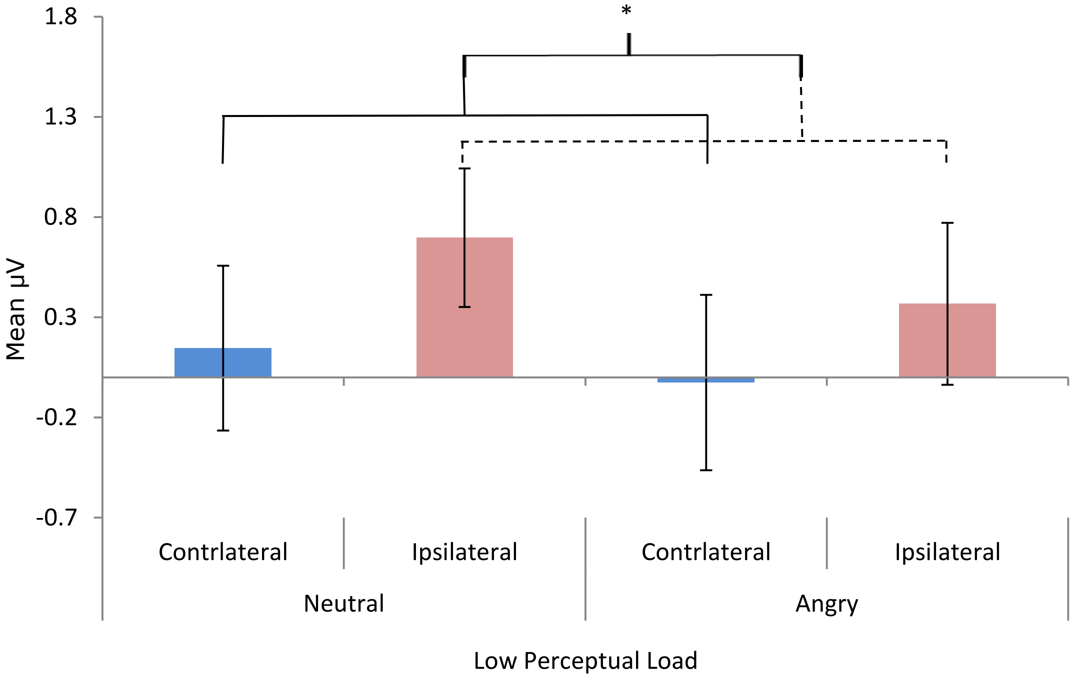


Figure 5.5. Grand average lateral eye-movement (HEOG) for right (solid line) and left (dashed line) stimulus presentation across all conditions.

5.1.3.2.2 Nd: 130-170 ms

Residual lateral eye-movement for the 130-170 ms time interval ranged between -1.21 and 1.67 μV. Mean amplitude values for the Nd were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of perceptual load (low, high), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality, $F(1,21) = 6.38$, $p < .05$ ($\eta^2_p = .23$), where mean amplitudes were more negative for electrodes contralateral to the ignored distractor (0.41 μV) compared to ipsilateral (0.82 μV); a significant main effect of perceptual load, $F(1,21) = 9.77$, $p < .01$ ($\eta^2_p = .32$), were mean amplitudes were more negative for low (0.30 μV) than high (0.93 μV); a significant main effect of valence, $F(1,21) = 16.38$, $p < .001$ ($\eta^2_p = .44$), where mean amplitudes were more negative for angry face distractors (0.42 μV) compared to neutral (0.81 μV); and a significant load x valence x laterality interaction, $F(1,21) = 5.52$, $p < .05$ ($\eta^2_p = .21$). There were no other significant main effects or interactions (all *F*s < 2.1).

The significant load x valence x laterality interaction was investigated by performing two valence x laterality ANOVAs for each level of perceptual load (low, high). Results for low perceptual load reveal a significant effect of laterality, *F*(1,21) = 7.68, *p* < .05 (η^2_p = .27) only, where mean amplitudes were more negative for electrodes contralateral (0.15 μV) compared to ipsilateral (0.70 μV). Results for high perceptual load show a significant effect of valence, *F*(1,21) = 38.55, *p* < .001 (η^2_p = .65), where mean amplitudes were more negative for angry face distractors (0.66 μV) compared to neutral (1.19 μV); and a valence x laterality interaction, *F*(1,21) = 9.93, *p* < .01 (η^2_p = .32), where the laterality effect appears greater for angry face distractors compared to neutral (while a laterality effect for high perceptual load did not reach significance (*F* = 3.19, *p* = .09)). Paired comparisons *t*-test on the valence x laterality interaction for high perceptual load reveal a significant effect of laterality for the angry face distractors, *t*(21) = 2.44, *p* < .05 (2-tailed), where electrodes contralateral to angry face distractors were more negative (0.43 μV) compared to ipsilateral (0.89 μV); but no similar effect was evident for the neutral face distractors (*t* < 1.2). Thus, neutral stimuli appear only to capture attention under low perceptual load conditions whereas threat-related stimuli capture attention under both low and high load conditions. Figure 5.6 shows means for low (upper) and high (lower) perceptual load across valence. These results indicate threat-related distractors capture attention under high load more than do neutral, and support the conclusion that threat is detected ‘automatically’, even under high task demands.



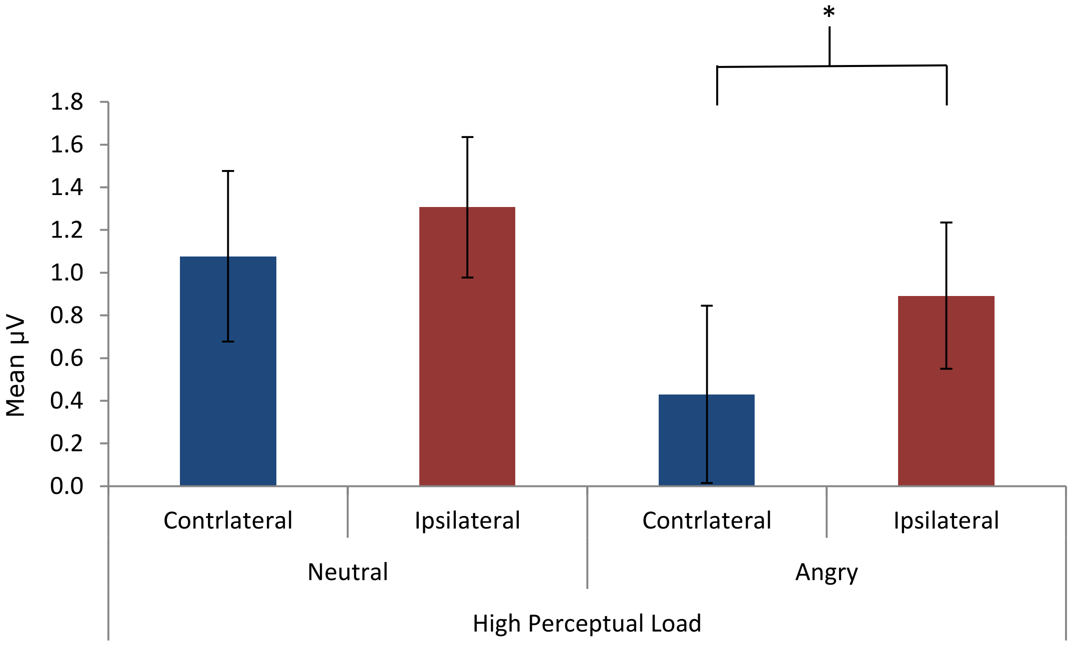


Figure 5.6. Mean amplitudes (µV) of the Nd in the 130-170 ms time interval for low (upper) and high (lower) perceptual load across valence (error bars represent 95% CI), **p* < .05.

5.1.3.2.3 Pd: 190-250 ms

Residual lateral eye-movement for the 190-250 ms time interval ranged between -1.81 and 2.94 μV. Figure 5.7 and 5.8 shows mean amplitudes of the Pd for contralateral vs. ipsilateral and angry vs. neutral respectively for low and high perceptual load. To investigate if the Pd (c.f. Hickey et al., 2009), as an index of the suppression of attention to an ignored distractor, is altered by the perceptual load of a central task, mean amplitude values were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of perceptual load (low, high), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality, $F(1,21) = 37.65$, $p < .001$ ($\eta^2_p = .64$), where mean amplitudes were more positive for electrodes contralateral to ignored distractors (3.41 μV) compared to ipsilateral (1.76 μV); a significant main effect of valence, $F(1,21) = 5.260$ $p < .05$ ($\eta^2_p = .20$), where mean amplitudes where more positive for neutral face distractors (2.69 μV) compared to angry (2.43 μV); a significant load x valence interaction, $F(1,21) = 12.50$, $p < .01$ ($\eta^2_p = .37$), where the valence effect appears greater for the high perceptual load task, compared to the low; and a significant load x laterality interaction, $F(1,21) = 10.49$, $p < .01$ ($\eta^2_p = .33$), where the laterality effect appears greater for high perceptual load, compared to low.

Paired comparisons *t*-test on the load x laterality interaction reveal a significant effect of laterality (contralateral vs. ipsilateral) for high perceptual load, $t(21) = 6.35$, $p < .001$ (2-tailed), where electrodes contralateral to the ignored distractor were more positive (3.50 µV) compared to ipsilateral (1.60 µV); and, a significant effect of laterality for low perceptual load, *t*(21) = 5.40, *p* < .001 (2-tailed), where electrodes contralateral to the ignored distractor (3.32 µV) were more positive compared to ipsilateral (1.92 µV). Paired comparisons *t*-test on the load x valence interaction reveal a significant effect of valence (neutral, angry) for high perceptual load, *t*(21) = 4.15, *p* < .001 (2-tailed), where neutral face distractors were more positive (2.78 µV) compared to angry (2.32 µV); but no similar effect was evident for low load (*t* < 1). There were no other significant main effects or interactions (all *F*s < 2.5).

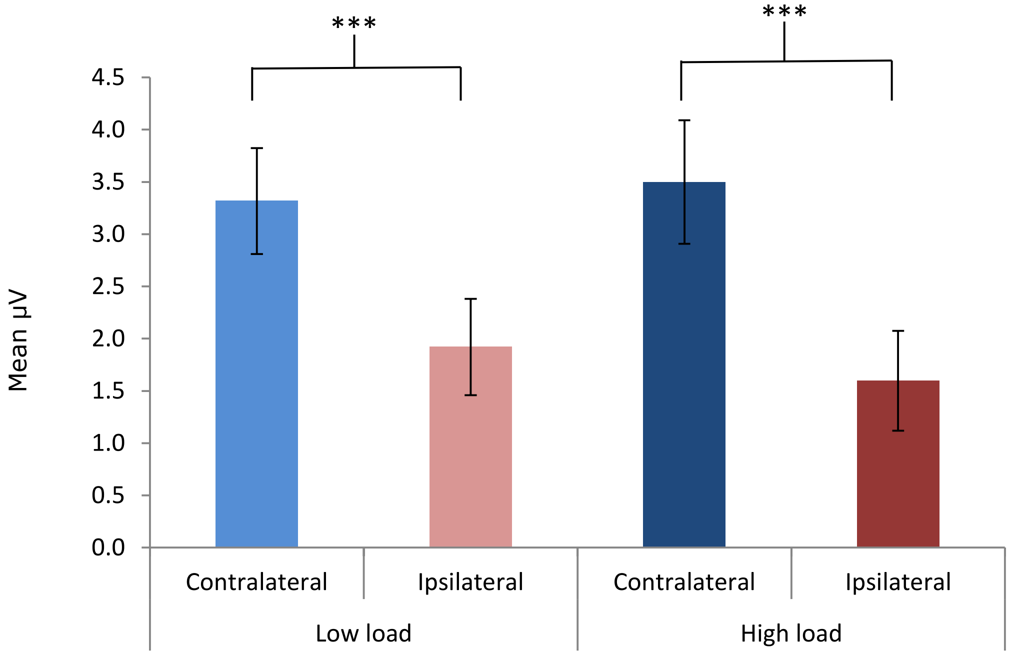


Figure 5.7. Mean amplitudes (µV) of the Pd in the 190-250 ms time interval for low and high perceptual task load across laterality (error bars represent 95% CI), *** *p* < .001.

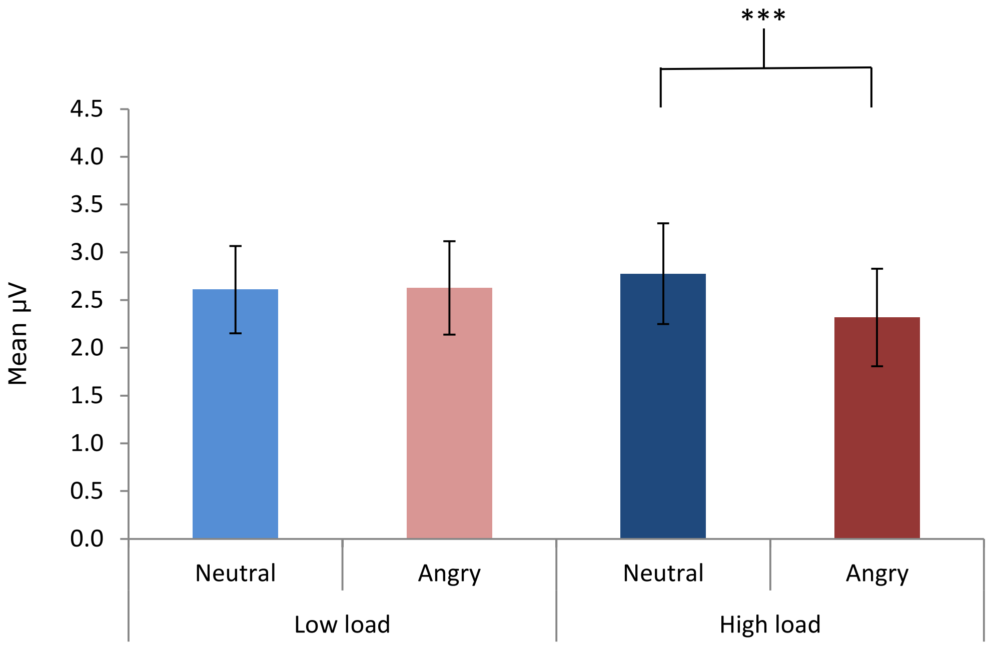


Figure 5.8. Mean amplitudes (µV) of the Pd in the 190-250 ms time interval for low and high perceptual task load across valence (error bars represent 95% CI), *** *p* < .001.

5.1.3.2.4 Pd$_{(cont.)}$: 250-400 ms

Residual lateral eye-movement for the 250-400 ms time interval ranged between -1.64 and 2.96 µV. Figure 5.4 shows mean amplitudes of the Pd for contralateral vs. ipsilateral for low and high perceptual load. To investigate if the Pd (c.f. Hickey et al., 2009), as an index of the suppression of attention to an ignored distractor, is altered by the perceptual load of a central task, mean amplitude values were submitted to a 2 x 2 x 2 repeated measures analysis of variance (ANOVA) with factors of perceptual load (low, high), distractor valence (angry, neutral), and laterality (electrodes contralateral to ignored distractor, electrodes ipsilateral to ignored distractor). There was a significant main effect of laterality, $F(1,21) = 63.65$, $p < .001$ ($\eta^2_p = .75$), where mean amplitudes were more positive for electrodes contralateral to ignored distractors

(5.32 μV) compared to ipsilateral (4.32 μV); a significant load x valence interaction, *F*(1,21) = 11.80, *p* < .01 (η^2_p = .36), where the valence effect appears greater for the high perceptual load task, compared to the low; and a significant load x laterality interaction, *F*(1,21) = 12.42, *p* < .01 (η^2_p = .37), where the laterality effect appears greater for high perceptual load, compared to low.

Paired comparisons *t*-test on the load x laterality interaction reveal a significant effect of laterality (contralateral vs. ipsilateral) for high perceptual load, *t*(21) = 8.34, *p* < .001 (2-tailed), where electrodes contralateral to the ignored distractor were more positive (5.35 μV) compared to ipsilateral (4.12 μV); and, a significant effect of laterality for low perceptual load, *t*(21) = 5.79, *p* < .001 (2-tailed), where electrodes contralateral to the ignored distractor (5.29 μV) were more positive compared to ipsilateral (4.52 μV). Paired comparisons *t*-test on the load x valence interaction reveal a significant effect of valence (neutral, angry) for high perceptual load, *t*(21) = 2.87, *p* < .01 (2-tailed), where neutral face distractors were more positive (4.92 μV) compared to angry (4.54 μV); but no similar effect was evident for low load (*t* < 1.3). These results indicate that the $\text{Pd}_{(\text{cont.})}$ shows an identical pattern of results as the Pd and likely reflects a continuation of the Pd. There were no other significant main effects or interactions (all *F*s < 2.8).

5.1.4 Discussion

The primary aim of experiment 6 was to investigate the effects of perceptual load on the allocation of attention to task-irrelevant threat. To increase perceptual load one must either increase the number of items that need to be perceived or increase perceptual difficulty distinguishing between stimuli for the same number of items (Lavie, 2006) with only the latter controlling for sensory characteristics of the target. The present study created perceptual load by increasing the difficulty in distinguishing letters within a target stimulus for one condition compared to another. The success of this was confirmed with the behavioural data where participant accuracy of the task not showing significant decline in the high perceptual load task compared to low, the RT did show a significant increase indicating that while the difficulty of the task resulted in the high load taking longer, it did not result in a decrease in participants ability to identify the target items.

5.1.4.1 Distractor Positivity (Pd & Pd$_{(cont.)}$)

The first aim of the present experiment was to investigate the effect of perceptual load on suppression to an ignored distractor as measured by the Pd. Results are consistent with experiments 1, 3, 4, and 5, and confirm the presence of the Pd as demonstrated by the increased positivity contralateral to the ignored distractor (compared to ipsilateral) within the 190-250 ms (and continued up to 400 ms) time range. However, contrary to predictions high perceptual load did not result in a significant reduction in the Pd despite RT results showing that the high load task resulted in a significant delay in response times. Accuracy, on the other hand, did not show a similar significant decline, indicating that participants favoured accuracy over speed as a coping strategy for the high perceptual load task. The second aim of the study was to investigate the effect of perceptual load on the suppression of threat-related distractors. The hypothesis that an increase in perceptual load will result in a decrease in suppression of the ignored distractor as indexed by the Pd was not supported in this experiment. By contrast, results indicate that the Pd is enhanced as a result of increased perceptual load. While both high and low perceptual load show significant laterality effects, high perceptual load appears to show a greater laterality effect than that of the low. The load x valence interaction indicates a reduced positivity for angry faces under high load, supporting the conclusion that threat-related information is processed automatically, irrespective of task demands. Although, some caution must be taken with this interpretation as there was no laterality effect in this interaction, meaning that activity directly related to the lateral ignored distractor cannot be directly attributed.

These results are broadly consistent with the results of experiment 4, if these earlier results are (tentatively) interpreted as reflecting an attentional/perceptual load manipulation. It should also be noted that an increase in suppression for a more difficult task compared to an easier task was also evident in Hickey et al. (2009) when comparing the discrimination task (experiment 1 & 3) to the detection task (experiment 2). The laterality of the Pd dropped to below significance in the detection task for Hickey et al. (2009) which required very few attentional/perceptual resources compared to the discrimination task, where the laterality of the Pd was significant.

This pattern of results differs from predictions that would arise from Lavie's (2005) perceptual load theory of attention where suppression should be greater under low perceptual load as the distractors have a greater influence on attention due to the available resources. The results of the Pd indicate that under high perceptual load, ignored distractors require greater suppression, therefore have an increased intrusion effect. This will be discussed further in the next section (Nd: Distractor Negativity). Lastly, the hypothesis that an increase in perceptual load will result in a decrease in suppression of the threat-related ignored distractor as indexed by the Pd was not supported in this experiment. However, a load x valence interaction indicates that under high load the voltage for angry face distractors were significantly less positive than for neutral face distractors, indicating automatic processing of threat-related information. However, the absence of a laterality effect in this interaction makes it difficult to attribute this effect directly to the lateral distractor. The results of experiment 5 indicate that suppression of irrelevant information is either not controlled by top-down cognitive processes or that the Pd itself is not sensitive to top-down suppression. While the results of experiment 1 showed that modulating high level semantic features of the distractor (intact faces vs. scrambled) did not result in a significant modulation of suppression as indexed by the Pd. The results of the present experiment indicate that either suppression is modulated by perceptual (bottom-up), rather than cognitive (top-down) processes or that the Pd itself is reflective of perceptual suppression (i.e. surround attenuation; Boehler, Tsotsos, Schoenfeld, Heinze, & Hopf, 2011) rather than cognitive suppression.

5.1.4.2 Distractor Negativity (Nd)

The third aim of the experiment was to investigate the effect of perceptual load on attentional capture as indexed by the Nd. Results are consistent with experiments 1, 3, 4 and 5, and confirm the presence of the Nd as demonstrated by the increased negativity contralateral to the ignored distractor (compared to ipsilateral) within the 130-170 ms time range. The hypothesis that an increase in perceptual load will result in a decrease in the laterality of the Nd as an index of attentional capture to the ignored distractor was generally supported by the results of this experiment. While a load x laterality interaction was not evident, a sustained laterality effect for angry faces (across perceptual load), but not for neutral faces under high perceptual load, is in line with previous conclusions that threat-related information is processed automatically irrespective of task load. Neutral face distractors showing a reduced laterality effect under high load demonstrates a reduction in attentional capture as a result of task demands. This observation, for neutral face distractors is in line with Lavie's (1995) predictions that increasing perceptual load will result in a reduction of attentional capture due to a depletion of available attentional/perceptual resources. Additionally, this could form part of the explanation for the increase of suppression as indexed by the Pd. It may be that the greater available resources of the low load condition resulted in increased evaluation of the lateral ignored distractor or it may be that a harder perceptual task might automatically lead to greater perceptual suppression of any potential distractors (irrespective of how salient they are) in order to protect target processing under more perceptually demanding conditions. This interpretation would be in line with surround attenuation theory (Boehler et al., 2011) and contrasts with the view that the potential intrusion strength of the distractor determines the amount of suppression (Lavie, 2005).

The final aim of the study was to investigate the effect of perceptual load on the attentional bias to threat-related distractor information as indexed by changes in the laterality of the Nd. If threat-related information is processed automatically, irrespective of attentional demands, it would be expected that under high perceptual load attentional capture of threat-related distractors would be greater than neutral, whereas this pattern would not be evident under low perceptual load. The results of the present study indicate that neutral distractors capture attention under low perceptual load conditions but not under high perceptual load conditions, a finding that is consistent with Lavie's (2005) predictions. Threat-related distractors, however, capture attention under both low and high conditions.

While it appears that increasing perceptual load results in fewer intrusions on attention from neutral distractors, threat-related distractors appear to be processed preferentially and capture attention under high perceptual load. However, under low load conditions, where resources are available no such preferential processing was observed. This is consistent with Anderson et al. (2003) whose results indicate that the automaticity of threat processing is not fundamental to the processing of all facial signals of threat, but is unique to amygdala processing of fear. Furthermore, their results indicate that amygdala processing of fear was not entirely automatic, coming at the expense of a specific type of response. Indicating amygdala processing is specific to fear information only during attended processing, when cortical processing is undiminished, and more broadly tuned to threat during unattended processing, when cortical processing is diminished. A consistent finding in previous research using the N2pc as a measure of attentional selection is that shifts of attention for threatening information arise rapidly with the N2pc emerging around 180-250 ms. Importantly, the results of the Nd reveal that this initial stage of visio-spatial selection (around 130-170 ms post stimuli onset) is modulated by concurrent perceptual demands and demonstrates that attentional capture can happen very rapidly after initial stimulus perception. Additionally, these results also show that threat-related distractor information can be processed irrespective of attentional demands. No ERP study to date (that I am aware of) has demonstrated attentional influence of an irrelevant threat-related distractor whilst manipulating perceptual load. One publication to date has found no alteration in the N2pc to fearful distractor faces in a perceptual load task (Fenker et al., 2010). In two MEG experiments, Fenker et al. (2010) presented participants with a target location discrimination task presented over either fearful or neutral faces that were themselves presented in either right or left visual fields. Results showed that in both the low and high perceptual difficulty experiments the N2pc component (contralateral to fearful face presentation) was unaltered, however in the high perceptual demand experiment RT were faster than the low, while accuracy was lower for the high load experiment.

5.1.4.3 Early Positivity (Pe)

As in all previous experiments a Pe was also observed for the present experiment as indicated by a significant positivity contralateral to the ignored distractor. Results show a very similar pattern of results for the Pe as the Pd and $\text{Pd}_{\text{(cont.)}}$ in the present experiment. It could perhaps be that the Pe is modulating due to attentional demands of the experiment. Heinze, Luck Mangun, and Hillyard (1990) noted an alteration in an early P1 for stimuli presented in an attended visual field, compared to an unattended visual field. When viewed in light of the more recent salient-signal suppression hypothesis (Jannati et al., 2013) it could be that the early positivity observed by Heinze et al. (1990) reflected a combination of basic feature processing of the stimuli array and subsequent generation of a salience map. With attention already directed toward the visual field of interest, it is reasonable to presume the salience of any stimuli presented in that visual field would be greater than that presented in an unattended visual field.

Alternatively, the Pe showing a similar pattern of results to the Pd, and subsequently $Pd_{(cont.)}$, could indicate both reflect lower level sensory processes more than that of suppression of the ignored lateral distractor. However, the findings of the previous experiments 1, 3, 4, and 5 indicate this is unlikely to be the case. It could be that presenting the high perceptual load tasks together in the same block of trials resulted in a carry-over effect from one trial to the next, leading to ‘attentional’ effects being present within this very early time window. Theeuwes, Kramer, and Belopolsky (2004) presented participants with low and high perceptual load trials both together in the same block and also in separate blocks. When presented in separate blocks results showed the processing of to-be-ignored stimuli in the low condition only, however, when presented in the same block participants showed processing of the to-be-ignored stimuli in both low and high conditions. Theeuwes et al. (2004) proposed that advance knowledge of perceptual load level rather than perceptual load *per se*, modulates the processing of irrelevant distractors. The present experiment presented high load trials in a separate block to the low which may explain why the Pe, Pd, and $Pd_{(cont.)}$ show a very similar pattern of results in this experiment and why the Pe in this experiment is showing a different pattern of results to its counterpart Pe in previous manipulations in this series of experiments.

Chapter 6: Discussion and conclusions

This thesis began with the consideration of two pieces of evidence: firstly that threat related information appears to hold a special status in, or is given privileged access to, attention (c.f. Vuilleumier et al., 2001; Dolan & Vuilleumier, 2003); and secondly, that spatial attention could be represented through the action of multiple cognitive mechanisms (c.f. Hickey et al., 2009) and thus attention deployment (i.e., using the N2pc) is represented both by facilitation of attentional selection and the suppression of irrelevant information. Therefore the following experiments utilized a paradigm first published by Hickey et al. (2009) that allowed for the processing of an ignored distractor and an attended target to be quantified independently. Measuring these processes independently allowed for the separation of the two mechanisms of suppression of irrelevant distractor information and attentional facilitation of a target that appear to be both represented by the N2pc ERP component. The experimental program of research outlined in this thesis aimed to examine primarily the suppression of irrelevant information, but also attentional facilitation of relevant (target) information, and the influence that threat related information has on suppression and attentional facilitation. The findings of the first experiments provided a partial replication of the original Hickey et al. (2009) paradigm and the subsequent experiments explored the role of processing load (cognitive and perceptual) on suppression and attentional capture. The findings, implications, and limitations of each experiment will be discussed in the following section with a particular focus on the implications of the results of previous and current load experiments.

6.1 Experiments 1 and 2 (Chapter 2)

The first experiment of the thesis is, to this author's knowledge, the first in the broader literature examining modulations of the Pd to assess a direct measure of suppression of threat related distractor information compared to non-threat or the comparison of socially relevant compared to socially non-relevant information. The results of experiment 1 show that the presentation of threat related irrelevant distractors does not influence suppression as indexed by modulations of the Pd. While there was an indication of a trend toward angry faces showing reduced suppression, this effect was apparent in the scrambled face images only. While it is possible that some face information was still present in the scrambled face images, if threatening information were, on some level, influencing the mechanism of suppression it would seem reasonable that this be evident, at least, for the intact faces more than for scrambled. With this in mind and the fact that this result did not actually reach significance, it was likely anomalous. However, given the evidence suggesting that threat related information is given privileged access to attention, follow up experiments examining the influence of threat related information on suppression under load were explored. Additionally, a comparison of the observed Ne (experiment 1) and Nt (experiment 2) indicated the likelihood that the Ne (renamed the Nd in subsequent experiments) reflects a process of attentional capture by the ignored lateral stimuli. Moreover, the negative results relating to the effects of valence (anger vs. neutral) on the components representing attentional capture/facilitation (Nd/Nt) and suppression (Pd/Pt) contrast with some (e.g., Mogg & Bradley, 1999; experiment 2) but not all (Holmes et al., 2014) previous findings. Also observed in experiment 2 was a lateral positivity (Pt) that appeared after attentional facilitation (Nt) of the target (c.f. Sawaki et al., 2012). The evidence that attentional selection is not followed by a positive deflection in manipulations where attention is maintained after attentional selection (Woodman et al., 2009) indicates the Pt reflects a process of disengagement of attention. The results of experiments 1 and 2 showing that the Pt shares a very similar pattern of results to the Pd (i.e. its position in the waveform and that it is similarly not altered by features of the lateral stimuli) indicates that this process of disengagement is likely being carried out by mechanisms of suppression.

6.2 Experiment 3 (Chapter 3)

Experiment 3 was designed to address the findings that the Pd and Pt, and similarly the Nd and Nt, demonstrated very similar patterns of results, with only a difference in their magnitude of laterality distinguishing one from the other, with the Pd (experiment 1) and Nt (experiment 2) demonstrating a greater laterality than their same polarity counterparts. This result is, perhaps, not surprising given that the experiments were designed to examine these very components. However, these similarities did leave the possibility that the Pd, Pt, Nd, and Nt components were a result of a sensory imbalance caused by the presentation of a stimulus in one visual field alone, rather than reflecting processes of attention. To explore this possibility, experiment 3 was designed to manipulate both the physical salience of the lateral image. Given that the comparison of these components in experiments 1 and 2 (similarly for Hickey et al., 2009) were between groups of participants, a direct within participants' comparison of the lateral and vertical target tasks was included. This manipulation would result in the comparison of the Nd and Nt; Nt and Pd; and Pd and Pt components while manipulating lateral stimulus salience and provide the clearest evidence that these components can be interpreted in terms of attentional processes rather than processes related to an imbalance in the sensory characteristics of the display.

The observation that the waveforms in the 180-250 ms time interval (Pd and Nt) showed opposite polarities demonstrates that these components reflect different neural processes. The subsequent comparison of the Pd generated by the vertical target task and Nt generated in the lateral target task show they are processes related to the suppression of irrelevant information and the selection of goal specific information, respectively, and confirm these components are not indicative of imbalances in lower level sensory processing. These findings are in line with Hickey et al. (2009) where the results of the Pd in experiment 3 (that show an increased positivity to the ignored lateral stimuli) were compared to those of experiment 4 (that show a negativity when the lateral stimuli was the target). Additionally, in experiment 3 of the thesis, a positive deflection contralateral to the lateral stimuli was observed following the Nt in the lateral target condition. This component shows a similar pattern of results to the Pd, but a different pattern to the Pe, which indicates that the Pt likely reflects a process of suppression of the irrelevant distractor similar to the Pd. However, given that it follows the allocation of attention on the lateral stimuli, meaning that attention is, at that moment, located on the lateral stimulus, it is likely that the Pt represents the disengagement of attention from the lateral stimulus. The alternate possibility is that after attention is no longer required at its focal location, it passively fades to zero (Sawaki et al., 2012), which would result in the negativity not being followed by a positivity which displays a similar pattern of results to the Pd.

Some researchers have suggested that covert attention, which is represented as a peak in a priority map that combines top-down and bottom-up inputs, is allocated to the location that currently has the highest attentional priority (Itti & Koch, 2000; Bisley & Goldberg, 2003; Fecteau & Munoz, 2006; Serences & Yantis, 2006; Mirpour, Arcizet, Ong, Bisley, 2009). According to this view when participants search for specific target items, the presence of target features at a given location creates a peak in the priority map at that location, which leads to the allocation of attention and a related improvement in the perception of the object. This covert deployment of visual attention is reflected by the N2pc component (Eimer, 1996; Luck et al., 1997; Luck, 2012) and analogous changes in monkey single-unit activity and measures of blood flow (Treue & Maunsell, 1999; Roelfsema, Lamme, & Spekreijse, 1998; Motter, 1993; Spitzer, Desimone, & Moran, 1988; Hopf et al., 2006). The findings of experiment 3 in the thesis are in line with those of Sawaki et al. (2012) and suggest that after attention has shifted to a location, the same active suppression mechanism used for preventing irrelevant information from intruding into attention also plays a role in terminating attention from the current point of focus, subsequently disengaging it from that location. It is also likely, although direct evidence for this is lacking, that disengagement of attention would function, irrespective of whether attention was allocated due to capture or goal directed selection. This may form part of the explanation of why the laterality of the Pd in experiment 3 was not statistically different from that of the Pt. The Pd in this case would likely include a process of disengagement (due to the previous capture of attention, i.e. Nd) and the subsequent suppression of the lateral image when attention was located on the target. For the lateral task, the goal directed processing had already been carried out resulting in suppression of the lateral stimuli when attention was directed elsewhere in the stimulus array resulting in disengagement of the lateral stimulus and its subsequent suppression. The idea that disengagement of attention would function irrespective of whether attention was captured or directed could be explored in future studies of suppression.

Also noted in experiment 3 was the appearance again of the lateralised distractor negativity (Nd) component, which did not seem to appear in the Hickey et al. (2009; experiment 4c) where participants were asked to distinguish a square from a diamond. However, an early contralateral negativity did appear in experiment 4b (Hickey et al., 2009), where the line to be attended was presented in the vertical position and the square (to-be-ignored) was presented in the lateral position. As the same is not evident when the square is the vertical target and the line is the to-be-ignored stimulus (c.f. Hickey et al., 2009) it may be concluded that an attend-to-me signal initiates attentional capture when it is greater than the goal directed top-down task set (Sawaki & Luck, 2013). The results of experiment 3 of the thesis that the Nd is not altered by the salience of the distractor demonstrate an all-or-nothing type process for attentional capture, where if the attend-to-me signal is greater than the top-down task set, attentional capture *is* initiated; however, if it is not greater, attentional capture is *not* initiated. The results showing that the 1-line condition did not alter the Nd significantly compared to the 3-line condition support this conclusion. If an increase in the salience of the distractor resulted in an increase in attentional capture, it would be evident by changes in the Nd. However, the results of experiment 3 show no significant change in the laterality of the Nd for the 1-line compared to the 3-line distractor condition as would be expected if attentional capture were altered by just the salience of the lateral ignored stimuli.

6.3 Experiment 4 & 5 (Chapter 4)

The fourth experiment in the thesis aimed to explore the possibility that the availability of cognitive resources for suppression of irrelevant information may be an important factor in determining the presence of threat related attentional bias. Additionally, by manipulating WM load in a 'Hickey et al. (2009)' type paradigm provided an opportunity to assess if the Nd, where evidence is mounting that it represents attentional capture of an ignored irrelevant stimulus, shows similar changes under WM load as reported in previous research (c.f. Holmes et al., 2014) where changes in the N2pc to threat related distractors were evident under high WM load but not low WM load. If the Nd is modulated similarly to the N2pc under high working memory load, it would provide evidence that the Nd shares a similar attentional function to the N2pc. Results showed an influence of the distractor on the laterality of the Nd for low WM load, but not for high, and an increase in the Pd for the high WM load task compared to the low. However, as noted in the discussion of chapter 4, a limitation of this experiment appears to have influenced the results in a way that makes them difficult to interpret. By using a detection task and a discrimination task, a change in attentional demands as well as WM load was introduced into the manipulation. Improvements to this design that would allow for the manipulation of WM load alone will be discussed in more detail in the 'limitations' section of this chapter.

Experiment 5 was designed to correct for the limitations of experiment 4 and examine the effects of increased cognitive load (i.e. reduced executive control resources) on the allocation of attention to task-irrelevant threat by comparing tasks that differ in cognitive resource requirements while keep attentional demands constant. Results show no change in the Pd as a function of cognitive load. As stated earlier, the absence of a significant change in the Pd may be due to the task not reaching a level of difficulty sufficient to deplete cognitive control resources. However, this is unlikely given that the behavioural results indicate that the task was sufficiently difficult to result in a significant reduction in both RT and accuracy for the high cognitive load task compared to the low. Alternatively, it may be that top-down suppression of irrelevant information is not being implemented in this task or possibly that the Pd itself is insensitive to manipulations of top-down suppression. Previous evidence has, however, indicated an increase in inhibition under cognitive (WM) load. de Fockert et al. (2001) presented participants with a WM load task that was interspersed with a 'Stroop-like' attention task. Results showed that under high WM load, RTs (incongruent minus congruent) for the attention task were greater for the high WM load task than the low, indicating an increase in distractor inhibition under high WM load and therefore potentially an increase in suppression of the incongruent distractors under high WM load. In a flanker task, Pecchinenda and Heil (2007) also report similar results for an increase in distractor processing under high WM load and interference effects due to processing of the valence of distractors occurred regardless of WM load. Results for threat related distractors of experiment 5 in of the thesis also show no effect of cognitive load on suppression, as measured by the Pd, indicating that automatic evaluation of incoming valence information occurs regardless of task priorities.

A secondary aim of experiment 5 was to investigate the effect of cognitive load on attentional capture as measure by the Nd. Results show a reduced laterality under high cognitive load conditions compared to low, despite RTs for the high load condition being significantly greater than the low cognitive load task. As noted in the discussion of experiment 5, this conflicts with the conclusions of Lavie and de Fockert (2005). However, closer inspection of the methods and results of the Lavie and de Fockert (2005) study lead this author to conclude that there is an error with their interpretation of the results. A more accurate interpretation of their reported data, in my opinion, would be that in the low WM load condition, an increase in attentional capture (distractor absent vs. distractor present condition) resulted in an increase in RT, rather than an increase in RT resulting in an increase in attentional capture as concluded by Lavie and de Fockert (2005). They also note that an increase in cognitive (WM) load resulted in an increase in RT. It would seem that the logic of their conclusion was that an increase in WM load results in an increase in RT and an increase in RT results in an increase in attentional capture, therefore an increase in WM load results in an increase in attentional capture. It is, perhaps, more likely that changes in attentional capture (i.e. a reduction) and changes in RT (i.e. an increase), under load, can be viewed as separate responses to the availability of resources, one that focusses attention on the goal directed task and the other that results in extended processing time, in this case both effects of load work to prioritise resources in favour of the goal directed task. Lavie and de Fockert's (2005) conclusion that an increase in cognitive load results in an increase in attentional capture leaves out the possibility that a decrease in attentional capture under high load might coincide with increases in RT as a result of depleted attentional resources, which would also fit the pattern of results they report. Additionally, a distractor present condition, compared to a distractor absent condition would also require suppression as well as result in an increase in attentional capture as is evident in the results of experiment 5 of this thesis. Lavie and de Fockert (2005) did not appear to consider that if attentional capture was not reduced under load, as a response for the conservation of resources, an additional increase in RT above that reported may well have been observed. This consideration would also mean that an increase in attentional capture would result in a decrease in RT under load, as a result of the conserved resources not otherwise allocated to the distractor, rather than the increase they report.

The reduced laterality of the Nd in the high cognitive load task of experiment 5 of this thesis indicates that when executive control resources are depleted, attentional capture of an irrelevant distractor is reduced presumably due to reduced available resources along with an increase in the time it takes to carry out the task. However, despite cognitive load influencing attentional capture, it did not appear to influence bias toward threat, as indicated by changes in the laterality of the Nd for angry face distractors compared to neutral, as has been reported in previous fMRI (e.g. Van Dillen et al., 2009) and N2pc (e.g. Holmes et al., 2014) studies. While the accuracy results indicate that attentional capture was reduced for threat related (angry) face distractors, this was not reflected in changes in the Nd. It seems that while the Nd is reflective of attentional capture, it does not appear to reflect attentional bias under cognitive load, as is evident in results of the N2pc to threat under high cognitive (WM) load experiments (e.g. Holmes et al., 2014).

6.4 Experiment 6 (Chapter 5)

Results of Experiment 5 show no significant change in the laterality of the Pd when executive control resources were depleted (high cognitive load) compared to when not (low cognitive load), despite the behavioural results showing significant reductions of both accuracy and speed of response for the high cognitive load task. These results indicate that suppression of the ignored lateral distractor was not altered by the depletion of available executive control resources. Moreover, the results of experiment 1 showed that modulating high level semantic features of the distractor (intact face distractors vs. scrambled) did not result in a significant modulation of suppression, as indexed by the laterality of the Pd. This led to the conclusion that suppression of irrelevant information may be more perceptually driven (bottom-up) rather than cognitively controlled (top-down). Load theory (Lavie, 1995; Lavie et al., 2004; Lavie, 2005; Lavie & de Fockert, 2005; Foster & Lavie, 2008) predicts that when perceptual load is high, resources are less available and therefore distractor processing is decreased. However, what is specifically meant by 'distractor processing' or 'distractor interference', in terms of attentional capture and suppression is not made clear in these studies. It appears that these descriptions of the influence on distractors include a mix of both suppression and attentional capture and perhaps other undocumented processes. Experiment 6 was designed specifically to test the effect of perceptual load on both attentional capture (as indexed by the Nd) and suppression (as indexed by the Pd) of irrelevant threat and non-threat related distractors in a 'Hickey et al. (2009)' type paradigm. In experiment 6 perceptual load of the central task was modulated by presenting two levels of difficulty in distinguishing two letters of a target stimulus in separate blocks. Typically, the most commonly used manipulation of perceptual load has involved visual search (Benoni & Tsal, 2013), which has included either a cognitive component or a task of distinguishing one colour from another. These designs also manipulate sensory characteristics as well as perceptual load. These confounds were controlled for in experiment 6 by comparing two tasks of identification, one that had a high difficulty to distinguish (letters 'E' & 'F') and one that was less difficult (letters 'I' & 'O').

Results of this experiment show that high perceptual load did not result in a reduction of suppression, as indexed by the Pd, as would be predicted by Load theory (Lavie, 2005). However, results did show the opposite effect with a significant increase in the laterality of the Pd under high perceptual load. A similar increase in the laterality of the Pd was not reflected in terms of valence though, where suppression of threat related distractors was not altered under high perceptual load. If threat related information is given privileged access to attention and increasing perceptual load resulted in fewer, rather than more, intrusions on attention, as might be predicted by Load theory (Lavie, 2005), then it would be expected that the presence of threat related information would result in a reduction of suppression. The results of experiment 6 of this thesis indicate that threat related processing did not alter suppression. Moreover, the early positivity (Pe) showing a very similar pattern of results to both the Pd and $\text{Pd}_{\text{(cont.)}}$, and the results of previous research (c.f. Kramer & Belopolsky, 2004), indicate a possibility that perceptual load manipulations may result in maintenance of suppression from one trial to another. In the case of experiment 6, it appears that perceptual load may have been maintained over trials and subsequently influenced the Pe thought to represent lower level perceptual processes and the generation of a salience map. This would mean though, that this result instead represents 'anticipatory suppression' of the ignored distractor. This seems unlikely given that each trial distractor location (upper, lower, left, right) was randomly chosen and this pattern of results would also have been evident in previous load experiments in the thesis. It is more likely that this effect is evidence of suppression demonstrated as surround attenuation (c.f., Boehler et al., 2011). The observation that the Pe showed a similar pattern of results to the Pd and $Pd_{(cont.)}$ in experiment 6 only and that previous research has identified spatial resolution as a requirement of surround attenuation theory (Boehler et al., 2009; Boehler et al., 2011) provides support for the idea that the Pd (and $Pd_{(cont.)}$) component itself may be sensitive to bottom-up suppression.

In regards to the index of attentional capture (Nd), the hypothesis that an increase in perceptual load will result in a decrease in attentional capture was generally supported by the results of experiment 6. This was evident in a 3-way interaction where the laterality of the Nd appeared to be influenced by the valence of the distractor under perceptual load. Under high perceptual load angry face distractors captured attention, as indexed by the laterality of the Nd, with neutral face distractors showing a reduced laterality, indicating a reduction in attentional capture. While under low perceptual load, both angry and neutral face distractors resulted in a significant (and similar) laterality of the Nd, again indicating the capture of attention and subsequently indicating that threat related distractors are given privileged access to attention, even when attentional/perceptual resources are depleted. These results appear to support both Load theory (Lavie, 2005) and the conclusion that threat related information is given privileged access to attention (e.g., Vuilleumier, Armony, Driver, & Dolan, 2001; Dolan & Vuilleumier, 2003). While other studies have investigated perceptual load effects on threat related processing, to this author’s knowledge this is the first ERP study that has investigated the effects of perceptual load on the processing of threat related distractor information.

6.5 Limitations

Perhaps the most serious limitation of the present series of experiments is the underlying rationale that if the specific (i.e. threat) distractor is processed automatically without attention then it is expected not to produce interference effects (i.e. the effects of distractor processing on task processing), irrespective of the level of load. If, on the other hand, distractor processing requires attention, then load is expected to alter distractor processing. This has the potential to be quite problematic as it appears to produce circular reasoning. The basic assumption of these experiments is that the distractors are attended in low load conditions and unattended in high load conditions, with the exception of threat related distractors that are given privileged access to attention, even under high load conditions. The issue is that this assumption cannot be stated as a theoretical deduction since it serves as both the *hypothesis* and as the end product of the investigation of load theory. Additionally, load theory uses the *same* manipulations of load to *test* this assumption (see Lamy et al., 2013, for a related criticism). That is, for example, if manipulating load does not affect distractor interference it may suggest that the processing of this distractor is not affected by attention. However, this same result can alternatively suggest that this finding is inconsistent with perceptual load theory thereby undermining its' very basic assumptions. The latter possibility is quite important given that various studies have failed to replicate load effects (e.g., Theeuwes et al., 2004; Tsal & Benoni, 2010a, experiments 2 & 4). Additionally, this suggestion is in agreement with several studies which have found that the "flanker effect" is not affected by spatial attentional resources (e.g., Cohen, Ivry, Rafal, & Kohn, 1995; Ro, Machado, & Kanwisher, 2002; Gronau, Cohen, & Ben-Shakhar, 2009). All of these arguments strongly suggest that the view of 'automaticity' cannot be independently verified by manipulations of load alone. The present series of experiments, however, do not suffer this circular reasoning as they independently measure both distractor and task processing. By presenting the distractor in one visual field and measuring the ERP contralateral to its presentation, the present series of experiments have allowed for the independent measure of distractor and task processing.

While some additional fine tuning could have been done on each experiment, for example, in experiment 1 and 2; a) increasing the number of divisions when scrambling the face distractors so that each square in the array is smaller subsequently preventing *any* potential face information from being perceived, or b) maintaining the response limit in the load experiments so that participants were forced to respond in the set time. The greatest limitation in any one experiment was the WM manipulation of experiment 4. By conflating a discrimination task to a detection task in the manipulation as well as WM for high and low load allowed for the introduction of attentional/perceptual processing to be different at different levels of load. This clearly confounded the experiment and made it very difficult to interpret the results reliably. A manipulation where the memory task and the attention task are presented separately would have avoided this issue (c.f. de Fockert et al., 2001; Holmes et al., 2014). de Fockert et al. (2001) presented participants with a set of numbers to memorise and a memory test, interspersed with a congruent/incongruent attention task, while Holmes et al. (2014) interspaced their WM task with a series of visual probe trials. This approach could have been adapted for experiment 4 interspersing the WM task with the manipulation of experiment 1 (without scrambled face distractors) as the attention task. One potential issue with this manipulation though would be the number of trials. The number of attention trials interspersed per memory set needs to be kept low (between 3-4) meaning that to maintain an equal number of attentional trials compared to experiments 1 and 2 (i.e., 1152 each), this manipulation would require a total of 384 memory set presentations (calculated based on Holmes et al., 2014, trial numbers) compared to 80 that were presented in the Holmes et al. (2014) study. This number of memory sets would very likely create an experiment too long for a participant to maintain attention throughout its entirety. Reducing this amount would result in a reduction of power that may well not be sufficient to observe the subtle effects being investigated, although increasing the number of participants could have helped alleviate this issue.

Appendix A

Consent form

Roehampton University London

ETHICS BOARD

PARTICIPANT CONSENT FORM FOR THE MAIN EXPERIMENT

Title of Research Project: Disentangling the N2pc: Investigating attentional modulation processes of suppression and enhancement towards threat using ERP's.

Brief Description of Research Project:

We are requesting your participation in a study (lasting around 2½ hours in total) that aims to further our understanding of how we perceive emotional faces.

You will be asked to respond with a key press as to whether a square or a diamond appears on the screen. Faces, which will have angry, happy or neutral expressions, will also appear on the screen, but you do not have to make a judgement about these. While you perform the task, we will record tiny electrical signals from your scalp (EEG: see Letter of Invitation). The experimental task will last around 60 minutes. First, however, we will need to place the head cap and prepare for the recording of EEG data. This set up process may take up to 1 hour. At the beginning of the session, you will be given a few short questionnaires to complete (which should take around 20 minutes), which contain questions relating to how you are feeling, your experience of anxiety, and your levels of distractibility. *Please note that the questionnaires are designed simply to look at normal variation in aspects of mood and personality in the population; not as tools to diagnose mental illness.*

The measurement of brain signals (ERPs) will involve the wearing of a head cap rather like a swimming cap with sensors connected to it. Each sensor will record tiny electrical brain signals via a conductive gel, which feels rather like ordinary hair gel. Prior to applying the gel, we will need to clean the areas of skin around your eyes and ears where some of the sensors will be placed, using alcohol. The conductive gel will then be applied using a syringe that will make light contact with your scalp. If you find this at all uncomfortable, please inform us and we will stop the procedure.

Some of the gel will wipe off but you will need to wash off the remainder either here (we have private facilities for you to do this) or at home. You may have a few red marks on your face from the head cap or electrodes but these should disappear after a few minutes. The electronic equipment has been subjected to full electrical testing by the manufacturers, and is used only to *measure* tiny pulses of electrical activity from your brain and not to apply electricity to you. Please be assured that the whole process, and the use of head-cap electrodes for measuring EEG, is safe.

Please do not take part if:

a) you are under 18 years of age; b) you have a skin condition on your scalp; c) you have any history of, or are taking medication for, psychiatric disorders or diseases (e.g., ADHD, depression, anxiety, or mood disorders), or neurological disorders or diseases (e.g. stroke, head injury, epilepsy, seizures, brain tumours, brain surgery, Parkinson's Disease).

Right to withdraw:

You are under no obligation to finish the experiment and can withdraw from participation from the whole experiment or any part of it at any point without needing to justify your decision. You can also request for your data to be withdrawn at any time after participation in the study. In order to do this, please contact the investigator with your participant number, which you will find on the Debrief Form. Please be aware, however, that data may already have been published in aggregate form at the time of request. Finally, if you are a student who is volunteering for course credits as part of an undergraduate module, please be advised that there will be no adverse consequences in relation to assessment for your degree if you decide to withdraw.

Confidentiality and anonymity:

All data relating to your participation in this study will be held and processed in the strictest confidence, in accordance with the Data Protection Act (1998). All data will be held securely in password protected computer files and locked filing cabinets. No one outside of the research team will have access to your individual data, and anonymity will be protected at all times. Researchers involved in the study will be unaware of any links between your identity and the data collected. Signed consent forms will be kept separately from all other data. Your identity will not be passed on to anyone who is not involved in this study, and will be protected in the publication of any findings.

Investigator Contact Details:

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Consent Statement:

I agree to take part in this research, and am aware that I am free to withdraw at any point. I understand that the information I provide will be treated in confidence by the investigator and that my identity will be protected in the publication of any findings.

I have read and understood the Information Sheet (i.e., Letter of Invitation) provided. I have been given a full explanation by the investigator(s) of the nature, purpose, location and likely duration of the study and of what I will be expected to do. I have been given the opportunity to ask questions on all aspects of the study and have understood the advice and information given as a result.

I agree to comply with instructions given to me during the study and to co-operate fully with the investigators.

I am 18 years or over, do not have a skin condition on my scalp, and have no history of, and am taking no medication for, any psychiatric disorders or diseases, or any neurological disorders or diseases.

Name ……………………………….

Signature ………………………………

Date ……………………………………

Please note: if you have a concern about any aspect of your participation or any other queries please raise this with the investigator. However if you would like to contact an independent party please contact the Dean of School.

Head of Department:
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020 8392 3617

Please retain a copy of this consent form.

Participant Number: __________

PARTICIPANT DEBRIEF

Title of Research Project: Disentangling the N2pc: Investigating anxiety-related attentional modulation processes of suppression and enhancement towards threat using ERP's.

Thank you very much for taking part in our study. We greatly appreciate your contribution.

This study is designed to examine patterns of brain waves elicited when people perceive faces with angry, happy or neutral expressions. Specifically, we are interested in how rapidly attention may be drawn towards emotional faces. This should help further our understanding of the extent to which attentional biases towards emotional (particularly threat-related) information are under the control of the individual.

All data gathered during this study will be held securely and anonymously. If you wish to withdraw your data from the study, please contact us with your participant number (above) and your information will be deleted from our files. Please be aware, however, that data may already have been published in aggregate form at the time of request, but your identity will always be protected in the publication of any findings.

Should you have any concern about any aspect of your participation in this study, please raise it with the investigator. However, if you would like to contact an independent party please contact the Director of Psychology.

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If you are a student at Roehampton University and are troubled or worried about any aspect of the study, or issues it may have raised, you may find it helpful to contact one of the following who will be able to advise you on agencies that can deal with your particular concern:

Student Welfare Officers:	Frobel	Anne-Marie Joyes	Ext 3304
	Digby Stuart	Jo Granger	Ext 3204
	Southlands	Belinda Stott	Ext 3402
	Whitelands	Ejiro Ejoh	Ext 3502

If you feel your concerns are more serious or complex you may wish to contact the **Student Medical Centre** on **Ext 3679.** If you are not a student at Roehampton University**,** please contact your GP.

Appendix B

Self-Evaluation Questionnaire

ID_____________________________ Date________________________

DIRECTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and mark the appropriate number to indicate how you feel *right now*, that is, *at this moment.* There are no right or wrong answers. Do not spend too much time on any one statement, but give the answer which seems to describe your present feelings best.

	NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1. I feel calm	1	2	3	4
2. I feel secure	1	2	3	4
3. I am tense	1	2	3	4
4. I feel strained	1	2	3	4
5. I feel at ease	1	2	3	4
6. I feel upset	1	2	3	4
7. I am presently worrying over possible misfortunes	1	2	3	4
8. I feel satisfied	1	2	3	4
9. I feel frightened	1	2	3	4
10. I feel comfortable	1	2	3	4
11. I feel self-confident	1	2	3	4
12. I feel nervous	1	2	3	4
13. I am jittery	1	2	3	4
14. I feel indecisive	1	2	3	4
15. I am relaxed	1	2	3	4
16. I feel content	1	2	3	4
17. I am worried	1	2	3	4
18. I feel confused	1	2	3	4
19. I feel steady	1	2	3	4
20. I feel pleasant	1	2	3	4

DIRECTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and then mark the appropriate number to indicate how you *generally* feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

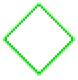
	ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
21. I feel pleasant	1	2	3	4
22. I feel nervous and restless	1	2	3	4
23. I feel satisfied with myself	1	2	3	4
24. I wish I could be as happy as others seem to be	1	2	3	4
25. I feel like a failure	1	2	3	4
26. I feel rested	1	2	3	4
27. I feel ‘cool, calm and collected’	1	2	3	4
28. I feel that difficulties are piling up so that I cannot overcome them	1	2	3	4
29. I worry too much over something that really doesn’t matter	1	2	3	4
30. I am happy	1	2	3	4
31. I have disturbing thoughts	1	2	3	4
32. I lack self-confidence	1	2	3	4
33. I feel secure	1	2	3	4
34. I make decisions easily	1	2	3	4
35. I feel inadequate	1	2	3	4
36. I am content	1	2	3	4
37. Some unimportant things run through my head and bothers me	1	2	3	4
38. I take disappointments so keenly that I can’t put them out of my mind	1	2	3	4
39. I am a steady person	1	2	3	4
40. I get in a state of tension or turmoil as I think over my recent concerns and interests	1	2	3	4

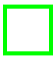
Appendix C

Stimuli

Experiment 1, 2, and 3

Vertical Stimuli

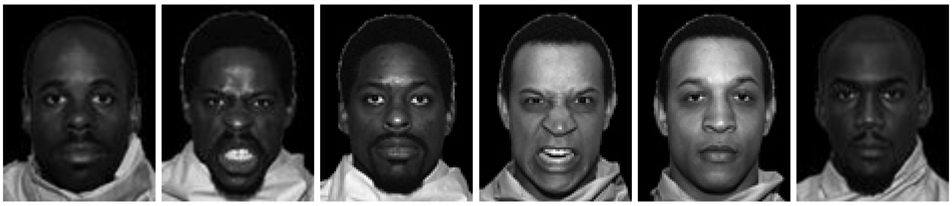




Lateral Stimuli

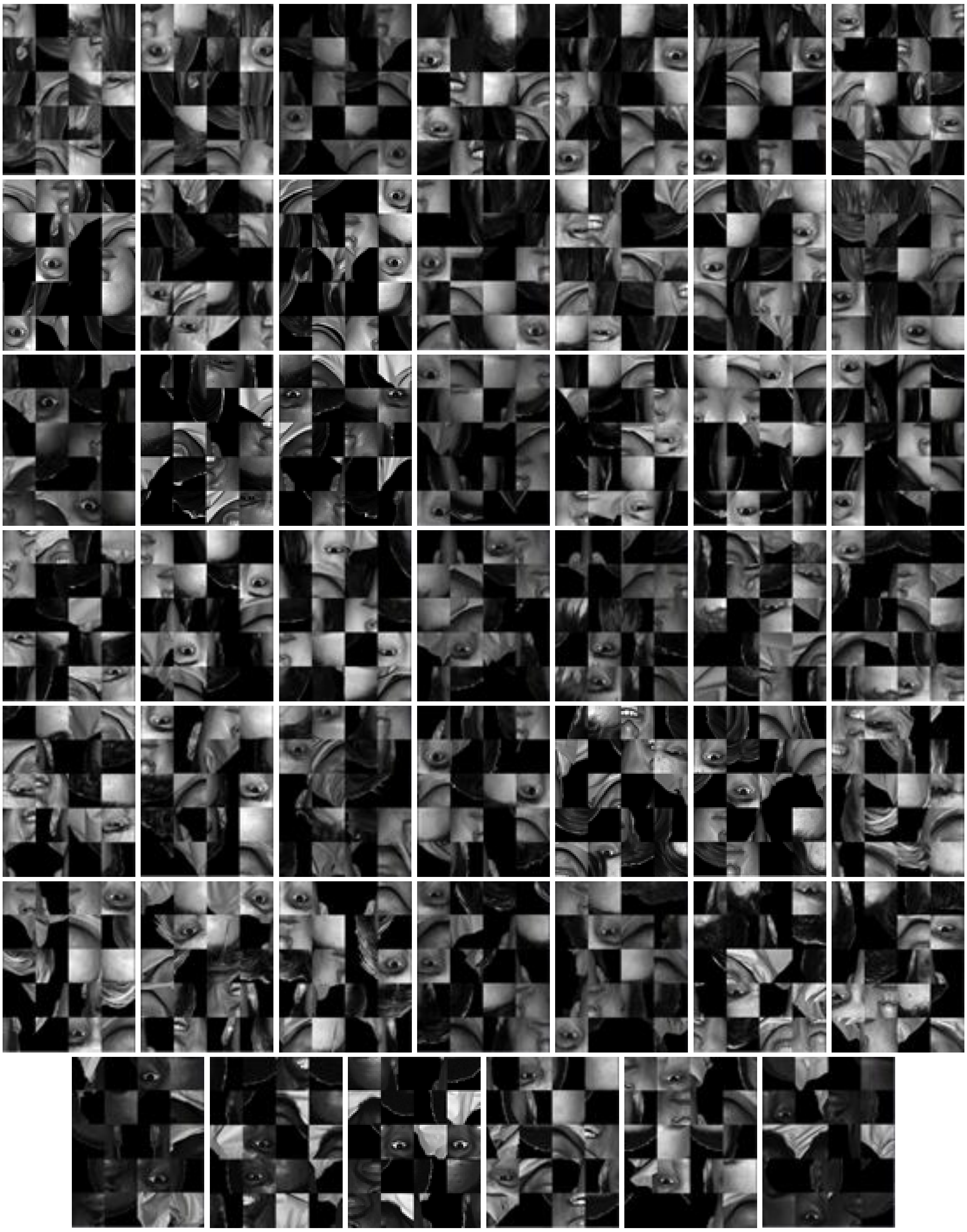
Experiment 1, 2, 4, 5, and 6

Intact faces



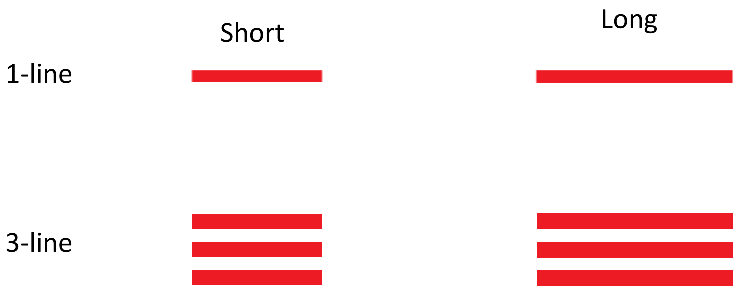
Experiment 1 and 2

Scrambled faces



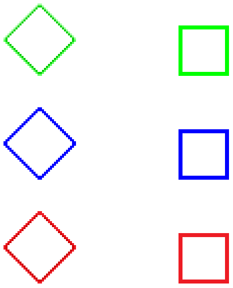
Experiment 3

Lateral Stimuli



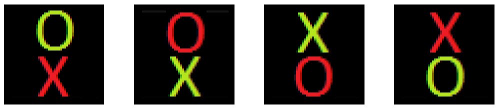
Experiment 4

Vertical Stimuli



Experiment 5

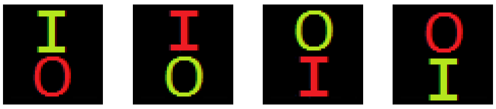
Vertical Stimuli



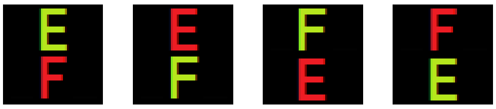
Experiment 6

Vertical Stimuli

Low perceptual load



High perceptual load



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