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An Investigation into the Emotion-Cognition Interaction and Sub-Clinical Anxiety

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Abstract

This thesis combines behavioural and electrophysiological approaches in the study of the emotion-cognition interaction and sub-clinical anxiety. The research questions addressed in this thesis concern, specifically: the impact of emotion on attention; the interplay between attention and emotion in anxiety; and the cognitive construct of affect.

Chapter 1 provides an introduction to emotion research, cognitive models of anxiety and motivates the thesis.

Chapter 2 investigates whether affective processing is automatic. More specifically, to elucidate whether facilitated processing of threat in anxiety, evidenced by emotion-related ERP modulations, requires attentional resources. It was previously reported that emotional expression effects on ERP waveforms were completely eliminated when attention was directed away from emotional faces to other task-relevant locations (Eimer et al., 2003). However, Bishop et al. (2004) reported that threat-related stimuli can evoke amygdala activity without attentional engagement or conscious awareness in high-anxious but not low-anxious participants. Spatial attention was manipulated using a similar paradigm as Vuilleumier et al. (2001) and Holmes et al. (2003), to investigate the mechanism underlying the threat-related processing bias in anxiety by examining the influence of spatial attention and trait anxiety levels on established ERP modulations by emotional stimuli. Participants were instructed to match two peripheral faces or two peripheral Landolt squares. The Landolt squares task was selected since this is an attentionally demanding task and would likely consume most, if not all, attention resources. The ERP data did not offer support to the claim that affective stimuli are processed during unattended conditions in high-anxious but not low-anxious participants. Rather, it questions whether a preattentive processing bias for emotional faces is specific to heightened anxiety. This is based on the finding of an enhanced LPP response for threat/happy versus neutral faces and an enhanced slow wave for threat versus neutral faces, neither modulated by the focus of attention for both high and low anxiety groups.

Chapter 3 investigated the delayed disengagement hypothesis proposed by Fox and colleagues (2001) as the mechanism underlying the threat-related attentional bias in anxiety. This was done by measuring N2pc and LRP latencies while participants performed an adapted version of the spatial cueing task. Stimuli consisted of a central affective image (either a face or IAPS picture, depending on condition) flanked to the left and right by a letter/number pair. Participants had to direct their attention to the left or right of a central affective image to make an orientation judgement of the letter stimulus. It was hypothesised that if threat-related stimuli are able to prolong attentional processing, N2pc onset should be delayed relative to the neutral condition. However, N2pc latency was not modulated by emotional valence of the central image, for either high or low anxiety groups. Thus, this finding does not provide support for the locus of the threat-related bias to the disengage component of attention.

Chapter 4 further investigated the pattern of attentional deployment in the threat-related bias in anxiety. This was done by measuring task-switching ability between neutral and emotional tasks using an adapted version of Johnson's (in press) *attentional control capacity for emotional representations* (ACCE) task. Participants performed either an emotional judgement or a neutral judgement task on a compound stimulus that consisted of an affective image (either happy versus fearful faces in the faces condition, or positive versus negative IAPS pictures in the IAPS condition) with a word located centrally across the image (real word versus pseudo-word). Participants scoring higher in trait anxiety were faster to switch from a neutral to a threatening mental set. This improved ability to switch attention to the emotional judgement task when threatening faces are presented is in accordance with a hypervigilance theory of anxiety. However, this processing bias for threat in anxiety was only apparent for emotional faces and not affective scenes, despite the fact that pictures depicting aversive threat scenes were used (e.g., violence, mutilation). This is discussed in more detail with respect to the social significance of salient stimuli.

Chapter 5 in a pair of experiments sought to investigate how affect is mentally represented and specifically questions whether affect is represented on the basis of a conceptual metaphor linking direction and affect. The data suggest that the vertical position metaphor underlies our understanding of the relatively abstract concept of affect and is implicitly active, where positive equates with ‘upwards’ and negative with ‘downwards’. Metaphor-compatible directional movements were demonstrated to facilitate response latencies, such that participants were relatively faster to make upward responses to positively-evaluated words and downward responses to negatively-evaluated words than to metaphor-incompatible stimulus-response mappings. The finding suggests that popular use of linguistic metaphors depicting spatial representation of affect may reflect our underlying cognitive construct of the abstract concept of valence.

Chapter 6 summarises the research in the thesis and implications of the present results are discussed, in particular in relation to cognitive models of anxiety. Areas of possible future research are provided.

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Declaration

This thesis has been composed by the undersigned. It has not been accepted in any previous application for a degree. The work, of which this thesis is a record, has been completed by myself, unless otherwise indicated in the text. I further state that no part of this thesis has already been, or is concurrently, submitted for any such degree or qualification at any other university.

Catherine F. McGrory

Abbreviations

ACC	anterior cingulate cortex
ACCE	attentional control capacity for emotional representations
ADM	affective decision mechanism
ANEW	affective norms for English words
CBT	cognitive behavioural therapy
CMS	common mode sense
cN	centinewton
DRL	driven right leg
EEG	electroencephalogram
EOG	electrooculogram
EPN	early posterior negativity
ERP	event-related potential
ERTS	experimental run time software
FACS	facial action coding system
fMRI	functional magnetic resonance imaging
FSQ	fear of spiders questionnaire
GAD	generalized anxiety disorder
GES	goal engagement system
GSR	galvanic skin response
HF	high frequency
HTA	high trait anxiety
IAPS	International Affective Picture System
LF	low frequency
LH	left hemisphere
LPP	late positive potential
LTA	low trait anxiety
LRP	lateralised readiness potential
LV	latent variable
LVF	left visual field
MEG	magnetoencephalography
ms	millisecond
μV	microvolt
PCA	principle components analysis

PLS	partial least squares
RAM	resource allocation mechanism
RH	right hemisphere
R-LRP	response-locked lateralised readiness potential
RT	reaction time
RVF	right visual field
S-LRP	stimulus-locked lateralised readiness potential
SPCN	sustained posterior contralateral negativity
S-R	stimulus-response
STAI	state-trait anxiety inventory
STM	short-term memory
SVD	singular value decomposition
VES	valence evaluation system

Chapter 1 General Introduction

1.1 Organisation

This thesis combines behavioural and electrophysiological approaches in the study of the emotion-cognition interaction and anxiety, addressing research questions concerning the attentional mechanisms underlying the threat-related processing bias in anxiety, the executive control processes that are modulated by anxiety and the cognitive representation of affect. The first part of the introduction chapter will introduce the historical background to the study of emotion and cognition and how developments in neurobiology set the path for subsequent research. Next, an overview of the leading cognitive theories of anxiety will be provided.

The last sections of the introduction will provide an overview of the literature within the area of emotion processing. This will include discussion of seminal papers in the area and also issues relevant to the forthcoming experimental chapters. First, an overview of the behavioural studies investigating the attentional bias to threat in anxiety will be introduced. Followed by the study of executive control and anxiety. This is relevant for the third experimental chapter.

The subsequent section will provide an overview of the relevant ERP components for emotion research. Alongside the discussion of relevant ERP components, the topic of attention will be touched upon. The reason for this is two-fold: first, ERPs have added a great deal of understanding to the mechanisms of attention and second, such attentional modulations of visual ERP components are relevant for experimental chapters 2 and 3 investigating the attentional mechanisms underlying affective processing. Next, event-related brain potential (ERP) studies detailing the temporal dynamics of emotion processing in the visual cortex are reviewed. Finally, the ERP and functional magnetic resonance imaging (fMRI) literature concerning the impact of emotional content on visual processing is reviewed and related to the threat-related bias in anxiety.

Details that are only relevant for specific experimental chapters will be introduced in the introduction of that specific chapter, for example, partial least squares analysis is introduced in Chapter 2. While each experimental chapter will be discussed separately, a final general discussion chapter will integrate and examine the most important findings.

1.2 The History of Emotion Research

The word emotion derives from the Latin ‘emovere’, literally meaning to induce physical movement, which evolved into a figurative term relating to thoughts, feelings, body changes and so on that drive behaviour. The study of emotion has proven difficult perhaps due to its many different facets grouped under the umbrella term of emotion. Nonetheless, the last twenty years has seen a surge of interest in emotion research, especially to those aspects of emotion related to cognitive processes. What is exciting in this popular area of research is that the fields of cognition and neuroscience are collaborating in this unified goal. No more so than at present do we recognise the dependency of these approaches to come together to help us better understand the complicated interaction between affective experience and cognitive processing.

Over the centuries the ancient Greeks and then later Western philosophers have contemplated the relationship between affect and cognition. The Platoistic tradition has exerted a lasting influence on subsequent theories of emotion, such as the James-Lange theory and related contemporary somatic theories of emotion. William James, in the article *‘What is an Emotion?’* (1884), argued that we experience bodily sensations and deduce our emotions from these. Plato’s ‘feeling theory’ saw emotions as uncontrollable ‘passions’, a by-product of bodily processes, that were in conflict with reason and judgement. The term hysteria, originated by Hippocrates, referring to loss of control in woman suffering emotional excesses is an exemplar of the legacy of this approach. This dichotomy of emotion and reason was greater emphasised by René Descartes, who took one step further than the Greek philosophers to propose a mind/body dualism where an intangible soul separate from the body was the seat of consciousness. An emotion was perceived as a condition of the soul, manifest in a bodily response, such as increased heart rate or voice tremor, which only served as an obstacle to clear thought. In Descartes' thinking, these external influences must be struggled with in an attempt to think and act rationally, reducing our affective experiences to merely distractions that serve no purpose other than to impede cognitive functioning. Philosophy of the 1800s, including the speculations of Immanuel Kant, continued to see cognition and emotion as distinct mental faculties that combined to produce a unified experience.

Beyond the intuitions of the philosophers, an influential biological theory of emotion was proposed by Charles Darwin in his book '*The expression of the emotions in man and animals*' (1872), which held that emotion was part of the human evolutionary legacy that served adaptive ends. Through the process of natural selection, his book tells us that our ancestors refined emotions and facial expression in order to facilitate social communication. Darwin, however, considered contemporary adult human emotion to be a non-functional by-product of our evolutionary past and that although we show emotions '*they may not … be of the least use*' (Darwin, 1872). This downplay of emotion merely perpetuated the view of emotions as impediments to rational thinking. Thus, the study of emotion was overshadowed by what was considered to be more important mental faculties.

A notable figure in the study of emotions, Paul Ekman has advanced Darwin's contribution with his own cross-cultural investigation of facial expressions. His research acknowledges that emotions have evolved via natural selection and are therefore biologically universal to all humans. Based on his research, Ekman (1972) devised a list of basic emotions: anger, disgust, fear, happiness, sadness, surprise, and neutral. This classification of emotional expression has made a marked contributed to the scientific study of emotions.

1.2.1 The Interaction of Emotion and Cognition

The notion that cognition and emotion are separate entities survived for the most part of the twentieth century, with the result that cognition and affect were studied in isolation of each other. However, a revival into emotion-cognition relations emerged with developments in neuroscience implicating emotion-related structures (e.g. the limbic system) and was further influenced by the progress of cognitive psychology, in particular the delineation of distinct mechanisms comprising cognitive processing (i.e. attention, encoding, storage, and retrieval, Nugent & Mineka, 1994). Thus, there was a burgeoning of research focused on the effects of different emotions on cognition and vice versa. Cognitive theories were also applied to the study of emotional disorders (for reviews see, Williams, Watts, MacLeod, & Mathews, 1997; Williams, Watts, Macleod, & Matthews, 1988) and have practical applications, especially in therapy. This cognitive-behavioural therapy (CBT) rests on the idea that anxiety promoting patterns of thinking are what cause anxiety and depressive disorders (Beck, 1976).

1.3 Emotion and its Neural Substrate

Neurobiological theories of emotion suggest that a complex network comprising of higher order sensory cortices and deep sub-cortical structures is responsible for the detection and analysis of emotionally significant information. The limbic system, working in concert with other connected structures, is recognised as being the hub within this network. The limbic system is a complex set of structures that includes the hypothalamus, the hippocampus, the amygdala, and several other nearby areas. Activity in these brain areas function to direct our attention, motivate our behavior and determine the significance of environmental events.

Specific neural activity within the amygdala is elicited in response to the detection of emotionally charged stimuli (e.g. Glascher & Adolphs, 2003). An amygdala response has even been reported under conditions where stimuli are masked and thus inaccessible to conscious awareness (e.g. Glascher & Adolphs, 2003) and also under some unattended conditions (e.g. Vuilleumier, Armony, Driver, & Dolan, 2001). Anderson and Phelps (2001) have suggested that a critical function of the amygdala may be to enhance perceptual encoding of emotionally salient stimuli, diminishing the need for attentional resources to procure the stimuli to awareness.

Recent neuroscientific investigations of emotional processing have uncovered a human fear system, incorportating a range of neural areas, in particular the amygdala, which are sensitive to naturally-occuring fear-relevant stimuli, such as spiders or angry faces (e.g. Morris, Ohman, & Dolan, 1998). When the amygdala is removed, monkeys become indifferent to stimuli that would have otherwise have caused fear and tameness ensues (Kluver & Bucy, 1939). On the flip side, electrical stimulation of the amygdala in animals produces fear and autonomic arousal, and similar responses are seen in people. The adaptive function of the fear-system is likely to enable rapid detection and a subsequent response to danger in the environment, which might suggest that fear-relevant stimuli have a biological basis for being prioritised by the attentional system. It follows that if anxiety stems from a highly sensitized fear system, which is especially responsive to threatening stimuli, then it is reasonable to assume that the attentional system of anxious individuals might be particularly sensitive to the presence of fear-relevant stimuli in the environment.

1.4 Overview of Cognitive Theories of Anxiety

1.4.1 The Anxiety-Related Attentional Bias to Threat

Rapid detection of aversive stimuli in an organism’s environment is crucial for survival. An attentional system that prioritises the processing of threat-related information would benefit the organism allowing them to make a swift and appropriate response to motivationally relevant stimuli. Emotions drive our motivations and consequently our actions; with some emotions invoking an appetitive and others an avoidant behavioural response. For example, a fearful state may enable defensive avoidant behaviour (e.g. escape from a highly threatening stimulus such as a tiger). Mathews (1990; , 1993) proposed that each of the primary emotions have a unique adaptive function. The underlying cognitive mechanisms specific to each primary emotion serve to influence processing in a specific way that optimises response to environmental stimuli. An anxious state was suggested to evoke a hypervigilant cognitive mode ensuing an automatic encoding of threat and hence, a rapid response. Studies of attentional responses to threat stimuli in anxiety-vulnerable individuals (i.e. individuals with high state and trait anxiety scores on the state-trait anxiety inventory (STAI; Spielberger, 1983) and generalised anxiety disorder (GAD) sufferers) have typically found that anxious individuals’ attention is preferentially allocated to threatening stimuli compared to normal controls (e.g. Mathews & Macleod, 1985). Such attentional biases to threat-relevant information have been suggested to be a vulnerability factor for clinical anxiety states (e.g. Eysenck & Calvo, 1992).

1.4.2 Beck's Schema Model (1976) and Bower's Semantic Network theory of Emotions (1981)

Beck's Schema model of emotional disorders (1976) has made a significant contribution to cognitive formulations of anxiety. Beck's logic has been implemented in the development of cognitive behavioural therapy (CBT), a successful treatment for depression and GAD. It is based on the belief that anxiety stems from dysfunctional schemata that are sensitive to threat or danger. Once these schemata are activated, selective processing of schema-congruent information occurs, leading to emotion-congruent biases that affect all aspects of information processing, including selective attention. Bower's semantic network theory of emotions (1981) also acknowledges emotion-congruent processing biases as a significant contributor to the etiology and/or maintenance of anxiety disorders. The difference with Bower's model being that each emotion is represented as a node in an associative network in memory. Each emotion node is connected to multiple representations of associated emotional memories. When one emotion node is activated this leads to increased activation of all the associated representations and incurs an information processing bias for emotionally congruent information.

1.4.3 Williams, Watts, Macleod, & Matthews' (1988) Model

Continued research into the cognitive biases underpinning anxiety disorders necessitated a revision of the antecedent models of anxiety postulated by Beck (1976) and Bower (1981). Many studies demonstrated attentional biases to threat to be characteristic of anxiety disorders (e.g. Mogg & Bradley, 2005), however a failure to report any recall biases indicated that processing biases in anxiety did not operate across all cognitive processes, inconsistent with the theories of Beck (1976) and Bower (1981), but instead were restricted to biases in selective attention. In light of these findings, Williams et al. (1988) developed a cognitive formulation of anxiety describing pre-attentional (i.e. without awareness) and attentional biases to threat as cognitive markers of anxiety. Using the terminology of Graf and Mandler's (1984) model of memory, Williams et al.'s (1988) model describes a preattentive, automatic processing bias for threat to be the underlying mechanism responsible for susceptibility to the development of anxiety disorders. As argued by LeDoux (2000), the functional evolution of the basic emotion of fear is to enable an organism to detect and respond rapidly to threat-provoking stimuli. From this perspective, it is not surprising that mood congruent attentional biases, rather than general cognitive biases as predicted by Beck's (1976) model, should characterise the cognitive mechanism associated with anxiety.

Williams et al.'s (1988) revised model of anxiety introduced a novel concept to the theory of cognitive bias; that the direction of the attentional bias was determined by trait anxiety levels, with high trait anxious individuals exercising an automatic orienting of attention towards threat and low trait anxious individuals automatically employing attentional avoidant strategies. Furthermore, these directional biases were proposed to be modulated by increased state anxiety. According to the interaction hypotheses (using Williams et al.'s (1988) terminology) the opposing effects of individual differences in trait anxiety (high vs. low) on attentional biases becomes more apparent as state anxiety is increased. In contrast, when state anxiety is low the cognitive differences between high and low trait anxious individuals may not be apparent. The model explains the interaction effect of state and trait anxiety on the attentional orienting bias to threat in anxiety in terms of two cogitative mechanisms: the Affective Decision Mechanism (ADM) and Resource Allocation Mechanism (RAM). The ADM assesses the threat value of stimulus inputs. When state anxiety is high the threat value of mild threat inputs are judged within the ADM to be equivalent to high threat inputs. The RAM receives the outputs (threat assessment units) from the ADM and it is at this level that trait anxiety determines the direction of the processing resources to be allocated to the salient stimulus; vigilance in high trait anxiety and avoidance of threat in low trait anxiety.

Williams et al.'s (1988) model was recently revised (Williams, Watts, MacLeod, & Mathews, 1997) using connectionist terminology, although the core assumptions remain unchanged. It still holds that individual differences in preattentive and attentive processing may underlie vulnerability to clinical anxiety. Cognitive behavioural therapy modifying preattentive and attentional biases towards threat in anxiety to be more akin to the attentional processes of low-anxious individuals may be an effective method for the treatment of anxiety. However, there is a serious problem with the predictions made by his model for severe threat stimuli, casting doubt on its application to the treatment of anxiety disorders. An effective threat-detection system must ensure that highly threatening stimuli receive preferential processing, irrespective of trait anxiety. It is counter-intuitive to predict that individuals with low trait anxiety would show increased avoidance of threat with increasing stimulus threat value. The cognitive-motivational formulations of anxiety overcome this limitation of the purely cognitive theories by recognising the importance of subjective appraisal of stimulus threat value.

1.4.4 Mogg and Bradley's (1998) Cognitive-Motivational Model

According to Mogg and Bradley's (1998) cognitive-motivational model, two motivational systems in combination mediate cognitive and behavioural responses to emotional stimuli, namely the valence evaluation system (VES) and the goal engagement system (GES). Attentional responses to emotional stimuli are determined by the output of the VES, which essentially reflects the subjective appraisal of stimulus threat value. The VES is influenced by a multitude of factors, which includes, for example: context, state anxiety, prior learning and individual differences in vulnerability to anxiety. Trait anxiety reflects reactivity of the VES to aversive stimuli. It is these individual differences in threat appraisal processes that mediate a vulnerability to anxiety. Individuals with high trait anxiety would therefore appraise a reasonably innocuous stimulus as having a high subjective threat value as compared to low trait anxious individuals. This output from the VES then feeds into the GES which determines the allocation of processing resources to the stimulus and hence mediates a response. When there is a low subjective threat value then the GES avoids the mildly negative stimuli, averting attention away from the stimulus, to pursue with current goals. In contrast, high subjective threat evaluation (a function of increasing objective stimulus threat value and/or individual differences in trait anxiety) incites a reallocation of attentional resources to the salient stimulus, interrupting current goals.

Unlike the interaction hypothesis (Williams, Watts, Macleod, & Matthews, 1988), the cognitive-motivational view makes more intuitive predictions about the attentional processes engaged in low trait anxious individuals when the objective threat value is significantly high. It predicts that both high and low trait anxious individuals will demonstrate an orienting response to severely threatening stimuli. The interaction hypothesis, on the other hand, stated that the key difference between high and low trait anxiety lay in the *direction* of the attentional bias. Thus, the more threatening the stimulus was evaluated to be, the more likely that strategic attentional avoidance strategies would emanate. It seems unlikely that such a maladaptive mechanism would have evolved in the potentially dangerous environment that our primitive ancestors had to endure therefore, the curvilinear relationship between the subjective threat value of a stimulus and the attentional bias (i.e. either vigilant or avoidant) suggested by the cognitive-motivational model appears to be more suitable. At mild levels of stimulus threat an attentional avoidant strategy would reduce distractibility from current goals. However, as stimulus threat level increases attention is much more likely to be oriented towards the salient stimulus in both high and low trait anxious individuals. This implies that attentional biases for threat are just as likely to be found in low trait as it is in high trait anxiety individuals when a severely threatening stimulus is presented. Therefore, attentional biases to threat may not be a causal factor in the etiology of clinical anxiety states. This does not, however, rule out the possibility that preattentive and attentional biases for mild threat may signify a vulnerability to anxiety, but not necessarily determining this vulnerability.

In the treatment of anxiety disorders it is irrelevant whether attentional biases necessarily play a causal role in the etiology of clinical states since the cognitive-motivational view doesn’t exclude the possibility that attentional processes are important for maintenance. Cognitive-behavioural treatment strategies targeting the appraisal process in highly anxious individuals may be effective in reducing anxiety and preventing relapse. Indeed, cognitive restructuring techniques have proven to be an affective therapeutic approach.

1.4.5 Attentional Control Theory of Anxiety

The theoretical distinction between goal-directed (top-down) and a stimulus-driven (bottom-up) attentional systems (Corbetta & Shulman, 2002) provides a framework for understanding how emotionally salient events might recruit attentional resources. According to Corbetta and Shulman (2002), the goal-directed attentional system is governed by expectations, knowledge, and current goals, while the stimulus-driven attentional system is sensitive to salient stimuli. A delicate balance between these inputs has to be maintained, which according to Eysenck et al.'s (2007) attentional control theory is distorted in anxiety favouring stimulus-driven influences over goal-directed attention. This purportedly leads to performance deficits in tasks involving the central executive of the working memory system. Evidence for this hypothesis comes from studies in which performance on a central task is negatively affected by interference from a task commanding attention from the stimulus-driven attentional system in high compared to low anxious individuals (e.g. Hopko, McNeil, Gleason, & Rabalais, 2002; Janelle, Singer, & Williams, 1999).

Attentional control theory further predicts that anxiety is especially associated with a decreased ability to inhibit interference from threat-related distractors (which engage the stimulus-driven attentional system) disrupting the goal-directed attentional system. Indeed, the attentional bias literature demonstrates that highly anxious individuals direct their attention to threat faster than low anxious individuals (e.g., review by Williams, Watts, MacLeod, & Mathews, 1997), and also show deficits in being able to disengage attention from threat (Fox, Russo, Bowles, & Dutton, 2001). Accordingly, it is a reasonable prediction that threat-related stimuli should engage the stimulus-driven attentional system to a greater extent than non-threatening stimuli in anxious individuals.

1.4.6 Conclusions

The theoretical accounts of the underlying mechanisms responsible for clinical and subclinical anxiety presented thus far provide a possible explanation for the development and maintenance of anxiety disorders. It is by no means a complete account, although what it does provide is a theoretical framework for future research into the cognitive and behavioural processes underling anxiety.

1.5 The Attentional Bias to threat in Anxiety - The Behavioural Studies

The cognitive literature reports that heightened anxiety is associated with increased interference from irrelevant threat-stimuli compared to low anxious individuals, as demonstrated using the emotional 'Stroop' and dot probe tasks (Macleod, Mathews, & Tata, 1986; Williams, Mathews, & MacLeod, 1996). The classical Stroop task presents words such as blue, green red etc. printed in a colour different from the semantic value of the word; for example, the word 'red' is displayed in blue ink. Since reading is a highly practiced skill, it is difficult to inhibit an attentional response to the word meaning and this produces interference when the task is to name the text colours. The Stroop effect demonstrates this interference in increased reaction times on trials where the colour and name of the word do not match. The emotional Stroop task is a variation on the original, which examines attentional selectivity of emotional words. Emotional and neutral words are presented in coloured ink and typically responses are slower to name the colour of negative emotional words than either positive emotional words or neutral words. This interference has been interpreted as a difficulty in suppressing responses to emotionally relevant words, while selectively maintaining attention to the colour of the word.

Pratto and John (1991) presented subjects with positive and negative trait adjectives in different coloured text and found that Stroop-like interference in the colour-naming task was greater for the negative trait words. They concluded that the negative information automatically captured attention, increasing response times to the colour of the text. Similar studies investigating the effect of sub-clinical anxiety on colour-naming latencies have found that anxious individuals had more interference on the colour-naming task when negative trait words were presented as compared to non-anxious subjects (see Williams, Mathews, & MacLeod, 1996). The slower colour naming latencies to threat stimuli in anxious individuals are held to reflect a selective orienting response towards these stimuli.

However, there are problems with this interpretation. The threat value of the single word stimuli is prone to confound with subjective frequency effects, i.e. there tends to be a higher usage of high threat words in highly anxious individuals. More significantly, the longer latencies in response to threat-related words may in fact be due to effortful avoidance rather than vigilance (Deruiter & Brosschot, 1994), or possibly reflect competition at a later response-selection stage of information processing (Macleod, 1991). In response to such criticisms, MacLeod, Mathews and Tata (1986) developed the dot-probe paradigm to allow for a more direct measure of attentional biases in anxious individuals. In this task, two emotional stimuli are presented on either side of a central fixation point (one neutral, one threat-related), following a brief presentation period one of these stimuli are replaced by a dot to which the participant must make a simple detection response. The theory is that response latencies in this task reflect initial shifts of attention; fast responses to the probe indicate that attention was initially oriented towards the preceding stimulus at the current probe's location; in contrast, longer latencies reflect the deployment of attention from the previous stimulus to the alternative spatial location of the probe. Anxious individuals tend to respond faster to probes replacing threat-related rather than neutral stimuli, whereas non-anxious subjects do not show this pattern (e.g. Fox, 1993; Macleod & Mathews, 1988). What is more, the dot-probe task, unlike the Stroop task, permits the use of more biologically and socially significant stimuli such as faces or images of threatening stimuli like lions, as opposed to single word stimuli with relatively mild threat value. The findings from the dot probe studies have been taken as further evidence that an anxiety-related bias exists in the initial orienting of attention towards threat material.

An anxiety-related processing bias has even been demonstrated when threat stimuli are presented subthreshold (e.g. Mogg, Bradley, Williams, & Mathews, 1993). Models of anxiety have interpreted such findings as evidence of an automatic preattentive threat evaluation system which is modulated by anxiety, making threat-detection much more likely for highly anxious individuals (Mathews, Mackintosh, & Fulcher, 1997; Williams, Watts, MacLeod, & Mathews, 1997). In summary, results from the Stroop and dot-probe tasks have been understood as reflecting an anxiety-related bias in the orienting of attention towards a threat source. Investigation into the mechanism underlying the prettentional bias to threat in anxiety thus necessitates the supplementation of behavioural studies with neuroimaging and electrophysiological techniques, employing a range of stimulus types, to provide a more detailed picture of affective processing.

1.5.1 Attentional Orienting to Threat versus Delayed Disengagement

However, there are some serious problems with the emotional Stroop and dot-probe tasks that casts doubt on the interpretation from such studies that threat-stimuli automatically attract attentive processing. One issue with the Stroop task is that given the general belief that information located within 1 degree radius from fixation is impossible to ignore (see Eriksen & Eriksen, 1974), it would be impossible not to attend to the semantics of the word since this is within foveal vision (Fox, Russo, Bowles, & Dutton, 2001). Thus, it is ambiguous whether threat stimuli capture attention or once attended are more difficult to disengage from. Both explanations would produce the same results. A similar ambiguity exists for the dot-probe task. Both probes are task relevant and are presented for a relatively long duration (500ms), as such it could be argued that the participant adopts a strategy to attend to both locations by rapidly shifting attention between stimuli. Under these circumstances the dot-probe task would not provide a ‘snapshot’ of the distribution of attention as once thought, since both locations would receive attentive processing. It is therefore possible that in the dot-probe task threat stimuli do not attract attention but rather make it more difficult to disengage attention once it has settled on the stimulus. Indeed, Cooper et al. (2006) demonstrated that the 500ms stimulus presentation time adopted in most dot-probe tasks is an unreliable measure of initial allocation of attention, and that a 100ms presentation time is likely to reflect automatic initial shifts of attention. Hence, it is ambiguous whether the attentional bias to threat in anxious individuals as measured by the dot-probe and Stroop tasks reflects attentional dwell time or attentional orienting.

Following the Stroop interference effects with threat-related words found by Pratto and John (1991), White (1996) conducted a study to investigate whether spatially separate adjectives would produce similar Stroop-like interference. Participants had to name coloured patches presented at fixation while ignoring trait adjectives presented spatially separate from fixation. However, no Stroop-like interference effects were found, weakening the theoretical position that threat stimuli automatically draw attention. Furthermore, Fox (1994) conducted a study employing the same design as White (1996) but in addition controlling for levels of anxiety. Again, no Stroop-like interference effects were found for either high- or low-trait anxious groups. Given these findings, a hypervigilant attentional system in anxious individuals seems unlikely and instead favours the notion that the attentional bias is influenced by the disengagement component of attention. Relying upon Posner and Petersen’s (1990) tripartite model of visual-spatial attention where separate mechanisms are involved in shifts of attention, engagement and disengagement, this hypothesis was directly investigated in a study conducted by Fox and colleagues (2001).

Employing a variant of the spatial cueing paradigm used by Posner, Inhoff, Friedrich, and Cohen (1987), Fox et al. (2001) assessed the precise mechanism responsible for the attentional bias. In this task, cues presented in one of two locations were either valid or invalid predictors of the spatial location of the succeeding target. What is generally found is that the cue orients attention to the cued location leading to faster responses on valid-cue trials and slower responses on invalid-cue trials. The cost of having to disengage attention from invalidly cued targets has been attributed to the slowing observed. Fox et al. (2001) found that for high-anxious participants their response to invalidly-cued targets was slower when threat-related cues were presented as compared to neutral or positive cues. No such effect was found for low-anxious participants. It was inferred that these results indicate that the attentional bias in anxious individuals is due to defective disengagement from threatening stimuli. What is more, no differences were found between responses on threat-related and non threat-related valid trials, suggesting that a threat-related cue did not affect the ability of the cue to draw attention. This finding tentatively implies that threat-related stimuli do not involuntarily draw attention, and provides further support to the theory that the attentional bias towards threat can be localised to the disengage component of attention.

However, an evaluation of the shift component of attention may not be best measured using the spatial cueing paradigm. The cue validity effect predicts that responses are faster in valid cue trials in general. Therefore, it may be presumptuous to expect any further speeding up of responses following threat-related cues (Fox, Russo, Bowles, & Dutton, 2001).

In conclusion, the behavioural studies investigating the attentional bias in anxiety, although informative, had their limitations. Consequently, the neuroimaging techniques have been imperative in furthering our understanding of the attentional mechanisms underlying the attentional bias in anxiety. Thus, one of the aims of the current thesis was to elucidate the underlying mechanisms responsible for the attentional bias to threat in anxious populations, supplementing behavioural measures with recordings of ERPs to provide additional information regarding the attentional processes.

1.6 Attentional Control Processes in Anxiety

Anxiety is assumed to increase attentional awareness, alerting the system to be always on the 'look-out' for signs of threat in the environment. The direct cost of broadening attentional resources means that goal-directed attention suffers. Corbetta and Shulman (2002) explain that two competing attentional systems are operating, a stimulus-driven and a goal-directed system, which must compromise on their performance to attain optimal attentional control. According to attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007) anxiety impairs this attentional control, a primary function of the central executive, and increases the tendency to place greater weight on stimulus-driven influences. As such, attentional bias to threat-related stimuli and reduced attention directed to goal-directed tasks are incurred.

Miyake et al. (2000) identify task switching as a major central executive function, which is assumed to reflect attentional control processes. Attentional control theory emphasizes the attentional demands imposed following a switch in task requirements are reflected in increased reaction times and/or errors. The further assumption that anxiety impairs attentional flexibility has found most validity in task switching studies whereby increased levels of anxiety are associated with elevated switching costs. Miyake et al. (2000) indentified the Wisconsin Card Sorting task as a useful tool for measuring central executive switching ability. Performance efficiency and accuracy on this task has been found to be hindered for anxious relative to non-anxious individuals (Goodwin & Sher, 1992). Comparable processing efficiency impairment can be found with the task switching paradigm. In the study of Santos and Eysenck (2006) target location served as a switch cue identifying three different tasks which had to be performed on the presented digit (odd vs. even; <5 vs. >5; A-R vs. S-Z). They successfully demonstrated that anxious participants took significantly longer than non-anxious participants to perform on trials following a switch. What is more, enhanced brain activation over areas associated with central executive functioning (right BA 9/46) during switching tasks were disproportionally active in high as opposed to low anxious individuals. This finding suggests cognitive inefficiency of attentional control processes in high anxiety in accordance with the predictions of attentional control theory.

Paradoxically, in some circumstances anxiety has been associated with attentional flexibility, marked by relatively reduced switching costs. Kofman et al. (2006) found that exam stress enhanced switching performance in a spatial cueing task. The observed facilitatory effect is likely the product of improved functioning on shifting and inhibition processes under conditions of induced environmental stress. As such, a naturalistic stress response can be interpreted as adaptive for goal-directed behaviour.

1.7 ERP waveforms and Cognitive Performance

The current thesis contends with the visual processing of affective information, therefore the review of ERP components will focus on the visual modality with respect to cognitive performance.

1.7.1 Attention-Sensitive components

1.7.1.1 P1

The P1 component occurs at lateral occipital sites, elicited 60 – 90 ms and peaking around 100 ms after stimulus onset. Dipole modelling of the P1 component has demonstrated that its scalp distribution is consistent with a neural generator source within lateral extrastriate cortex (Clark & Hillyard, 1996).

The P1 is sensitive to variations in stimulus parameters, for example, P1 peak latency will be delayed for stimuli presented in lower contrast. Taylor (2002) reported enhanced P1 amplitudes in response to images of upright faces compared to inverted faces and natural scenes containing animals compared to natural scenes not containing animals. These results were taken as evidence that P1 amplitude is sensitive to stimulus saliency.

However, it is typically assumed that P1 is the earliest component that is sensitive to the top-down influence of visual spatial attention. P1 peak amplitude is reportedly larger for stimuli presented at the attended location. For example, in the endogenous cueing paradigm, cue validity resulted in amplitude differences in P1 peak with larger peaks for valid trials (Hillyard, Luck, & Mangun, 1994). Attentional P1 modulations are assumed to reflect sensory gating mechanisms in early visual processing.

1.7.1.2 N170

ERP studies have identified a negative component over lateral occipital regions that peaks 170 ms after stimulus onset. This electrophysiological component responds maximally to face stimuli compared to other object categories and has been termed the N170. The N170 has been interpreted as reflecting a face-specific structural encoding stage, performed prior to the recognition of a face as familiar or not (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer & McCarthy, 1999).

Holmes, Vuilleumier, and Eimer (2003) investigated the effect of selective attention on the N170. Participants were presented with two face stimuli and two house stimuli arranged in horizontal and vertical pairs. The participants task was to perform a matching task (same vs. different) on either the face stimuli or the house stimuli. The relevant stimulus dimension was cued on a trial-by-trial basis by a cue that directed attention to either the vertical or horizontal dimension. The researchers compared the amplitude of the N170 when the face was presented at the cued location (task-relevant) and when the face was presented at the uncued location (task-irrelevant). Results indicated that the N170 component showed increased amplitude on trials where attention was focused toward the face stimuli relative to trials where attention was focused toward the house stimuli. These observations suggest that the structural encoding of faces can be affected by attention.

1.7.1.3 N2pc

The N2pc is an attention-sensitive ERP component that is typically elicited between 200 and 350 ms after stimulus onset at posterior electrode sites contralateral to the side of a visual target. Brain source analyses based on magnetoencephalography (MEG) recordings have demonstrated that its scalp distribution is consistent with a neural generator source within extrastriate visual areas (e.g. Hopf et al., 2000).

Luck and his colleagues have proposed that the N2pc is a possible index of attentional suppression of surrounding non-targets, which in effect highlight the target input (Luck, Chelazzi, Hillyard, & Desimone, 1997; Luck, Girelli, McDermott, & Ford, 1997; Luck & Hillyard, 1994). Eimer (1996) contends this conjecture in demonstrating N2pc modulation by single target stimuli, which runs counter to the supposition that the N2pc reflects distractor suppression. Generally, the N2pc is assumed to reflect the spatially selective processing of task-relevant versus distractor items in visual search.

1.7.1.4 SPCN

This sustained posterior contralateral negativity (SPCN) typically arises approximately 350 to 400 ms after stimulus onset over posterior cortical areas. An SPCN has previously been observed when lateralised target stimuli appeared among nontargets, and is thought to reflect additional processing of target stimuli after their attentional selection, including their maintenance in visual short-term memory (Dell'Acqua, Sessa, Jolicoeur, & Robitaille, 2006; Mazza, Turatto, Umilta, & Eimer, 2007; McCollough, Machizawa, & Vogel, 2007; Vogel & Machizawa, 2004).

1.7.2 LRP

The Lateralised-Readiness Potential (LRP) is an index of hand-specific response preparation that appears several hundred milliseconds prior to voluntary hand movements and is larger contralateral to the hand to be moved. The LRP component is calculated as the asymmetrical cortical activation contra- minus ipsilateral to the responding hand, which is proposed to offer an index of response preparation (Kutas & Donchin, 1980). Thus, the LRP is a proposed index of hand-specific activity (Coles, 1989; Osman & Moore, 1993) that is mainly generated in the primary motor cortex (M1) (cf. Leuthold & Jentzsch, 2002).

The locus of experimental effects can be inferred from the LRP calculated time-locked to either the stimulus or the response (Leuthold, Sommer, & Ulrich, 1996; Osman & Moore, 1993). The interval between stimulus onset and LRP onset is defined as the stimulus-locked LRP (S-LRP) latency and is related to the duration of pre-motor processes. The interval between the onset of the LRP and the overt response is referred to as the response-locked LRP (LRP-R) latency and is related to the duration of motor processes (Osman, Moore, & Ulrich, 1995). Thus, LRP measures are useful chronometric markers of different cognitive operations from pre-motor (S-LRP) to motor processing (LRP-R).

1.7.3 ERP Components Sensitive to Stimulus Emotion and Arousal

1.7.3.1 Early Anterior Negativity

Eimer and Holmes (2002) report a reduced frontocentral negativity elicited by upright fearful faces relative to neutral faces within 120 ms after stimulus onset. The authors propose that this early emotional modulation of the ERP waveform reflects an initial rapid detection and analysis of facial expression. In a later study (Holmes, Vuilleumier, & Eimer, 2003), this early emotional expression effect was replicated however, it was also shown to be modulated by spatial attention.

1.7.3.2 EPN

An early posterior negativity (EPN), typically elicited at post-stimulus latencies of 200 to 300 ms at lateral posterior and occipital locations, is larger for emotionally arousing (i.e. both pleasant and unpleasant) than for neutral pictures (Schupp, Junghofer, Weike, & Hamm, 2003a, 2004; Schupp et al., 2003). This component is thought to have its neural source within the visual cortex, reflecting increased activity in relatively early visual processing (Schupp, Junghofer, Weike, & Hamm, 2003b, 2004).

However, there is evidence to suggest that visual processing capacity, as reflected by EPN modulations, is limited. In one study (Schupp et al., 2007), an emotion-linked EPN response to the processing of emotional pictures from the International Affective Picture System (IAPS) was strongly attenuated when participants performed demanding attention tasks.

Larger EPN amplitude for highly arousing pleasant and unpleasant stimuli has been interpreted as indexing greater attentional engagement with motivationally relevant appetitive and aversive cues (Lane et al., 1997; Schupp, Junghofer, Weike, & Hamm, 2003a; Schupp, Ohman et al., 2004; Schupp, Weike, & Hamm, 2000). The finding of an EPN enhanced for individuals with high versus low levels of social anxiety in response to fearful and angry facial expressions (Muhlberger et al., 2009) is consistent with the notion of motivationally-driven attention. Notably, enhancement of the EPN is more pronounced for highly arousing pictures, such that erotic stimuli and mutilations produce the largest effects (Schupp, Junghofer, Weike, & Hamm, 2003a; Schupp et al., 2003), perhaps because they have important relevance for survival.

1.7.3.3 LPP

A later, sustained emotional expression ERP positivity referred to as the late positive potential (LPP) (sometimes referred to as the P3b component) is evoked in response to both pleasant and unpleasant stimuli compared to neutral, which develops around 300-400 ms following picture onset, lasts for several hundred milliseconds and is maximal over centro-parietal sites (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Foti & Hajcak, 2008; Hajcak, Moser, &

Simons, 2006; Hajcak & Nieuwenhuis, 2006; Hajcak & Olvet, 2008a; Keil et al., 2002; Lang, Bradley, & Cuthbert, 1997; Schupp et al., 2000b; Schupp, Cuthbert et al., 2004). The LPP is sustained for as long as the affective stimulus is presented (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000), and even persists after the stimulus is removed (Hajcak & Olvet, 2008a).

The LPP can be thought of as the emotional equivalent of the classic P300 component. Just as the P300 appears to index transient increases in attention toward targets, the LPP might reflect the commitment of attentional resources toward emotional stimuli, thus mediating appropriate survival behaviours (Lang, Bradley, & Cuthbert, 1997). In combining fMRI and ERP techniques, Sabatinelli et al. (2007) reported that neural activity in the lateral occipital, inferotemporal, and parietal visual areas, correlated with the LPP supporting the notion that it reflects increased perceptual and/or attentional processes engaged by motivationally relevant, emotional stimuli.

Larger LPP amplitudes evoked in response to both pleasant and unpleasant stimuli compared to neutral are assumed to reflect the processing of arousal information, as LPP amplitude has been shown to co-vary with arousal level (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000) and amplitudes are enhanced in response to highly arousing pleasant and unpleasant stimuli with respect to comparably low arousing stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000b). Variations in arousal level between negative and positive facial expressions might therefore explain why an LPP is commonly found for negative facial expressions (Eimer, Holmes, & McGlone, 2003; Marinkovic & Halgren, 1998), but evidence for the presence of this component in response to happy facial expression is less consistent (e.g. Williams, Palmer, Liddell, Song, & Gordon, 2006).

1.8 Evidence for Enhanced Processing of Emotional Information - the ERP Studies

Increased allocation of attention to threatening stimuli is particularly evident in the emotional Stroop task. Mathews and MacLeod (1985) reported delayed response latencies on threat vs. non-threat word trials, and markedly so in individuals with high levels of anxiety. These data provide behavioural evidence that threatening words capture attention, however it is questionable whether this also implies that anxiety modulates the depth of semantic processing of threat-related words on a psychophysiological level. Weinstein (1995) directly addressed this question, demonstrating two event-related potential components of facilitated processing of threatening information by high, compared to low trait-anxious, individuals. Subjects had to decide whether a visually presented probe word (positive, neutral, or threat) matched semantically with a previously presented priming sentence (threat or positive). The high anxiety group showed an enhanced frontocentral N100 and central P400 amplitudes in the threat priming conditions in comparison to the low anxiety group. The low anxiety group showed similar processing in both threat related and positive situations. The results of this experiment suggest that the attentional bias in anxiety prioritises threatening information over all else and deploys more resources to process this information.

The facilitated encoding of threat has been reported to occur within the first 100ms of stimulus presentation, supporting the hypothesis that it is a fast, involuntary perceptual process. ERP studies using the dot-probe paradigm have shown that the occipitoparietal P1 component is enhanced by targets, which follow a valid vs. invalid cue (Mangun & Hillyard, 1991). This so-called ‘P1 effect’ is believed to reflect enhanced sensory processing which facilitates the visual processing of attended locations (Hillyard & Anllo-Vento, 1998) and supports the notion that the faster response times on validly cued trials are due to enhanced visual processing (Luck, Woodman, & Vogel, 2000).

Pourtois et al. (2004) investigated the effect of emotional faces on the visual P1 component. In this study a pair of horizontal faces were briefly presented, one fearful and the other neutral in expression. The participants then had to make a manual response to the target stimulus, which appeared in the location previously occupied by one of the face stimuli. The results showed that the lateral occipital P1 was larger when the target replaced a fearful face as opposed to a neutral face. Hence, they managed to demonstrate enhanced perceptual processing of fearful faces, which subsequently influenced later visual inputs. Li et al. (2005) were interested whether trait-anxiety levels could modulate the enhanced early visual processing of threatening information as reported by Pourtois et al. (2004). Using colour pictures selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) as location cues they found that highly anxious individuals were faster to respond and the occipitoparietal P1 amplitude was enhanced when targets appeared at the same location as threatening images, relative to non-threatening ones. In comparison, the low anxious individuals showed enhanced P1 amplitudes when the target replaced the non-threatening pictures, as opposed to the threatening one. Such dissociation of P1 activation in response to the same visual target demonstrated that an attentional bias to threat in high anxious individuals, and conversely attentional-avoidance of threat in the low-anxiety group, facilitated the processing of subsequent visual inputs as early as 90ms post stimulus. A number of studies have reported enhancement of the visual P1 component for negative relative to neutral faces over posterior regions peaking around 130ms post stimulus onset (Batty & Taylor, 2003; Eger, Jedynak, Iwaki, & Skrandies, 2003; Holmes, Kragh Nielsen, & Green, 2008; Pizzagalli, Regard, & Lehmann, 1999; Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005; Streit et al., 1999). In contrast, an enhanced P1 for happy relative to neutral faces has been less reliable, hence augmented P1 effects have been attributed to an attention bias to negative affect (Holmes, Kragh Nielsen, & Green, 2008), possibly via feedback from the amygdala to the extrastriate visual cortex (Amaral, Behniea, & Kelly, 2003). Using a dot-probe task, Santesso et al., (2008) even reported enhancement in response to neutral faces relative to happy, and from this they inferred that attention was diverted towards the relatively more threatening stimulus within the visual field. Anxiety related enhancement of the P1 component for negative as compared with neutral or happy faces has also been reported in the literature; with the magnitude of this effect being significantly enhanced for the high-trait group in comparison with the low-trait group (e.g. Holmes, Kragh Nielsen, & Green, 2008; Li, Zinbarg, Boehm, & Paller, 2008). However, other studies have failed to replicate this finding (Fox, Derakshan, & Shoker, 2008; Moser, Huppert, Duval, & Simons, 2008; Rossignol, Philippot, Douilliez, Crommelinck, & Campanella, 2005), thus it is questionable whether an individual’s level of anxiety is an important determinant of this early electrophysiological response to a negative stimulus.

Facilitated emotional stimulus encoding has also been observed over posterior visual areas in the form of an early posterior negativity (EPN), which is maximally pronounced around 200-300ms post stimulus onset for pleasant and unpleasant compared to neutral images (Eimer, Holmes, & McGlone, 2003; Holmes, Kragh Nielsen, & Green, 2008; Schupp, Ohman et al., 2004; Schupp et al., 2007). As with the P1 component, augmented EPNs in response to emotional expressions have been proposed to reflect activity of an underlying motivational system involving the amygdala and interconnected subcortical regions (Sato, Kochiyama, Yoshikawa, & Matsumura, 2001) that operates at an early perceptual level (Junghofer et al., 2002). Subsequent to the emotion-specific modulation during perceptual encoding, researchers found a sustained positivity (LPP) for emotional faces with a broad fronto-parietal scalp distribution, most apparent around 400-600ms post stimulus. Although the LPP appears to represent facilitated attention to both pleasant and unpleasant stimuli compared with neutral, in general the LPP effect is larger for unpleasant than pleasant pictures, in accordance with the notion of a negativity bias (Ito, Larsen, Smith, & Cacioppo, 1998). Moreover, in the face literature an LPP response to negative versus neutral facial expressions is routinely detected, contrasting with the relatively inconsistent reportage of an LPP response to positive facial expressions (e.g. Holmes, Kragh Nielsen, & Green, 2008). The LPP appears to be highly significant in the investigation of emotional processing biases in anxiety; since a large body of literature indicates that modulations of the LPP serves as a neural index of the intrinsic relevance of emotional stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000a). Such ERP modulations in response to affective faces may provide direct evidence for the chronometry of emotional face processing, thus enabling the investigation of a threat processing bias in anxiety at each successive stage.

1.9 The Role of Attention in Emotional Processing - Evidence from fMRI and ERP studies

In the investigation of attentional biases in anxiety, the fundamental conception that emotional processing can occur independently of attention has been the subject of much controversy. Attempts to determine the extent to which our visual perception is reliant upon our limited attentional resources has brought mixed results. Under most circumstances, attention constrains our perceptual capabilities and with an exhausted store of attentional resources, consumed by the demands of competing tasks, perception fails. ‘Inattentional blindness’, the failure to perceive an object in the visual field because attention is elsewhere engaged, can be accounted for by such a conception of the critical role of attention, as can many other psychological phenomenon. However, there has been some evidence to suggest that the perceptual processing of emotional stimuli may be an exception to this rule. For example, neglect and extinction patients, two forms of brain injury where hemi-inattention results, are more likely to detect emotionally significant rather than neutral stimuli presented in their affected visual hemifield (Vuilleumier & Schwartz, 2001a, 2001b), and secondary task performance does not modulate an amygdala response to emotional scenes (Lane, Chua, & Dolan, 1999).

An influential study by Vuilleumier et al., (2001) systematically compared amygdala activity to fearful faces while varying attentional focus. On a trial-to-trial basis, spatial attention was manipulated by having subjects attend to pairs of images presented at relevant locations. Faces or houses could unpredictably appear in the relevant or irrelevant locations and participants performed a matching task for the relevant stimuli. The study revealed that there was a differential response to fearful and neutral faces in the amygdala but that this effect was not modulated by the focus of attention (i.e. whether faces were the attended stimuli or not), supporting the view that amygdala responses to threat-related stimuli may be independent of attentional resources.

However, contradictory findings have also emerged within the neuroimaging literature. Pessoa et al. (2002) hypothesised that the a failure to consume all attentional resources in the competing task in Vuilleumier et al.’s (2001) study may explain the apparent attentional redundancy in the processing of emotional stimuli. Using a similar paradigm but employing a more demanding competing task with a high attentional load, Pessoa et al. (2002) demonstrated differential fMRI responses to fearful vs. neutral faces in the amygdala only when sufficient attentional resources were available. In a follow-up study, attentional demands on a central task varied as a function of task difficulty, enabling a direct comparison between evoked amygdala activity to unattended emotional faces under conditions of both high and low attentional load (Pessoa, Padmala, &

Morland, 2005). In contrast to the high attentional load condition, when the attentional demands of the central task were low differential responses to fearful faces in the right amygdala were observed just as Vuilleumier et al. (2001) reported. The modulation of amygdala responses to emotional stimuli by attention is in accordance with Lavie's (1995; Lavie, 2000) proposed model of selective attention, which predicts failed distracter processing when attentional capacity limitations are exhausted during task processing. Lavie's hybrid model favours the notion that capacity limitations steer early selective attention processes under conditions of high perceptual load, however she also argues that it is impossible to suppress the processing of irrelevant information in situations of low perceptual load. This model leaves no room for pre-attentive selective processes preceding selective attention. The study of Pessoa et al. (2002) confers the predictions made by the model and further suggest that emotional stimuli are not 'special' in the sense that they receive automatic preferential processing, but rather highlights the mandatory role of attention in emotion perception.

The significance of amygdala activation in emotional processing is certain, however recent studies challenge the preattentive nature of processing in this limbic structure (Pessoa, Kastner, & Ungerleider, 2002; Pessoa, Padmala, & Morland, 2005). Recently, a series of experiments employing the ERP technique have investigated the impact of selective attention on the processing of emotional facial expressions (Eimer, Holmes, & McGlone, 2003; Holmes, Vuilleumier, & Eimer, 2003). It was consistently reported that when faces were attended, emotional faces elicited an enhanced positivity relative to neutral faces. These emotional expression effects were completely eliminated on trials where faces were presented at unattended locations. The emotional expression effects were very similar across all six basic emotional facial expressions, suggesting that emotional expression processing, as reflected by ERP modulations, are gated by spatial attention. This finding challenges the hypothesis that there is preattentive processing of emotional facial expressions, including processing of highly salient fearful faces (Eimer, Holmes, & McGlone, 2003). However, fMRI studies showing that amygdala responses to fearful faces appear to be unaffected by spatial attention (e.g. Vuilleumier, Armony, Driver, & Dolan, 2001), and that secondary task performance does not modulate amygdala activations triggered by highly arousing emotional scenes (Lane, Chua, & Dolan, 1999) are apparently at odds with the ERP findings. Eimer and Holmes (2007) propose that a fast sub-cortical system (involving the amygdala) provides the substrate for the automatic processing of emotional stimuli, which only high spatial resolution measures can tap into. Emotion-specific ERP modulations by attention, they suggest, reflect neocortical stages of emotional processing, which may lack *'immunity to attentional capacity limitations'*. Undoubtedly, there are many functionally important neural processes that electrophysiological measures cannot tap into. The arrangement of neurons in deep subcortical regions, including the amygdala, makes activity within these regions undetectable to surface electrodes. Therefore, it is reasonable to assume that the activity measured in ERP and fMRI studies of attention and emotion processing are indicative of different stages of information processing, which would explain the discrepancies.

1.9.1 Research Gap

Interestingly, none of these studies addressed whether anxiety modulates attentional requirements of emotional processing. It is an important factor for consideration given the expansive cognitive literature on anxiety proposing an automatic preattentive bias to threat. Eminent models have been presented proposing that anxiety modulates the output of an amygdala-based preattentive threat evaluation system (Mathews & Mackintosh, 1998; Öhman & Wiens, 2004). Bishop et al. (2004) tested this model and found evidence to suggest that anxiety may interact with attentional focus to determine the magnitude of the amygdala response to threat-related stimuli. In this study, high anxious participants showed an increased amygdala response to fearful versus neutral faces which was unaffected by attentional focus. However, in the low-anxious group amygdala response to fearful faces reduced when these stimuli were not the focus of attention. Bishop et al. (2004) propose that this finding may help to explain the discrepancies of previous research in this area; Vuilleumier at al.'s (2001) results are fitting with the results of the high-anxious group alone, as are Pessoa et al.'s (2002) findings consistent with the low-anxiety group. Bishop et al. (2004) suggest it may be the lack of consideration of this covariate of interest, which produced these apparently contradictory findings.

1.10 Forthcoming Studies

Cognitive theories have described anxiety in terms of a biased information-processing system, with particular emphasis on a bias in attention (e.g. Beck, 1976). According to these theories, anxious individuals are characterised by an attentional bias specifically related to the processing of threat-related stimuli. Chapters 2, 3, and 4 of the present thesis intend to address the nature of this anxiety-related processing bias and its regulation by attentional control processes.

Chapter 2 tests the hypothesis that anxiety modulates a preattentive threat evaluation system by examining whether threatening faces may be processed ‘automatically’, unconstrained by the availability of attentional resources. The aim of this study was to investigate the influence of focal spatial attention on ERP modulations sensitive to emotional facial expression.

The pattern of attentional deployment to threat-related stimuli in anxiety is still a matter of debate in the literature. Chapter 3 will test the specific hypothesis that heightened anxiety is associated with an increased attentional dwell-time on emotional relative to neutral stimuli. Chapter 4 will investigate attentional control capacity for emotional representations using a task-switching paradigm. A primary finding in the anxiety literature is that anxiety increases attention to threat-related stimuli (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijendoorn, 2007; Macleod, Mathews, & Tata, 1986; Mogg, Bradley, Miles, & Dixon, 2004), however, Eysenck et al.’s attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007) predicts that anxiety impairs attentional control processes. Therefore, this study will investigate whether anxiety modulates the ability to shift attention toward and away from threatening mental sets.

Finally, Chapter 5 investigates the metaphorical representation of affect. It was tested whether a spatial metaphor that associates *good* with *up* and *bad* with *down* underlies our cognitive representation of positivity and negativity. More specifically, this study examined how the association between valence and verticality influences motor responses (upwards and downwards) to the locations of emotional word stimuli.

Chapter 2 An Investigation into the Role of Attention in Affective Processing

2.1 Introduction

Vigilance towards threatening stimuli in our environment serves the evolutionary advantage of enabling a fast response to potential danger. Correspondingly, preferential attentional engagement of threat-related stimuli has been demonstrated with a variety of stimulus types, from spiders in spider-phobics which are detected more easily than relatively innocuous flowers or mushrooms (see Öhman & Mineka, 2001), to angry faces which appear to ‘pop-out’ in a crowd of emotionally discrepant faces, regardless of array size (Ashwin, Wheelwright, & Baron-Cohen, 2006). Such findings suggest that we possess a tendency to prioritise threatening stimuli, perhaps as a result of a preattentive, parallel search for immediate signals of threat (Hansen & Hansen, 1988).

Rapid attentional engagement of threat-related stimuli is certainly adaptive; however, an over-sensitive threat detection mechanism may result in maladaptive cognitive processing, as is implicated in the etiology and maintenance of anxiety disorders such as generalised anxiety disorder (GAD) and social anxiety disorder. The clinical-cognitive literature reports that heightened anxiety is associated with increased interference from irrelevant threat-stimuli, as demonstrated using the emotional Stroop and dot probe tasks (Macleod, Mathews, & Tata, 1986; Williams, Mathews, & MacLeod, 1996). Models of anxiety have interpreted such findings as evidence of an automatic preattentive threat evaluation system which is modulated by anxiety, making threat-detection much more likely for highly anxious individuals (Mathews, Mackintosh, & Fulcher, 1997; Williams, Watts, MacLeod, & Mathews, 1997). The aim of the present study was to investigate the mechanism underlying the threat-related processing bias in anxiety by examining the influence of spatial attention and trait anxiety levels on established ERP modulations by emotional stimuli. To assess the accuracy of the cognitive models of anxiety we wished to investigate whether threat-related stimuli receive preferential processing, irrespective of the focus of spatial attention, and if this is a rapid, involuntary process.

2.1.1 Electrophysical effects of emotional processing-previous findings

Research into the electrophysical effects of emotional processing at scalp electrodes has provided insights into the automaticity of affective processing. Although we cannot directly identify the neural generators of the scalp-recorded ERPs, the ERP technique is particularly suitable for investigating the temporal characteristics of the threat-related processing bias. Facilitated encoding of threat has been reported to occur within the first 100 ms of stimulus presentation, supporting the hypothesis that a fast, involuntary process is involved in threat-related visual processing (Lang, Bradley, Drobes, & Cuthbert, 1995; Pourtois, Grandjean, Sander, & Vuilleumier, 2004). Reduced negativity over frontocentral areas has been observed for negative relative to neutral facial expressions as early as 120 ms post-stimulus onset (Eimer, Holmes, & McGlone, 2003; Holmes, Vuilleumier, & Eimer, 2003). Subsequent modulations of the occipital P1 component by facial expression peaking around 130 ms post stimulus onset (Batty & Taylor, 2003; Eger, Jedynak, Iwaki, & Skrandies, 2003; Holmes, Kragh Nielsen, & Green, 2008; Pizzagalli, Regard, & Lehmann, 1999; Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005; Streit et al., 1999) have been shown to precede the N170. As the N170 is taken to reflect the structural encoding of faces, this result raises the possibility that discrimination of negative from neutral/positive facial affect may occur at early perceptual stages prior to the structural encoding of faces (Eimer, 2000). In comparison, the aforementioned P1 effect has been less reliable for happy relative to neutral faces, suggesting that the observed augmented P1 effects relating to emotional facial expression processing can be attributed to attentional biases to negatively valenced stimuli (Holmes, Kragh Nielsen, & Green, 2008).

Anxiety-related enhancement of the occipital P1 component for negative as compared with neutral or happy faces has also been reported in the literature; with the magnitude of this effect being significantly enhanced for the high-trait anxiety group in comparison with the low-trait group (e.g. Holmes, Kragh Nielsen, & Green, 2008; Li, Zinbarg, Boehm, & Paller, 2008). These findings provide additional information regarding the attentional bias towards threat in anxiety reported in many behavioural studies (see, Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007 , for a review). However, the modulation of the occiptial P1 by emotional expression has not been consistently reported (Dennis & Chen, 2007; Leppanen, Moulson, Vogel-Farley, & Nelson, 2007), nor have anxiety-related modulations of the P1 component (Fox, Derakshan, & Shoker, 2008; Moser, Huppert, Duval, & Simons, 2008; Rossignol, Philippot, Douilliez, Crommelinck, & Campanella, 2005). Thus it is questionable whether the occipital P1 component is a reliable electrophysiological marker of early facilitated processing of threat or emotionality in general.

Effects of emotional expression on the face-specific N170 component have also been examined. The results of these studies have not been conclusive, with some studies showing differentiation between fearful and happy/neutral facial expressions (Batty & Taylor, 2003; Leppanen, Moulson, Vogel-Farley, & Nelson, 2007; Rossignol, Philippot, Douilliez, Crommelinck, & Campanella, 2005) and others revealing no evidence of emotion specific effects (Bobes, Martin, Olivares, & Valdes-Sosa, 2000; Eimer & Holmes, 2002; Eimer, Holmes, & McGlone, 2003; Holmes, Kragh Nielsen, & Green, 2008). If the structural encoding of faces is an independent and parallel process to emotional expression detection, as postulated by the most prominent model of face recognition (Bruce & Young, 1986), one would expect there to be no systematic emotional expression effects on the N170 component.

Facilitated emotional stimulus encoding has also been observed over posterior visual areas in the form of an early posterior negativity (EPN), which is maximally pronounced around 200-300 ms post stimulus onset for pleasant and unpleasant compared to neutral images (Eimer, Holmes, & McGlone, 2003; Holmes, Kragh Nielsen, & Green, 2008; Schupp, Ohman et al., 2004; Schupp et al., 2007) and is assumed to originate from extrastriate visual areas sensitive to the selective attentional processing of negative affect (Holmes, Kragh Nielsen, & Green, 2008). Investigating the influence of trait anxiety on the attentional processing of threat-related facial expressions, Holmes et al. (2008) reported a diminished EPN in response to fearful stimuli in high- relative to low-anxious individuals. The authors took this to be indicative of an attentional avoidance strategy, an attempt of highly anxious individuals to reduce their sense of fear evoked by the stimulus.

Subsequent to the EPN, researchers have found a sustained positivity (LPP) for stimuli of high emotional arousal with a broad centro-parietal scalp distribution, most apparent around 400-600 ms post stimulus (e.g. Eimer & Holmes, 2002; Krolak-Salmon, Fischer, Vighetto, & Mauguiere, 2001; Williams, Palmer, Liddell, Song, & Gordon, 2006). Although the LPP appears to represent facilitated attention to both pleasant and unpleasant stimuli compared with neutral stimuli, in general the LPP effect is larger for unpleasant than pleasant stimuli, in accordance with the notion of a negativity bias (Cacioppo & Berntson, 1994). Moreover, in the face literature an LPP response to negative versus neutral facial expressions is routinely detected, contrasting with the relatively inconsistent reportage of an LPP response to positive facial expressions (e.g. see Holmes, Kragh Nielsen, & Green, 2008). The LPP appears to be highly significant in the investigation of emotional processing biases since a large body of literature indicates that modulations of the LPP serves as a neural index of the intrinsic relevance of emotional stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000a).

2.1.2 Pre-attentive Affective Processing

A strong notion of automaticity assumes that affective processing is uncompromised by attentional resources (Kahneman & Treisman, 1984). If the threat-related processing bias in anxiety is indeed preattentive then we would expect to observe facilitated processing of threat under conditions where attention is otherwise engaged. Over the last two decades neuroimaging studies have established the significant role of the amygdala in responding to the emotionality of a stimulus, especially when pertaining to threat. Reports of amygdala activation in response to unattended threatening faces (Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003; Lane, Chua, & Dolan, 1999; Vuilleumier, Armony, Driver, & Dolan, 2001) and briefly presented, masked threat-related stimuli have led to the proposal that threat-related stimuli can evoke amygdala activity without attentional engagement or conscious awareness. However, evidence of an amygdala-based fear response that is compromised by current task processing demands contests the notion that amygdala activation by emotional stimuli is attention-independent (Bishop, Jenkins, & Lawrence, 2007; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002;

Phillips et al., 2004). Based on these findings it is questionable whether salient information receives preferential processing by means of a fast subcortical thalamo-amygdala route, by-passing top-down processing strategies (Dolan & Vuilleumier, 2003).

Eimer and his colleagues (Eimer, Holmes, & McGlone, 2003; Holmes, Vuilleumier, & Eimer, 2003) carried out a series of experiments employing the ERP technique to investigate the impact of selective attention on ERP correlates of emotional processing. Using a similar paradigm to that employed in Vuilleumier et al.'s (2001) fMRI study, participants had to selectively attend to a face-pair or house-pair randomly located either above/below or flanking fixation. When faces were attended, emotional faces elicited an enhanced early frontocentral positivity relative to neutral faces between 160 and 215 ms post-stimulus. These emotional expression effects were completely eliminated on trials where faces were presented at unattended locations. The emotional expression effects were very similar across all six basic emotional facial expressions (i.e. angry, disgusted, fearful, happy, sad, and surprised; Ekman & Friesen, 1976) in comparison to neutral, suggesting that emotional expression processing, as reflected by ERP modulations, are gated by spatial attention. This challenges the hypothesis that there is preattentive processing of emotional facial expressions, including processing of highly salient fearful faces (Eimer, Holmes, & McGlone, 2003).

Interestingly, few studies have addressed whether anxiety modulates the attentional requirements of affective processing (e.g. Bishop, Duncan, & Lawrence, 2004; Bishop, Jenkins, & Lawrence, 2007). Given the expansive cognitive literature on anxiety proposing an automatic preattentive bias to threat this is perhaps surprising. Eminent models of anxiety propose a modulatory effect on the output of an amygdala-based preattentive threat evaluation system (Mathews & Mackintosh, 1998; Öhman & Wiens, 2004). The findings of Bishop et al. (2004) are in accordance with these predictions. Manipulating spatial attention to facial expressions of emotion, they reported that attentional focus did not modulate the increased amygdala activation to fearful- versus neutral- faces in high-anxious participants, unlike the low-anxious group. The observed modulatory effect of anxiety on fMRI correlates of emotional face processing highlights a contingency between heightened anxiety and automaticity. Based on these findings the authors posited that elevated anxiety does not necessitate attention to ensure an amygdala response to threatening stimuli and is capable of running concurrently with other attentionally demanding processes. On the contrary, emotional processing in low-anxious individuals was subject to attentional constraint.

These findings may help to reconcile earlier discrepancies in the literature (i.e. Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Vuilleumier, Armony, Driver, & Dolan, 2001), whereby individual differences in anxiety between the subject pools could have contributed to the inconsistencies in the amygdala response to unattended emotional stimuli across these studies (Bishop et al., 2004). However, we cannot so easily extend this argument to the ERP findings of Holmes et al. (2003). Eimer and Holmes (Holmes, Kiss, & Eimer, 2006) propose that a fast sub-cortical system (involving the amygdala) provides the substrate for the automatic processing of emotional stimuli, which only high spatial resolution measures can tap into. Emotion-specific ERP modulations by attention, they suggest, reflect neocortical stages of emotional processing, which may lack ‘immunity to attentional capacity limitations’. Undoubtedly, ERP responses to emotional stimuli are unlikely to have originated from the amygdala, given its neuronal arrangement, and as such both measures may have been reflecting distinct processes. Therefore, it is reasonable to assume that the activity measured in ERP and fMRI studies of attention and emotion processing are indicative of different stages of information processing (Holmes, Vuilleumier, & Eimer, 2003). However, it remains to be seen whether individual differences in anxiety modulate affective processing as recorded at scalp electrodes.

2.1.3 Present Study

Thus, in the present study the primary aim was to investigate whether trait anxiety modulates preattentive threat-related processing at neocortical stages by investigating the impact of spatial attention on ERP correlates of emotional facial expression. Modulations by anxiety which parallel the neuroimaging studies (i.e. Bishop, Duncan, & Lawrence, 2004; Bishop, Jenkins, & Lawrence, 2007; Vuilleumier, Armony, Driver, & Dolan, 2001) would implicate direct communications between visual cortical areas and the amygdala.

The current investigation adopted the experimental design used in earlier ERP and fMRI studies investigating affective processing (Holmes, Vuilleumier, & Eimer, 2003; Vuilleumier, Armony, Driver, & Dolan, 2001). The study aimed at testing the strict notion of automaticity, which assumes complete independence from attentive processing. Therefore, the house task employed in the Vuilleumier et al. (2001) and Holmes et al. (2003) studies was replaced by a difficult Landolt-square matching task. This maximized the task difficulty of the non-face task to ensure exhausted attentional resources on the faces-unattended condition. Spatial attention was manipulated on a trial-to-trial basis towards either face-pairs or a pair of Landolt squares, which randomly appeared either above/below or flanking fixation while participants performed the matching task for the relevant stimuli.

ERPS were recorded in order to examine the influence of trait-anxiety and spatial attention on early and later ERP components implicated in emotional processing (P1, N1, EPN, LPP and slow wave). Fearful, happy and neutral facial stimuli were selected from the California facial expressions (CAFE) database (Dailey, Cottrell, & Reilly, 2001). Stimuli were selected from the CAFE database in preference to the commonly used Ekman faces set (Ekman & Friesen, 1976) since these stimuli are controlled for low-level features such as contrast and luminance, therefore any modulation of the ERP waveform by these stimuli are likely due to the affective properties of the stimulus. In addition to the standard repeated measures ANOVA analysis, a task partial least squares (Task-PLS) analysis was performed. PLS is a multivariate approach, which was used to assess simultaneously the spatial and temporal features of attentional effects across the scalp.

It was hypothesised that if threatening facial expressions are detected preattentively and automatically, the facilitated processing of threat versus neutral faces should be unaffected by the focus of attention. Conversely, if essential attentional resources are allocated away from the face stimuli, towards an attentionally demanding task and we fail to observe ERP modulations by emotional expression then this would strongly challenge the notion of preattentive processing and correspondingly the automaticity of threat processing. Evidence of facilitated processing of threat relative to neutral faces that was unaffected by spatial location in the high anxiety group alone would provide evidence of a threat-related preattentive/attentional bias in anxiety. Closely linked to this, the secondary goal was to test the emotionality hypothesis, to directly address whether the attentional bias in anxiety implies enhanced processing of negative stimuli or to emotional faces in general; for this purpose, positively (happy) and negatively (fearful)-valenced facial expressions were included. Positive and negative affective faces producing comparatively larger ERP effects than neutral faces would be evidence in favour of a general emotional bias. However, larger differences in ERP outcomes between negative valence stimuli and neutral controls than between positive and neutral stimuli would be supportive of a negativity bias.

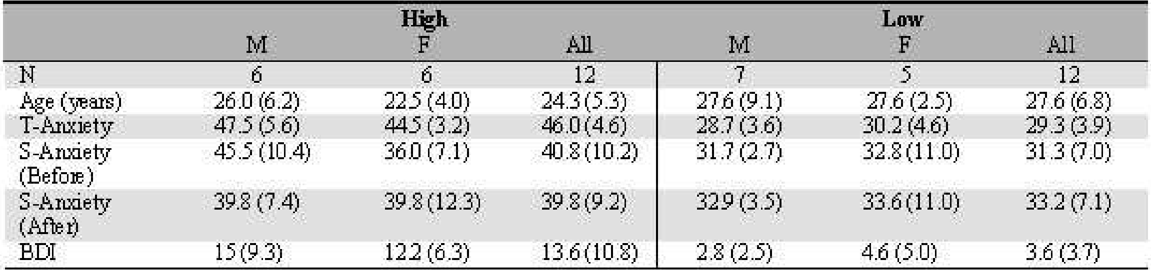
2.2 Methods

2.2.1 Participants

The participants were 34 healthy volunteers from the University of Glasgow undergraduate population. Ten participants were excluded because of excessive eye blinks and other muscle artifacts during EEG recording, so that 24 participants (13 male and 11 female; 18–33 years old; average age, 26 years) remained in the sample. All had normal or corrected-to-normal vision. Participants performed an adapted version of the matching-task used by Vuilleumier et al. (2001) while event-related potential (ERP) data were collected. The study was approved by the Glasgow University Research Ethics Committee and performed in appliance with their guidelines. Individuals with a history of inpatient psychiatric care, neurological disease, or head injury were excluded, as were individuals on medication for anxiety or depression. Participants scoring ≤35 on the trait version of the State-Trait Anxiety Inventory (STAI; Spielberger, 1983) were classed as the low-anxiety group and those scoring ≥40 were included in the high-anxiety group. Twelve participants (6 males and 6 females; mean age, 24 years) were grouped as high-anxious (*M* = 46.00, SD = 4.59 on the trait-anxiety scale of the STAI and 13.58 on Beck Depression Inventory (BDI; Beck, Steer, & Brown, 1996). Twelve participants (7 males and 5 females; mean age, 28 years) were grouped as low-anxious (*M* = 29.33, SD = 3.94 on the trait-anxiety scale of the STAI and 3.64 on the BDI). A *t*-test showed that the two groups were significantly different in trait-anxiety score ($t(22) = -4.95$, $p < .05$). Participant statistics for the two groups are summarized in Table 2-1.

Participants completed the state version of the STAI before the ERP session and both the state and trait subscales were completed immediately following the experiment. A *t*-test showed that the two groups were significantly different in state-anxiety score with the high-anxious group scoring higher than the low-anxious group ($t(22) = -2.69$, $p < .05$). Participants' state anxiety scores before the ERP session ranged from 21 to 62 (*M* = 36.04, SD = 9.68) and immediately following the ERP session their scores ranged from 20 to 53 (*M* = 36.50, SD = 8.74). A paired *t*-test showed that state anxiety scores were not significantly different before and after the experimental session ($t(22)= -0.02$, $p > .05$), suggesting that state-anxiety score is a stable measure of anxiety across the testing period. Participants' trait anxiety scores ranged from 23 to 57 (*M* = 37.67, SD = 9.49). These scores are similar to the published norms for college students (*M*(state) = 37.61, SD = 10.98; *M*(trait) = 39.35, SD = 9.66) (Spielberger, 1983).

Table 2-1. Participant scores on the trait and state subversions of the STAI.
Means and standard deviations (in brackets) for scores on the Trait and State versions of the STAI taken before and after the experiment and BDI scores. Statistics are provided for high and low anxiety groups and separately for males and females within each group.



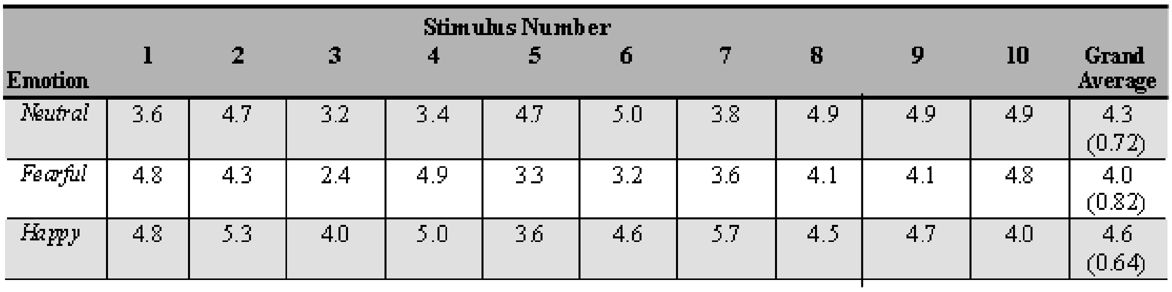
	High			Low		
	M	F	All	M	F	All
N	6	6	12	7	5	12
Age (years)	26.0 (6.2)	22.5 (4.0)	24.3 (5.3)	27.6 (9.1)	27.6 (2.5)	27.6 (6.8)
T-Anxiety	47.5 (5.6)	44.5 (3.2)	46.0 (4.6)	28.7 (3.6)	30.2 (4.6)	29.3 (3.9)
S-Anxiety (Before)	45.5 (10.4)	36.0 (7.1)	40.8 (10.2)	31.7 (2.7)	32.8 (11.0)	31.3 (7.0)
S-Anxiety (After)	39.8 (7.4)	39.8 (12.3)	39.8 (9.2)	32.9 (3.5)	33.6 (11.0)	33.2 (7.1)
BDI	15 (9.3)	12.2 (6.3)	13.6 (10.8)	2.8 (2.5)	4.6 (5.0)	3.6 (3.7)

2.2.2 Stimuli

The face stimuli were selected from the California Facial Expressions (CAFE) database (Dailey, Cottrell, & Reilly, 2001), comprising 5 male and 5 female faces with fearful, happy and neutral expressions (making a total of 30 stimuli normalised for the location of eyes and the mouth). All 30 stimuli used met the Facial Action Coding System (FACS; Ekman & Friesen, 1976) criteria. After the experiment, participants were asked to fill out a questionnaire, rating each of the 30 face stimuli according to their perceived intensity of emotion displayed by the stimulus. Each stimulus was rated on a 6 point scale from 1- *not at all* to 6-*very much* for the representativeness of the of emotion depicted in the stimulus (see Table 2-2). Following a significant main effect of emotion in a repeated-measures ANOVA of the stimulus evaluation data ($F(2,60) = 8.21$, $p < .05$), contrast analyses revealed that participants rated the fearful face stimuli as statistically less representative of the depicted emotion than either the happy face stimuli ($F(1,30) = 14.31$, $p < .05$) or the neutral face stimuli ($F(1,30) = 5.89$, $p < .05$). The face stimuli covered a visual angle of about 2.5×3.5°.

The Landolt square stimuli were black outlined squares covering a visual angle of about 1.1×1.1°, which on some trials had a gap on the side closest to the fixation point (covering a visual angle of about 0.1°) and on other trials a complete square.

Table 2-2. Stimulus evaluation scores.
Mean scores, from a six-point scale (1=not at all, to 6=very much), for the degree to which each of the thirty facial stimuli represents the emotion portrayed in the stimulus. A grand average score over all stimuli for each individual emotion is provided. Standard deviations are in brackets.



	Stimulus Number										
Emotion	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Grand Average**
Neutral	3.6	4.7	3.2	3.4	4.7	5.0	3.8	4.9	4.9	4.9	4.3 (0.72)
Fearful	4.8	4.3	2.4	4.9	3.3	3.2	3.6	4.1	4.1	4.8	4.0 (0.82)
Happy	4.8	5.3	4.0	5.0	3.6	4.6	5.7	4.5	4.7	4.0	4.6 (0.64)

2.2.3 Procedure

Participants were seated in a dimly lit sound-attenuated cabin, and a 21” computer screen was placed at a viewing distance of 80 cm. Participants used a chin rest to maintain a constant viewing distance throughout the experiment. The experiment consisted of one practice block of 20 trials followed by 15 experimental blocks, each containing 48 trials. Two practice trials were performed at the start of each block, which were excluded from the data analysis. On each trial, two faces and two white Landolt squares were presented in vertical and horizontal pairs around a central fixation cross and all stimuli were presented in front of a black background. The eccentricity of these stimuli, measured as the distance between the centre of each stimulus and the central fixation cross, was 2.5°. At the beginning of each trial a cue was presented that instructed participants to direct attention either to the two vertically aligned or the two horizontally aligned positions. This cue consisted of two white rectangles (each rectangle covering a visual angle of 3.0×3.5°) presented at either both horizontal or both vertical locations. Each trial began with an 83 ms presentation of the attentional cue followed by a 717 ms blank interval. Then, the face/Landolt square stimulus array was briefly presented for 300 ms. The interval between the offset of these stimuli and the beginning of the next trial was 1300 ms.

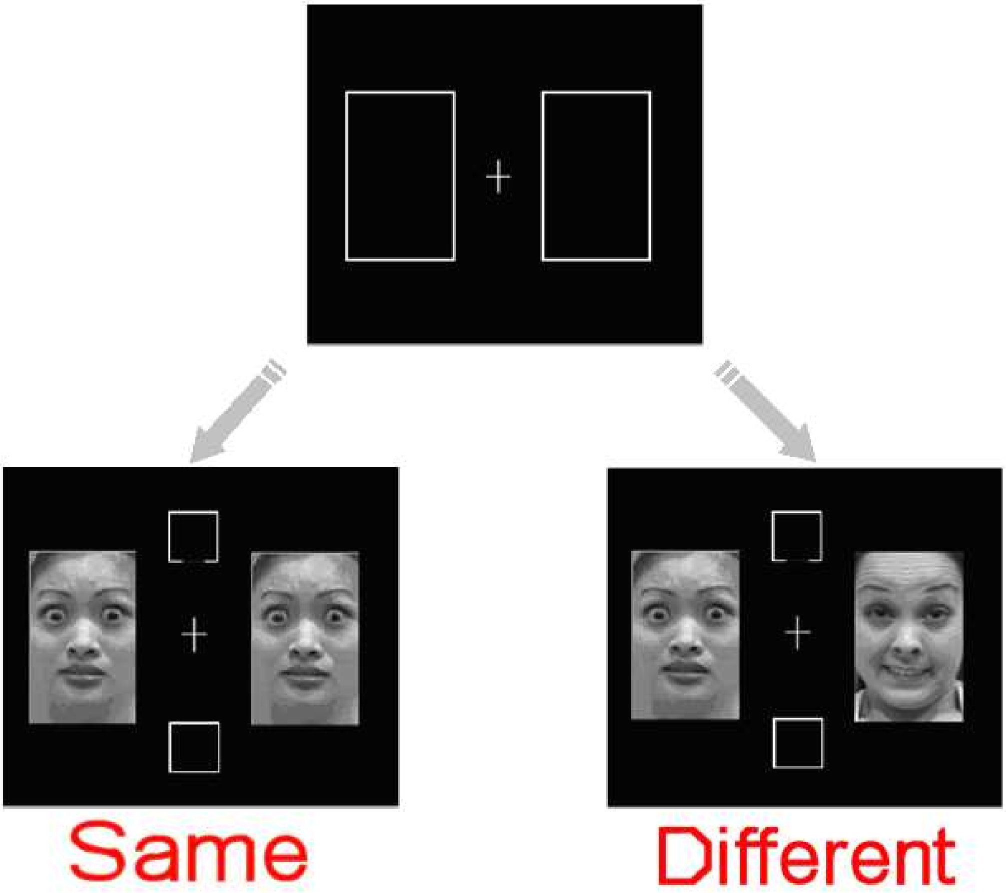


Figure 2-1. Example of the cue and stimulus presentation. The figure at the top represent a horizontal cue trial and the bottom two figures show two alternative responses on a faces attended trial.

Participants were instructed to maintain fixation while directing their attention to the locations indicated by the cue, and to respond as fast as possible with either a left or right hand keypress whenever they deemed the cued stimulus pair as the *same* or *different* (the S-R assignment was balanced across participants), see Figure 2-1. On face-attended trials, participants had to make a same/different identity judgement for the face pair. The faces presented varied in identity, but both always showed the same expression (fearful, happy or neutral) and were of the same gender. On face-unattended trials, participants had to identify whether the Landolt squares were the same (i.e. both squares either had a gap in the side closest to the fixation point or neither of them had a gap) or different (i.e. only one of the squares had a gap in the side closest to fixation). Stimuli at uncued locations had to be ignored. There were four conditions for the presented stimuli; *faces-same*, *squares-same, all-same and all-different*. The factorial design of the experiment ensured that half of the trials required a *same* response and half a *different* response. Within each block of trials, paired faces and paired squares appeared randomly and with equal probability in the vertical and horizontal positions, and these positions were equally likely cued or uncued. For face pairs presented in the horizontal position one third of the stimuli displayed neutral, happy and fearful effect, respectively.

Bishop et al. (2004) reported that the rostral anterior cingulated cortex (ACC) was strongly activated by infrequent rather than frequent threat-related distracters. This finding suggests that salient emotional stimuli induce processing conflict (from bottom-up interference) and are especially disruptive when they occur infrequently. To increase stimulus-driven effects in the present study, expressive faces (fearful and happy) in addition to neutral faces were presented only in the horizontal display condition, whereas all vertically presented face pairs were neutral. As a result, emotionally expressive faces (fearful and happy) occurred less frequently than neutral faces throughout the experiment.

2.2.4 Electrophysiological Recording

A BIOSEMI Active-Two amplifier system was used for continuous recording of electroencephalographic (EEG) activity from 72 Ag/AgCl electrodes over midline electrodes Fpz, AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz, and Iz, over the left hemisphere from electrodes IO1, Fp1, AF3, AF7, F1, F3, F5, F7, F9, FC1, FC3, FC5, FT7, C1, C3, C5, M1, T7, CP1, CP3, CP5, TP7, P1, P3, P5, P7, PO3, PO7, O1, two nonstandard positions PO9’ and O9’ which were located at 33% and 66% of the M1-Iz distance, and from the homologue electrodes over the right hemisphere. Two additional electrodes (Common Mode Sense (CMS) active electrode and Driven Right Leg (DRL) passive electrode) were used as reference and ground electrodes, respectively (cf. www.biosemi/faq/cms&drl.htm). EEG and EOG recordings were sampled at 256 Hz. Off-line, all EEG channels were recalculated to an average reference. Trials containing blinks were corrected using the adaptive artifact correction method of Brain Electromagnetic Source Analysis (BESA) software (Ille, Berg, & Scherg, 2002). Automatic artifact detection software (BESA) was run and trials with non-ocular artifacts (drifts, channel blockings, EEG activity exceeding ± 75 µV) were discarded. The analysis epoch of a total duration of 1400 ms started 200 ms prior to the onset of the stimulus.

2.2.5 EEG Data Analysis

Only trials without EEG or EOG artifacts were included in the EEG data analysis. The signal at each electrode site was averaged separately for each experimental condition time-locked to the onset of the target stimulus. Before the measurement of ERP parameters EEG and EOG activity was band-pass filtered (0.03-25 Hz, 6 dB/oct). The ERP waveforms were aligned to a 100-ms baseline prior to the onset of the stimulus. Mean amplitude of the ERP waveform was measured in average waveforms within time intervals during which specific ERP deflections were found to be most pronounced upon visual inspection (see Figure 2-2 for the topographies). Successive post-stimulus time windows defined the P1 from 85-125 ms; the N170 from 145-190 ms; the EPN from 200-300 ms; the early LPP from 300-500 ms; the late LPP from 500-700 ms and the Slow Wave from 700-1,000 ms. For the P1 and EPN components mean voltages were computed across four right hemisphere (RH) sites (P6, P8, PO8, PO10’) and four homologous electrodes over left hemisphere (LH) sites (P5, P7, PO7, PO9’). Mean N170 amplitude was measured across lateral occipitoparietal sites (P7/8, PO7/8). Mean amplitude measured in the early LPP, late LPP, and slow wave time intervals (300 - 500 ms, 500 – 700, 700 – 1,000 ms, respectively) was measured across three parietal midline electrodes (CPz, Pz, and POz for the early LPP; Cz, CPz, and Pz for the late LPP and slow wave), where activity was found to be maximal.

For the horizontal face trials I performed 2 (Group: High Trait Anxiety (HTA), Low Trait Anxiety (LTA)) × 2 (Attention: Attended, Unattended) × 3 (Emotion: Fearful, Happy, Neutral) × 2 (Hemisphere: LH, RH) repeated measures mixed ANOVAs, using the Huynh-Feldt correction, on the average voltage data in the P1, N170, EPN, early LPP, late LPP and slow wave time windows. For the early and late LPP, I performed a similar ANOVA, replacing the factor Hemisphere with Electrode. Finally, analysis of the N170 component was carried out on mean voltage data at lateral parietal regions (comprising P7/8, PO7/8) within a 145-190 ms time window. Analogous analyses were performed on the Vertical face trials with the omission of the factor emotion. RT data analysis mirrored that of the ERPs, excluding the variables hemisphere/electrode.

To address the multivariate nature of the data an additional partial least squares (PLS) analysis was performed to assess simultaneously the spatial and temporal features of attentional effects across the scalp. The PLS analysis of this data set was conducted using Matlab-based (v. 7.5, Mathworks, Inc.) graphical user interface (PLS; http://www.rotman-baycrest.on.ca/pls). Using this method, the whole epoch can be analysed across all electrodes rather than focusing on selected electrodes for a particular peak. The PLS analysis was conducted on the 1200 ms post-stimulus interval (excluding the pre-stimulus baseline) for 66 scalp electrodes (excluding left and right mastoid electrodes and the EOG channels). Results are based on permutation and Bootstrapping tests with 100 replications each.

2.2.6 Task-Partial Least Squares (Task-PLS) Analysis

Partial Least squares analysis is a multivariate approach to the analysis of neuroimaging data that was first introduced to the field in 1996 (McIntosh, Bookstein, Haxby, & Grady, 1996). In its original application, PLS was applied to one-dimensional images from spectrographs but recent adaptations of the mathematical formulation has allowed for an extension into the temporal domain. Spatiotemporal PLS (ST-PLS) allows data in a time series format such as fMRI, EEG and MEG data to benefit from this novel approach.

The PLS method is not unlike principle components analysis (PCA), whereby it computes the best fit between modelled and observed data in its least-squares sense, but diverges in its approach to fit only *part* of a correlation or covariance matrix (Wold, 1982). The solution is constrained to the covariation among two or more defined ‘blocks’ of variables and produces a new set of variables that relates the optimal covariance between the blocks using the fewest dimensions. The unique contribution of PLS among alternative multivariate approaches is that it concerns itself with extracting the covariance between spatial patterns of brain activity, such as scalp potentials in an ERP dataset, and changing task demands (Task-PLS). Allowing the study of the whole epoch simultaneously for all electrodes, one of the advantages of PLS analysis is that it has a data-driven as opposed to a data-mining approach. PLS is also useful for highly correlated data sets, a common feature of neuroimaging data, since within-block adjustments for correlation are unnecessary.

PLS operates on a matrix containing the entire data structure at once, which is compiled as follows. The rows of the matrix correspond to the conditions and subjects, while the columns contain electrode and time information. Singular value decomposition (SVD) is applied to the data matrix generating latent variable (LVs) and the associated vectors defining their structure: a vector of singular values and orthogonal vectors defining design saliences and electrode saliences for each latent variable. The singular values are used to calculate the proportion of cross-block covariance accounted for by a LV, in decreasing order of magnitude. Permutation tests are used to determine the significance of the singular values. The remaining set of vectors contain the structure of the LVs. The design saliences vector defines the contrasts among conditions and the electrode saliences vector identifies the spatial location and timing for the effects in the design saliences for each LV. Bootstrap resampling is applied to the electrode saliences to provide a measure of their stability at each timepoint and location in space (Efron & Tibishirani, 1985).

2.3 Results

2.3.1 Behavioural Results

Trials in which participants made errors were excluded from the RT data analysis. The RT data were subjected to two trimming procedures; items with RTs less than 250 ms or greater than 1500 ms were excluded from further analysis.

2.3.1.1 Horizontally Presented Face Stimuli

2.3.1.1.1 RT Analysis

Responses were faster for face targets (816 ms) relative to square targets (887 ms), resulting in a main effect of target category, $F(1, 22) = 11.4$, $p < .05$. RTs to targets were significantly influenced by the emotional expression of the face stimuli; responses to cued face targets and to vertically presented square targets were significantly affected by emotional expression, $F(2, 44) = 5.9$; $p < .05$. Follow-up analysis revealed delayed responses to targets when fearful faces were presented relative to neutral faces (864 vs. 847 ms), $F(1, 22) = 5.7$; $p < .05$. Similarly, fearful relative to happy face pairs produced delayed RTs to square targets (864 vs. 844 ms), $F(1, 22) = 14.5$, $p < .05$. On the contrary, happy vs. neutral horizontal faces did not produce significantly different effects on responses to targets (844 ms vs. 847 ms) $F(1, 22) = 0.2$; $p < .05$. There was no significant group effect on RT, $F(1, 22) = 0.05$, $p > .05$, nor any significant interaction effects, all *F*s < 2.08, *p*s > .05.

2.3.1.1.2 Error Analysis

Participants made 10.1% of errors when faces were cued and 18.2% errors to cued squares, $F(1, 22) = 5.06$, $p < .05$. The percentage of error was affected by facial emotional expression, $F(2, 44) = 3.7$, $p < .05$, and this effect was further modulated by group, $F(2, 44) = 6.2$, $p < .05$. Simple main effects of group for each level of the factor emotion revealed that when fearful faces were presented the high anxiety group made more errors in comparison to the low anxiety group, irrespective of target category (16.8 vs. 10.3%), $F(1, 22) = 6.0$, $p < .05$. No significant group differences were found for either the neutral condition, *F*(1, 22) = 0.4, *p* > .05, or the happy condition, *F*(1, 22) = 2.2, *p* > .05. The Target x Emotion interaction was insignificant, *F*(2, 44) = 2.5, *p* > .05, as were all other effects, all *F*s < 2.48, *p*s >.05.

2.3.1.2 Vertically Presented Face Stimuli

2.3.1.2.1 RT Analysis

Responses were faster for square targets (821 ms) relative to face targets (881 ms), resulting in a main effect of target category, *F*(1, 22) = 7.4, *p* < .05. No other effects were significant, all *F*s < 0.43, *p*s >.05.

2.3.1.2.2 Error Analysis

Participants made 18.9% of errors on face target trials and 16.1% of errors when squares were cued, although this difference failed to reach significance, *F*(1, 22) = 0.8, *p* > .05. No effects of error rate were significant, all *F*s < 0.43, *p*s >.05.

2.3.2 Electrophysiological Results

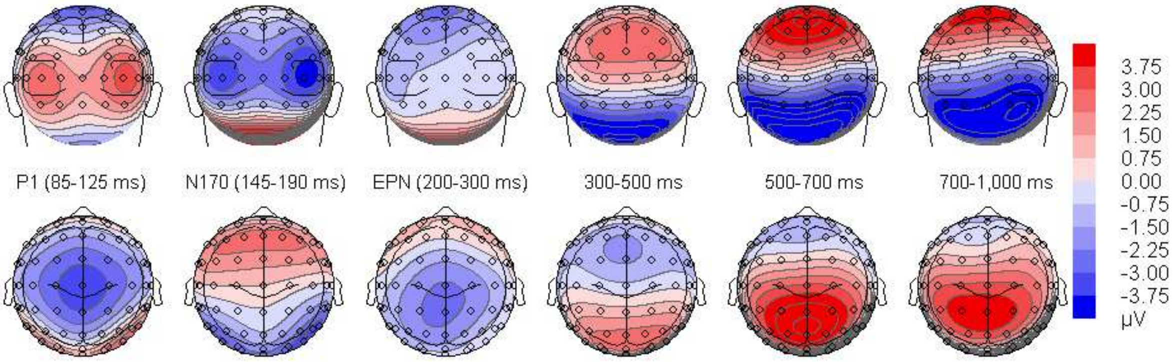


Figure 2-2. Spline-interpolated topographic maps representing the P1, N170, EPN, early LPP, late LPP, and slow wave, respectively. Isopotential line spacing is 0.75 µV.

2.3.2.1 P1 Component at Lateral Posterior Locations (85-125ms post-stimulus)

2.3.2.1.1 Horizontally Presented Face Stimuli

Figure 2-3 (top row) shows P1 amplitudes in the faces horizontal condition at electrode sites PO7 and PO8, where activation was maximal within the analysis region. A main effect of attention revealed enhanced P1 amplitudes on the faces unattended condition relative to the faces attended condition (2.69 vs. 2.96 µV), F(1,22) = 5.54, *p* < .05. Amplitudes were larger over the right hemisphere region as revealed in a main effect of hemisphere (1.95 vs. 2.45 μV), F(1,22) = 11.42, *p* < .01. No other effects were significant, all *F*s < 2.72, *p*s > .05.

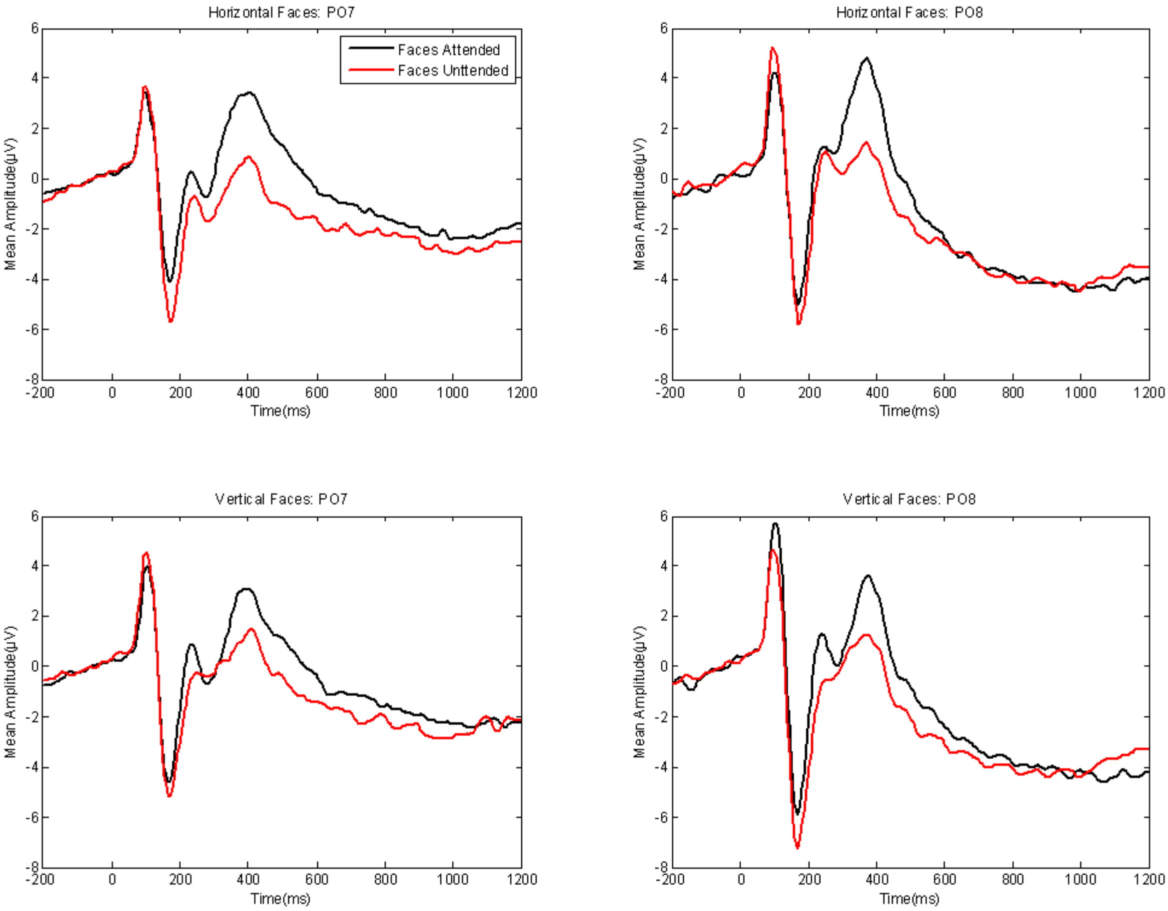


Figure 2-3. Grand-averaged ERP waveforms at PO7 and PO8 elicited by face-target trials and square-target trials. Faces horizontal condition is shown in the top row and faces vertical condition in the bottom row.

2.3.2.1.2 Vertically Presented Face Stimuli

None of the main effects were significant (attention: *F*(1,22) = 0.79, *p* > .05; hemisphere: *F*(1,22) = 2.64, *p* > .05). There was a significant Attention x Hemisphere interaction, *F*(1,22) = 6.65, *p* < .05, P1 amplitudes were enhanced when faces were attended than unattended over the right hemisphere region (3.09 vs. 2.55 μV), F(1,22) = 5.52, *p* < .05, however there were no significant attention effects over the left hemisphere, *F*(1,22) = 3.79, *p* >.05, see Figure 2-3 (bottom row). A significant Hemisphere x Group interaction effect, *F*(1,22) = 4.31, *p* < .05, revealed that for the LTA group, P1 amplitudes were enhanced over the right hemisphere region (2.49 vs. 3.07 μV), *F*(1,11) = 5.43, *p* < .05, while for the HTA group P1 amplitudes were not lateralized, *F*(1,11) = 0.14, *p* > .05.

2.3.2.2 N170 Component Over Occipito-Parietal Regions (145-190ms post-stimulus)

2.3.2.2.1 Horizontally Presented Face Stimuli

Within this time window, at lateral parietal regions where the N170 component is maximal, no main effects were significant, all *F*s < 1. There was a strong trend for an Attention x Hemisphere interaction, *F*(1, 22) = 4.17, *p* = .05, unattended faces tended to elicit a larger N170 than attended faces over the left hemisphere (-2.13 vs. -1.85 µV), with a reverse in amplitudes over the right hemisphere (-2.03 vs. -2.23 µV) (see Figure 2-4). The Attention x Emotion x Hemisphere interaction was significant, *F*(2, 44) = 3.74 , *p* < .05. Follow-up contrasts revealed that unattended rather than attended fearful faces elicited a larger N170 over the left hemisphere (-2.81 vs. -1.75 µV), *F*(1,22) = 11.83, *p* < .01, however this effect was not significant over the right hemisphere region (-2.04 vs -2.30 µV), *F* < 1. Neither the neutral nor happy face conditions were modulated by attention at lateral regions, all *F* < 2.43 and *p*s > .05.

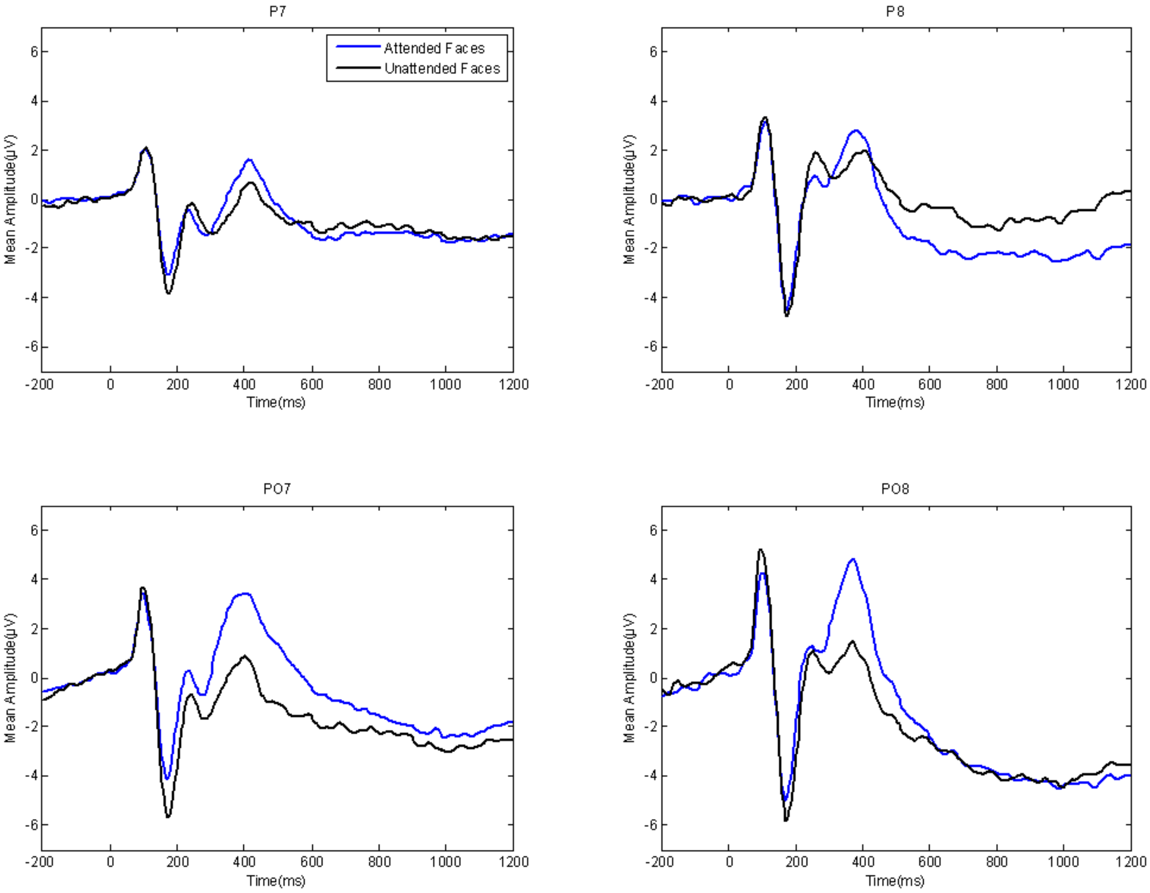


Figure 2-4. Grand-averaged ERP waveforms at P7/8 and PO7/8 elicited by face-target trials and square-target trials for the horizontal face condition.

There was a significant Emotion x Group interaction, $F(2,44) = 3.39$, $p < .05$, although none of the simple main effects were significant, all *F*s < 1. Overall the HTA group showed a pattern of enhanced N170 amplitudes relative to the LTA group, which was most pronounced for neutral (-2.63 vs. -1.60 µV) followed by fearful (-2.68 vs. -1.76 µV) and lastly happy faces (-2.24 vs. -1.92 µV).

2.3.2.2.2 Vertically Presented Face Stimuli

Only the main effect of attention was significant, $F(1,22) = 15.15$, $p < .0001$. N170 amplitudes were enhanced on faces unattended trials relative to faces attended trials (-3.12 vs. -2.53 µV), see Figure 2-5. All other effects, $F < 3.81$, *p*s > .05.

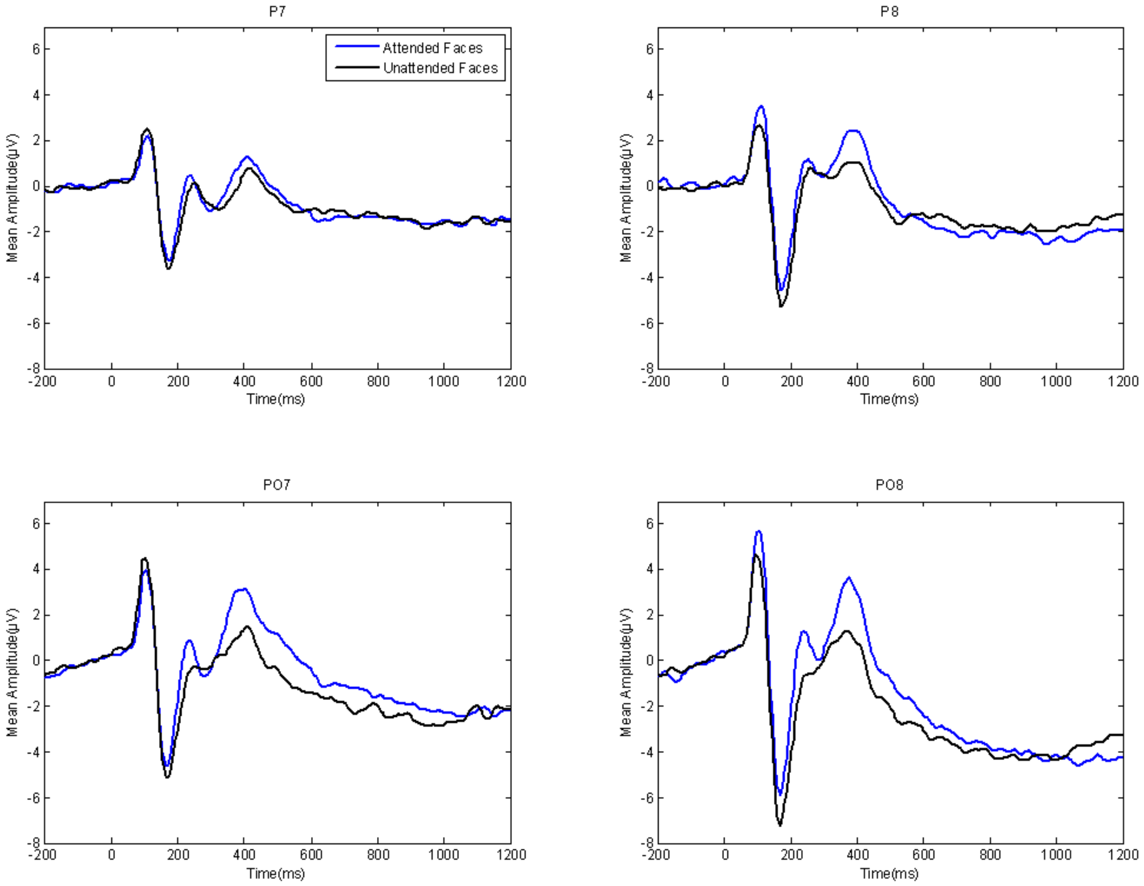


Figure 2-5. Grand-averaged ERP waveforms at P7/8 and PO7/8 elicited by face-target trials and square-target trials for the vertical face condition.

2.3.2.3 Enhanced Posterior Negativity (EPN) (200-300ms post-stimulus)

2.3.2.3.1 Horizontally Presented Face Stimuli

Significant main effects of emotion, *F*(2,44) = 10.46, *p* < .001, and hemisphere, *F*(1,22) = 6.38, *p* < .05, were qualified in an Attention x Emotion x Hemisphere interaction, *F*(2,44) = 3.99, *p* < .05. Follow-up contrasts revealed significant emotion effects over the right hemisphere region when faces were attended; Figure 2-6 shows that fearful and happy faces showed larger EPN amplitudes (-0.38 and -0.06 µV) than neutral faces (0.58 µV), both *F*s >8.64, *p*s < .0001. There was a trend for fearful faces to have enhanced EPN amplitudes relative to happy faces, although this was not confirmed in the analysis, *F*(1,22) = 3.53, *p* = .07. No emotional expression effects were observed over the left hemisphere region when faces were attended, *F*(2,44) = 1.07, *p* > .05. In the unattended faces condition, no significant effects were observed at lateral regions, all *F*s < 1, *p*s > .05. All other *F*s < 2.41, *p*s > .05.

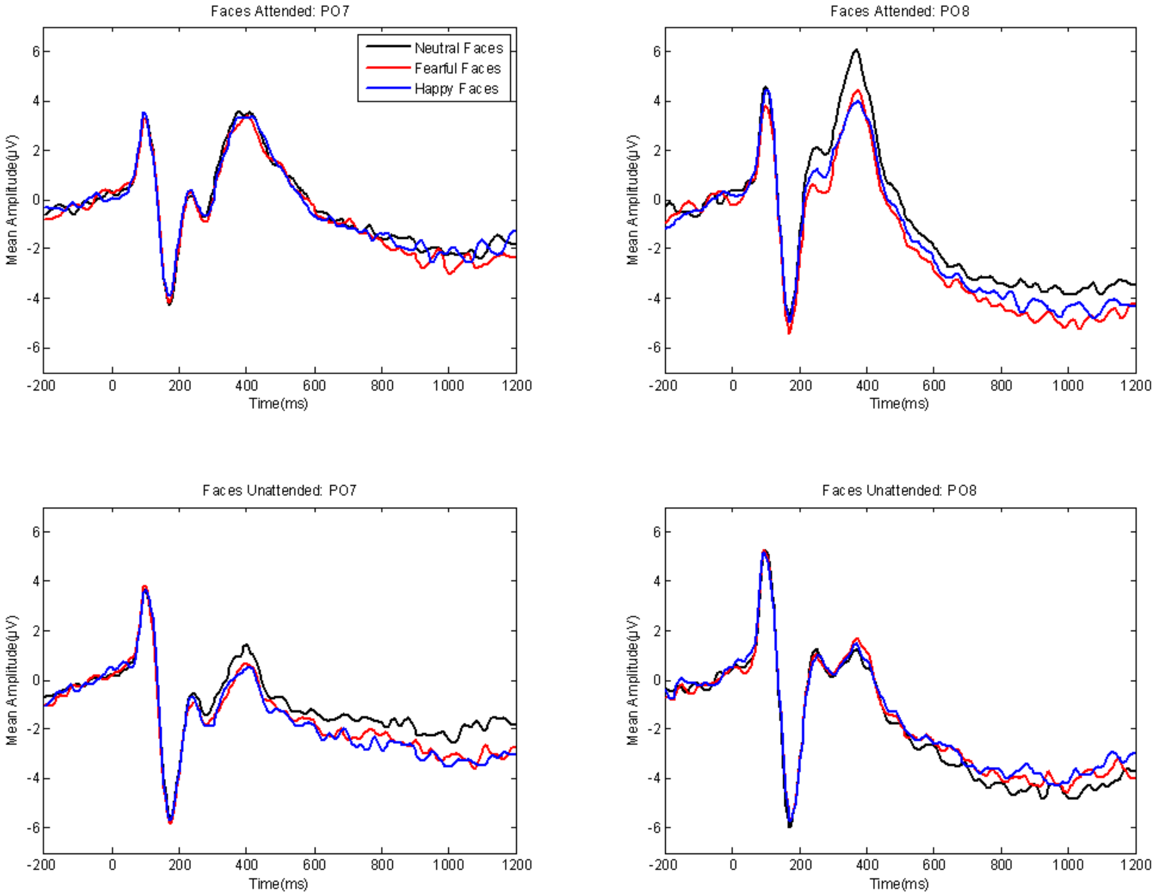


Figure 2-6. Grand-averaged waveforms at PO7 and PO8 for faces attended and unattended trials are shown on the top and bottom rows, respectively.

2.3.2.3.2 Vertically Presented Face Stimuli

A main effect of attention, *F*(1,22) = 7.49, *p* < .05, was further enveloped in an Attention x Group interaction effect, *F*(1,22) = 6.81, *p* < .05. The LTA group showed enhanced negativity for the faces unattended than attended condition (-1.58 vs. -0.57 μV), *F*(1,11) = 9.81, *p* < .01, whereas this effect was not significant for the HTA group (0.08 vs. -0.06 μV), *F*(1,11) = 0.01, *p* > .05. All other *F*s < 1.52.

2.3.2.4 Early LPP Time Window (300-500ms post-stimulus)

2.3.2.4.1 Horizontally Presented Face Stimuli

There was a main effect of attention, *F*(1,22) = 8.66, *p* < .01, however this was modulated by electrode, *F*(2,44) = 29.95, *p* < .0001. Follow-up analyses revealed enhanced positivity for attended relative to unattended faces at electrode sites Pz (3.45 vs. 2.31 μV), *F*(1,22) = 9.99, *p* < .01, and POz (3.57 vs. 1.07μV), *F*(1,22) = 25.80, *p* < .0001. However, there was no significant effect of attention at CPz

(1.28 vs. 1.89 μV), *F*(1,22) = 2.53, *p* > .05. There was a trend for the HTA group to have enhanced early LPP amplitudes for faces attended relative to faces unattended trials, whereas the LTA group did not show this pattern, *F*(1,22) = 4.18, *p* = .05, see Figure 2-7. No other effects were significant, all other *F*s< 3.40 and *p*s > .05.

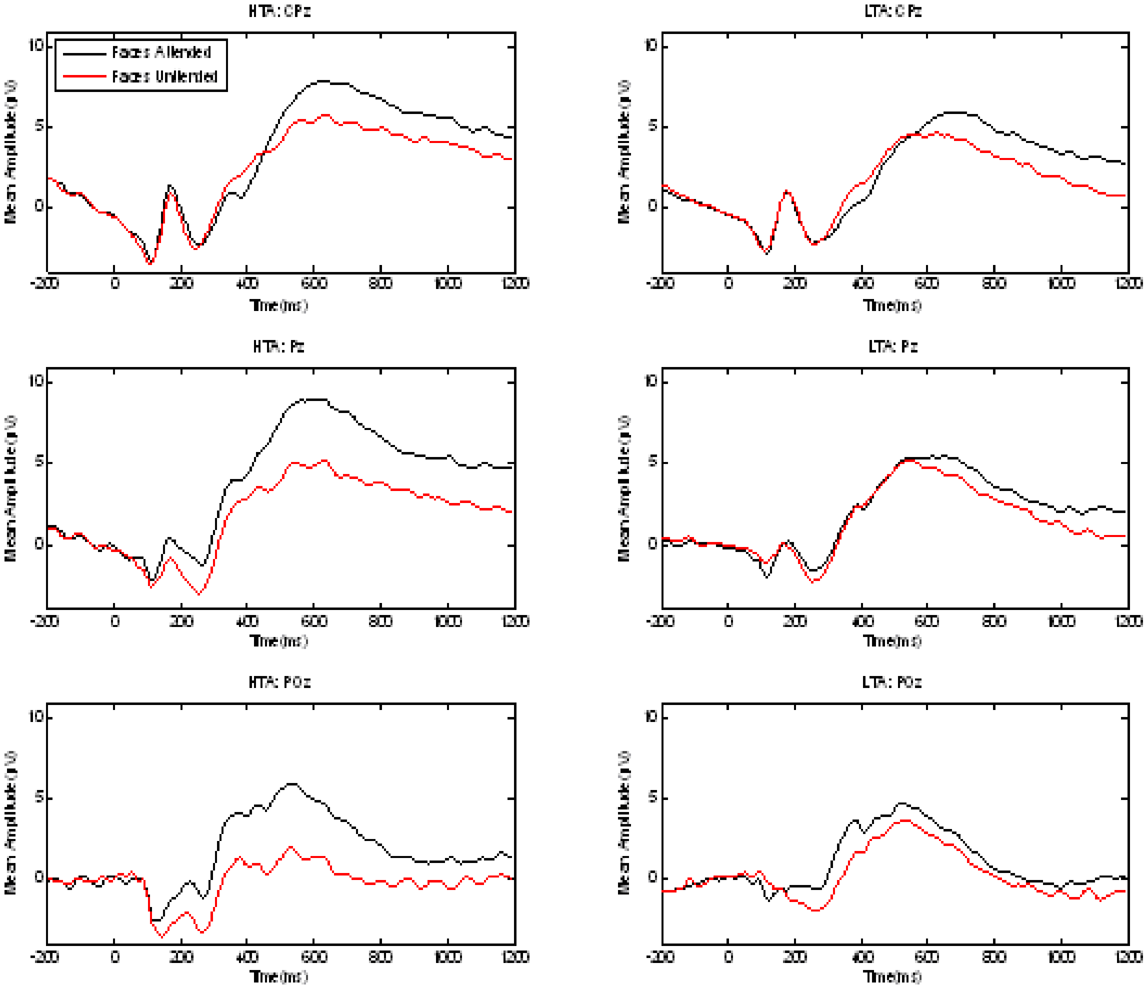


Figure 2-7. Grand-averaged waveforms for attended vs. unattended horizontal faces at CPz, Pz, and POz for HTA and LTA groups. The HTA group are shown on the left and the LTA group on the right.

2.3.2.4.2 Vertically Presented Face Stimuli

The main effect of electrode was significant, *F*(2,44) = 5.14, *p* < 0.05, as was a significant Attention x Electrode interaction, *F*(2,44) = 35.11, *p* < 0.0001, see Figure 2-8. Enhanced positivity for unattended relative to attended faces was present at electrode site CPz (2.59 vs. 0.29 μV), *F*(1,22) = 23.43, p < .0001. However, enhanced positivities for *attended* relative to unattended faces was observed at POz (3.35 vs. 2.07 μV), *F*(1,22) = 9.62, p < .01. The effect of attention was not significant at electrode Pz (3.08 vs. 2.68 μV), *F*(1,22) = 0.73, p > .05. No other effects were significant, all *F*s <1.56.

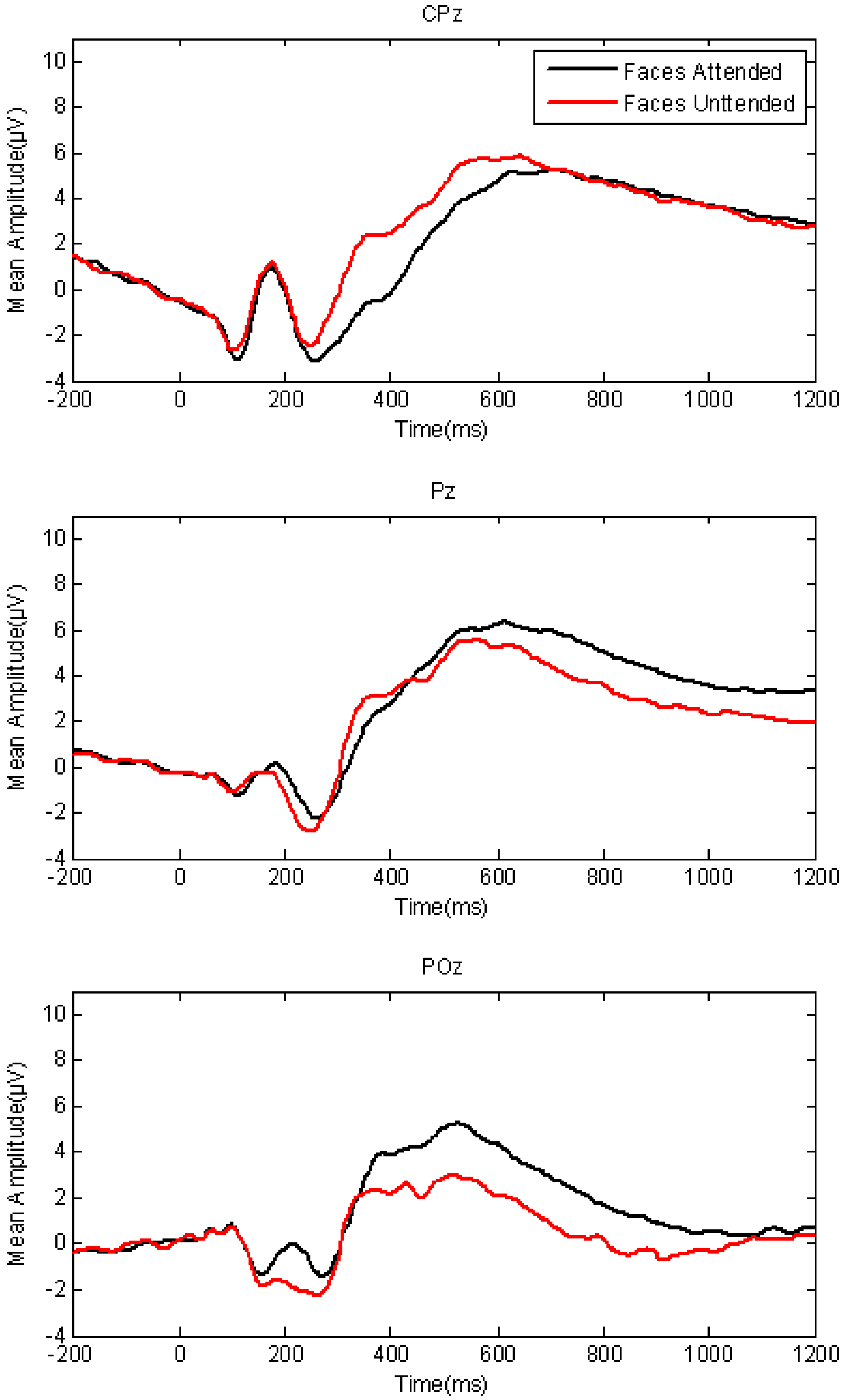


Figure 2-8. Grand-averaged waveforms for attended versus unattended vertical faces at electrode sites CPz, Pz and POz.

2.3.2.5 Late LPP Time Window (500-700ms post-stimulus)

2.3.2.5.1 Horizontally Presented Face Stimuli

A main effect of Emotion was observed, $F(2,44) = 4.59$, $p < .05$. Follow-up contrasts showed that there was enhanced positivity for fearful (5.27 μV), $F(1,22) = 8.80$, $p < .01$, and happy faces (5.11 μV), $F(1,22) = 6.59$, $p < .01$, as compared to neutral faces (4.62 μV), see Figure 2-9. Notably, the emotional expression effect was not modulated by attention, $F(2,44) = 0.07$, $p > .05$.

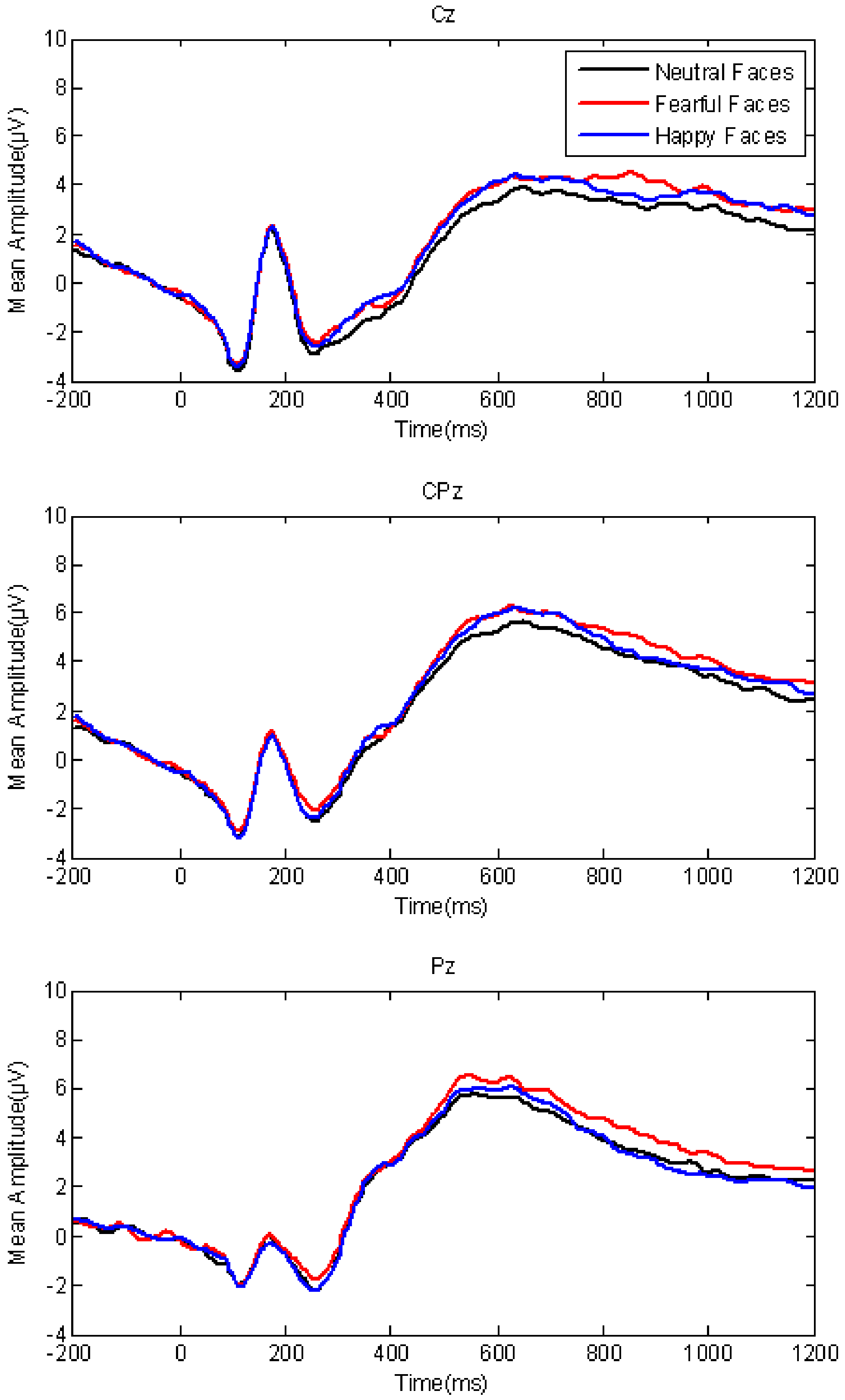


Figure 2-9. Grand-averaged waveforms for neutral, fearful and happy faces presented horizontally.

The main effect of attention was significant, *F*(1,22) = 11.93, *p* < .01, as was the Attention x Group interaction, *F*(1,22) = 4.48, *p* < .05. Attention effects were further modulated by electrode, *F*(2,44) = 8.92, *p* < .001, and Electrode x Group, *F*(2,44) = 7.52, *p* < .01. Follow-up analyses revealed a significant Attention x Electrode interaction, for the HTA group, *F*(2,22) = 10.61, *p* < .01, but not the LTA group, *F*(2,22) = 0.22, *p* > .05, see Figure 2-10. As can be seen in Figure 2-10, the HTA group showed enhanced positivities for attended than unattended faces at electrode site Pz (8.60 vs. 4.71 µV), *F*(1,11) = 17.91, *p* < .01, however attention effects were not present at CPz, (7.31 vs. 5.29 µV), *F*(1,11) = 6.68, *p* > .05, or Cz, (3.96 vs. 2.94 µV), *F*(1,11) = 3.47, *p* > .05. This group difference mirrors the earlier LPP modulations by attention, thus the observed effect in the late LPP window may indicate the sustained attention towards faces in heightened anxiety, replicating prior research (e.g. Hajcak & Olvet, 2008b).

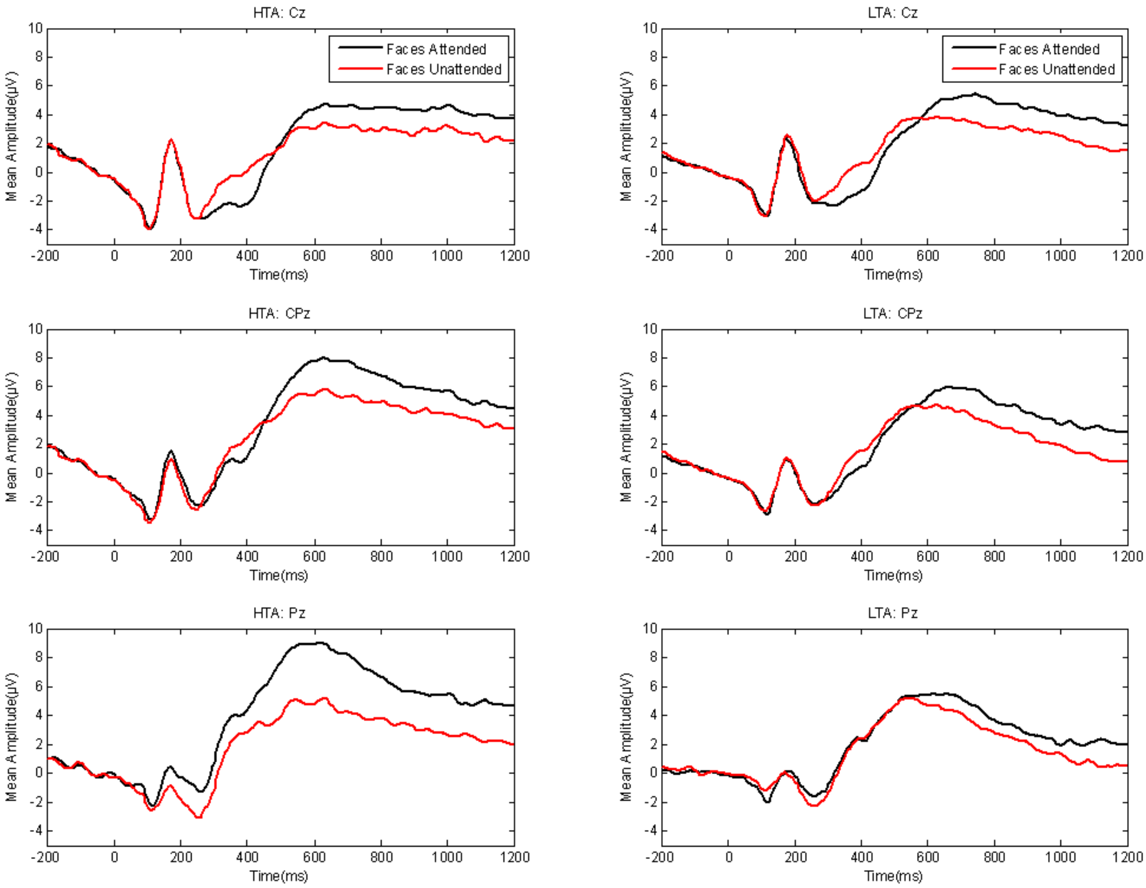


Figure 2-10. Grand-average waveforms for attended versus unattended horizontal faces for the HTA (left column) and LTA (right column) groups at electrode sites Cz, CPz and Pz.

2.3.2.5.2 Vertically Presented Face Stimuli

There was a main effect of electrode, *F*(2,44) = 10.69, *p* < 0.01, and a significant Attention x Electrode interaction, *F*(2,44) = 21.18, *p* < 0.001. Enhanced positivities for unattended versus attended faces was significant at electrode site Cz (4.07 vs. 2.57 µV), *F*(1,22) = 10.68, *p* < 0.01, with a similar tend at CPz, (5.50 vs. 4.52 µV), *F*(1,22) = 4.86, *p* > 0.016, however attention effects were non-significant at Pz, (5.14 vs. 6.00 µV), *F*(1,22) = 2.51, *p* > 0.05. *F*(2,44) = 10.69, *p* < 0.01

2.3.2.6 Slow Wave (700-1,000 ms)

2.3.2.6.1 Horizontally Presented Face Stimuli

There was a main effect of emotion *F*(2,44) = 4.54, *p* < 0.05, see Figure 2-9. Follow-up contrasts revealed enhanced positivities for fearful versus neutral faces (4.52 vs. 3.78 µV), *F*(1,22) = 10.27, *p* < 0.01, and a trend for enhanced positivites for fearful versus happy faces, although this did not reach significance, (4.52 vs. 3.99 µV), *F*(1,22) = 3.24, *p* = 0.08. However, amplitudes within this time window did not significantly differ between neutral and happy faces (3.99 vs. 3.78 µV), *F*(1,22) = 0.84, *p* > 0.05.

A main effect of attention revealed enhanced positivities for attended than unattended faces (4.96 vs. 3.23 µV), *F*(1,22) = 18.69, *p* < 0.001. A significant Attention x Electrode x Group interaction, *F*(2,44) = 6.18, *p* < 0.01, revealed that both the HTA and LTA groups showed enhanced positivities for attended than unattended faces at electrode sites Cz, both *F*s >5.65 and *p*s < .05, and CPz, both *F*s > 6.58 and *p*s < .05, see Figure 2-10. However at Pz, the HTA group demonstrated significant attention effects (6.27 vs. 3.42 µV), *F*(1,11) = 12.46, *p* < 0.001, whereas for the LTA group attention failed to reach significance (3.36 vs. 2.44 µV), *F*(1,11) = 3.22, *p* > 0.05, see Figure 2-10. All other *F*s < 1.99, *p*s > .05.

2.3.2.6.2 Vertically Presented Face Stimuli

A significant Attention x Electrode interaction, *F*(2,44) = 10.5, *p* < 0.001, revealed enhanced positivities for attended than unattended faces at electrode site Pz, *F*(1,22) = 9.40, *p* < 0.01, see Figure 2-8. However, effects of attention were not significant at sites Cz, *F*(1,22) = 0.03, *p* > 0.05, or CPz, *F*(1,22) = 0.04, *p* > 0.05. All other *F*s < 1.96, *p*s > .05.

2.3.2.7 Task ST-PLS results

2.3.2.7.1 Horizontally Presented Faces

An analysis including all 12 conditions (6 conditions x 2 groups) was run. PLS identified three major effects, three latent variables, which were significant by permutation test, *p*s ≤ .01, 100 permutations, see Figure 2-11. For the first LV, the dominant effect reflected the distinction between attended and unattended faces. It also indicated ERP amplitude differences between high and low anxiety groups for the attention effect. The second and third latent variables expressed complex interaction patterns between attention, emotion, and groups. These are described below.

2.3.2.7.1.1 Attention to Faces Modulated by Anxiety

The design saliences for the first latent variable (LV1) indicated that the largest difference among the conditions was between attended and unattended faces; it represented 60.19% of the cross-block covariance. The magnitude of the attended-unattended difference varied across groups. The electrode saliences indicate where the differences are being expressed, shown in Figure 2-11. The stable differences, as assessed by bootstrap tests (100 samples), are shown by the blue markers at the top of each channel plot. Close inspection of the saliences revealed that the attention effect was primarily posterior with a reversal in polarity at frontal sites (cf. F3/F4). It is largest where the saliences are maximal, and this occurred over the occipital and parietal-occipital electrodes (O1/O2, Oz, PO3/PO4, and POz). The effect emerged around 400 ms and had a long duration, until around 700 ms.

To more fully appreciate the nature of the differences in ERP amplitude related to attention, the ERPs are shown in Figure 2-13, collapsed across emotional expression (as the effects were similar across emotional expression), for the channels showing the largest differences. Blue markers at the top indicate the time points of stable differences for the attention by group interaction pattern. Because the frontal sites reflected only a polarity reversal, we describe only the posterior electrodes.

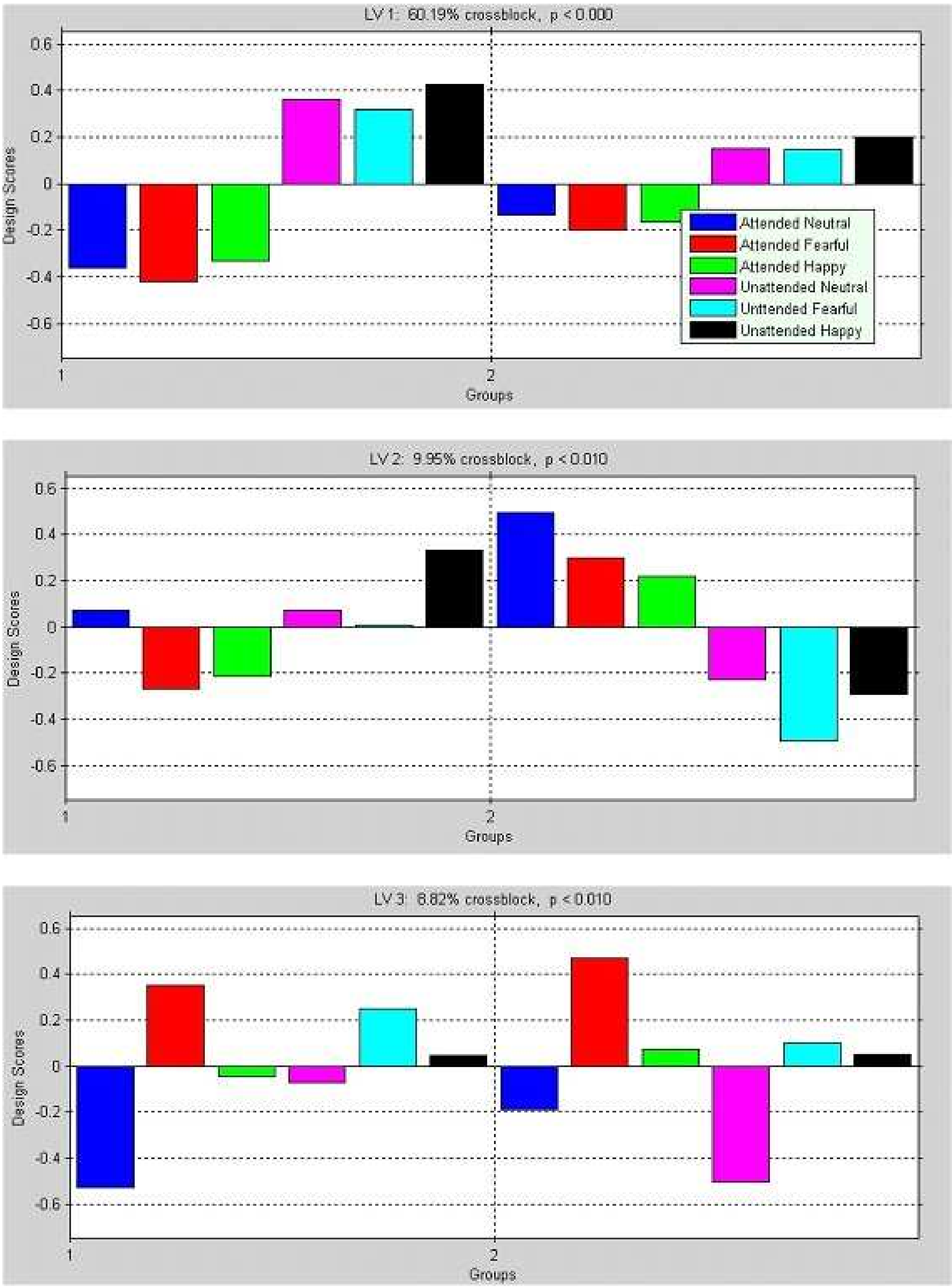


Figure 2-11. Design Saliences for LV1, LV2 and LV3. Group 1 refers to the HTA group and group 2 refers to the LTA group.

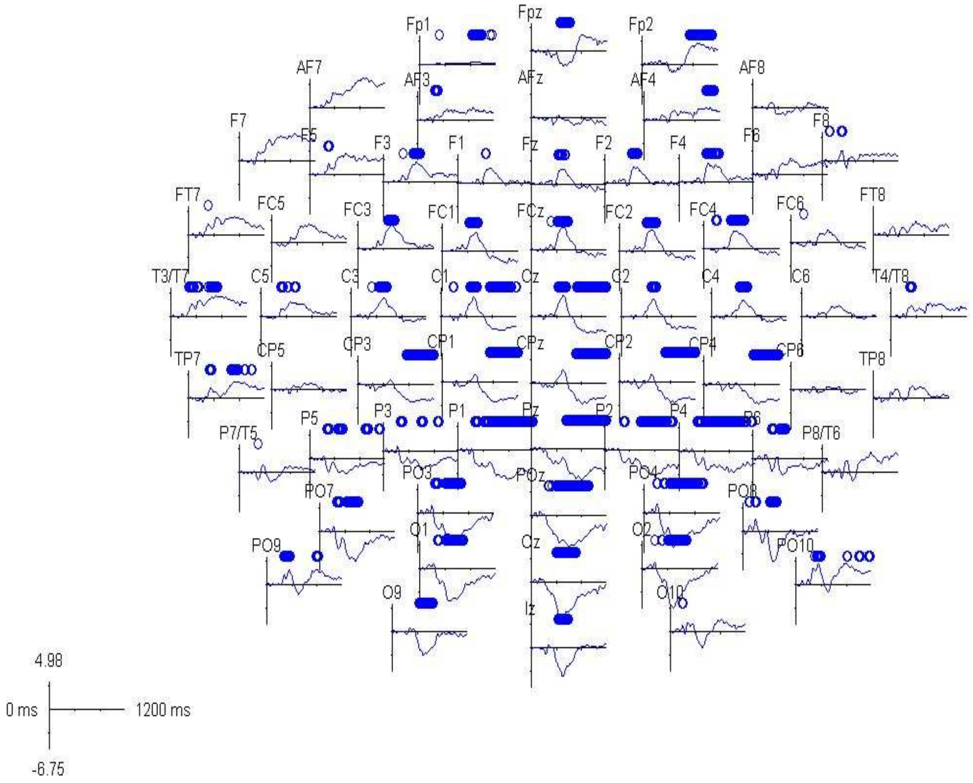


Figure 2-12. Electrode Saliences for LV1.

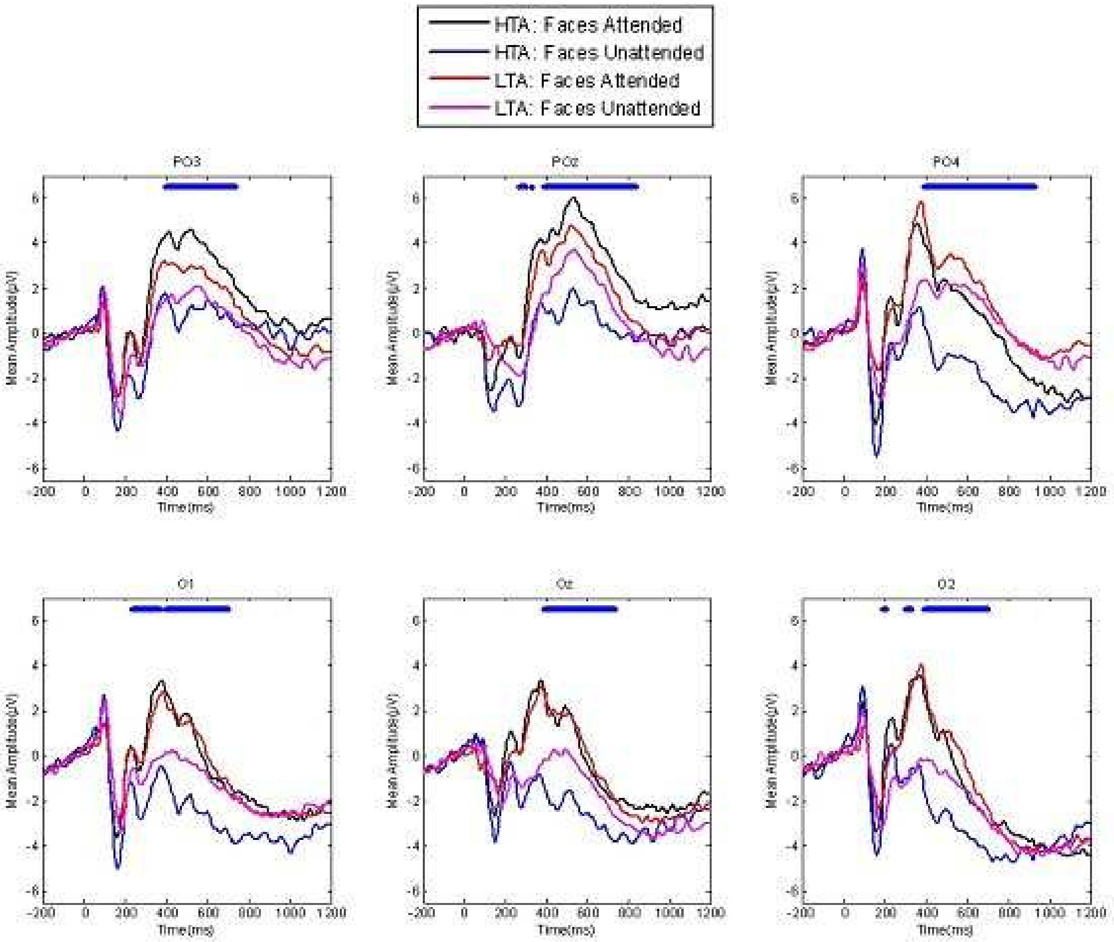


Figure 2-13. ERP waveforms showing attention effects across anxiety groups. The blue dots indicate the time points at which the effects were significant by bootstrap.

The attention by group interaction pattern started around 400 ms and prolonged until around 750 ms. The effect reflected larger amplitudes for the attended than unattended condition, with this difference being greater for the HTA in comparison to the LTA anxiety group. The negative saliences seen in Figure 2-12 reaching a maximum around 500 ms reflected the larger LPP amplitudes obtained for attended faces, which was more pronounced for the HTA group.

2.3.2.7.1.2 Interaction of Attention by Emotion and Group

The second significant LV accounted for 9.95% of the cross-block covariance and reflected an interaction between all three factors; attention, emotion and group. The design saliences (Figure 2-11) showed that in the attended faces condition, amplitudes varied as a function of emotion for the HTA group, the effects being in opposite directions between neutral and emotional faces. The LTA, in comparison, did not show any modulations by emotion. The electrode saliences with the strongest effects (Figure 2-14) show where these differences were being expressed. The emotion effect was maximal at centro-parietal and occipito-parietal sites, with a polarity shift at central electrodes. The electrode saliences showed that these differences were robust ~600 to 750 ms across all electrodes.

To more fully appreciate the nature of the differences in ERP amplitude related to emotion and group, the ERPs for faces attended and unattended conditions are shown in Figure 2-15 and Figure 2-16 respectively, for the channels showing the largest difference. Time points of the stable differences are indicated on the ERP plots (blue marker).

Effects of emotion were robust around the 600 - 750 ms interval for the HTA group, but only when faces were attended. The effect reflected larger slow wave amplitudes for attended emotional (fearful and happy) compared to neutral faces, whereas for the LTA group amplitudes were equally large for neutral and emotional faces. However, for the unattended faces condition, enhanced amplitudes were observed for emotional compared to neutral faces at occipito-parietal locations for the LTA group.

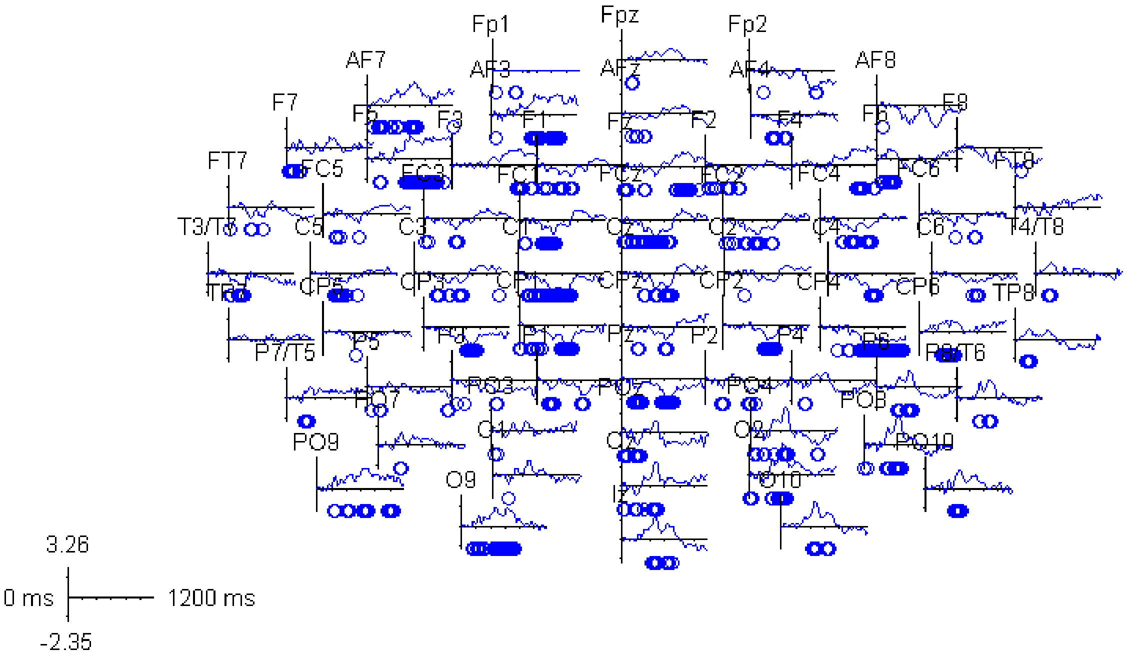


Figure 2-14. Electrode saliences for LV2.

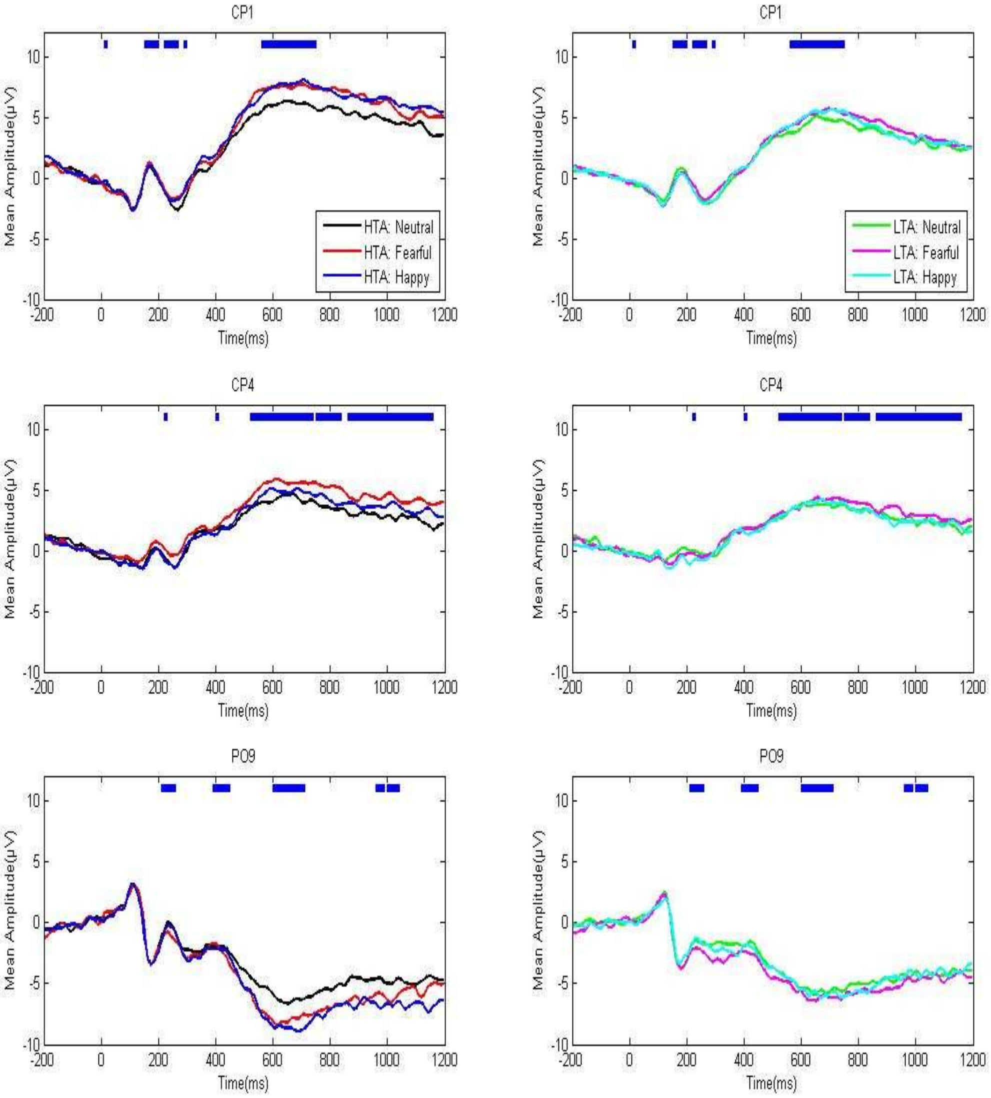


Figure 2-15. ERP waveforms for faces attended condition for HTA (left column) and LTA (right column) groups. The stable differences by bootstrap are indicated for each electrode as in Figure 2-14 (blue = LV2).

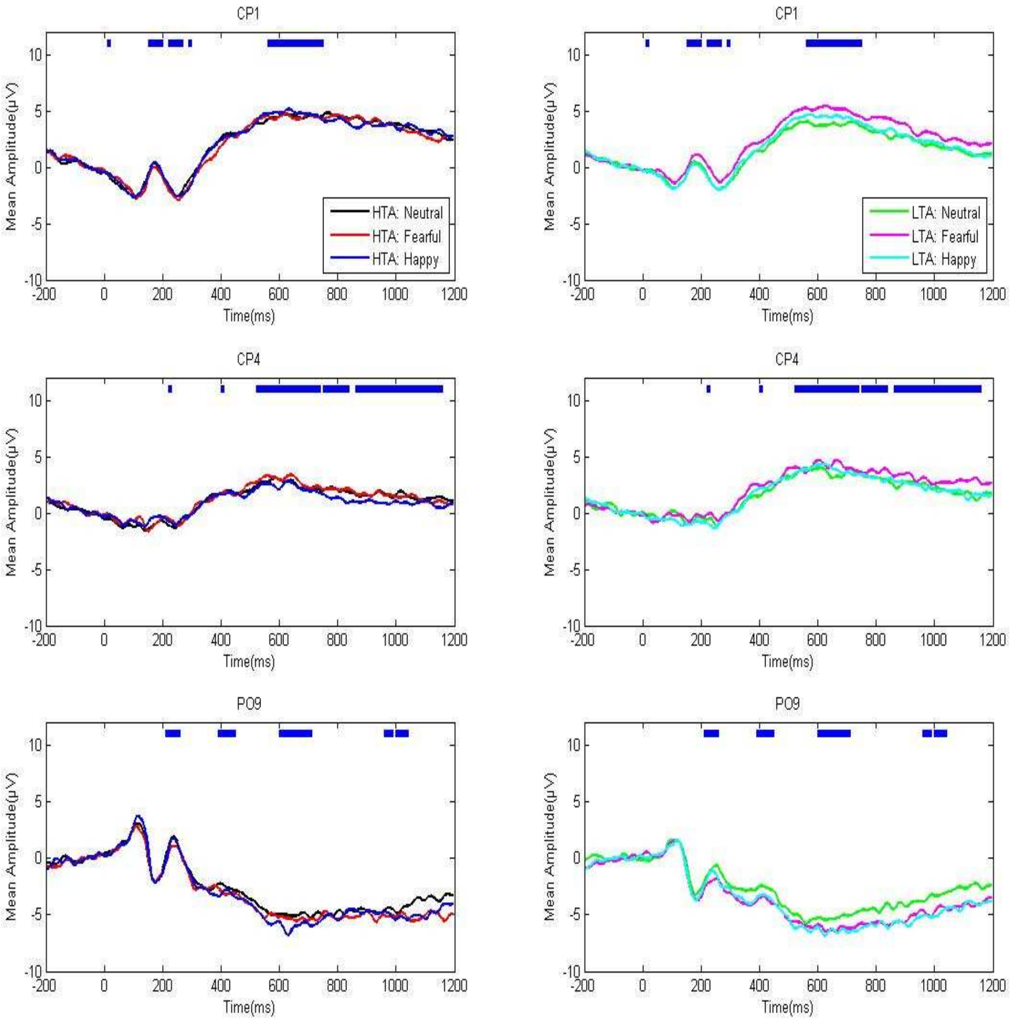


Figure 2-16. ERP waveforms for faces unattended condition for HTA (left column) and LTA (right column) groups. The stable differences by bootstrap are indicated for each electrode as in Figure 2-14 (blue = LV2).

2.3.2.7.1.3 Further Interactions Between Attention, Emotion, and Group.

The third (and last) significant LV accounted for 8.82% of the cross-block covariance and reflected further interactions among the factors attention, emotion, and group. The design saliences (Figure 2-11, bottom panel) showed that attention effects, the effects being in opposite directions between attended and unattended faces, varied as a function of emotion and group.

The electrode saliences with the strongest effects were selected for inspection (O1, Oz, Iz, O9, and PO9). The effect was maximal at left hemisphere and central occipito-parietal sites, with a polarity shift at frontal electrodes. The electrode saliences showed that these differences were expressed from ~650 to

1200 ms at all electrodes except Iz where differences were robust from ~650 to 800 ms.

The ERPs for faces attended and unattended conditions are shown in Figure 2-18 and Figure 2-19 respectively, and separately for HTA and LTA groups, for the channels showing the largest difference. Time points of the stable differences are indicated on the ERP plots (blue marker). The effect reflected larger slow wave amplitudes for attended fearful compared to neutral and happy faces in the HTA group (O1, Oz, Iz, PO9), and for the LTA group (Iz, O9). For the faces unattended condition, the effect reflected larger amplitudes for emotional versus neutral faces in the HTA group around ~650 to 800 ms at Iz, whereas the LTA group showed more sustained amplitude effects for emotional versus neutral faces (O1, O9, and PO9)

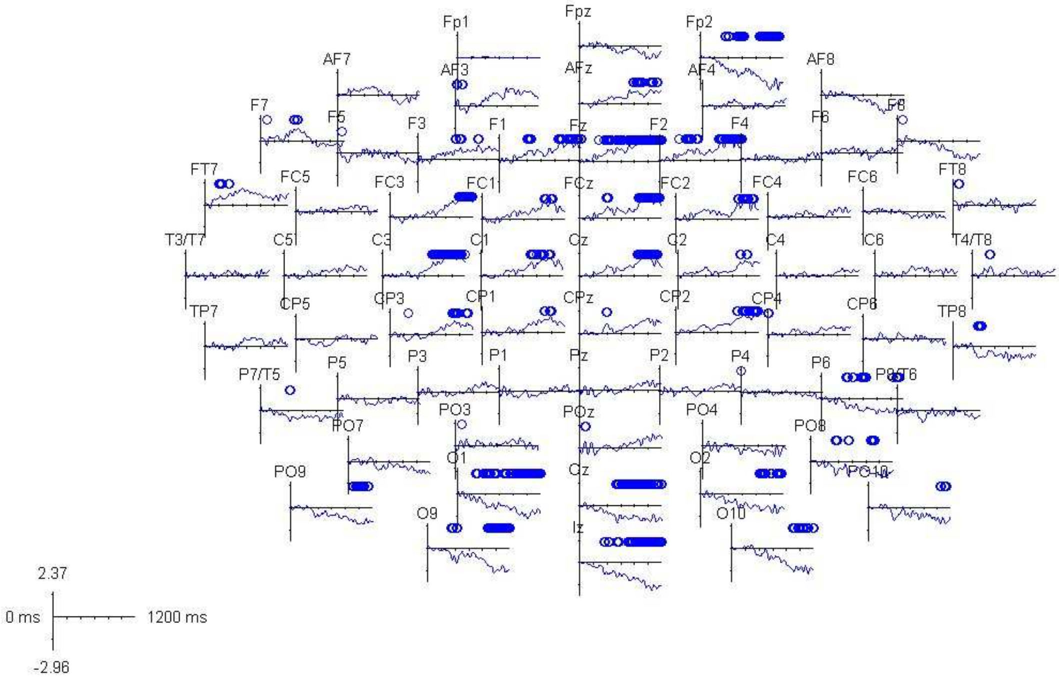


Figure 2-17. LV3 electrode saliences.

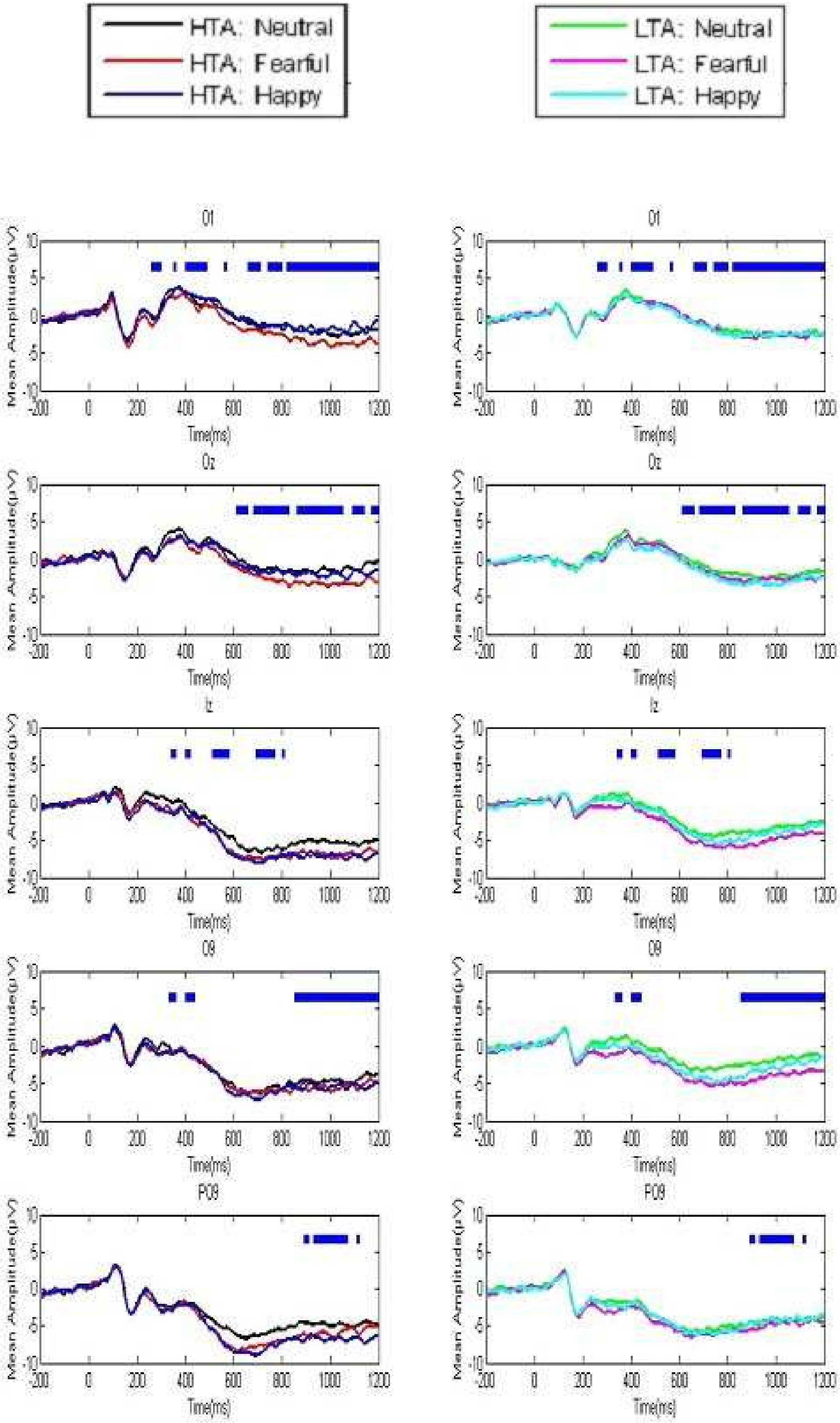


Figure 2-18. ERP waveforms for faces attended condition for HTA (left column) and LTA (right column) groups. The stable differences by bootstrap are indicated for each electrode as in Figure 2-14 (blue = LV3).

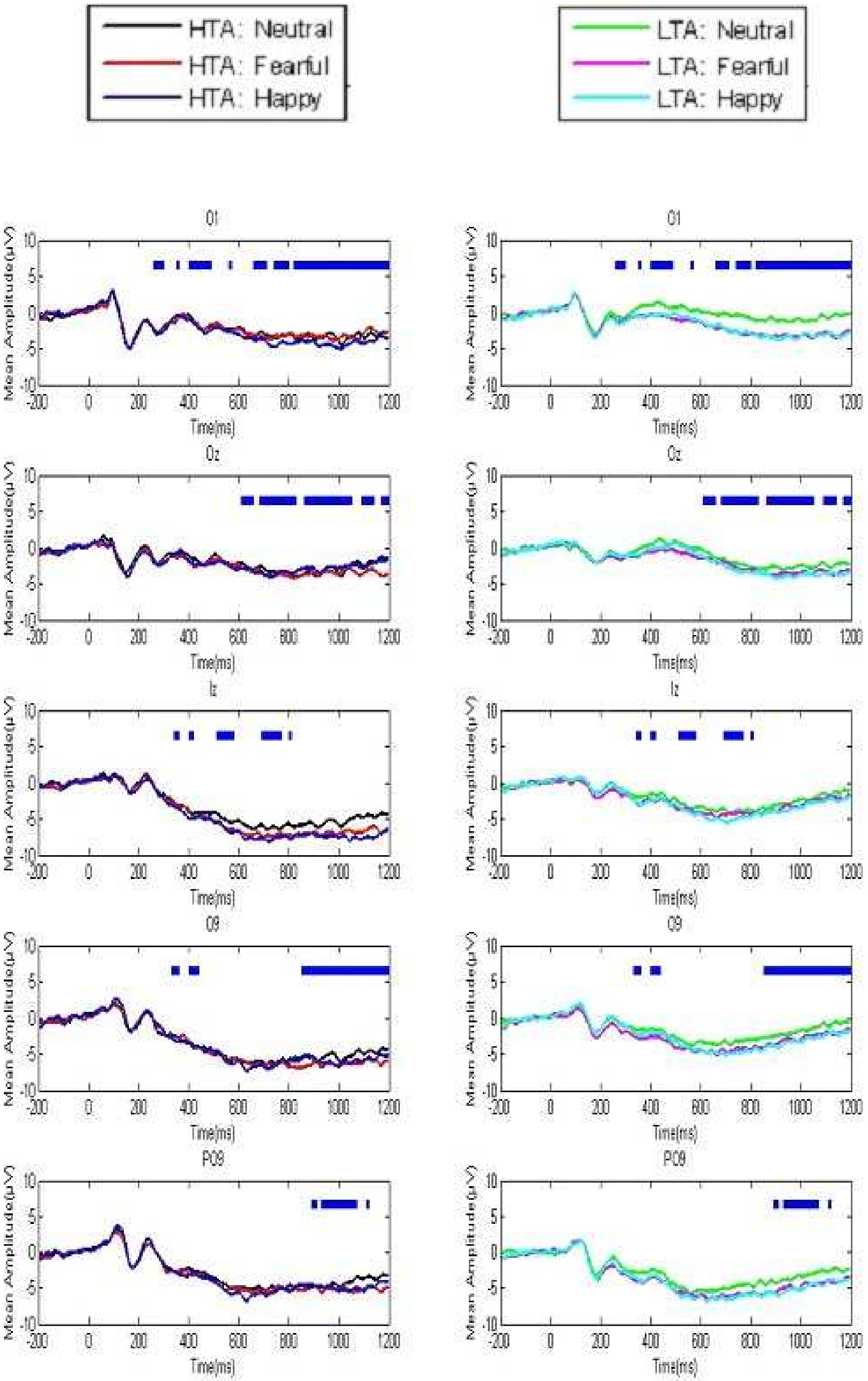


Figure 2-19. ERP waveforms for faces unattended condition for HTA (left column) and LTA (right column) groups. The stable differences by bootstrap are indicated for each electrode as in Figure 2-14 (blue = LV3).

2.3.2.7.2 Vertically Presented Faces

An analysis including all 4 conditions (2 conditions x 2 groups) was run. PLS identified one latent variable, which was significant by permutation test, $p \leq 0.0001$, 100 permutations, see Figure 2-20. The design saliences showed the effect reflected the distinction between attended and unattended faces, which was the same across anxiety groups, see Figure 2-20.

Electrode saliences indicate where the differences are being expressed, shown in Figure 2-21. The stable differences, as assessed by bootstrap tests (100 samples), are shown by the blue markers at the top of each channel plot. Close inspection of the saliences revealed that the attention effect was primarily posterior with a reversal in polarity at central sites (cf. C1/C2). The effect is largest where the saliences are maximal, and this occurred over the occipital region (O1/O2, Oz, O9/O10, and Iz). The effect emerged around 400 ms and persisted until around 700 ms.

ERPs displayed in Figure 2-22, show effects for the channels showing the largest differences. Blue markers at the top indicate the time points of stable differences for the attention effect. The ERP waveforms showed enhanced positivites for attended relative to unattended faces for both HTA and LTA groups across the 400 – 700 ms time window, reflecting an enhanced late positivity when faces were attended.

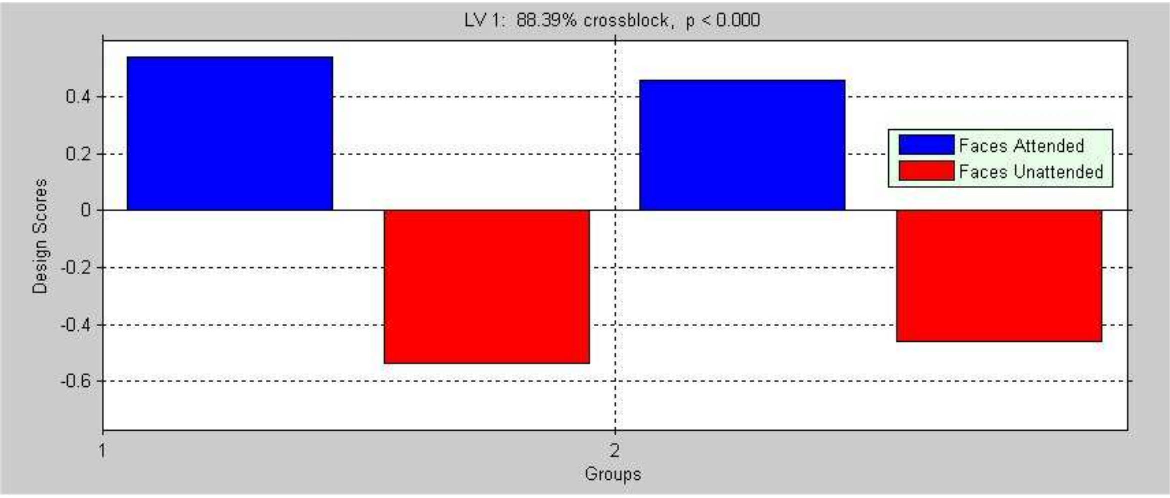


Figure 2-20. LV1 for the faces vertical condition PLS analysis. Group 1 refers to the HTA group and group 2 refers to the LTA group.

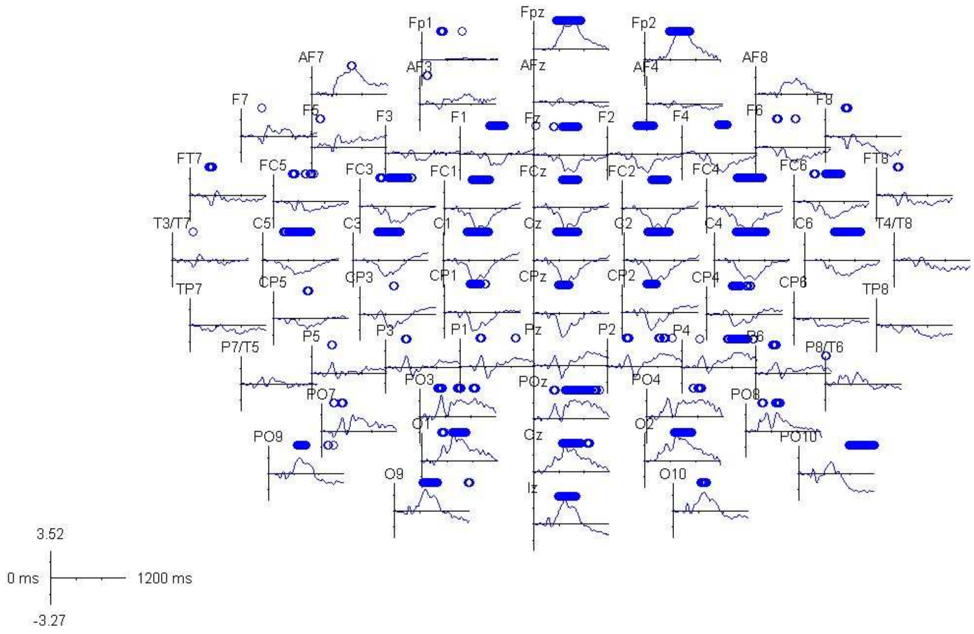


Figure 2-21. Electrode salience for the faces vertical condition, LV1.

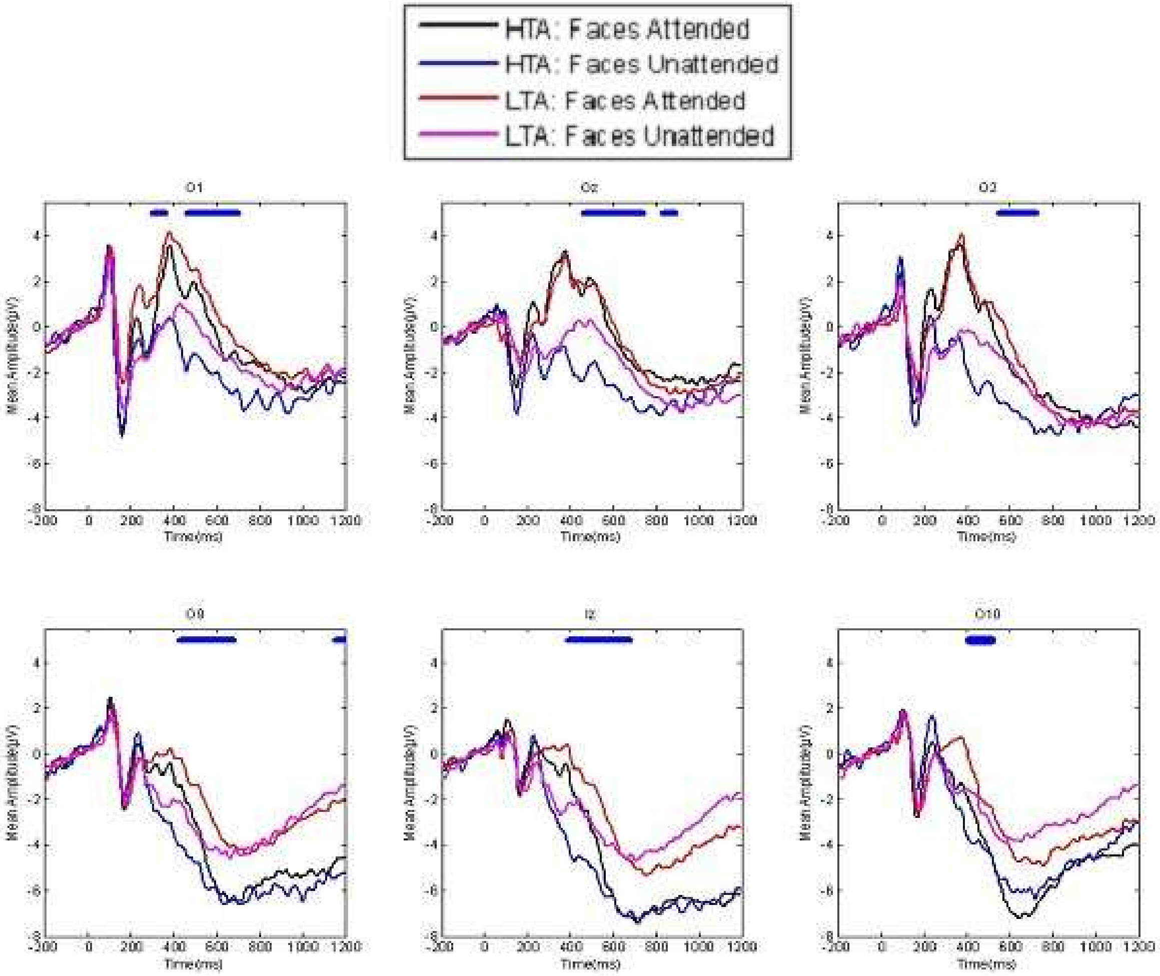


Figure 2-22. ERP waveforms for faces attended versus unattended conditions, displayed separately for HTA and LTA groups at electrodes O1/O2, Oz, O9/O10 and Iz. The stable differences are indicated for each electrode as in Figure 2-21 (blue = LV1).

2.4 Discussion

The primary aim of this study was to investigate the mechanism underlying the threat-related processing bias documented in the anxiety literature. To answer the question of automaticity, one sought to elucidate whether facilitated processing of threat evidenced by emotion-related ERP modulations would occur rapidly and preattentively. It was hypothesized that stimuli that were automatically evaluated according to their emotional significance would not be subject to attentional constraints. In line with a number of studies, the evidence suggests that emotional processing occurs after facial configuration processes, with the earliest discrimination of emotional from neutral facial expressions reflected in the EPN component (~ 200–300 ms post stimulus). Replicating previous results (e.g. Schupp et al., 2007), emotional modulation of the EPN over the right hemisphere was observed in the faces attended task condition but not when attentional resources were directed towards non-face task-relevant stimuli. Homologous emotional expression effects persisted after stimulus presentation in the late LPP time window (~ 500-700ms post stimulus), with enhanced positivities for negative versus neutral facial expressions continuing throughout the recording interval (~ 700-1,000 ms post stimulus). Unlike the earlier EPN response, these later modulations were uninfluenced by the attentional demands of the task. However, the experiment failed to reveal any group differences in electrophysical correlates of emotional facial expression processing that would support the notion of a threat-related processing bias in anxiety. Instead, the data support a general processing bias for information of emotional significance, independent of anxiety level. Collectively, these data likely reflect distributed neural activation involved in a complex affective face processing network.

Consistent with evolutionary theories of cognitive bias (e.g. seeBuss, 2001), our neural systems appear to be specialized for priority processing of emotional information. However, the neurophysiological and neuroimaging data is mixed as to whether automatic processing of emotional information is immune to attentional constraints, with a growing conviction that individual differences in trait anxiety modulate attentional dependency. By definition, automaticity assumes rapid, involuntary processing, but above this it also implies immunity from attentional limitations. To address the issue of automaticity the current study was interested in investigating whether the detection and processing of affective faces can proceed when spatial attention is averted, particularly when anxiety levels are high. ERP responses to affective facial stimuli were compared across conditions where spatial attention was manipulated either towards or away from the affective stimulus. The experiment failed to reveal any emotion-specific modulations of the ERP response throughout the 200 ms post-stimulus interval for either faces attended or unattended conditions, which would contradict the notion of a rapid, automatic processing of emotional information occurring prior to facial configuration and identification processes.

Notably, the study found no evidence of a greater deployment of processing resources to emotional faces (fearful or happy) relative to neutral faces within the P1 time range in either high or low anxiety groups. Several challenging reports have, however, demonstrated that emotion-specific processes can impact ERP components as early as 120–160 ms (e.g. Eimer & Holmes, 2002) and an enhanced P1 for negative and positive faces relative to neutral has been observed (Batty & Taylor, 2003; Eger, Jedynak, Iwaki, & Skrandies, 2003). Anxiety-related effects have similarly been linked with early ERP responses to threatening face stimuli (Bar-Haim et al., 2005; Holmes et al., 2008). This is consistent with increased levels of trait anxiety potentiating attentional vigilance for threat-related material. In accordance with the present study, other studies have also failed to reproduce this P1 effect (see Eimer at al., 2003; Schupp et al.,2004; Holmes et al., 2003), thus the reliability of the early emotional modulations reported in the literature is questionable and may be the product of differences in design rather than due to affective properties of the stimulus. For example, Holmes et al. (2008) presented participants with emotional faces interspersed with neutral faces, blocked according to emotional category. The fearful block would have undoubtedly built up an expectation of threat, which may have reinforced a state of hypervigilance, particularly in individuals with high levels of anxiety, possibly inflating P1 amplitudes.

The onset of emotional expression effects in the current study was observed around 200-300 ms post stimulus as a pronounced ERP difference for the processing of fearful and happy faces relative to neutral faces. This differential ERP, known as the EPN, appeared as a negative-going waveform over the right hemisphere occipito-temporal region and is generally considered the propagation of selective attention mechanisms originating in extrastriate visual areas. Right hemisphere lateralization for emotion specific effects converges with considerable evidence that the right hemisphere may be dominant for the perception of emotion, irrespective of valence (Davidson, 1992). EPN amplitudes for fearful and happy faces relative to neutral faces were enhanced when faces were attended, however, this effect was absent when attention was diverted away from the faces. This result is incompatible with a notion of automaticity, thus demonstrating that the EPN response to affective faces are subject to interference by competing processing demands. Previous studies have similarly found that significant emotional stimuli could only be processed when attention was either directed towards the stimulus and not otherwise occupied with an attentionally demanding competing task (e.g. Eimer et al., 2003), or when attentional load on a competing task was reduced (Okon-Singer, Tzelgov, & Henik, 2007).

However, attentional gating of the ERP response to emotional faces is at odds with the results from neuroimaging studies (i.e. Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003; Vuilleumier, Armony, Driver, & Dolan, 2001). These studies report attention independent amygdala activation in response to threat-related stimuli. While it is futile to suggest that scalp-recorded activations are echoes of an elusive amygdala response, they may very well represent a propagation of activation via a highly specialized and interconnected emotional circuit. Re-entrant pathways between the amygdala and visual cortical areas have been established in monkey brains (Amaral & Price, 1984; Amaral & Price, 1992), which quite possibly control for limbic regulation of sensory cortical areas (Derryberry & Tucker, 1991). For instance, Sabatinelli et al. (2005) reported parallel BOLD (Blood Oxygen Level Dependent) activation in the amygdala and inferotemporal cortex for fear-relevant stimuli. While recent data emphasize obligatory activation of the amygdala for the enhanced perception of emotional stimuli (Anderson & Phelps, 2001), the present findings suggest that attentional gating processes play a crucial role during the perceptual stage of information processing associated with cortical stages of processing, which are likely to be the neural source of the EPN. Other ERP studies have also reported attentional-gating of emotional processing (i.e. Eimer, Holmes, & McGlone, 2003; Holmes, Vuilleumier, & Eimer, 2003), in line with the hypothesis that top-down processes affect emotional processing beyond the amygdala (Pessoa et al., 2002).

However, unlike the early EPN, later stages of stimulus processing were not subject to attentional-gating. Irrespective of whether the participants performed the faces task or the non-affective attention-consuming Landolt squares task, the findings reflect enlarged LPP amplitudes to emotional compared to neutral faces with a centro-parietal topography over the late LPP 500-700 ms time window, and enhancement of the slow wave amplitude to fearful compared to neutral faces from 700 – 1,000 ms. The neural changes indexed by the LPP were proposed to demonstrate modulations of the waveform as a function of the intrinsic emotional properties of the affective stimulus, driving attention towards these motivationally salient stimuli (Cuthbert et al., 1995; Schupp et al., 2000b; Schupp, Ohman et al., 2004). This finding is at odds with the hypothesis that this component reflects motivational engagement that necessitates attentional resources (Lang et al., 1998). However, none of these studies examined the impact of spatial attention on the LPP component. Therefore, the present study extends on previous studies of the LPP response by demonstrating that selective emotional processing as revealed by augmented LPP amplitudes reflects a default selective mechanism, insensitive to concurrent task demands.

Considering the reputed role of the amygdala in regulating cortical stimulus processing under incidences of inattention (see Bishop, Duncan, & Lawrence, 2004), one might speculate that direct projections from this emotion-sensitive structure to visual cortical areas subserve the LPP response to unattended affective faces. The EPN component, in contrast, may reflect top-down influences operating via re-entrant projections to the amygdala during emotional perception originating from attention-related cortical networks (Pessoa et al., 2002). If similar pathways were implicated in the EPN and LPP response to emotional stimuli one would expect similar modulations by attention, however this was not the case. Therefore, the EPN and LPP data suggest the distributed activation of affective processing. In support, differing neural pathways are highly likely given the contrasting topography for these two components and their staggered latency in response. In summary, the findings suggest that the automatic selectivity of affective faces involves neural structures that are at least partially separate from those involved in the regulation of explicit attention.

2.4.1 Anxiety–Related Effects

If we consider the accumulating evidence that highly anxious individuals selectively attend to threatening information (e.g. Macleod, Mathews, & Tata, 1986; Williams, Mathews, & MacLeod, 1996), one would expect there to be a neural basis which modulates such behaviour. However, it was found that the automatic encoding of emotionally significant events as evidenced in the evoked LPP response was evident for both high and low anxiety groups on the faces-unattended trials. From this result one can infer a preattentive processing bias subserves the attentional selective mechanism, but it would not appear that this processing bias is specifically characteristic of heightened anxiety. Thus, this finding is at odds with studies implicating a preattentional bias to threat unique to highly anxious individuals (e.g. Mathews & Macleod, 1985; Mattia, Heimberg, & Hope, 1993).

Group differences in this later window were, however, observed in the PLS analysis; revealing a comparatively larger attention effect for the HTA group. Larger positivites in the faces attended condition relative to the unattended condition occurred for both groups in the time frame of the P300 component (~ 400 – 700 ms), although this effect was significantly greater for highly anxious participants. Comparable morphological characteristics of the observed LPP and P300 components would seem to suggest that they are reflective of similar cognitive processes (Donchin & Coles, 1988). However, their topography and the experimental findings would suggest otherwise; the affective modulation of the LPP was observed at central midline sites, whereas the attention effect highlighted in the PLS analysis was pronounced at more occipital parietal locations. In line with previous studies of the classical P300, amplitudes were larger for attended than unattended stimuli. Going beyond previous studies, increases in P300 amplitude were associated with heightened anxiety, a variation which is generally accepted to relate to increases in the intensity, or level of arousal tied to a specific task (Hansenne, 2000). Thus, these data indicate that arousal-elicited attention was the driving force behind the group differences in the attentional bias. However, arousal was not modulated by the emotional valence of the stimulus, which again is evidence against an attentional bias to threat in anxiety.

A hypervigilant state incurring a threat-related bias may be more pronounced in individuals with clinical levels of anxiety, therefore a student sample may not be sufficient to produce visible anxiety-related effects on the ERP response to emotional faces. However, anxiety-related effects have previously been reported with sub-clinical samples (e.g. Bishop, Duncan, & Lawrence, 2004). The inconsistency in group selection criteria across studies makes cross-comparison difficult and undoubtedly contributes to lack of replication of group effects, which may explain the failure to find any affective ERP modulations by anxiety in the current study. Future research might also consider supplementing self-reported anxiety measures with online monitoring of the galvanic skin response (GSR) as a measure of the relationship between sympathetic activity and emotional arousal during the experiment.

A further possible limitation is that the stimuli used in the present study may not have been arousing enough to induce group-specific effects on the ERP response to affective faces. Notably, happy and fearful faces produced similar effects on the ERP response, which may indicate that sensitivity thresholds were comparable. Indeed, the LPP response is presumably related to the intensity of the emotional stimulation and is generally more pronounced for images of high arousal (Cuthbert et al., 2000; Schupp 2000; 2003b). Angry expressions, in comparison to fearful faces, signify a direct source of threat for the observer and as such may attract attention more readily. Schupp et al. (2004), for instance, reported that angry faces enhanced EPN and LPP amplitudes in comparison to happy and neural faces. Sensitivity of response to direct threat may increase with increasing levels of anxiety and valence-specific effects may only become apparent once emotional arousal surpasses some threshold value unique to the individual.

2.4.2 Attention Effects on the P1 component

Effects of attention were reflected in modulations of P1 amplitudes. Spatial attention oriented towards the vertically-cued square stimuli relative to the horizontally-cued faces inflated P1 amplitude. This effect was not predicted and so one can only speculate about the meaning of this finding. Attentional modulation of P1 has been proposed to reflect competition between attended and ignored stimuli for processing resources (Zhang & Luck, 2008). Therefore, enhanced P1 amplitudes on faces unattended trials is consistent with the hypothesis that salient face stimuli involuntarily draw attentional resources, since under these circumstance they must undergo effortful suppression, thus inflating P1 amplitude. Indeed it has been shown that the affective information contained in facial expression is perceived involuntarily (Eastwood & Smilek, 2005), and is able to constrict the focus of attention. Therefore, it is conceivable that facial stimulus processing occurred preattentively, which created a competition between task-oriented attentional allocation and salient bottom-up influences. Nevertheless, the emotional expression of the face did not interact with the attentional effect on P1 amplitude. This is perhaps surprising given the numerous studies reporting a processing bias for threat-related information. Based on this observation it seems less likely that the effect of attention on P1 amplitude was driven by stimulus saliency. An alternative explanation is that the enhancement of P1 amplitudes on the faces unattended task arises due to the increased attentional demands of the Landolt squares task. Corroborating evidence comes from participants' self-reports of increased difficulty on the squares task, which was confirmed by statistical analysis. Clearly when task difficulty is high 'top-down' influences on attentional resource allocation might constitute an important neural mechanism allowing the visual system to prioritize the processing of task-relevant stimuli overriding 'bottom up' influences. A third possible explanation takes into account that vertically presented faces elicited larger P1 amplitudes over the right hemisphere when attended. Thus, relevant stimuli along the vertical axis may elicit larger P1 amplitudes in comparison to horizontally cued stimuli. This suggests that the observed P1 amplitude modulations by attention reflects the distribution of attention in visual space, consistent with selective mechanisms that prioritise vertically versus horizontally located stimuli.

2.4.3 Face Processing and the N170

In accordance with the Bruce and Young (1986) model, the present study found no reliable modulation of the P1 component or temporally successive N170 amplitude to emotional expression. Thus, the data confer that the intrinsic relevance of affective stimuli affects processes only once initial face configuration and identification is complete.

The influence of emotional expression on the N170 response to faces has been the subject of several investigations. The renowned Bruce and Young face recognition model (Bruce & Young, 1986) differentiates between facial identity and facial expression processes. This model is supported by event-related potential studies linking the structural analysis of faces to the N170 component, while later ERP components (i.e. EPN and LPP) are thought to reflect successive affective processing stages. The current study's failure to find emotional modulations of the N170, while the preceding EPN and LPP components were affected, is fitting with the model. Further support for this finding comes from that of Holmes et al. (2003) who, using a similar paradigm as the present study, also reported null effects of emotion during the N170 window. This result demonstrates that the operation of face identification occurred independently of affective encoding.

Regarding sensory features of the stimulus, the current study employed well-controlled face stimuli in contrast to other studies that have reported emotion effects of the N170. Apparent modulations of the N170 by emotion might therefore stem from low-level variations between stimuli rather than their intrinsic affective properties, which would explain the discrepancy between such studies and the current investigation. In line with previous ERP (Eimer & Holmes, 2002) and depth electrode studies (McCarthy et al., 1999) the present findings imply that the N170 reflects only basic structural encoding of facial information and is insensitive to affective properties of faces.

While the N170 response on the horizontally presented face condition was uninfluenced by attentional focus, a rather surprising finding for the vertically presented face condition was that the N170 component was enhanced when faces were unattended. From visual inspection of the ERP waveforms we can conclude that this effect was not due to attentional modulations of the P1 carrying over to the N170 component. The common conception is that the N170 is a face-specific response reflecting the rapid structural encoding of faces (Eimer, 2000). Holmes et al. (2003), for example, showed that N170 amplitudes were enhanced when faces were attended, however this effect was absent when spatial attention was directed away from the face stimuli. The authors conclude that the N170 response to faces is modulated by spatial attention. However, enhanced N170 amplitude in the faces unattended versus attended condition is at odds with this conclusion. Given the assumption that modulation of the N170 reflects the detection and global processing of facial images, the current findings imply face processing under conditions of inattention (see Carmel & Bentin, 2002; Cauquil, Edmonds, & Taylor, 2000). In fitting with an automaticity account, one might expect unattended versus attended faces to enhance N170 amplitudes since facial configuration is hampered by comparison, thus producing effects akin to the face inversion effect (see Rossion et al., 2000). However, it is questionable whether the observed N170 modulation is meaningful, especially since there was a null effect of attention for the horizontal face condition.

2.4.4 Conclusions

Overall, the results suggest that the attentive processing of emotional faces consists of an initial rapid registration of facial expression (reflected by an enhanced posterior negativity), which is followed by sustained obligatory analysis of the emotional significance of faces (reflected by later centro-parietal emotional expression effects). Attention-dependent and -independent biases for emotional faces appeared to develop over a different time frame, suggesting different underlying mechanisms may be responsible. This study aimed to investigate these biases in anxiety, however the results argue against hypotheses that facilitated affective processing is modulated by anxiety. Moreover, the data support the emotionality hypothesis since neural selectivity was evident for happy as well as threat faces. Future imaging studies are necessary to determine communications between limbic and cortical regions as a function of explicit attention demands, which may provide the neural substrate for the observed effects.

Chapter 3 Investigating the effect of valence on the disengage component of attention in anxious individuals

3.1 Introduction

Attentional capture of threat is generally considered to be a survival adaptation to enable interruption of goal-oriented behaviour, allowing a fast response to imminent threat (Öhman, 1996). The preferential detection of threat is therefore advantageous for all organisms and a purported marker of our evolutionary past (Mathews & Mackintosh, 1998; Mogg & Bradley, 1998). However, several cognitive models of anxiety propose that individual variations in threat-detection mechanisms may underlie vulnerability to develop or maintain anxious states (e.g., Eysenck, 1997; Mogg & Bradley, 1998).

Studies of attentional allocation in affective processing implicate biases in processing threat-related information, particularly in high anxious individuals. Attentional capture of threat-related material is most notably reported in behavioural studies using classic attention selective tasks where competing threat and neutral stimuli are presented simultaneously. For example, Bradley et al. (1998), using a modified version of the dot-probe task, presented an emotional face (threatening or happy) alongside a neutral face of the same person. After the offset of the face pair, a dot probe replaced one of the faces and participants were required to respond to the probe. Faster responses to threat-related than neutral stimuli on this task for high anxious in comparison to low anxious participants has been interpreted as reflecting an anxiety-related attentional orienting bias towards threat. Accumulating evidence concurs that there is a general tendency to orient towards a source of threat and that anxiety is indeed associated with a disproportionate attentional selection bias (e.g. Mathews, Ridgeway, & Williamson, 1996; Mogg, Bradley, & Williams, 1995; Mogg, Bradley, Williams, & Mathews, 1993). Therefore, probe detection task studies lend support for the hypothesis that anxiety-related disorders are characterised by increased vigilance for threat (e.g. Williams, Watts, MacLeod, & Mathews, 1997).

Complicating the issue, however, are studies indicating that threat-related stimuli may affect attentional dwell time rather than automatically attracting attention (Pratto & John, 1991; White, 1996), consistent with the ‘delayed disengagement’ hypothesis. A similar doubt was raised concerning the reliability of the dot-probe studies (Fox, Russo, Bowles, & Dutton, 2001). It was argued that the pattern of RT data in the dot-probe tasks might reflect both attentional capture and attentional confinement by threat. Following this criticism, a second wave of studies employed a variation of the exogenous cueing paradigm (Posner, 1980) designed to be a more accurate measure of attentional bias. In contrast to the dot-probe paradigm, the exogenous cueing task presents only one stimulus at a time. Conceivable shifts of attention between emotional and neutral stimuli suggested to be a confounding factor in the dot-probe studies (see Fox, Russo, Bowles, & Dutton, 2001) are consequently eliminated. On a given trial, a single cue (typically an affective face stimulus; emotional or neutral) is presented to either the left or right of the monitor. Valid cue trials describe the situation where the probe replaces the location of the preceding cue. When the probe appears at the opposite location these are termed invalid cue trials. Using this task, Fox and colleagues (2001) reported relatively longer response times in the high state-anxious group for invalid threat as opposed to invalid neutral cued trials as evidence of delayed disengagement from threat in anxiety. By comparison, anxiety-enhanced attentional orienting was not found; responses on valid cued trials were similar for threat and neutral conditions. Such anxiety-related bias exclusive to the disengage component of attention has been replicated in a number of studies (Fox, Russo, & Dutton, 2002; Tipples & Sharma, 2000; Yiend & Mathews, 2001).

Although evidence of delayed disengagement of threat-related stimuli has been reported in studies using the spatial cueing paradigm (e.g. Amir, Elias, Klumpp, & Przeworski, 2003; Fox, Russo, Bowles, & Dutton, 2001; Yiend & Mathews, 2001), it has been argued that differences in RT between threat cue and neutral cue trials in these studies may be confounded by threat-related response slowing (Mogg, Holmes, Garner, & Bradley, 2008). The so-called ‘freeze’ response is a well-documented survival mechanism in mammals. It is an automatic and involuntary response of the autonomic nervous system that occurs when faced with highly threatening environmental stimuli. Motor inhibition in the face of threat was suggested by Fox et al. (2001) as a possible explanation for the delayed response times following threat versus neutral invalid cues. Mogg et al. (2008) readdressed this issue by adjusting for the RT slowing effect of emotional cues (using data provided from a central cueing task[1]) and found that the corrected RT data analysis provided evidence of an anxiety-related bias in the shifting component but not the disengage component of attention. Notably, the uncorrected data analysis reflected the earlier findings from the spatial cueing studies of an attentional bias located to the disengage component of attention (e.g., Fox, Russo, Bowles, & Dutton, 2001).

The aforementioned limitations of the dot-probe and spatial cueing studies make it difficult to interpret the locus of the attentional bias in anxiety as it is beyond the experimental methodology to differentiate between threat-related attentional cueing and response slowing effects (Mogg, Holmes, Garner, & Bradley, 2008). Therefore, as suggested by Mogg and colleagues (2008), the present study investigated threat-related biases solely in the disengage component. To provide a more detailed account of the attentional bias to threat, a covert measure of attentive processing was accomplished by recording EEG activity as participants performed a variation of the spatial cueing task.

The successful application of the ERP technique in the investigation of the early neuronal response to threat has revealed the N2pc component to be a useful index of selective attention (i.e., Eimer & Kiss, 2007; Fox, Derakshan, & Shoker, 2008; Holmes, Bradley, Kragh Nielsen, & Mogg, 2009). The N2pc component is typically elicited between 200 and 350 ms after stimulus onset, at posterior electrode sites contralateral to the side of a visual target. The temporal dynamics of the allocation of visual attention is represented by the emergence of the N2pc component. Recently, Eimer and Kiss (2007) demonstrated that task-irrelevant fearful faces elicited an early N2pc response (170 – 220 ms), suggesting that threat-related stimuli can rapidly bias attentional selection

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[1] An RT difference score was calculated for each participant by subtracting the mean RT on neutral cue trials from the mean RT on threat cue trials. The RT data from threat trials in the spatial cueing task were adjusted by subtracting this difference value from the corresponding mean RT in each cue condition for each participant.

processes in favour of salient stimuli. Furthermore Holmes et al. (2009), using the N2pc as an index of attentional selection, found evidence for attentional capture of both positive and threatening faces. However, attentional orienting occurred earlier for angry than happy faces. As the authors note, these electrophysiological findings confirm that attentional mechanisms indeed prioritize threat-related stimuli.

Attentional biases in anxiety have also been investigated using the N2pc response to threat as a marker of the distribution of attention. Using a spatial-cueing task, in which an emotional face (angry or happy) was presented alongside a neutral expression, Fox and colleagues (2008) demonstrated that angry faces elicited an enhanced N2pc relative to happy faces, but only for the high anxiety group. Their results are consistent with the cognitive models of anxiety that posit an enhanced early shift of attention towards the source of threat (e.g. Mathews & Mackintosh, 1998).

Given the usefulness of the N2pc component as a tool for investigating the mental chronometry of attentional deployment, investigation into the ‘delayed disengagement’ hypothesis was similarly derived in the present study by examining the N2pc modulation by affective material. In the current task, the affective stimulus was presented centrally, simultaneously flanked on either side by a letter/digit stimulus, each of a different colour. The target letter/digit was defined by its colour and participants were required to direct their visuospatial attention away from the central image towards the location of the target in order to make a discrimination judgement. If negative stimuli are able to prolong attentional processing even when they are task irrelevant, the N2pc onset should be delayed relative to the neutral condition. The observance of an N2pc was expected because it was assumed that the task would require the deployment of visual-spatial attention to the letter/digit targets on the side cued by colour. P300 latency has been held to index stimulus evaluation time (Donchin & Coles, 1988), therefore given that the topography and time course of the LPP are similar to that of the P300 it has been suggested that these components reflect the same underlying processes[2], hence LPP latency was assessed as an additional measure of the time course of the allocation of processing resources dedicated to the irrelevant emotional stimulus. Evidence in favour of prolonged processing of threat in anxiety would, in combination with the reportage of a rapid orienting towards threat (Fox, Derakshan, & Shoker, 2008), be consistent with Beck's (1976) schema model and Bower's (1981) network model, which propose that a general cognitive bias exists throughout the cognitive system for anxious individuals.

A further ERP deflection, which often immediately follows the N2pc, is the sustained posterior contralateral negativity (SPCN) originating around 300 ms post-stimulus. Generally observed in explicit memory tasks and tasks that presumably rely upon the process of retaining visual information for immediate goals, the SPCN is thought to indicate neural activity specifically associated with the encoding and maintenance of visual information in short-term memory (STM). Jolicoeur et al. (2008) provided further evidence that the amplitude of the SPCN increased as memory load increased but in particular, they showed a clear dissociation between the functionality of the N2pc and SPCN. This is because the number of items to be retained greatly influenced the amplitude and latency of the SPCN, whereas the N2pc was unaffected by memory load. In the present study, it was of interest to examine the role of the N2pc and SPCN components in emotion-related information processing. If there exits a stimulus driven bias in the maintenance of a visual representation of threat in STM, then it would be predicted that task-irrelevant yet salient stimuli would enhance SPCN amplitude relative to neutral visual stimuli.

Another aim of this study was to examine the lateralised readiness potential (LRP) on emotional and neutral trials in order to assess whether potential response slowing on threat-related trials is indeed due to prolonged attentional engagement or rather inhibition of motor response. In chronopsychophysiology, the properties of stimulus-locked lateralised readiness potential (S-LRP) and

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[2] N.B. The LPP is sometimes referred to as a P3b (e.g., Schupp, Flaisch, Stockburger, & Junghofer, 2006).

response-locked lateralised readiness potential (LRP-R) latencies were applied to determine whether emotional processing influences processes before the onset of hand-specific lateralization (S-LRP), after it (LRP-R), or both. If there are anxiety-related differences in speed of stimulus analysis, this should become evident in the S-LRP, which represents the time required from the onset of visual presentation until initiation of central motor activation. It was hypothesised that manipulations of central distracter valence would influence the S-LRP interval, such that negative stimuli would result in a longer S-LRP interval compared to neutral stimuli; evidence in favour of prolonged attentional engagement. Comparing LRP-R recordings of high and low anxious individuals represents a feasible test for the validity that the latency of central response organization should be longer in high anxious than low anxious individuals following threat-related response-freezing. The experimental design also allows the opportunity to assess an alternative theory for the maintenance of anxiety; a vigilance-avoidance account (see, Amir, Foa, & Coles, 1998) would predict decreased S-LRP latency for high anxious than low anxious individuals under threat.

Other ERP components associated with affective and attentive processing were also evaluated to provide a more full account of affective processing. Rapid spatial orienting towards fearful faces has reportedly been reflected in enhanced P1 amplitudes (Pourtois, Grandjean, Sander, & Vuilleumier, 2004), with similar modulatory reports for threat-related affective pictures (IAPS) (Li, Li, & Luo, 2005). Thus, it was of interest whether irrelevant threatening pictures would selectively increase perceptual processes, and if trait anxiety would further influence this early stage of visual processing. The proceeding N170 component was also of interest since there has been some reportage in the literature of N170 amplitudes being modified by facial expressions of emotion, especially for fearful expressions (Batty & Taylor, 2003; Righart & de Gelder, 2006; Williams, Palmer, Liddell, Song, & Gordon, 2006), while others have found no such effects (Eimer & Holmes, 2002; Holmes, Vuilleumier, & Eimer, 2003). The apparent discord regarding affective modulation of the face-sensitive N170 was further investigated.

Numerous studies have examined ERP responses to affective facial stimuli (e.g. CAFE database, Dailey, Cottrell, & Reilly, 2001; Ekman database, Ekman &

Friesen, 1976) and complex images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) to study both emotion and emotion regulation (Foti & Hajcak, 2008; Hajcak, Moser, Nieuwenhuis, & Simons, 2006; Hajcak & Nieuwenhuis, 2006; Hajcak & Olvet, 2008a; Sabatinelli, Lang, Keil, & Bradley, 2007; Schupp et al., 2000a; Schupp, Cuthbert et al., 2004; Schupp, Junghofer, Weike, & Hamm, 2003a, 2004). Particularly relevant to the current study, both positive and negatively valenced stimuli are associated with increases in two particular ERP components: the early posterior negativity (EPN) and the late positive potential (LPP). Modulation of these ERP components are thought to reflect the facilitated processing of, and increased attention to, motivationally salient stimuli at perceptual (EPN) and post-perceptual (LPP) stages of processing. The results should provide an indication of the time course of attentional resource allocation towards task-irrelevant emotional stimuli. Based on previous work on the attentional bias to threat, it was predicted that the EPN would be enhanced for negative compared to neutral images. Emotion-related LPP modulations might reflect the continued increase in attention towards emotionally salient stimuli.

Emotional faces are the typical choice of stimulus given that they have a high biological significance. A popular alternative are IAPS pictures (Lang, Bradley, & Cuthbert, 2008); a standardized set of hundreds of colour photographs that are designed to evoke a range of emotional responses. Their content ranges from unpleasant (e.g., threat scenes, mutilation), to neutral (e.g., household objects) to pleasant (e.g., erotica, sports scenes) and they are strictly controlled for both valence and arousal ratings. In the present study two conditions were implemented; one with face stimuli and another with IAPS, all else held constant. Fearful, happy, and neutral faces were selected to examine whether threat-related faces were more engaging than positively valenced faces. Highly arousing negative and positive IAPS pictures were selected, along with neutral IAPS pictures, which consequently have a low arousal level. If biologically and socially significant stimuli were important for evoking the threat-related bias then it would be expected that the face stimuli would produce stronger emotional effects than the IAPS. Otherwise, face stimuli and IAPS would not be expected to differ concerning their ability to maintain attentional engagement.

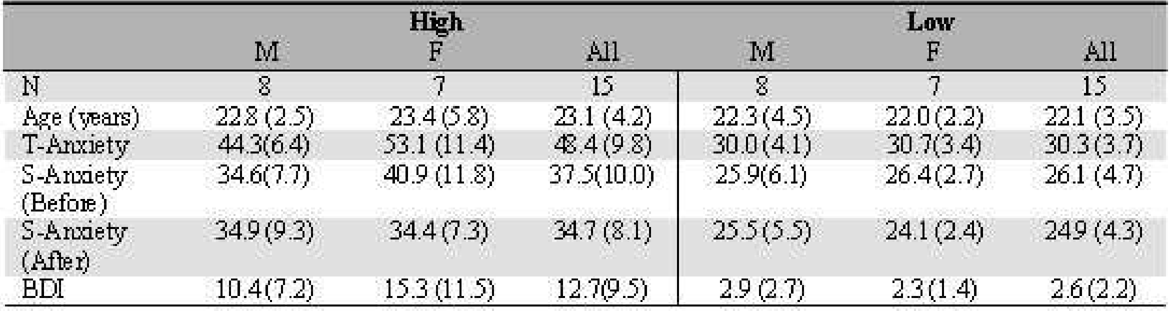
3.2 Methods

3.2.1 Participants

Thirty University of Glasgow undergraduate students with normal or corrected-to-normal vision participated in the experiment. The study was approved by the Glasgow University Research Ethics Committee and performed in appliance with their guidelines. Individuals with a history of inpatient psychiatric care, neurological disease, or head injury were excluded, as were individuals on medication for anxiety or depression. Participants were categorized into high and low anxiety groups based on sample norms of the trait version of the State-Trait Anxiety Inventory (STAI; Spielberger, 1983; 50th percentile=35.5, low N=15, high N=15), see Table 3-1. Fifteen participants (8 males and 7 females; mean age, 23 years) were grouped as high-anxious (48.4 average on the trait-anxiety scale of the STAI and 12.7 on Beck Depression Inventory (BDI; Beck, Steer, & Brown, 1996). Fifteen participants (8 males and 7 females; mean age, 22 years) were grouped as low-anxious (30.3 average on the trait-anxiety scale of the STAI and 2.6 on the BDI). A *t*-test showed that the two groups were significantly different in trait-anxiety score ($t(28) = 6.65$, $p < .05$).

Participants completed the state version of the STAI before the ERP session and both the state and trait subscales were completed immediately following the experiment. Participants' state anxiety scores before the ERP session ranged from 20 to 56 (M = 31.8; SD=9.6) and immediately following the ERP session their scores ranged from 20 to 53 (M =29.8; SD=8.1). A paired *t-test* showed that state anxiety scores were not significantly different before and after the experimental session ($t(29)=0.86$, $p >0.05$), suggesting that state-anxiety score is a stable measure of anxiety across the testing period. Participant's trait anxiety scores ranged from 22 to 72 (M =39.4; SD=11.7). These scores are similar to the published norms for college students (M(state) = 37.61, SD = 10.98; M(trait) = 39.35, SD = 9.66) (Spielberger, 1983).

Table 3-1. Means and standard deviations (in brackets) for scores on the Trait and State versions (before and after the experiment) of the STAI and BDI. Statistics are provided for high and low anxiety groups and separately for males and females within each group.



	High			Low		
	M	F	All	M	F	All
N	8	7	15	8	7	15
Age (years)	22.8 (2.5)	23.4 (5.8)	23.1 (4.2)	22.3 (4.5)	22.0 (2.2)	22.1 (3.5)
T-Anxiety	44.3(6.4)	53.1 (11.4)	48.4 (9.8)	30.0 (4.1)	30.7(3.4)	30.3 (3.7)
S-Anxiety (Before)	34.6(7.7)	40.9 (11.8)	37.5(10.0)	25.9(6.1)	26.4(2.7)	26.1 (4.7)
S-Anxiety (After)	34.9 (9.3)	34.4 (7.3)	34.7 (8.1)	25.5 (5.5)	24.1 (2.4)	249 (4.3)
BDI	10.4(7.2)	15.3 (11.5)	12.7(9.5)	2.9 (2.7)	2.3 (1.4)	2.6 (2.2)

3.2.2 Stimuli

The face stimuli were selected from the California Facial Expressions (CAFE) database (Dailey, Cottrell, & Reilly, 2001), comprising 5 male and 5 female greyscale faces with fearful, happy and neutral expressions (making a total of 30 stimuli normalised for the location of eyes and the mouth). All 30 stimuli used met the Facial Action Coding System (FACS; Ekman & Friesen, 1976) criteria. The face stimuli covered a visual angle of about 2.9×4.3 °. Pictures of emotionally neutral, positive, and negative (threat-related) scenes were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). A total of 30 colour pictures were selected, 10 allocated to each emotional category[3]. The IAPS were selected to exclude pictures with front-view faces to avoid a possible confound with emotional facial expression. IAPS with people present were carefully selected to include only side-view faces or pictures where fine details of the face were not easily discernable. Normative rating data on affective valence is available for each picture in the IAPS database (Lang, Bradley, & Cuthbert, 2008). On a 9-point scale ranging from unpleasant (1) to pleasant (9), mean valence for the neutral pictures was 5.08, 2.60 for the negative pictures, and 7.39 for the positive pictures. A one-way ANOVA for the three categories yielded a significant effect, $F(2, 27) = 129.23$, p

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[3] According to their IAPS number, the neutral pictures were: 7550 (side view of man working at a computer), 2880 (black shadow Figure), 7090 (book), 7009 (cup), 7050 (hairdryer), 7233 (plate), 7595 (cars), 7004 (spoon), 7496 (street scene), 7150 (umbrella); the negative pictures were: 6550 (aimed knife), 1930 (shark), 1302 (aggressive dog), 6510 (knife attack), 3000 (mutilation), 3071 (mutilation), 9405 (mutilation), 9433 (mutilation), 6821(armed attack on car); and the positive pictures were: 1440 (seal), 5831 (beach), 1610 (bunny), 1602 (butterfly), 8502 (money), 5628 (mountain), 5450 (NASA), 7230 (roast dinner), 5621 (skydive), 8420 (water slide).

< .0001. Bonferroni-corrected multiple post-hoc comparisons showed differences in valence between all emotional categories (all *p*s < .0001). The IAPS pictures covered a visual angle of about 4.7×3.3°.

The target/non-target stimuli consisted of uppercase letters F, G, P, and R and numbers 2, 3, 4, and 5, which could appear normally or as a mirror image in either green (RGB: 64, 128, 102) or blue (RGB: 75, 132, 171). The luminance was measured using a Minolta digital photometer and green and blue stimuli were matched on this measure (Green: 6.60 cd/m^2; Blue: 7.58 cd/m^2). The letter/number stimuli covered a visual angle of about 1.8×2.2°. All stimuli were presented upon a black background.

3.2.3 Procedure

Participants were seated in a dimly lit sound-attenuated cabin, and a computer screen was placed at a viewing distance of 80 cm. The experiment consisted of two successive experimental sections; one for the face stimuli and the other for the IAPS pictures. The order of presentation was balanced across participants so that half completed the face experimental blocks followed by the IAPS blocks, and vice versa. Each section was comprised of a practice session, which familiarised the participant with the two alternate response-mappings, followed by 12 experimental blocks, each containing 48 trials. Each trial commenced with the presentation of a central fixation cross, which was quickly replaced by a central distracter image (either a face or IAPS picture) flanked to the left and right by a letter/number pair, simultaneously presented in front of a black background, see Figure 3-1. The eccentricity of these stimuli, measured as the distance between the centre of each letter/number stimulus and the centre of the distracter image, was 5.4º. Each trial began with a 500-ms presentation of the fixation cross followed immediately by the visual stimulus for 300 ms. The interval between the response and the beginning of the next trial was 800 ms.

Figure 3-1. Example stimulus for the faces condition.

Participants were instructed to focus their eye gaze initially on the location of the fixation cross and to shift their attentional focus to the target following stimulus presentation. The target was defined by colour (green or blue) and varied across participants; half responding to green targets and the other half responding to blue targets. The participants' task was to decide whether the target stimulus was displayed in normal orientation or as a mirror image by making a left or right hand key press response. The S-R assignment alternated from block to block, and this order was balanced across participants. The emotional valence of the central distracter image varied randomly across trials. One third of the face distracters were happy, fearful, and neutral, respectively. Similarly, for the IAPS, one third of the images presented were positive, negative, and neutral, respectively. The factorial design of the experiment ensured that in half of the trials target stimuli appeared in the right visual field (RVF) and the other half in the left visual field (LVF). For each of the target locations, half the stimuli required a *right-hand* response for normally presented letter/number stimuli and half a *left-hand* response for normally presented letter/number stimuli. Within each block of trials, the valence of the distracter images varied randomly and with equal probability so that a 3 (valence) × 2 (target location) × 2 (response) factorial design ensued.

3.2.4 Electrophysiological Recording

Electroencephalographic (EEG) activity was continuously recorded from 70 Ag/AgCl electrodes over midline electrodes Fpz, AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz, and Iz, over the left hemisphere from electrodes IO1, Fp1, AF3, AF7, F1, F3,

F5, F7, F9, FC1, FC3, FC5, FT7, C1, C3, C5, M1, T7, CP1, CP3, CP5, TP7, P1, P3, P5, P7, P9, PO3, PO7, O1, and from the homologue electrodes over the right hemisphere using a BIOSEMI Active-Two amplifier system. Two nonstandard electrodes (PO9 and P10) were positioned at 33 % and 66 % of the M1-Iz distance (M2-Iz for the right hemisphere). EEG and EOG recordings were sampled at 256 Hz. Vertical electroocular (vEOG) and horizontal EOG (hEOG) waveforms were calculated offline as follows: vEOG(t) = Fp1(t) - IO1(t) and hEOG(t) = F9(t) - F10(t). Trials containing blinks were corrected using the adaptive artifact correction method of Brain Electromagnetic Source Analysis (BESA) software (Ille, Berg, & Scherg, 2002) and EEG activity was re-referenced off-line to an average reference. EEG and EOG activity was filtered (band-pass 0.01-40 Hz, 6 db/oct), averaged time-locked to stimulus onset (S-locked data) or to response onset (R-locked data). In addition, an automatic artifact detection software (BESA) was run and trials with non-ocular artifacts (e.g. drifts, channel blockings, EEG activity exceeding ± 75 μV) were discarded. The analysis epoch of a total duration of 1400 ms started 200 ms prior to the onset of the stimulus.

3.2.5 Data Analysis

Statistical analyses were performed by means of Huynh-Feldt corrected repeated measures analyses of variance (ANOVA). Separate analyses were performed for the faces and IAPS conditions. The ANOVA for the reaction time data included group (HTA, LTA) as the between-subjects factor and the within-subjects factors: valence (positive, neutral, negative), target location (RVF, LVF) and orientation (normal, mirrored). To ensure a reasonable signal-to-noise ratio in the ERP analyses and since valence effects were of primary interest in the present study, the factor orientation was dropped from the ERP analyses[4].

The ERP waveforms were aligned to a 100-ms baseline prior to the onset of the stimulus. Mean amplitude of the ERP waveform was measured in average waveforms within time intervals during which specific ERP deflections were

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[4] An initial omnibus analysis was performed for the EEG data including the factor orientation. No Valence x Orientation interaction effects were significant, which further justified its exclusion from the reported analysis.

found to be most pronounced upon visual inspection. Successive post-stimulus time windows defined the P1 from 85-125 ms; the N170 from 150-200 ms; the EPN from 200-300 ms; the early LPP from 300-400 ms; the late LPP from 400-700 ms. For the P1 component mean voltages were computed across sites O1/O2 and Oz, where the P1 was maximally observed. Mean N170 amplitude was measured at lateral occipitoparietal sites P7/8 and PO7/8 and separate analyses were conducted for the electrode pairs. Early Posterior Negativity (EPN) mean voltage was computed across four posterior electrodes over right hemisphere (RH) sites (P6, P8, PO8, PO10’) and four homologous electrodes over left hemisphere (LH) sites (P5, P7, PO7, PO9’). In the analysis of the early LPP and late LPP, mean amplitude was measured across parietal midline sites CPz, Pz, and POz where activity was found to be maximal, see Figure 3-5 and Figure 3-10 for the topographic maps for the faces and IAPS conditions, respectively. In addition a computerized peak-picking program was used to measure P1 peak latency at O2, and LPP peak latency at Pz (i.e., the time point, from 400-900 ms, when the voltage at Pz was maximally). For the N170 and EPN analyses a group (HTA, LTA) x valence (positive, neutral, negative) x target location (RVF, LVF) x hemisphere (left, right) repeated measures ANOVA was performed. For the P1, early LPP, and late LPP, a similar ANOVA was performed, replacing the factor hemisphere with electrode.

3.2.5.1 N2pc and SPCN

A second set of analyses focused on ERPs triggered in response to lateralised targets elicited at lateral occipital electrodes PO7/PO8. The ipsilateral waveform (average of voltage at the left-sided electrode for a left visual field target and voltage at the right-sided electrode for a right visual field target) and the contralateral waveform (average of voltage at the right-sided electrode for a left visual field target and voltage at the left-sided electrode for a right visual field target) time-locked to the stimulus onset were computed. The N2pc and SPCN were quantified by subtracting the signal recorded from the ipsilateral electrodes (with respect to the visual field of the target stimuli) from that of the contralateral electrode. N2pc onset latency and mean amplitude of the N2pc and SPCN were measured and analysed by applying the Jackknife-based procedure, suggested by Miller, Patterson, and Ulrich (1998) and Ulrich and Miller (2001). This jackknife procedure estimates voltages from grand averages computed for subsamples of participants by successively excluding one participant from the original sample.

N2pc onset latency was measured as the time point at which the voltage value on the ascending flank of the difference waveforms exceeded 40% of the N2pc mean amplitude. For the N2pc onset analyses a group (HTA, LTA) x valence (positive, neutral, negative) repeated measures ANOVA was performed for both the faces and IAPS conditions. N2pc mean amplitudes were computed relative to a 100ms pre-stimulus baseline for the 225-275 ms post-stimulus time window (where the N2pc was maximal), separately for the faces and IAPS conditions and for high and low anxiety groups. Mean amplitudes were also computed for a second longer-latency time interval (425-475 ms post-stimulus) that was included to measure the SPCN. ERP mean amplitudes were analysed with repeated measures ANOVAs, for the factors anxiety group (HTA, LTA) as a between-subjects factor and valence (negative, neutral, positive) as a within-subjects factor.

3.2.5.2 LRP

For each participant and each experimental condition, the ERP at recording sites ipsilateral to the response hand was subtracted from the ERP at homologous contralateral recording sites. For each homologous electrode site-pair (e.g., C3/C4) the resulting difference waveform was averaged across hands to eliminate any ERP activity unrelated to hand-specific motor activation (cf. Coles, 1989). LRP was calculated for electrode pair C3/4. These positions were chosen because of their correspondence to the hand areas of the pre-central motor cortex (cf. Coles, 1989). Difference waveforms were computed time point by time point between recordings at C3 and C4 as a function of the response hand appropriate in a given trial. In every trial, the recording from the ipsilateral hemisphere was subtracted from contralateral recordings. The single-trial difference waveforms were then averaged separately for left – and right-hand trials. Finally, the LRP was computed as the mean of the average difference waves. Deviations towards negativity of the resultant LRP wave indicate the activation of the correct response hand at the level of the motor cortex.

S-LRP onsets were measured relative to a 200-ms pre-stimulus baseline to the point in time where LRP amplitude exceeded a predefined criterion of -0.5 µV in that specific condition (cf. Miller, Patterson, & Ulrich, 1998). The LRP-R interval was determined using the same onset criteria as the S-LRP with waveforms aligned to a 200 ms baseline that started 600 ms before the response. Onsets were measured within a 200 ms wide time-span that preceded response execution. LRP onsets were measured and analysed by applying the Jackknife-based procedure suggested by Miller, Patterson, and Ulrich (1998) and Miller (2001), to increase the signal-to-noise ratio. For the LRP analyses a group (HTA, LTA) x valence (positive, neutral, negative) repeated measures ANOVA was performed.

Since the standard error of the mean differences becomes strongly reduced by the Jackknife procedure, for the analyses of the N2pc, SPCN and LRP the *F*-values were corrected as follows: $F_C = F/(n-1)^2$, where F_C denotes the corrected *F*-value and n the number of participants (cf. Ulrich & Miller, 2001). For all post-hoc comparisons the level of significance was Bonferroni adjusted with the alpha level per measure set at $p = .05$.

3.3 Results

3.3.1 Behavioural Results

3.3.1.1 Faces

3.3.1.1.1 Reaction Times

The main effect of emotion was not significant (fearful: 738 ms; Neutral: 738 ms; happy: 736 ms), F < 1. There were significant main effects of visual field, *F*(1,28) = 14.23, *MSE* = 6022.18, $p < .001$, and orientation, *F*(1,28) = 33.00, *MSE*= 3994.86, $p < .0001$, indicating faster responses to normal as opposed to mirror targets (718 ms vs. 756 ms) and faster responses to targets presented in the LVF than the RVF (722 ms vs. 753 ms). However, the significant Visual Field × Orientation interaction, *F*(1, 28) = 4.94; *MSE* = 1189.32; $p < .05$, indicated a larger orientation effect for targets presented to the LVF than the RVF (LVF: 699 vs. 745 ms; RVF: 738 vs. 768 ms), see Figure 3-2. There was a trend for the high anxiety group to respond slower overall compared to the low anxiety group (766 vs. 708 ms), *F*(1, 28) = 3.23; MSE=92817.91; *p* = 0.08. No other effects were significant (All *F*s < 2.52).

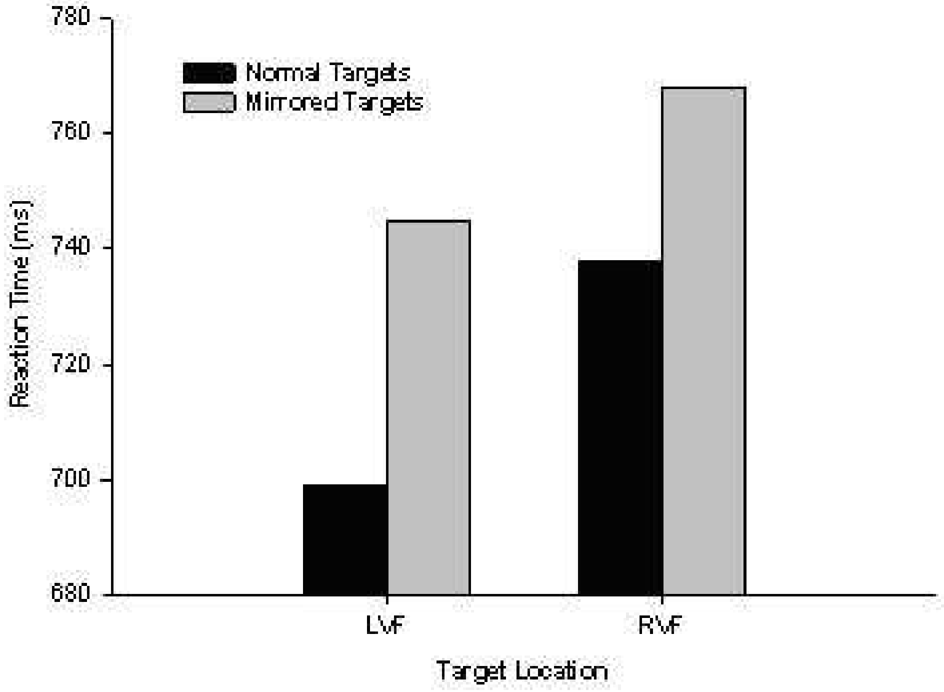

Figure 3-2. Reaction time to targets in the face condition according to their visual field location and stimulus type (normal or mirrored).

3.3.1.1.2 Error Analysis

A higher percentage of errors were made to targets presented in the RVF than the LVF (12.1 vs. 9.9 %), *F*(1,28) = 13.37, *MSE* = 31.94, *p* < .05, and to targets in mirrored than normal orientation (12.5 vs. 9.6 %), *F*(1,28) = 8.34, *MSE* = 90.02, *p* < .05. The main effect of emotion, *F*(2, 56) = 3.20; *MSE*= 16.90, *p* < .05, was further modified by group, *F*(2,56) = 3.46, *MSE* = 16.90, *p* < .05. Simple main effects analysis revealed that emotional valence significantly modulated error rates in the high anxiety group, *F*(2,28) = 4.69, *MSE* = 23.85, *p* < .05, but not for the low anxiety group, *F*(2,28) = 0.07, *MSE* = 9.95, *p* > .05. Bonferroni corrected post-hoc pairwise comparisons revealed that the high anxiety group made significantly more errors on fearful than happy trials (13.2 vs. 10.7 %), *F*(1,14) = 8.05, *MSE* = 186.29, *p* < .025, however the difference in percentage error rate between fearful and neutral trials marginally failed to reveal a significant effect (13.2 vs. 11.0 %), *F*(1,14) = 6.07, *MSE* = 191.31, *p* = .027, see Figure 3-3. No other effects were significant (All *F*s < 4.06).

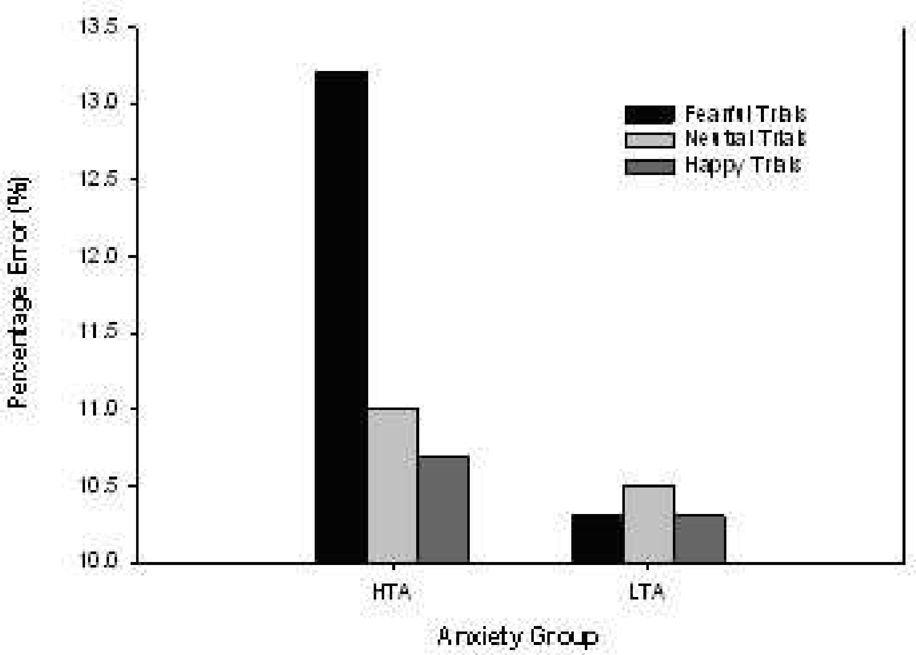

Figure 3-3. Percentage error to targets in the face condition for fearful, neutral, and happy trials, shown separately for high and low anxiety groups.

3.3.1.2 IAPS

3.3.1.2.1 Reaction Times

A main effect of emotion, *F*(2,56) = 3.51, *MSE* = 958.11, *p* < .05, was present. Bonferroni corrected post-hoc contrasts revealed a strong trend for faster responses for IAPS pictures displaying positive rather than negative affect (733 ms vs. 743 ms), *F*(1,28) = 5.14, *MSE* = 9383.95, *p* = .03, however, responses were not significantly different for neutral relative to fearful pictures (735 ms vs. 743 ms), *F*(1,28) = 2.99, *MSE* = 10179.86, *p* > .025, see Figure 3-4. Responses were faster when targets appeared in the LVF relative to the RVF (719 vs. 754 ms), resulting in a main effect of visual field, *F*(1, 28) = 26.47, *MSE* = 4169.00, *p* < .05. Finally, a main effect of target orientation revealed faster responses for targets presented in normal than mirror orientation (714 vs. 759 ms), *F*(1, 28) = 42.73, *MSE* = 4359.14, *p* < .05). No other effects were significant, all *F*s < 3.29, *p* > .05.

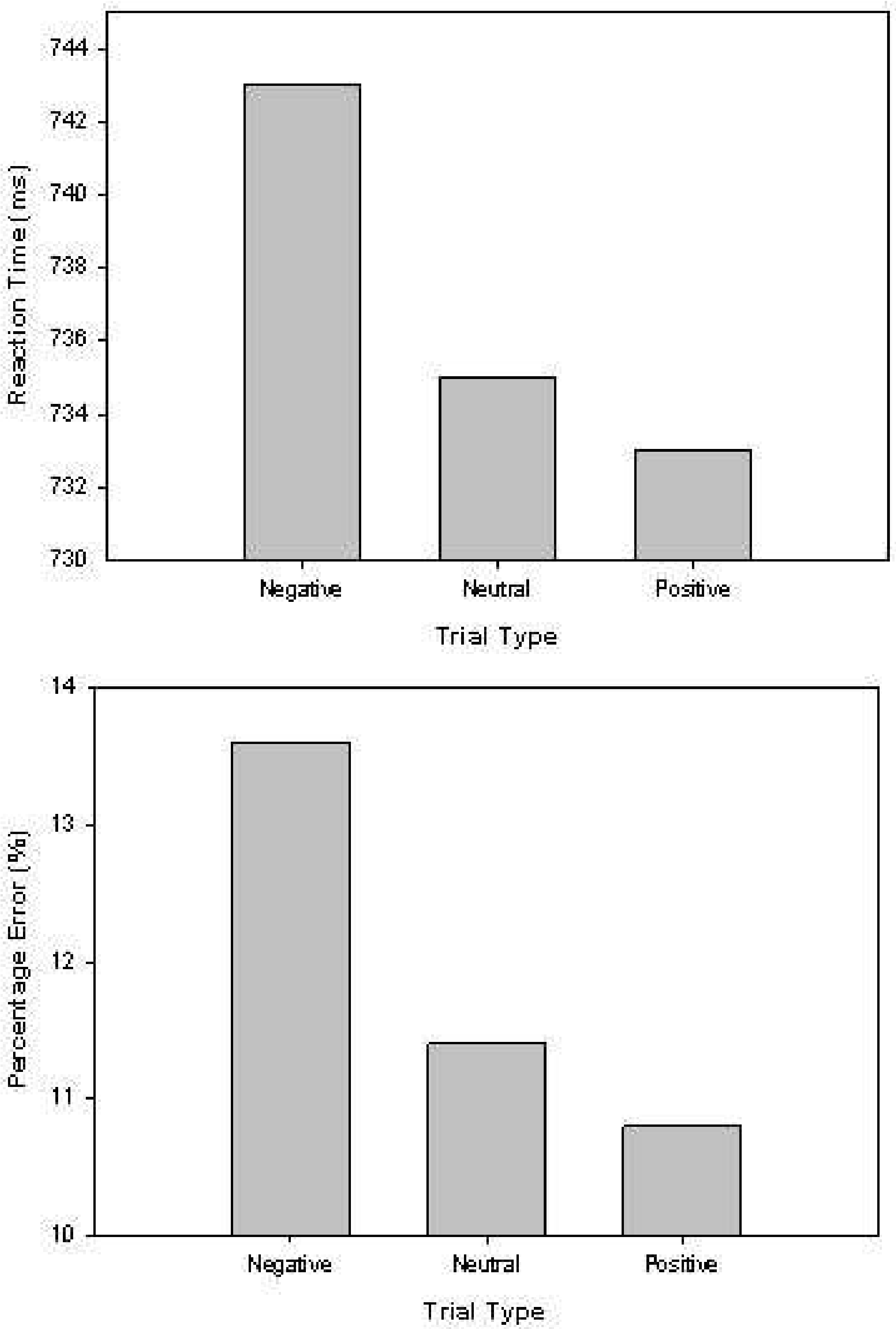

Figure 3-4. Reaction times (top) and percentage error (bottom) to targets in the IAPS condition for negative, neutral, and positive pictures.

3.3.1.2.2 Error Analysis

The main effect of emotional valence was significant, *F*(2,56) = 7.47, *MSE* = 34.46, *P* < .05. Bonferroni corrected post-hoc contrasts revealed significantly higher percentage error rate for the negative condition relative to both positive (13.6 vs. 10.8 %), *F*(1,28) = 9.79, *MSE* = 375.28, *p* < .01, and neutral (13.6 vs. 11.4 %) conditions, *F*(1,28) = 9.87, *MSE* = 239.05, *p* < .01, see Figure 3-4.

Participants made more errors when targets were presented in the RVF than the LVF (13.0 vs. 10.9 %), *F* (1, 28) = 10.02, *MSE* = 38.76, *p* < .05, and when target stimuli were presented in mirror as compared to normal orientation (13.5 vs. 10.3 %), *F*(1, 28) = 20.52, *MSE* = 44.6, *p* < .05. No other effects were significant, all *F*s < 1.58, *p* > .05.

3.3.2 ERP Results

3.3.2.1 Faces

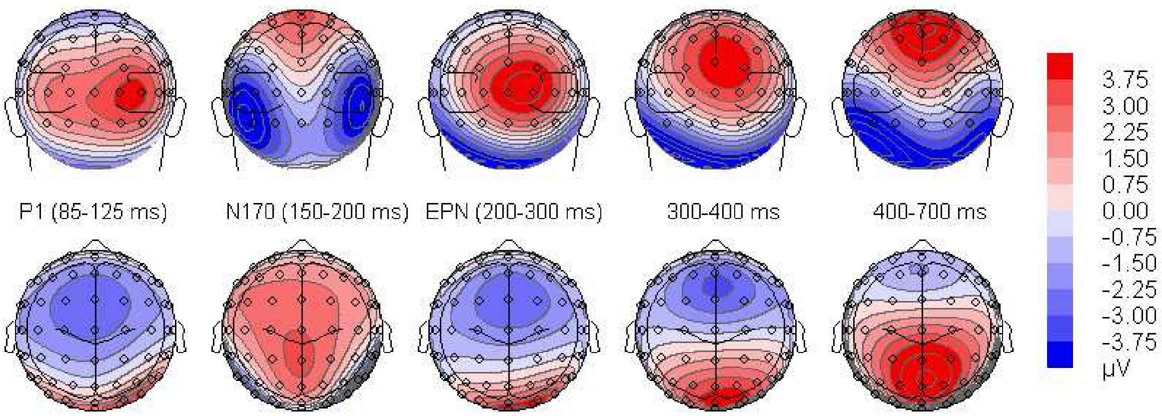

Figure 3-5. Spline-interpolated topographic maps for the faces condition. P1, N170, EPN, early LPP and late LPP time windows are represented, respectively. Isopotential line spacing is 0.75 µV.

3.3.2.1.1 P1 Window (85 - 125 ms)

As can be seen in Figure 3-6, there was a strong trend for mean P1 amplitude on face trials to be larger for the high anxiety group in comparison to the low anxiety group (4.2 vs. 1.6 µV), *F* (1, 28) = 3.84, *MSE* = 244.93, *p* = .06. The main effect of emotion was significant, *F*(2, 56) = 3.21, *MSE* = 0.69, *p* < .05. Follow-up contrasts revealed that P1 amplitude was reduced in the fearful relative to the happy condition (2.76 vs. 2.98 µV), *F*(1, 28) = 4.67, *MSE* = 10.75, *p* < .05, and that there was a trend for reduced P1 amplitudes in the fearful relative to the neutral conditions also (2.76 vs. 2.92 µV), *F*(1, 28) = 3.86, *MSE* = 6.66, *p* = .06, see Figure 3-7. A main effect of electrode revealed enhanced positivity over the right hemisphere, *F*(2, 56) = 3.92, *MSE* = 12.26, *p* < .05; enhanced P1 amplitudes were observed over O2 relative to Oz(3.48 vs. 2.54 µV), *F*(1, 28) = 8.36, *MSE* = 114.01, *p* < .01, however, P1 amplitudes over O1 and Oz were not statistically different (2.64 vs. 2.54 µV), *F*(1, 28) = 3.09, *MSE* = 247.78, *p* > .05. No other effects were significant in the analysis of mean P1 amplitude for face trials, all Fs < 1.93.

3.3.2.1.2 P1 Latency

For P1 latencies at O2, there was a significant effect of target location, with RVF targets having an earlier P1 peak than LVF targets, (117 vs. 118 ms), $F(1,28) = 6.05$, $p < .05$. No other effects were significant, all *F*s < 2.10.

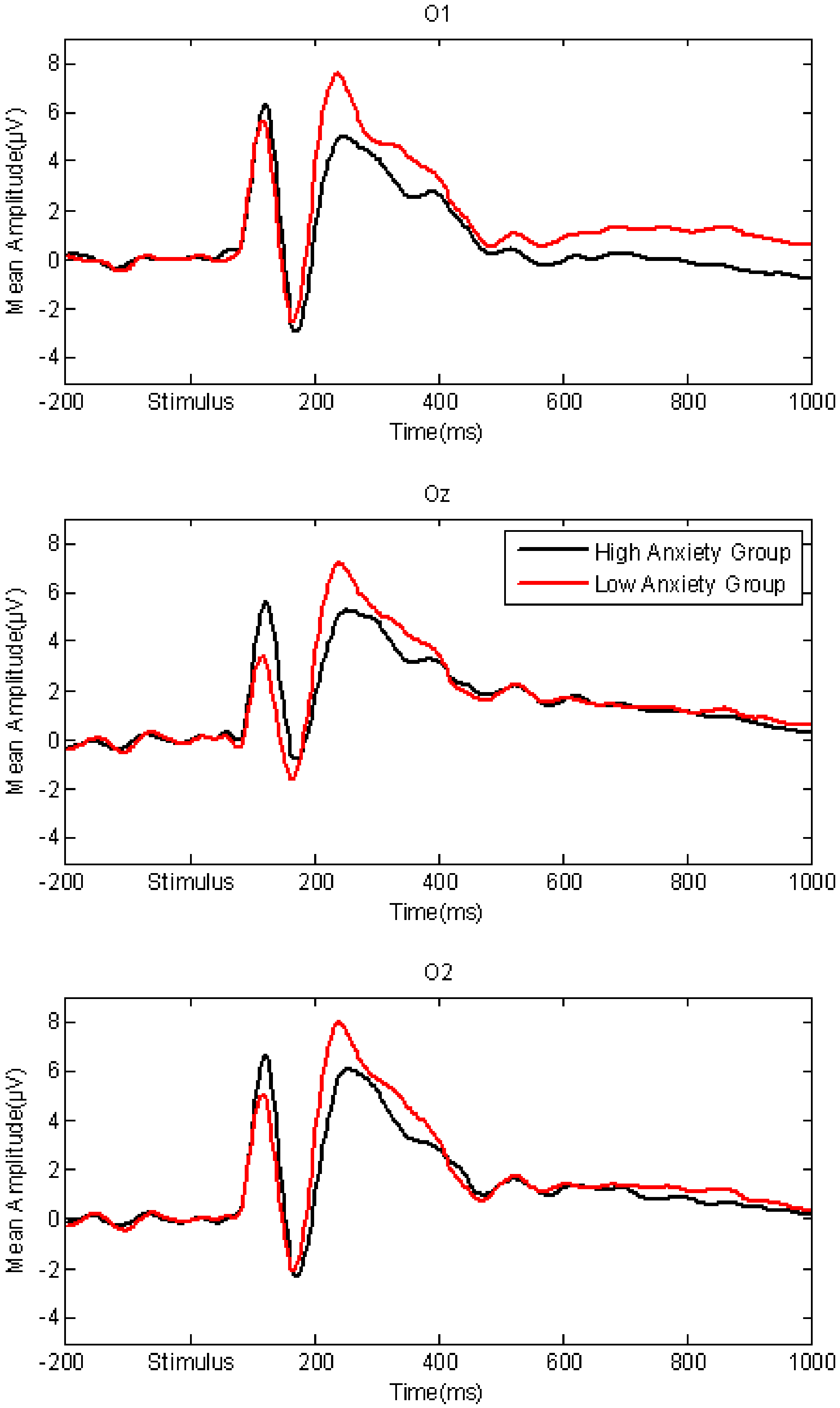

Figure 3-6. Grand-averaged ERP waveforms elicited at lateral posterior electrodes O1/2 and midline electrode Oz for high and low anxiety groups in the face condition, collapsed across emotion (fearful, neutral, happy), target location (LVF, RVF), and orientation (normal or mirrored targets).

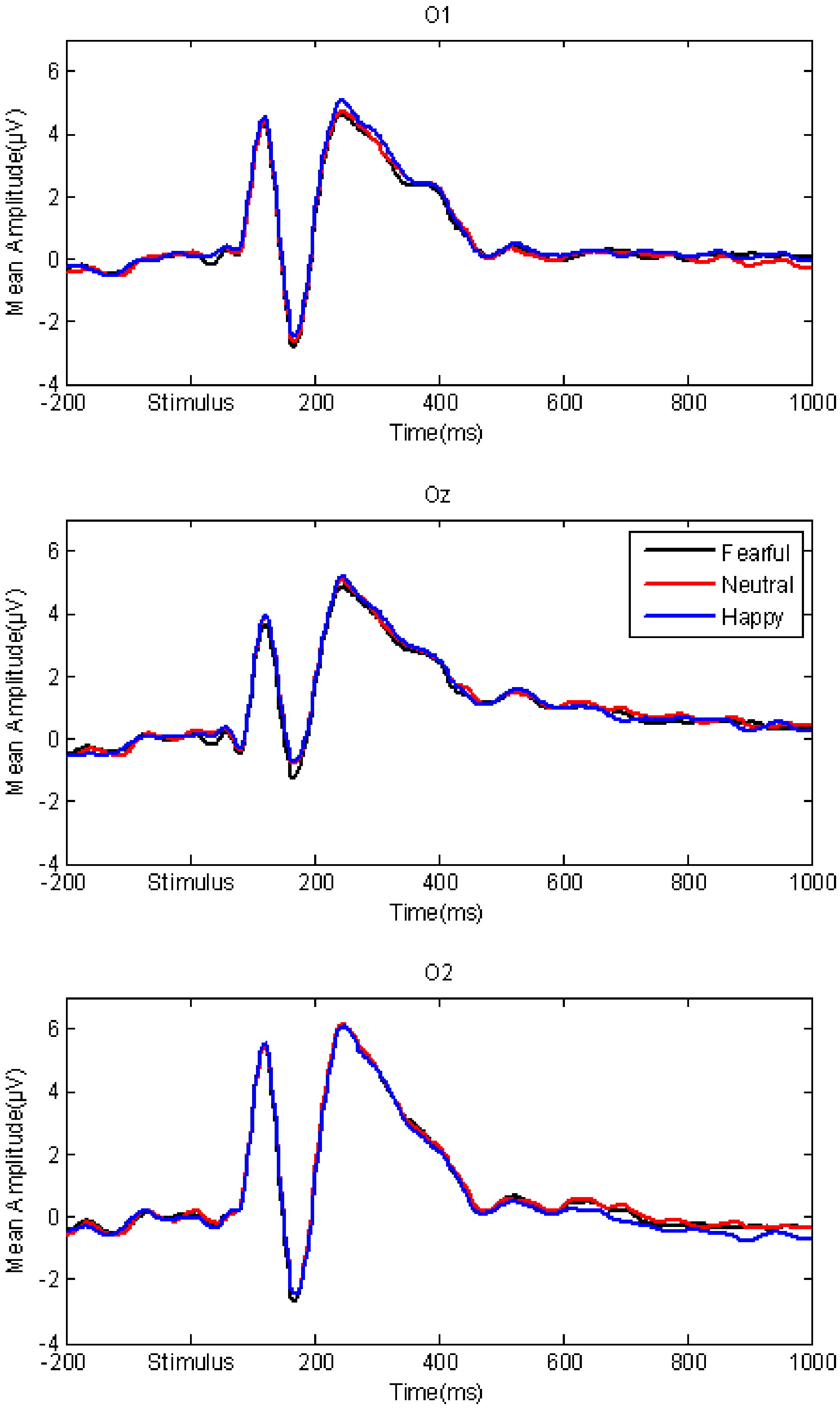

Figure 3-7. Grand-averaged ERP waveforms elicited at lateral posterior electrodes O1/2 and midline electrode Oz for fearful, neutral and happy trials in the face condition, collapsed across emotion (fearful, neutral, happy), target location (LVF, RVF), orientation (normal or mirrored targets), and anxiety group (HTA, LTA).

3.3.2.1.3 N170 Window (150 - 200 ms)

The face-specific N170 component was not modulated by the emotional expression of the face stimuli. No effects were significant at lateral posterior electrodes P7/8 (all *F*s < 3.15, *p*s > .05) or PO7/8 (all *F*s < 1.93, *p*s > .05).

3.3.2.1.4 EPN Window (200 - 300 ms)

The main effect of emotion was significant, *F*(2, 56) = 7.59, *p* < .01. Planned contrasts revealed significantly reduced positivity for fearful faces relative to neutral faces (0.63 vs. 0.90 µV), *F*(1, 28) = 13.616, *p* < .01. However there was no significant difference in amplitudes between happy and neutral face conditions (0.88 vs. 0.90 µV), *F*(1, 28) = 0.07, *p* > .05. Amplitudes were significantly reduced over the left relative to the right hemisphere (-0.25 vs. 1.86 µV), *F*(1, 28) = 16.65, *p* < .001. No other main effects or interactions were significant across this time window, all *F*s < 3.07 and all *p*s > .05.

3.3.2.1.5 Early LPP Window (300-400 ms)

A main effect of electrode was observed, *F*(2, 56) = 17.03, *p* < .0001, indicating the typical posterior distribution of the P300 with larger positivity over Pz and POz than CPz (about 3.8 vs. 1.7 µV). The main effect of emotion marginally failed to reach significance, *F*(2, 56) = 3.15, *p* = .05. Planned contrasts revealed significantly reduced positivity for the fearful relative to the neutral trials (2.98 vs. 3.27 µV), *F*(1, 28) = 5.25, *p* < .05. Amplitudes across this time range were not significantly different for either happy or neutral face trials, (3.10 vs. 3.27 µV), *F*(1, 28) = 2.62, *p* > .05. Enhanced amplitudes were observed for LVF versus RVF targets, *F*(1, 28) = 4.56, *p* < .05. There were no amplitude differences at sites Pz and POz (3.57 vs. 4.06 µV), *F*(1, 28) = 1.81, *p* > .05. No other effects were significant across this time window, all *F*s < 3.17 and all *p*s > .05.

3.3.2.1.6 Late LPP Window (400-700 ms)

Enhanced positivity was observed for LVF than RVF targets (5.13 vs. 4.71 µV), *F*(1, 28) = 8.03, *p* < .01. There was a main effect of Electrode, *F*(2, 56) = 4.74, *p* < .05, again demonstrating a posterior distribution like for P300. All other main effects and interactions failed to reach significance, all *F*s < 2.91 and all *p*s > .05.

3.3.2.1.7 LPP Latency (400-900ms)

No effects were significant, all *F*s < 1.42 and all *p*s > .05.

3.3.2.1.8 N2pc

3.3.2.1.8.1 Onset Latency

The N2pc effect appears to be similar across conditions and this was confirmed in the statistical analysis. None of the effects were significant, all *F*s < 1. Mean latency was 189 ms, see Figure 3-8.

3.3.2.1.8.2 Mean Amplitude

None of the effects were significant, all *F*s < 1.

3.3.2.1.9 SPCN

3.3.2.1.9.1 Mean Amplitude

None of the effects were significant, all *F*s < 1.04, see Figure 3-8.

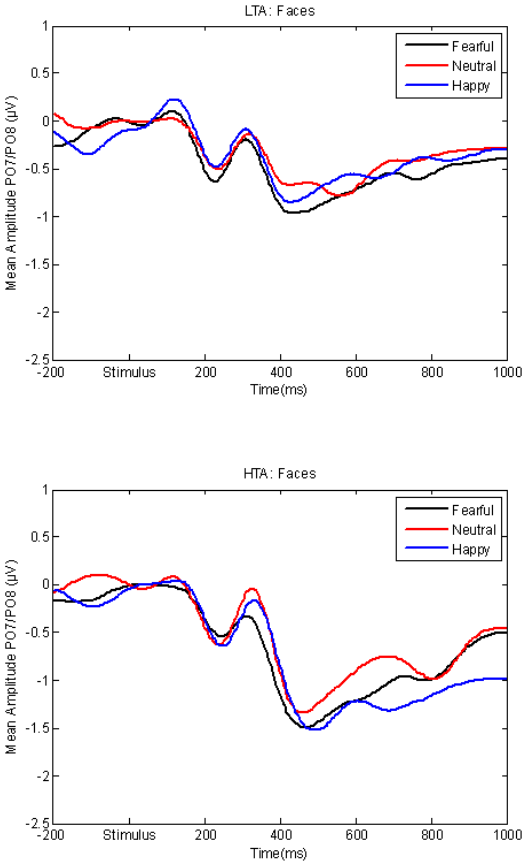

Figure 3-8. Grand average contralateral minus ipsilateral difference waves time-locked to the onset of the stimulus at electrode site PO7/PO8 for the faces condition, separately for LTA (top) and HTA (bottom) groups.

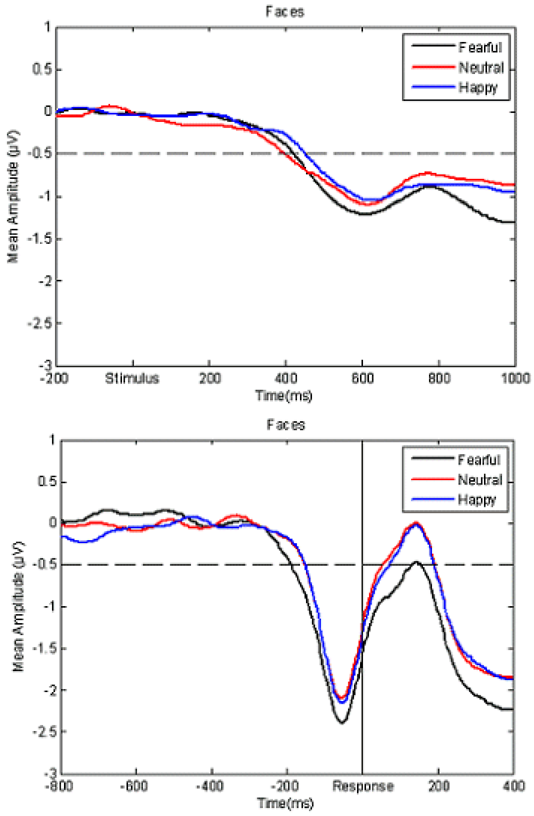

Figure 3-9. Stimulus-locked LRP (top) and response-locked LRP (bottom) for the faces condition. The vertical line indicates the time point of response and horizontal lines indicate the LRP onset cut-off.

3.3.2.1.10 Stimulus-Locked LRP Onset

None of the effects were significant, all *F*s < 1. Mean onset at 432 ms, see Figure 3-9.

3.3.2.1.11 Response-Locked LRP Onset

The main effect of emotion was significant, *F*(2, 56) = 3.85, *p* < .05, see Figure 3-9. Planned comparisons revealed a strong trend of longer intervals for fear vs. neutral faces (234 vs. 197 ms), *F*(1, 29) = 3.60, *p* = .06. Fearful versus happy faces show significantly longer intervals (234 vs. 187 ms), *F*(1, 29) = 6.50, *p* < .05. Neutral versus happy face trials were not significantly different (197 vs. 187 ms), F < 1. No other effects were significant, all *F*s < 1.21.

3.3.2.2 IAPS

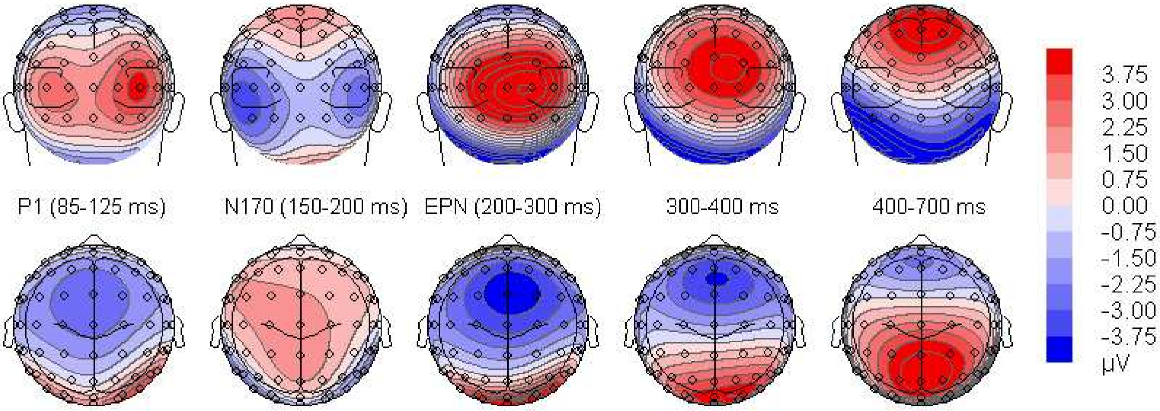

Figure 3-10. Spline-interpolated topographic maps for the IAPS condition. P1, N170, EPN, early LPP and late LPP time windows are represented, respectively. Isopotential line spacing is 0.75 µV.

3.3.2.2.1 P1 Window (85 – 125 ms)

There was a strong trend for the mean P1 amplitude to be larger for the high anxiety group in comparison to the low anxiety group (2.76 vs. -0.19 µV), *F*(1, 28) = 3.25, *p* = .08, see Figure 3-12. The main effect of emotion, *F*(2,56) = 34.10, *p* < .0001, indicating reduced positivity for negative relative to neutral pictures (0.57 vs. 1.87 µV), *F*(1,28) = 42.0, *p* < .0001, and reduced positivity for fearful relative to positive pictures (0.57 vs. 1.39 µV), *F*(1,28) = 40.78, *p* < .0001, with positive pictures also showing reduced positivity relative to neutral pictures (1.39 vs. 1.87 µV), *F*(1,28) = 11.95, *p* < .01. The main effect of emotion was modulated by group, *F*(2, 56) = 3.73, *p* < .05. Simple main effects analysis performed separately for each group revealed that the effect of emotion was significant for the high anxiety group, *F*(2, 28) = 16.45, *p* < .0001, and low anxiety group, *F*(2, 28) = 20.0, *p* < .0001. For the high anxiety group, P1 amplitudes were significantly reduced for negative pictures relative to both neutral (2.18 vs. 3.10 µV), *F*(1, 14) = 19.78, *p* < .001, and positive pictures (2.18 vs. 2.99 µV), *F*(1, 14) = 27.24, *p* < .001, however P1 amplitude did not significantly differ for neutral and positive pictures (3.10 vs. 2.99 µV), *F*(1, 14) = 0.45, *p* > .05, see Figure 3-13. For the low anxiety group, P1 amplitudes were significantly reduced for negative pictures relative to both neutral (-1.03 vs. 0.65 µV), *F*(1,14) = 23.88, *p* < .001, and positive pictures (-1.03 vs. -0.2 µV), *F*(1,14) = 16.38, *p* < .01, and positive pictures showed significantly reduced P1 amplitudes in comparison to neutral pictures (-0.2 vs. 0.65 µV), *F*(1,14) = 14.05, *p* < .01, see Figure 3-13. A main effect of electrode, *F*(2, 56) = 7.92, *p* < .01, was indicative of enhanced P1 amplitudes over the right hemisphere relative to the midline (2.01 vs. 0.27 µV), *F*(1, 28) = 18.89, *p* < .001, and similarly enhanced P1 amplitude over the left hemisphere relative to the midline (1.56 vs. 0.27 µV), *F*(1, 28) = 15.34, *p* < .001. P1 amplitude was not statistically different over left and right hemisphere sites (1.56 vs. 2.01 µV), *F*(1, 28) = 0.57, *p* > .05. No other effects were significant in the analysis of mean P1 amplitude for the IAPS condition, all *F*s < 2.58 and *p*s > .05.

3.3.2.2.2 P1 Latency

For P1 latencies at O2 in the IAPS condition, there was a main effect of emotion, *F*(2, 56) = 4.37, *p* < .05, see Figure 3-11. Planned contrasts revealed significantly earlier P1 peaks for negative IAPS pictures relative to neutral IAPS pictures (111 vs. 114 ms), *F*(1,28) = 5.08, *p* < .05 , whereas positive and neutral IAPS pictures did not differ, (113 vs. 114 ms), *F*(1,28) = 0.80, *p* > .05. No other effects were significant, all *F*s < 1.62.

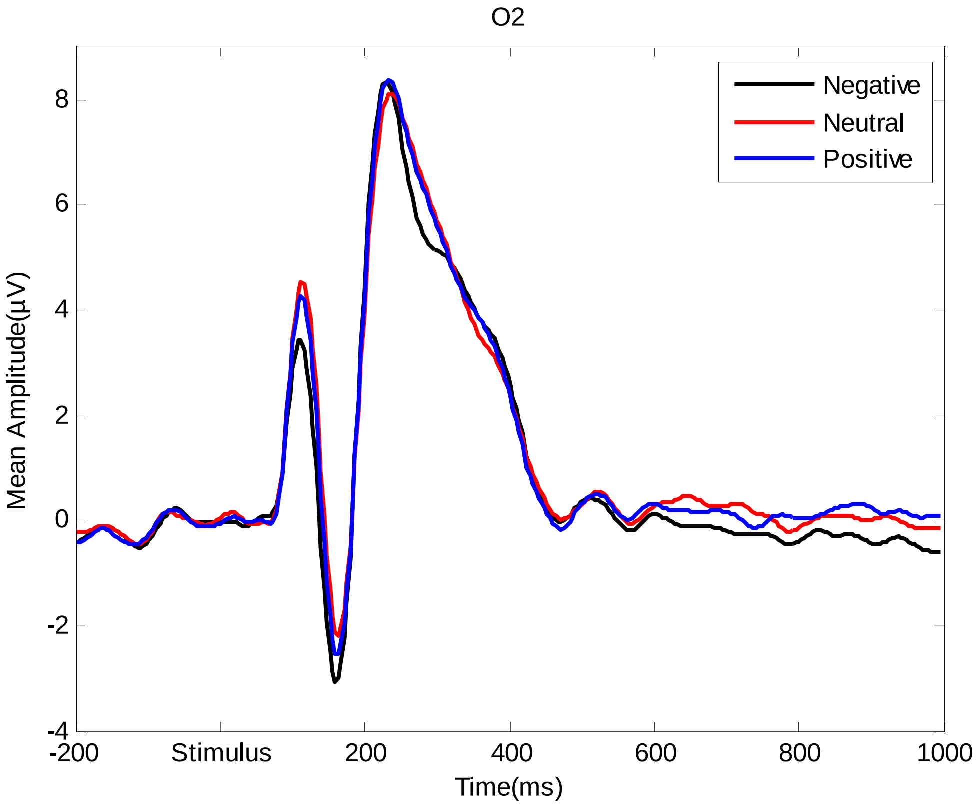

Figure 3-11. Grand-averaged ERP waveforms elicited at electrode O2 for negative, neutral, and positive IAPS pictures, collapsed across anxiety group (HTA, LTA), target location (LVF, RVF), and orientation (normal or mirrored targets).

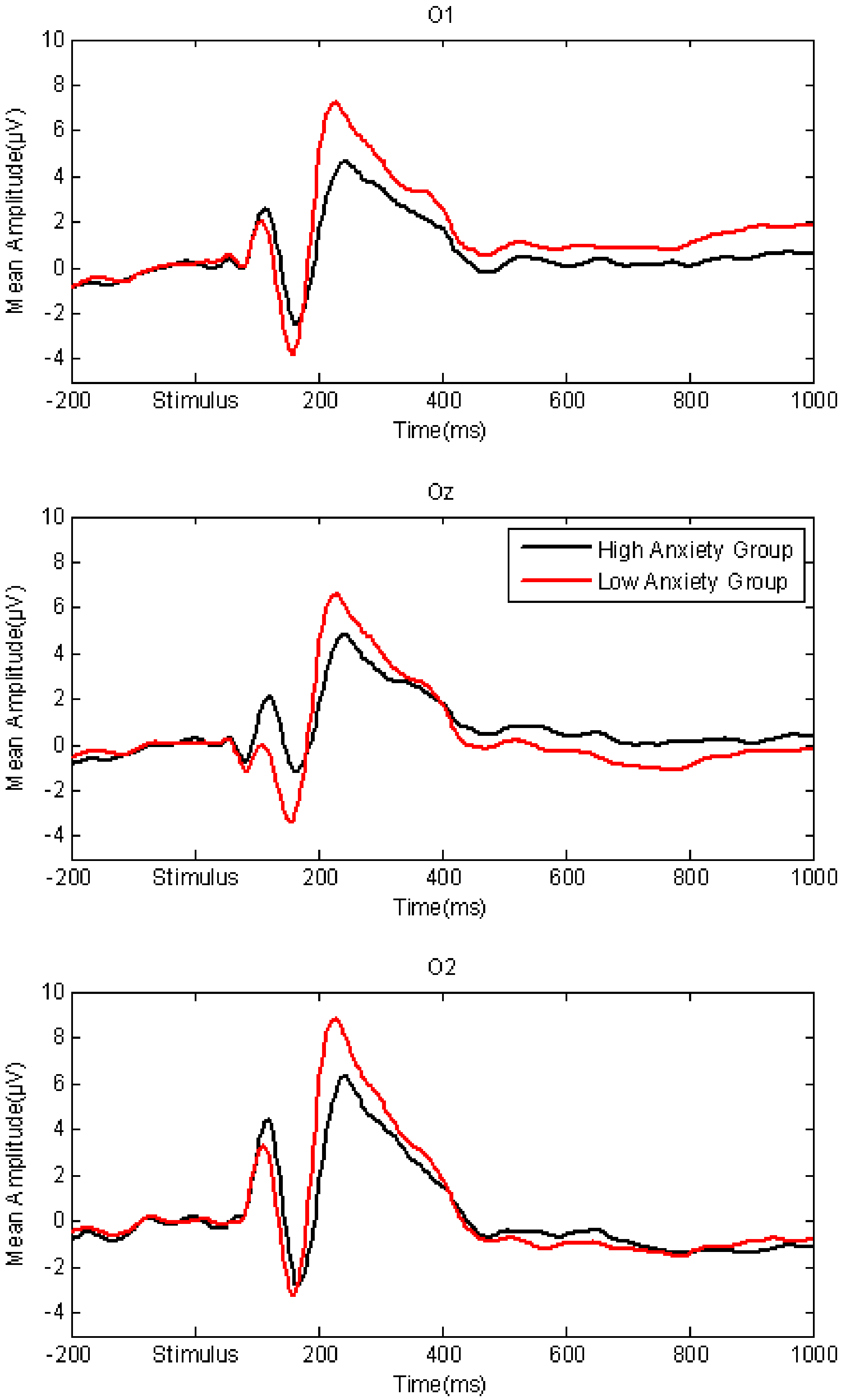

Figure 3-12. Grand-averaged ERP waveforms elicited at lateral posterior electrodes O1/2 and midline electrode Oz for high and low anxiety groups in the IAPS condition, collapsed across emotion (negative, neutral, positive), target location (LVF, RVF), and orientation (normal or mirrored targets).

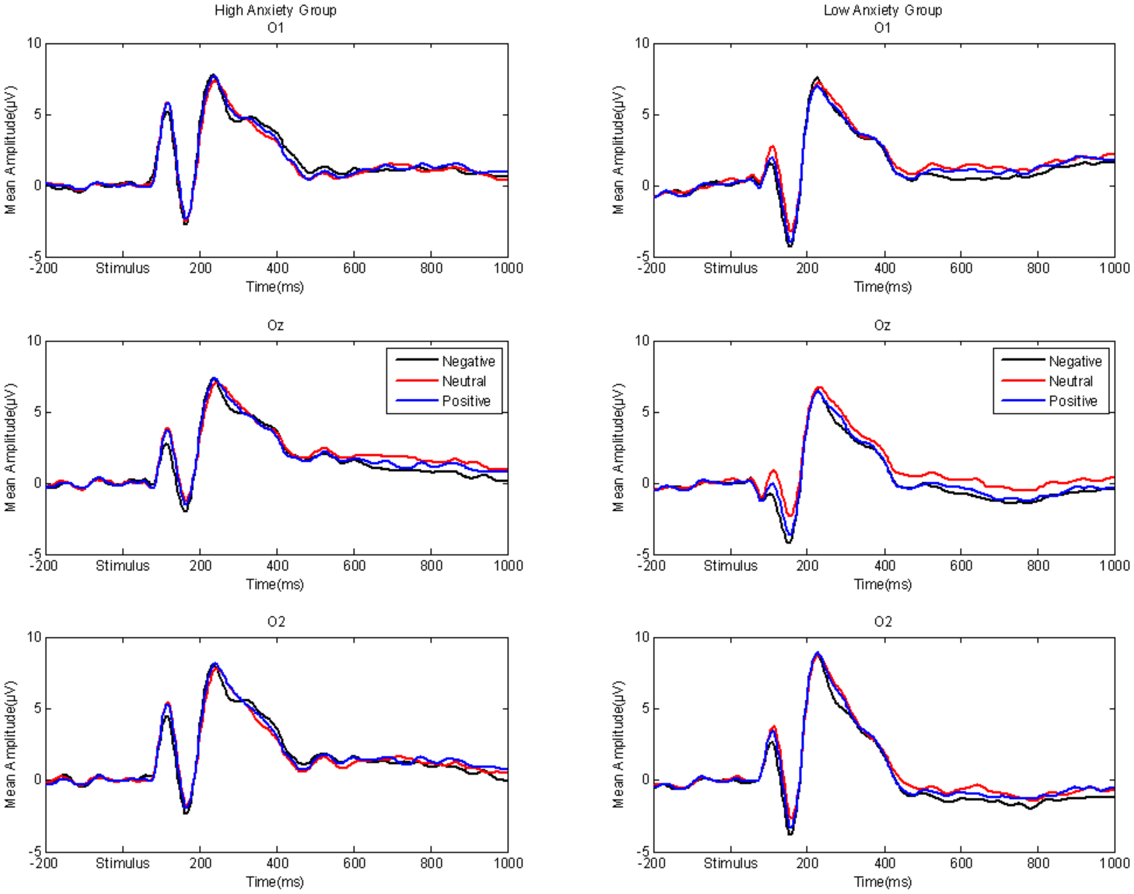

Figure 3-13. Grand-averaged ERP waveforms elicited at lateral posterior electrodes O1/2 and midline electrode Oz in response to negative, neutral and positive trials for the HTA group (left column) and the LTA group (right column) in the IAPS condition, collapsed across target location (LVF, RVF), and orientation (normal or mirrored targets).

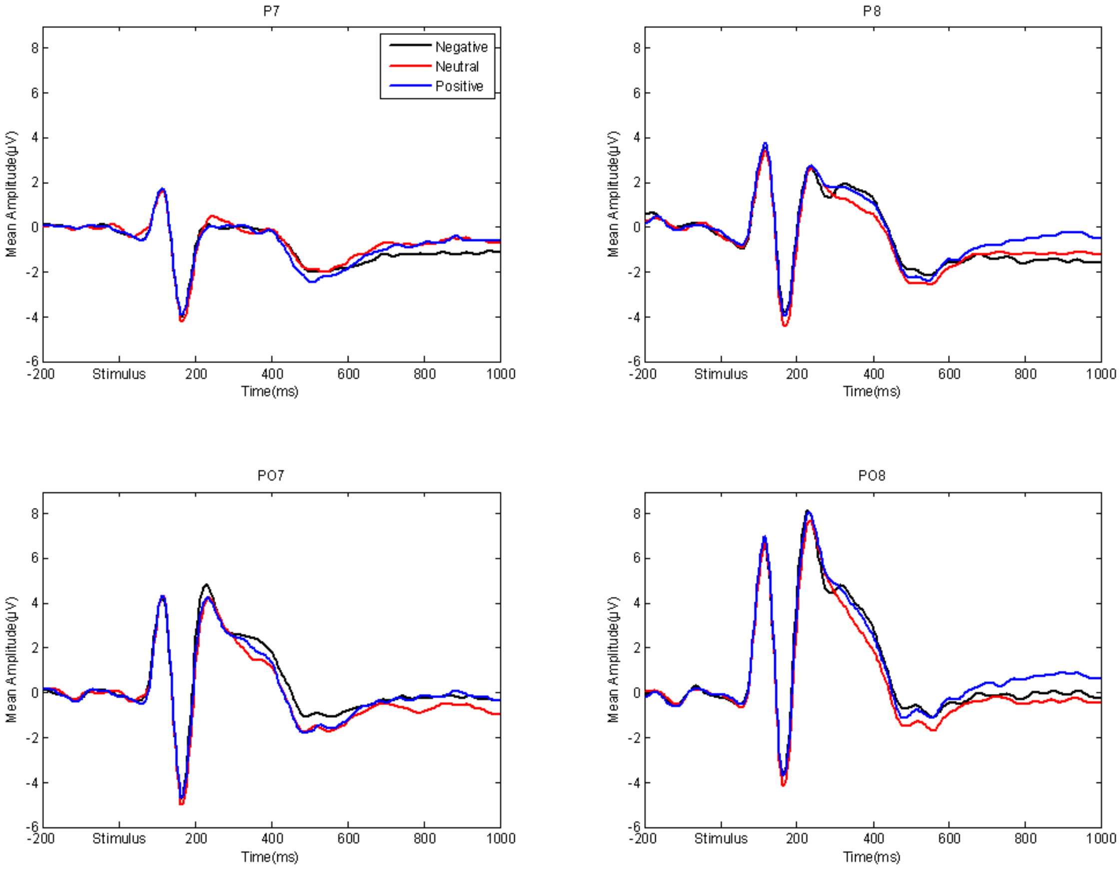

Figure 3-14. Grand-averaged ERP waveforms elicited at lateral posterior electrodes P7/P8 and PO7/PO8 in response to negative, neutral and positive IAPS pictures, collapsed across target location (LVF, RVF), and orientation (normal or mirrored targets) and anxiety group (HTA, LTA).

3.3.2.2.3 N170 Window (150 - 200 ms)

For the P7/P8 analysis, the main effect of emotion was significant, $F(2, 56) = 6.68$, $p < .01$. Follow-up contrasts revealed smaller N1 amplitudes for negative than neutral pictures (-2.80 vs. -3.28 μV), $F(1, 28) = 8.01$, $p < .01$, and smaller amplitudes for positive than neutral pictures (-2.90 vs. -3.28 μV), $F(1, 28) = 16.56$, $p < .001$, see Figure 3-14. N1 amplitudes were enhanced for LVF than RVF targets (-3.07 vs. -2.91 μV), $F(1, 28) = 5.92$, $p < .05$. However these effects were further qualified by a significant Emotion x Target Location interaction, $F(2, 56) = 3.49$, $p < .05$, and a significant Emotion x Target Location x Electrode interaction, $F(2, 56) = 4.04$, $p < .05$. Simple main effects analysis examined the effect of emotion at each hemisphere separately for LVF and RVF targets. Results showed that over the left hemisphere (P7), there was no effect of emotion for RVF targets, $F(2, 56) = 2.27$, $p < .05$, or for LVF targets, $F(2, 56) = 2.15$, $p < .05$. Over the right hemisphere contralateral to the target location, N1 amplitudes were significantly smaller for negative than neutral pictures (-2.72

vs. -2.99 μV), *F*(1, 28) = 14.59, *p* < .001, and for positive than neutral pictures (-3.02 vs. -2.99 μV), *F*(1, 28) = 33.41, *p* < .0001. Similarly, over the right hemisphere ipsilateral to the target location, N1 amplitudes were significantly smaller for negative than neutral pictures (-2.54 vs. -3.54 μV), *F*(1, 28) = 14.59, *p* < .001. However, LVF targets did not significantly modulate N1 amplitudes according to emotion (negative: -2.72 μV; neutral: -2.99 μV; positive: -3.02 μV), *F*(2, 56) = 0.70, *p* > .05. No other effects were significant at P7/P8, all *F*s < 1.99, *p*s >.05.

For the PO7/PO8 analysis, the main effect of emotion was significant, *F*(2, 56) = 9.38, *p* < .01. Follow-up contrasts revealed that negative pictures reduced N1 amplitudes relative to neutral (-1.87 vs. -2.54), *F*(1,28) = 10.79, *p* < .01, as did positive pictures reduce N1 amplitudes relative to neutral (-2.08 vs. -2.54), *F*(1,28) = 10.78, *p* < .01. There was a trend for enhanced N1 amplitudes over the left relative to the right hemisphere (-2.79 vs. -1.54), *F*(1, 28) = 3.44, *p* = .07, however the Electrode x Target Location interaction was significant, *F*(1, 28) = 6.03, *p* < .05. Simple main effects analysis revealed that at PO7 N1 amplitude was enhanced for LVF than RVF targets (-3.24 vs. -2.94), *F*(1, 28) = 6.02, *p* < .05, while at PO8, the effect of target location was not significant (-2.91 vs. -2.88), *F*(1, 28) = 0.05, *p* > .05. No other effects were significant at PO7/PO8, all *F*s < 1.99, *p*s >.05.

3.3.2.2.4 EPN Window (200 – 300 ms)

A main effect of hemisphere revealed that amplitudes were more negative-going over the left than the right hemisphere (1.05 vs. 3.13 μV), *F*(1, 28) = 11.70, *p* < .01. No other main effects or interactions were significant across this time window, all *F*s < 1.79 and all *p*s > .05.

3.3.2.2.5 Early LPP Window (300-400 ms time window)

A main effect of electrode was present, *F*(2, 56) = 20.21, *p* < .0001. Follow-up contrasts revealed enhanced positivity at POz relative to CPz (4.12 vs. 1.78 μV), *F*(1, 28) = 20.87, *p* < .0001, and at Pz relative to CPz (3.36 vs. 1.78 μV), *F*(1, 28) = 59.71, *p* < .0001. There were no amplitude differences at sites Pz and POz (3.36 vs. 4.12 μV), *F*(1, 28) = 2.93, *p* > .05. No other effects were significant across this time window, all *F*s < 3.15 and all *p*s > .05.

3.3.2.2.6 *Late LPP Window (400-700 ms)*

Enhanced positivity was observed for LVF than RVF targets (4.89 vs. 4.60 μV), $F(1, 28) = 5.64$, $p < .05$. There also was a significant three-way interaction between Emotion x Target Location x Group, $F(2, 56) = 3.33$, $p < .05$. However simple, main effects analysis examining emotion effects for RVF and LVF targets separately for the two groups did not reveal any significant emotion effects, all *F*s < 3.05 and all *p*s > .05. No other effects reached significance, all *F*s < 2.62 and all *p*s > .05.

3.3.2.2.7 *LPP Latency (400-900ms)*

The main effect of emotion was significant, $F(2, 56) = 4.06$, $p < .05$. Planned contrasts revealed delayed LPP peaks for the negative IAPS pictures relative to the neutral pictures (558 vs. 524 ms), $F(1,28) = 10.31$, $p < .01$. LPP latency on positive and neutral pictures did not significantly differ (545 vs. 524 ms), $F(1, 28) = 2.65$, $p > .05$, and negative and positive pictures did not significantly differ either (558 vs. 545 ms), $F(1, 28) = 1.07$, $p > .05$. No other effects were significant, all *F*s < 1.70 and all *p*s > .05.

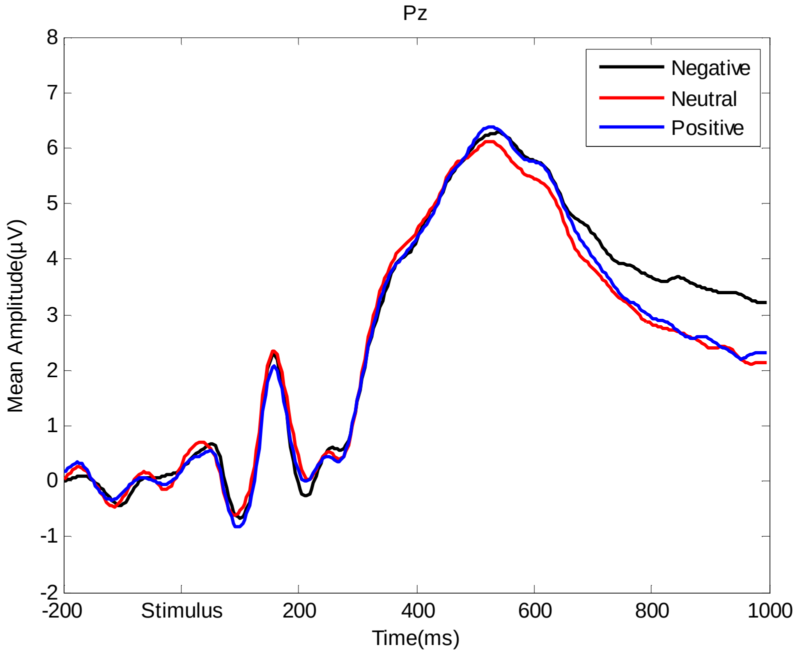

Figure 3-15. ERP waveforms at the Pz electrode in response to negative, neutral and positive IAPS pictures.

3.3.2.2.8 N2pc

3.3.2.2.8.1 Onset Latency

Mean N2pc onset latency was 198 ms. None of the effects were significant, all *F*s < 1, see Figure 3-16.

3.3.2.2.8.2 Mean Amplitude

There was a significant Emotion x Group interaction effect, $F(2, 56) = 3.68$, $p < .05$, however none of the simple main effects were significant, all *F*s < 2.48 and all *p*s > .05. On visual inspection of the N2pc waveform in Figure 3-16, the interaction pattern seems to indicate that for the LTA group, the N2pc was numerically larger for positive than negative IAPS pictures (-1.61 μV vs. -0.86 μV), and similarly was larger for positive than neutral IAPS pictures (-1.61 vs. -1.05 μV). This pattern was reversed for the HTA group, with a larger N2pc for negative than positive IAPS pictures (-1.24 vs. -0.86 μV). The N2pc did not appear to be much larger for negative than neutral IAPS pictures for the HTA group, (-1.24 vs. -1.10 μV). No other effects were significant, all *F*s < 1.

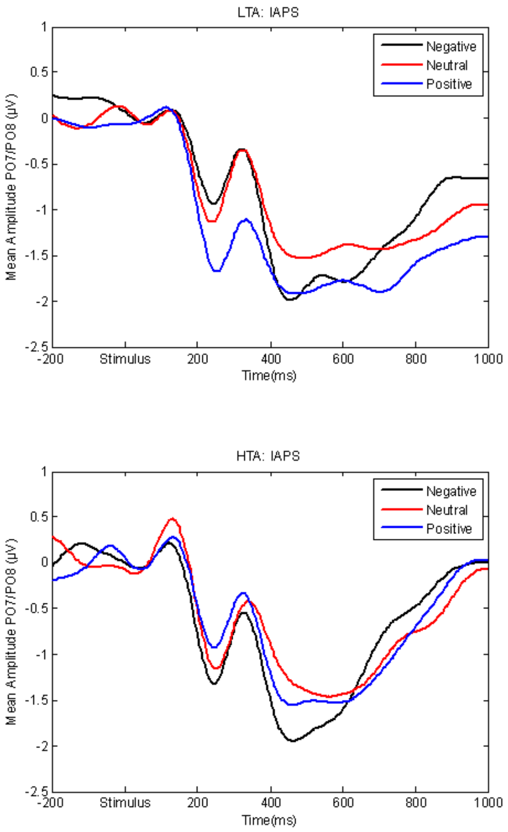

Figure 3-16. Grand average contralateral minus ipsilateral difference waves time-locked to the onset of the stimulus at electrode site PO7/PO8 for the IAPS condition, separately for LTA (top) and HTA (bottom) groups.

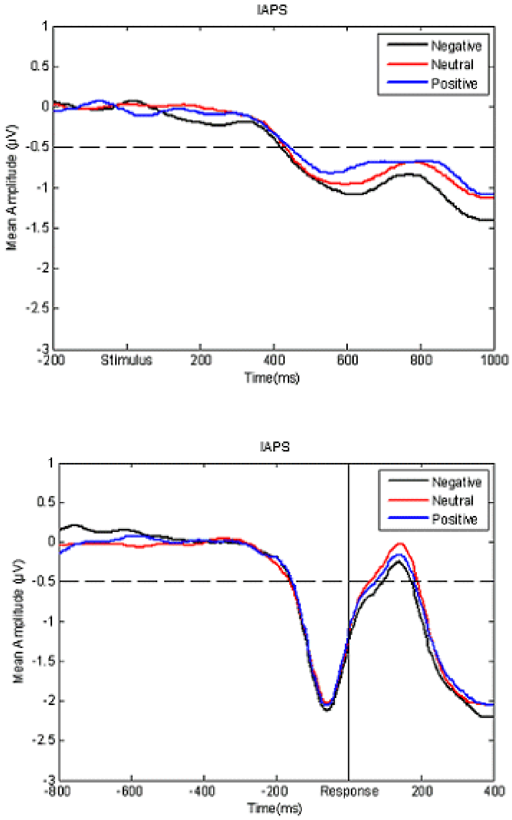

Figure 3-17. Stimulus-locked LRP (top) and response-locked LRP (bottom) for the IAPS condition. The vertical line indicates the time point of response and horizontal lines indicate the LRP onset cut-off.

3.3.2.2.9 SPCN

3.3.2.2.9.1 Mean Amplitude

The main effect of emotion was significant, *F*(2, 56) = 3.93, *p* < .05. Planned contrasts revealed significantly larger SPCN for negative than neutral IAPS pictures (-1.93 vs. -1.36 µV), *F*(1, 28) = 7.26, *p* < .01, and there was a trend for larger SPCN amplitudes for positive than neutral IAPS pictures (-1.71 vs. -1.36 µV), *F*(1, 28) = 3.66, *p* = .06, see Figure 3-16. The SPCN for negative and positive IAPS pictures did not differ (-1.93 vs. -1.71 µV), *F* < 1. No other effects were significant, all *F*s < 1.

3.3.2.2.10 Stimulus-Locked LRP Onset

Mean onset was 424 ms. None of the effects were significant, all *F*s < 1, see Figure 3-17.

3.3.2.2.11 Response-Locked LRP Onset

None of the effects were significant, all *F*s < 1. Mean LRP-R interval was 199 ms. See Figure 3-17.

3.4 Discussion

The focus of the present study concerns the issue of whether threat-related information sustains visual attention as postulated by the delayed disengagement hypothesis (Fox et al., 2001). Notably, no emotion-specific modulations of the N2pc latency were observed, thus failing to support the delayed disengagement hypothesis. However, since LPP latency has been held to index stimulus evaluation time (Donchin & Coles, 1988), delayed LPP latency for negative relative to neutral IAPS pictures implies that information with a negative emotional value can prolong analysis and evaluative processes. Moreover, the data suggest that the threat-related bias may not be restricted to an evaluative stage of processing but may also affect the late motor stage. The finding of a longer LRP-R interval for threatening faces compared to neutral and happy is consistent with the view that motor responses freeze in face of threat. Hence, the present findings advance beyond previous speculation about threat-related effects of response freezing (e.g., Fox, Russo, Bowles, & Dutton, 2001) in providing electrophysiological evidence in support of this view.

The present study investigated reaction times to make an orientation judgement of a letter stimulus presented to the left or right of a central image. The emotional valence of this central image was manipulated to assess whether the emotional significance of this irrelevant image would affect behavioural and electrophysiological responses. Overall, the mean reaction time for mirror judgments was significantly faster than for normal letter judgements. Impaired recognition of mirrored targets was also reflected in the error rates. These findings match those of other studies adopting normal and oriented capital letters as stimuli (Bryden, 1966; Harcum, 1966). Normally oriented language symbols are encountered much more frequently and this familiarity is likely to be responsible for the observed speeding of responses. Replication of the orientation effect shows that the paradigm was successful; participants were diverting their attention away from the central affective image to the target stimulus as the task required.

The P1 component is thought to represent the earliest stage of visual processing that is modulated by voluntary shifts of attention (Mangun & Hillyard, 1991), whereby directing attention to the location of a stimulus typically results in an amplitude enhancement of the P1 evoked by that stimulus. Given that highly anxious individuals enhanced P1 amplitudes relative to low anxious individuals would seem to suggest that individual variation in sensory processing mechanisms presumably modulates inputs from attended locations so that more information can be extracted from relevant portions of the visual field in high-trait anxious individuals. This would equate with the notion of anxiety being associated with heightened attentional vigilance, but not specifically to threatening information.

Affective images (faces and IAPS) were found to modulate P1 amplitudes, which implies that sensory processes were influenced by the emotional property of irrelevant stimuli. Thus, the present study provides additional evidence for the notion that there is very rapid attentional orienting towards emotional information, although not just for those individuals with heightened anxiety. Rest assured that the affective stimuli influenced early visual attention, the aim was to assess the time course of attentional biases in the allocation of attention *away* from threatening, as compared with neutral and positive stimuli, towards the target stimulus. The observance of an N2pc in each condition is evidence that participants shifted attention to the target location as directed on each trial. In comparing the N2pc onset latencies across the conditions, affect was not found to modulate the onset of an N2pc in either the face or IAPS condition. These data alone could be taken as evidence that covert shifts of attention are not delayed when orienting away from threatening images. On this basis, the ‘delayed disengagement’ hypothesis was not supported.

Using the LRP in order to investigate the time course of cognitive bias within information processing, additional insights could be made into the influence of threat-related stimuli on pre-motoric versus motor stages of processing. The significant valence-related difference in LRP-R latencies in the face condition clearly indicates that the time required from the onset of central hand-specific activation to the completion of response was longer for fearful than either neutral or happy faces. A longer LRP-R interval for threatening stimuli is consistent with the view that motor responses freeze in face of threat. S-LRP and LRP-R intervals should be additive according to Sternberg’s additive factors logic (1969), therefore since RTs were not modulated by facial affect it was expected that pre-motoric stages of processing would consequently be shorter to explain the observed LRP-R effect. There was no significant effect of emotion on the S-LRP response. However, in face of the significant effect of emotion on the LRP-R interval and the RT findings, one might be tempted to argue that this null effect merely reflects a lack of statistical power that disguises a real effect. This suspicion receives some support from the fact that detecting the onset of the LRP can be difficult due to its low signal-to-noise ratio. A secondary point worth mentioning is that inspection of the standard deviations of mean onset latency of the S-LRP revealed markedly higher variance for neutral faces relative to fearful and happy faces, which might also contribute to the failure to reach significance. Nevertheless, S-LRP onset was numerically earlier for fearful relative to happy faces, consistent with the above interpretation of the LRP-R interval and RT effects.

However, a longer LPP latency for negative compared to neutral IAPS suggests that there is relatively delayed processing of negative information. Commonly, the LPP component is considered to reflect aspects of stimulus analysis, such as stimulus evaluation (e.g. Donchin & Coles, 1988; Doucet & Stelmack, 1999). Therefore, the finding that negative IAPS had a significantly longer LPP latency may suggest prolonged stimulus analysis processes compared to neutral IAPS. Hence, it is possible that the negativity bias may operate at the evaluative stage of processing.

Overall, there was a tendency for the HTA group to respond slower than the LTA in the faces condition, but this effect was not modulated by emotion. However, overt presentations of motor slowing cannot distinguish slowness due to cognitive factors from slowness due to motor-related influences. Nevertheless, the failure to observe group differences in cognitive measures of information processing speed (i.e. N2pc or LPP latency) favours the notion that anxiety has an antagonistic effect on motor execution stages, although future study is necessary to provide a more assured conclusion.

Although the N2pc component did not reveal any attentional bias in terms of mental chronometry, affective modulation of N2pc amplitude for the IAPS pictures could be attributed to an attentional bias related to depth-of processing. Indeed, brain-imaging studies reveal enhanced activation in visual-processing regions for emotionally arousing than neutral pictures (e.g., Bradley et al., 2003). Thus, the results of the present study could imply that engaging with a motivationally significant stimulus may result in subsequent facilitation of selective attentional processing of a lateralized visual target. A functional comparison could be made between this N2pc amplification and of the occipital P1 to non-emotional targets replacing fearful face stimuli in a dot-probe task (Pourtois, Grandjean, Sander, & Vuilleumier, 2004). Together these data suggest that engaging with an emotional stimulus can bias processing of subsequent unrelated stimuli. Moreover, the current data found that the high anxiety group demonstrated a larger N2pc for negative than positive IAPS pictures, possibly reflecting effortful suppression of irrelevant information. The low anxiety group, on the other hand, showed enhanced N2pc amplitudes for targets following positive versus negative or neutral IAPS pictures. The presence of anxiety-related effects on enhancement of the N2pc amplitude to emotional pictures is suggestive of an attentional bias to self-relevant stimuli. This fits nicely with Beck’s schema model (1985), which posits that anxiety is characterised by a processing bias favouring threat-related information. Furthermore, Williams et al (1997) suggest that this attentional bias for threat cues is a distinctive cognitive vulnerability factor in anxiety. This selective processing has been demonstrated in a wide range of emotional disorders; for example, people with generalized anxiety disorder (Mogg, Mathews, & Weinman, 1989), panic disorder (Mcnally, Riemann, & Kim, 1990), and posttraumatic stress disorder (Mcnally, Kaspi, Riemann, & Zeitlin, 1990). Low anxious participants, on the other hand, may have adopted a positive visual attention bias as a means of emotion regulation (see, Wadlinger & Isaacowitz, 2008).

Emotion-related effects were uninfluenced by trait-anxiety level for the following SPCN component. The amplitude of the SCPN was larger for negative than neutral IAPS trials for both high and low anxious individuals. Given that the SPCN is believed to reflect neural activity associated with retention in visual short-term memory (Jolicoeur, Sessa, Dell'Acqua, & Robitaille, 2006; McCollough, Machizawa, & Vogel, 2007; Vogel & Machizawa, 2004), the increased amplitude of the SPCN for negative IAPS pictures most likely reflects an increased memory load for affective negative versus neutral information. Typically, the SPCN is observed in experiments explicitly investigating visual short term memory (e.g., Brisson & Jolicoeur, 2007; Eimer, 1996; Robitaille & Jolicoeur, 2006), and has been proposed to be an index of memory load. In the present study, however, the affective stimuli were task-irrelevant and therefore were not required to be memorised. Holmes et al. (2009) similarly found the SPCN to be enhanced for task-irrelevant angry and happy relative to neutral faces, however, since the nature of their task ensured attentional engagement towards the location of the emotional cues they interpreted their findings as indicating the maintenance of attention towards emotional faces. The presence of an N2pc in the present study is consistent with the proposal that attention was oriented towards the lateralised target stimulus, away from the location of the emotional pictures when the SPCN emerged. Therefore, is does not seem plausible that the immediately proceeding SPCN reflects an attention-related effect. Rather, the presence of an enhanced SPCN to threat-related pictures may reflect an obligatory mechanism for emotionally arousing stimuli to have priority access to working memory, with more information stored in working memory when presented with negative versus neutral affective material. Taken together, these different patterns of N2pc and SPCN modulations by affective picture are supportive of the view that these two components reflect independent cognitive functions (cf. Jolicoeur, Brisson, & Robitaille, 2008).

3.4.1 The Influence of Emotion on Stimulus Processing

3.4.1.1 N170

The N170 is associated with the structural encoding of faces (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2000), a process proposed to operate in parallel with facial expression discrimination (Eimer & Holmes, 2002). In accordance with this, it was shown in the present study and earlier studies (Eimer & Holmes, 2002; Holmes, Vuilleumier, & Eimer, 2003) that the N170 was insensitive to facial expressions. Further consensus is met in the observance of early (P1) and post-N170 (EPN) components being selectively modulated by expression while the N170 time window remained unaffected.

Notably, emotion-related effects were observed for the IAPS condition in the N170 time window. N170 amplitudes were reduced for positive and negative relative to neutral IAPS pictures. This effect is unlikely to be driven by affective properties of facial stimuli since IAPS pictures were selected to exclude frontal face views or pictures where facial expressions were identifiable. Thus, it would seem that this ERP modulation by affective pictures is dissociable from the face-specific N170. However, future research is necessary to investigate the possible implications of this finding.

3.4.1.2 P1

In emotion research the P1 component is generally of interest because of its relation to spatial attention and sensory processing (Batty & Taylor, 2003; Hillyard & Anllo-Vento, 1998). The finding that facial expressions affect P1 amplitude is consistent with other reports (Batty & Taylor, 2003; Eger, Jedynak, Iwaki, & Skrandies, 2003), which suggests that emotional information may affect a stage of face detection prior to the structural encoding of the face, as reflected by the N170.

Emotional content of the IAPS pictures was also found to be discriminated from neutral content very early in the information processing stream (~ 100 ms at occipital locations). The finding that P1 latencies were faster to negative IAPS also adds to the accumulating evidence that the P1 is sensitive to emotional information. Moreover, these findings are interesting because they document that the P1 component is differentially sensitive to stimuli of negative valence, not only emotional versus neutral stimuli. This early and relatively automatic mechanism of selective attention indexed by P1 latency reflects the special status of threat-related stimuli, in the speed of allocation of attentional resources.

One interesting finding, however, was that although negative IAPS evoked an attentional orienting response as seen in the P1 latency effect, P1 amplitudes were in fact reduced for negative than either positive or neutral IAPS pictures. Similarly, fearful faces reduced P1 amplitudes relative to happy faces. Modulation of P1 amplitude by affective valence has been attributed to feedback signals originating in the amygdala triggered by rapid perceptual detection of a motivationally significant stimulus (see, Vuilleumier & Pourtois, 2007). However, the typical finding is for an enhanced P1 component in response to negative, relative to neutral or positive, facial expressions (Holmes, Kragh Nielsen, & Green, 2008; Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005), purportedly since motivationally significant stimuli have attentional priority. One can only speculate as to why a reversal was observed in the present study. Firstly, one difference between this and other studies was that the affective stimulus was task irrelevant. However, it could be argued that salient stimuli should nonetheless have attentional gain and consequently inflate P1 amplitude. Clearly, negative IAPS pictures demonstrated priority processing in their earlier evocation of the P1, which leaves room for the possibility that emotional modulation of P1 amplitudes in this instance reflects inhibition that is related to top-down control. Suppression of task-irrelevant positive and neutral stimuli may have enhanced P1 amplitudes (cf. Freunberger et al., 2008), whereas negative information may have received less input from top-down control mechanisms, with bottom-up influences exerting greater influence. The RT data support this view, in that negative stimuli induced more errors than either neutral or positive valence stimuli for both the faces[5] and IAPS conditions. Also, the HTA group made more errors on fearful versus happy face trials. It may have been more difficult to perform the judgement task when negatively-valenced distractor stimuli were presented and attentional suppression may have been necessary to ensure attentional re-allocation towards the task-relevant stimulus. An alternative interpretation of the observed P1 modulations by emotion is that these effects are not driven by the emotional nature of the stimulus but rather they reflect variations in the low-level features of the stimuli, such as contrast and spatial frequency. Indeed, the stimuli were not controlled in this respect. The P1 component is renowned for its sensitivity to variations in stimulus parameters, as would be expected given that it arises from activity originating in the extrastriate visual cortex. Thus, it cannot be ruled-out that the observed effects are simply stimulus parameter effects.

3.4.1.3 EPN and LPP

The finding of an enhanced EPN to fearful compared with neutral facial expressions is consistent with previous ERP studies (e.g., Eimer, Holmes, & McGlone, 2003; Sato, Kochiyama, Yoshikawa, & Matsumura, 2001; Schupp, Ohman et al., 2004). The results suggest that the attentional capture of threat-related facial expression is an automatic response. However, unlike previous reports of enhanced EPN amplitudes to happy relative to neutral faces (e.g., Marinkovic & Halgren, 1998; Schacht & Sommer, 2009), the present study failed to observe such an effect. The emotion-linked EPN was not present for the IAPS pictures. The reason for this finding is unclear given that previous studies have reported emotion-related EPN effects with positive and negative IAPS pictures (Herrmann et al., 2009); however, a vital difference between this and other studies was that the affective stimuli were in fact task-irrelevant. Nevertheless, the EPN response to threatening faces suggests that socially relevant stimuli

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[5] Increased RT error rate for fearful versus happy faces was only observed in the HTA group. The LTA group, by comparison, did not show modulation of error rates by emotion.

have an obligatory influence on perceptual stages of processing, that perhaps negative IAPS, although highly arousing, fail to engage.

In the context of the present EPN results, the failure to find an emotion-related effect on LPP in the faces condition may suggest that after the relatively early and automatic detection of fearful faces indexed by the EPN, attention was not sustained towards fearful faces. This may not be surprising since the nature of the task required that attention be oriented towards the non-affective lateralised target.

Chapter 4 Emotional Attention Set-Shifting and Anxiety

4.1 Introduction

The executive system theoretically functions to manage the myriad of cognitive processes performed by the brain to help coordinate goal-directed behaviour (e.g., Baddeley, 1986; Shiffrin & Schneider, 1977). Attentional control processes are thought to be regulated by this ‘supervisory system’ (Shallice, 1988), suppressing automatic responses and consequently enabling selection based on intentional aims. However, it is well documented that negative affect is prioritized by the attentional system (e.g., Fox, Russo, Bowles, & Dutton, 2001; Öhman & Mineka, 2001; Pratto & John, 1991) and can command both covert attention (Eastwood, Smilek, & Merikle, 2001; Öhman & Mineka, 2001) and overt attention (i.e., eye movements; Rinck, Reinecke, Ellwart, Heuer, & Becker, 2005). These studies suggest an important role for emotionally salient stimuli in executive control processes.

Maladaptive executive control processes associated with affective stimuli have been implicated in the etiology and maintenance of anxiety-related disorders (see, Mathews & MacLeod, 2005, for a review). For example, the attentional biases for emotionally-relevant stimuli found in generalised anxiety disorder (GAD) and social phobia could be characterised as failures of executive control. Even within sub-clinical populations, anxiety is associated with an increased influence of the stimulus-driven attentional system via automatic threat-detection processes (e.g. Fox, Russo, & Georgiou, 2005). Evidence from studies employing visual search (Öhman & Mineka, 2001) and dot-probe tasks (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijendoorn, 2007; Mogg, Bradley, Miles, & Dixon, 2004; Rohner, 2002) provide converging evidence of a hypervigilance to threat in sub-clinical anxiety.

Adaptive action control requires a degree of flexibility in the ability to switch goals or detect task-irrelevant yet significant stimuli. However, a heightened sensitivity for irrelevant information would promote distractibility and stimulus-driven behaviour. According to the attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007) it is this imbalance between top-down and bottom-up inputs that characterises cognitive performance in anxiety, incurring deficits in mental set-shifting and inhibition. One self-proclaimed criticism however, is that the theory focuses on cognitive tasks using non-emotional stimuli (Eysenck, Derakshan, Santos, & Calvo, 2007), therefore it is accepted that further research is required to examine cognitive flexibility in the context of, say, negative affect. Given that anxious individuals are believed to be selectively biased toward processing threatening information (e.g., Mogg & Bradley, 1998), the theory would predict that stimulus-driven attentional mechanisms would be more susceptible to threat-related stimuli. Thus, enhanced bottom-up processing of threat-related stimuli in anxiety might incur a cognitive advantage when switching towards the aversive stimulus is the task goal. Consequently, it would also predict impairment of task performance when attention must be diverted away from the source of threat. Empirical support for these predictions comes from a recent study investigating the role of emotion in executive control processing. Paulitzki, Risko, Oakman, and Stolz (2008) had participants switch between emotionally aversive and neutral tasks. A number digit superimposed upon an image of a spider served as the trial stimulus and participants had to switch between the spider-task (hairy vs. smooth) and the digit task (odd vs. even) as indicated by a pre-trial cue. Regressing participants' scores on the fear of spiders questionnaire (FSQ) with RT performance revealed FSQ score to be a significant predictor of RTs on switch trials. More fearful participants were faster to switch *to* and slower to switch *away* from the aversive spider task. Thus, individuals scoring high on the FSQ demonstrated *accelerated engagement* towards (reduced RT in switching to the spider task) and *decelerated disengagement* from (increased RT in switching from the spider task) the emotionally aversive stimulus. Most importantly, this study clearly demonstrates that the emotional relevance of a task can affect the attentional shifting process of the central executive.

Alternative models of anxiety have made explicit the role of behavioural (Mowrer, 1960) and cognitive (Foa & Kozak, 1986; Hayes, Wilson, Gifford, Follette, & Strosahl, 1996) avoidance of anxiety-producing cues in the development and maintenance of anxiety disorders. For example, Beck and colleagues (1985) suggest that following the initial shift of attentional resources towards threat, individuals high in anxiety effortfully try to reduce the impact of those events via a cognitive avoidance strategy. Similarly, the central assumption of Sibrava and Borkovec's (2006) cognitive avoidance theory of anxiety is that worry functions as a cognitive avoidance response to danger. Although the theory stresses that worry involves primarily verbal-linguistic thought, rather than imagery, Johnson (2009) recently linked trait anxiety and a propensity to experience worrisome thoughts with a difficulty in switching from a neutral to an emotional mental representation in a task-switching paradigm. Johnson interpreted this result as supportive of cognitive avoidance theory since an attempt to avoid attention to emotional mental representations is predicted to hinder the ability to switch to the emotional set.

The task-switching paradigm is a popular means for empirically investigating executive control processes since it requires the regulation of processes from current and previous tasks, and the ability to resist interference from previous tasks. Generally, it takes more time to switch between tasks than it does to repeat the same task, with the difference in RT being referred as a 'switch cost'. Switch costs are thought to reflect the extra time required to reconfigure the cognitive system to perform a new task (Logan, 2003; Monsell, 2003; Rogers & Monsell, 1995). To help elucidate the cognitive mechanisms underlying emotional attention set-shifting in anxiety the present study examined switch costs as a measure of cognitive control.

4.1.1 Experimental Aims

There exists a myriad of studies investigating the pattern of attentional deployment in anxiety. However, the study of Johnson (2009) is, to my knowledge, the only study to date that has examined the relation between emotional attention set-shifting and trait anxiety. The study is based on an adapted version of the explicit-cueing task-switching paradigm which measures controlled attention between emotional and neutral mental sets (Johnson (in press)). Participants performed either an emotional judgement or a neutral judgement task on a compound stimulus that consisted of a face (happy, angry, or neutral) with a shape centred between the eyes (circle, square, or triangle).

A patterned versus solid bar served as the task cue; when the face stimulus was relevant participants had to identify the emotional expression, and for the emotionally neutral task participants had to indentify the type of shape. Emotional attention set-shifting in this context was defined as assessing *attentional control capacity for emotional representations* (ACCE) (Johnson, 2009). Overall, switching from an emotional set to a neutral set took significantly longer than switching from a neutral set to a neutral set. More specifically, individuals higher in trait anxiety and worrisome thoughts[6] were slower to switch from a neutral to an emotional mental set. Based on these findings Johnson asserts that the ACCE task captured individual differences in attentional control capacity for emotional material.

However, the experiment was designed such that emotion repetition trials were more frequent than any other type of trial; therefore, as Johnson (2009) points out, the attentional control demand was increased for an emotional to neutral task switch and decreased for a neutral to emotional task switch. Thus, the observed task-switching asymmetry may reflect the attentional control demands imposed by the task design rather than emotional attention set-shifting ability per se. The present study aimed to address this issue, to investigate individual differences in emotion attention set-shifting ability while ensuring equiprobability of repetition and repeat trial types for both emotional and neutral tasks.

The central aim, however, was to extend Johnson’s (2009) investigation to determine whether attentional control for specifically threat-related stimuli is modulated by trait anxiety. Goal-directed attention is necessary to reconfigure stimulus-response task sets on switch trials (Rogers & Monsell, 1995), a process purported to be limited by increasing levels of anxiety (e.g. Miyake et al., 2000; Santos & Eysenck, 2006). Attentional control theory (Eysenck et al., 2007) suggests that competing resources for attention may contribute to this lack of executive control in anxiety. However, the stimulus-driven attentional system

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[6] Trait anxiety was measured using the State-Trait Anxiety Inventory (Spielberger, 1983). The Dundee Stress State Questionnaire (Matthews et al., 1999) was used to assess the degree to which an individual experienced worrisome thoughts.

may in fact facilitate switch performance when presented with an emotionally salient target stimulus (i.e. a threatening face). As such, individuals higher in anxiety should exhibit a reduced neutral to threat switch cost. Therefore, trait-anxiety scores should be negatively correlated (i.e. performance improves as anxiety increases) with the switch cost on the threat-related task. Similarly, a threat-related bias of the stimulus-driven attentional system may hinder switch performance when a threat to neutral switch is necessary. In this instance, it was predicted that an increased threat to neutral switch cost will be observed with increasing levels of anxiety. Thus, trait-anxiety sores should be positively correlated (i.e. performance declines as anxiety increases) with the switch cost on the emotionally neutral task. If, however, individual differences in emotion set-shifting ability are not valence specific, it would be expected that switch costs between positive and neutral mental sets would mirror that of the threat-related effects.

Cognitive avoidance theory (Sibrava & Borkovec, 2006) makes competing predictions. Namely, that increasing levels of anxiety should be associated with increased switch costs when switching from a neutral to an emotional task since the cognitive avoidance of threat would result in an attentional bias towards the formerly neutral task. It would follow that trait-anxiety scores should be positively correlated (i.e. performance declines as anxiety increases) with the switch cost on the emotional task. On the other hand, when switching from an emotional to a neutral task cognitive avoidance theory predicts that individuals higher in anxiety will show a reduced switch cost. Support of this theory would require that trait-anxiety scores are negatively correlated (i.e. performance improves as anxiety increases) with the switch cost on the neutral task.

A secondary aim was to examine emotional attention set-shifting using a variety of emotional stimulus types to assess whether attentional control capacity for emotional representations (ACCE; Johnson, 2009) could be generalised across emotional stimulus types. Thus, participants performed two task-switching sessions; one for affective face stimuli (fearful and happy) and another for positively and negatively valenced IAPS pictures. In both sessions, the neutral task was a word/non-word judgement task.

4.2 Methods

4.2.1 Participants

Thirty-two University of Glasgow undergraduate students with normal or corrected-to-normal vision participated in the experiment. The sample comprised of 19 females and 13 males, between the ages of 19 to 37 years, who were right-handed. The study was approved by the Glasgow University Research Ethics Committee and performed in appliance with their guidelines. Individuals with a history of inpatient psychiatric care, neurological disease, or head injury were excluded, as were individuals on medication for anxiety or depression.

Participants were measured on established scales relevant to emotion processing: state and trait anxiety, using the State-Trait Anxiety Inventory (STAI; Spielberger, 1983); and depression, using the Beck Depression Inventory II (BDI-II: Beck, Steer, & Brown, 1996). Participants completed the state version of the STAI before the experimental session and the trait subscale and BDI was completed immediately following the experiment. Participants' state anxiety scores before the experiment ranged from 22 to 65 (*M* = 33.0, SD = 9.3). Participant's trait anxiety scores ranged from to (*M* = 39.2, SD = 10.2). These scores are similar to the published norms for college students (*M*(state) = 37.61, SD = 10.98; *M*(trait) = 39.35, SD = 9.66) (Spielberger, 1983). Participants' BDI scores ranged from 0 to 19 (*M* = 5.9, SD = 4.3).

4.2.2 Stimuli

The visual stimulus consisted of a word stimulus superimposed on an affective picture, see Figure 4-1. Face stimuli were gray-scale photographs from the Ekman and Friesen database (Ekman & Friesen, 1976). Eight identities (four male, four female) were used, each with a fearful and a happy expression. The face images subtended approximately 10° visual angle in height and 7° visual angle in width.

Figure 4-1. Example stimulus showing a fearful face/real word combination.

Pictures of positive and negative (threat-related) valenced scenes were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). A total of 16 grey-scale pictures were selected, 8 allocated to each emotional category: negative and positive[7]. Normative rating data on affective valence are available for each picture in the IAPS database on a 9-point scale ranging from unpleasant (1) to pleasant (9) (Lang, Bradley, & Cuthbert, 2008). Positive IAPS were rated as significantly more positive than the negative IAPS (M = 1.90 vs. 7.30), $t(14) = 36.16$, $p < .0001$, although they did not differ in respect to arousal (M = 6.51 vs. 5.66), t(14) = 2.14, p > .05. The IAPS pictures subtended approximately 7° visual angle in height and 10° visual angle in width.

Four word sets were used; two real-word sets and two pseudo-word sets (see Appendix A). The real word sets were compiled from the Affective Norms for English Words (ANEW) database (Bradley & Lang, 1999) consisting of forty neutral words each. The following criteria for word selection were employed: arousal values for words were less than 5.45 and valence levels between 4.00

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[7] According to their IAPS number, the negative pictures were: 3000 (mutilation), 3071 (mutilation), 6212 (sniper), 9050 (plane crash), 9405 (mutilation), 9410 (soldier), 9433 (mutilation), 9921 (fire); and the positive pictures were: 1340 (women with parrots), 1811 (laughing monkeys), 2655 (child on beach), 5831 (seagulls on beach), 8030 (skier), 8180 (cliff divers), 8490 (roller-coaster), 8502 (money).

and 6.00. The two real-word sets did not differ with respect to valence (5.17 vs. 5.26), $t(78) = 0.70$, $p > .05$, or arousal (4.35 vs. 4.11), $t(78) = 1.93$, $p > .05$. Words selected had a maximum occurrence of 57 per million (according to the CELEX norms; Baayen, Piepenbrock, & van Rijn, 1993). In addition, two sets of forty pseudo-word stimuli were generated from the ARC Nonword Database (Rastle, Harrington, & Coltheart, 2002), which were orthographically legal pronounceable non-words (e.g. uttle) and ranged between 4 and 10 letters. A one-way ANOVA revealed that the number of letters was similar across the four word sets, $F < 1$, with a grand mean of 6.6 letters. Word stimuli were presented in red font and lowercase letters (Times New Roman) subtending 1° visual angle in height and varied in width according to the length of the word. Approximately three characters subtended 2.5° of visual angle.

4.2.3 Procedure

Participants were seated in a dimly lit sound-attenuated cabin, and a computer screen was placed at a viewing distance of 80 cm. The task was a cued task-switching paradigm. The experiment consisted of two successive experimental sections; one for the face stimuli and the other for the IAPS pictures. The order of presentation was balanced across participants so that half completed the face section followed by the IAPS section, and vice versa. Each section started with a practice block of 10 trials, which familiarised the participant with the response-mapping (different response-mappings were used on the face and IAPS sessions so as to eliminate practice effects), followed by 9 experimental blocks, each containing 65 trials. Therefore, each participant completed 18 experimental blocks in total; 9 face blocks and 9 IAPS blocks.

Mix, a pseudorandomisation program (Van Casteren & Davis, 2006; www.mrc-cbu.cam.ac.uk/personal/maarten.van-casteren/Mix.htm) was used to generate orders for stimulus presentation. Within each block, trials were pseudorandomised to produce approximately equal repeat and switch trials for all possible word-picture stimulus combinations and to ensure that different stimuli were presented on successive trials. Different real-word and pseudo-word sets were used for faces and IAPS sessions to eliminate possible familiarity effects on response rates.

Each trial commenced with the presentation of a central fixation cross for 300 ms, after which a brief tone (100 ms) cued the trial type (word or image task) followed by a blank screen for another 100 ms. Therefore, after a cue-stimulus interval of 200 ms, a central image appeared (either a face or IAPS picture) with a word stimulus presented centrally across the image and remained on the screen for a maximum of 2000 ms or until a response was made. Stimuli were presented in front of a black background. Feedback was provided on incorrect trials, misses, and anticipations. The inter-trial interval was 1000-ms.

Participants were instructed to focus their attention initially on the location of the fixation cross and to shift their attentional focus to the target as indicated by the cue preceding stimulus presentation. The cue was a tone of either 1000 or 2000 Hz. The mapping of the cue varied across participants; for half of the participants the high tone cued the emotional picture and the low tone the word stimulus and vice versa for the other half of the participants. Responses were made with either a left or right hand keypress whenever they deemed the target image as positive/negative or the word stimulus as a word/pseudo-word. The four possible response-mappings were balanced across participants and different mappings were used for the faces and IAPS blocks to eliminate practice effects.

4.2.4 Data Analysis

Data reduction for the RT analysis included the elimination of the first trial of each experimental block since it could not be determined which task participants were set to perform prior to beginning each block. Trials with RT < 100 ms (anticipations) and RT > 2,000 ms (misses) were excluded from data analysis, as were incorrect response trials and trials where an error was made on the preceding trial since the incorrect task set was activated prior to performing the current task. Separate analyses were performed on the faces and IAPS data sets. Where the assumption of sphericity was not met, Huynh-Feldt corrected p-values were examined.

Primary analyses focused on the attention set-shifting of emotional mental sets in general. Firstly, a repeated measures ANOVA was performed on RT differences between EE, NN, NE, and EN trials. Individual differences in set-shifting ability were operationalised by means of switch costs, calculated as a difference score between switch and repeat trials. Thus, a-priori contrasts were then performed to examine the significance of NE and EN switch costs via pairwise contrasts between NE and EE trials and EN and NN trials, respectively. A subsequent repeated measures ANOVA investigated whether the emotionality of the task influenced the task-switching process by comparing mean NE and EN switch costs. Switch costs were calculated as follows. The mean RT for the NN (neutral→neutral) repetition trials was subtracted from the mean RT for the EN (emotional→neutral) switch trials to obtain individual differences in EN switch cost. The mean RT for the EE (emotional→ emotional) repetition trials was subtracted from the mean RT for the NE (neutral → emotional) switch trials to obtain individual differences in NE switch cost.

Secondary analyses were concerned with attention set-shifting of happy versus fearful emotional representations. To investigate the cost of switching from an emotional to a neutral mental set a repeated measures ANOVA on RT with the variable trial type (EN(fearful), NN(fearful), EN(happy), and NN(happy)) was performed. A-priori contrasts were then performed to examine the significance of FN (fearful → neutral) and HN (happy → neutral) switch costs via pairwise contrasts between EN(fearful) and NN(fearful) trials and EN(happy), and NN(happy) trials, respectively. A repeated measures ANOVA with the variable switch cost (FN, HN) was then performed to investigate whether the emotionality of the task influenced the task-switching process. Switch costs were calculated as follows. The mean RT for the NN (neutral→neutral) repetition trials was subtracted from the mean RT for the FN (fearful→neutral) switch trials to obtain individual differences in FN switch cost. The mean RT for the FF (fearful → fearful) repetition trials was subtracted from the mean RT for the NF (neutral → fearful) switch trials to obtain individual differences in NF switch cost. Only neutral word trials where fearful faces were presented simultaneously were included in this analysis to avoid possible confounding with changes of expressions. Analogous switch costs were calculated for the happy faces condition except that only neutral word trials where happy faces were presented simultaneously were included in this analysis. To investigate the cost of switching from a neutral to an emotional mental set, analogous analyses were performed on the NE(fearful), EE(fearful), NE(happy), and EE(happy) trials and the neutral → emotional switch costs (NF, NH).

For the IAPS data, comparable switch costs were calculated and analyses performed. General emotional switch costs were also referred to as EN and NE, whereas the emotion specific switch costs were termed NegN, NNeg, PosN, and NPos to reflect the positive and negative valence of the IAPS pictures.

To test whether trait anxiety moderates switch cost, four separate regression analyses were performed where each type of emotional switch cost (i.e. FN, NF, HN, NH switch costs) served as the predictor and trait-anxiety score served as the criterion variable. For the IAPS data analysis, separate regression analyses were also performed where each type of switch cost (i.e. NegN, NNeg, PosN and NPos switch costs) served as the predictor and trait-anxiety score served as the criterion variable.

4.3 Results

4.3.1 Faces

4.3.1.1 Emotional Attention Switch Costs

A one-way repeated measures ANOVA on RT with the variable trial type (EE, NN, NE and EN) revealed a significant effect, *F*(3, 93) = 79.72, *p* < .0001. Planned contrasts revealed a significant NE switch cost (*M* = 173 ms; i.e., NE minus EE trials), *F*(1, 31) = 228.43, *p* < .0001, and a significant EN switch cost (*M* = 172 ms; i.e., EN minus NN trials), *F*(1, 31) = 196.73, *p* < .0001. As Figure 4-2 shows, a speed-accuracy trade-off cannot explain these results as faster RTs were associated with lower error rates. This inverse relationship between RT and accuracy provides compelling evidence that task reconfiguration processes are more demanding of attentional control processes than repetition trials. A repeated measures ANOVA with the variable switch cost (NE, EN) revealed that there was no significant difference between switch costs when either switching from an emotional set to a neutral set or switching from a neutral set to an emotional set, *F* < 1.

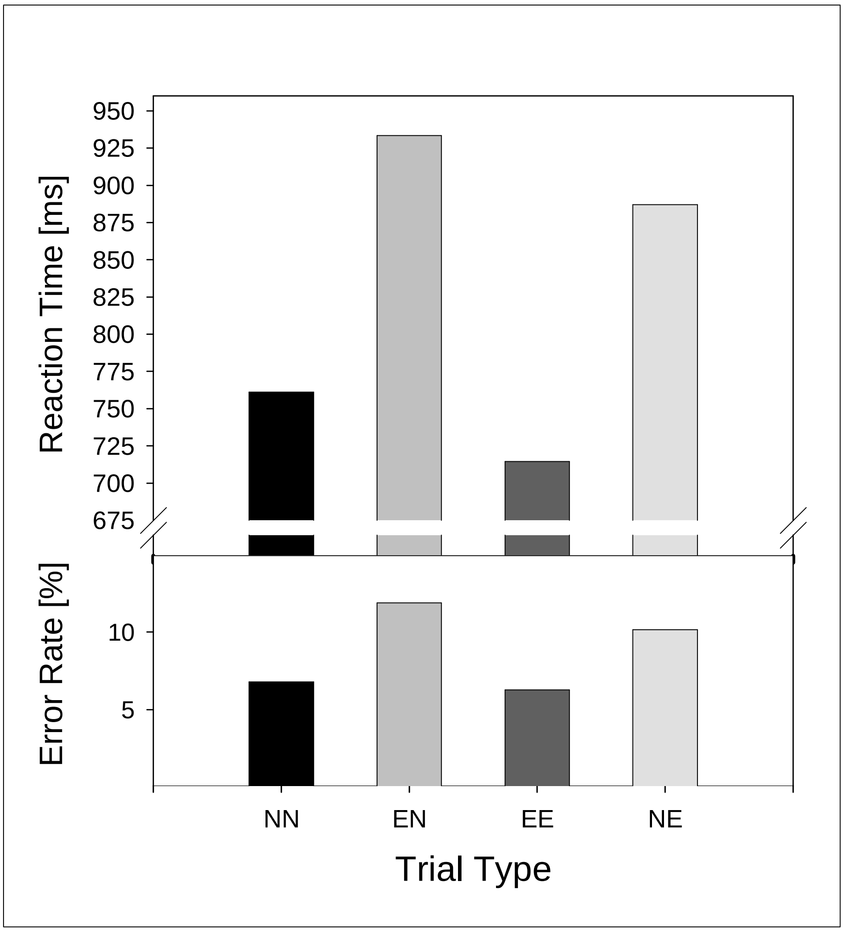

Figure 4-2. Reaction time and accuracy for NN, EN, EE, and NE trials for the faces condition.

4.3.1.1.1 Switching from an Emotional Set to a Neutral Set

A repeated measures ANOVA on RT with variable trial type (EN(fearful), NN(fearful), EN(happy), and NN(happy)) revealed a significant main effect, F(3, 93) = 98.10, *p* < .0001. Planned contrasts revealed a significant FN switch cost when switching from a fearful set to a neutral set (*M* = 206 ms; i.e., EN(fearful) minus NN(fearful) trials), *F*(1, 31) = 162.28, *p* < .0001, and a significant HN switch cost when switching from a happy set to a neutral set (*M* = 180 ms; i.e., EN(happy) minus NN(happy) trials), *F*(1, 31) = 114.46, *p* < .0001. As Figure 4-3 shows, a speed-accuracy trade-off cannot explain these results as faster RTs were associated with lower error rates. A repeated measures ANOVA with the variable switch cost (FN, HN) revealed that there was no significant difference between FN and HN switch costs, *F*(1, 31) = 2.07, *p* > .05.

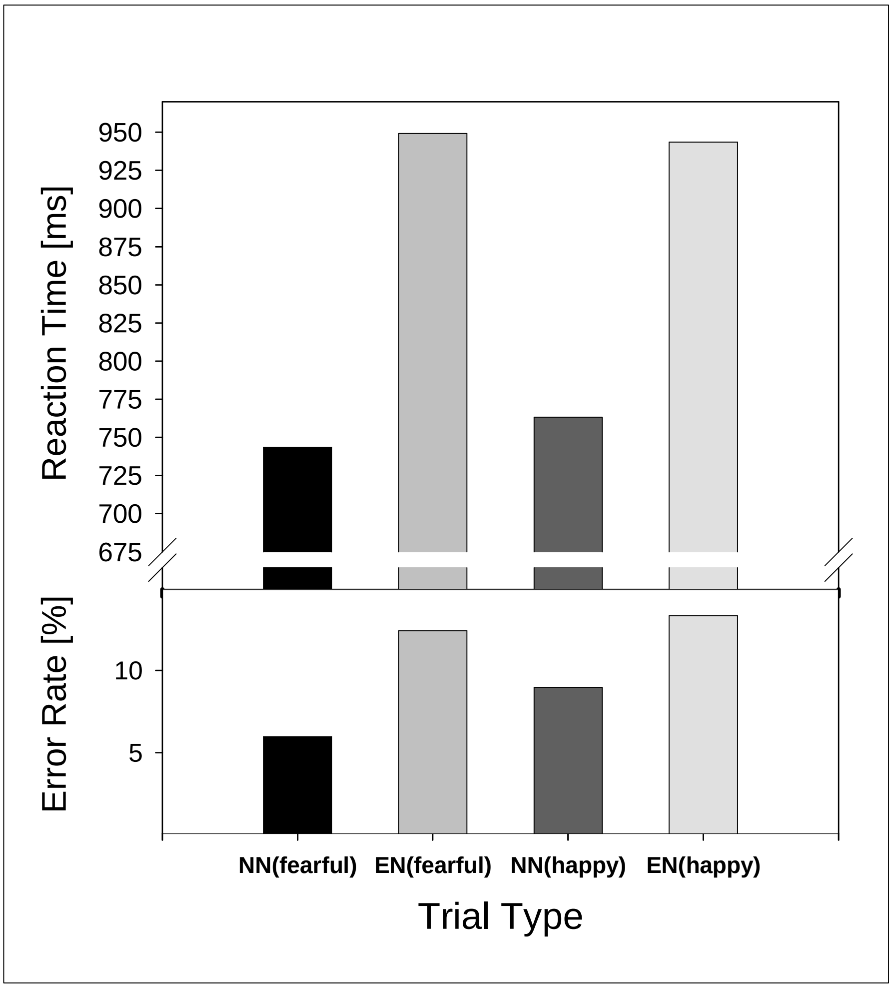

Figure 4-3. Reaction time and accuracy for NN(fearful), EN(fearful), NN(happy) and NE(happy) trials for the faces condition.

4.3.1.1.2 Switching from a Neutral Set to an Emotional Set

A repeated measures ANOVA on RT with variable trial type (NE(fearful), EE(fearful), NE(happy), and EE(happy)) revealed a significant main effect, *F*(3, 93) = 60.23, *p* < .0001. Planned contrasts revealed a significant NF switch cost when switching from a neutral set to a fearful set (*M* = 146 ms; i.e., NE(fearful) minus EE(fearful) trials), *F*(1, 31) = 86.32 , *p* < .0001, and a significant NH switch cost when switching from a neutral set to a happy set (*M* = 206 ms; i.e., NE(happy) minus EE(happy) trials), *F*(1, 31) = 118.68, *p* < .0001. As Figure 4-4 shows, a speed-accuracy trade-off cannot explain these results as faster RTs were associated with lower error rates. A repeated measures ANOVA with the variable switch cost (NF, NH) revealed that the switch cost associated with switching from a neutral set to a fearful set was significantly smaller (*M* = 60) than the switch cost associated with switching from a neutral set to a happy set, *F*(1, 31) = 7.73, *p* < .01. This provides evidence that disengaging a neutral set and engaging a fearful emotional set was less demanding on attentional control processes than when disengaging a neutral set and engaging a happy emotional set.

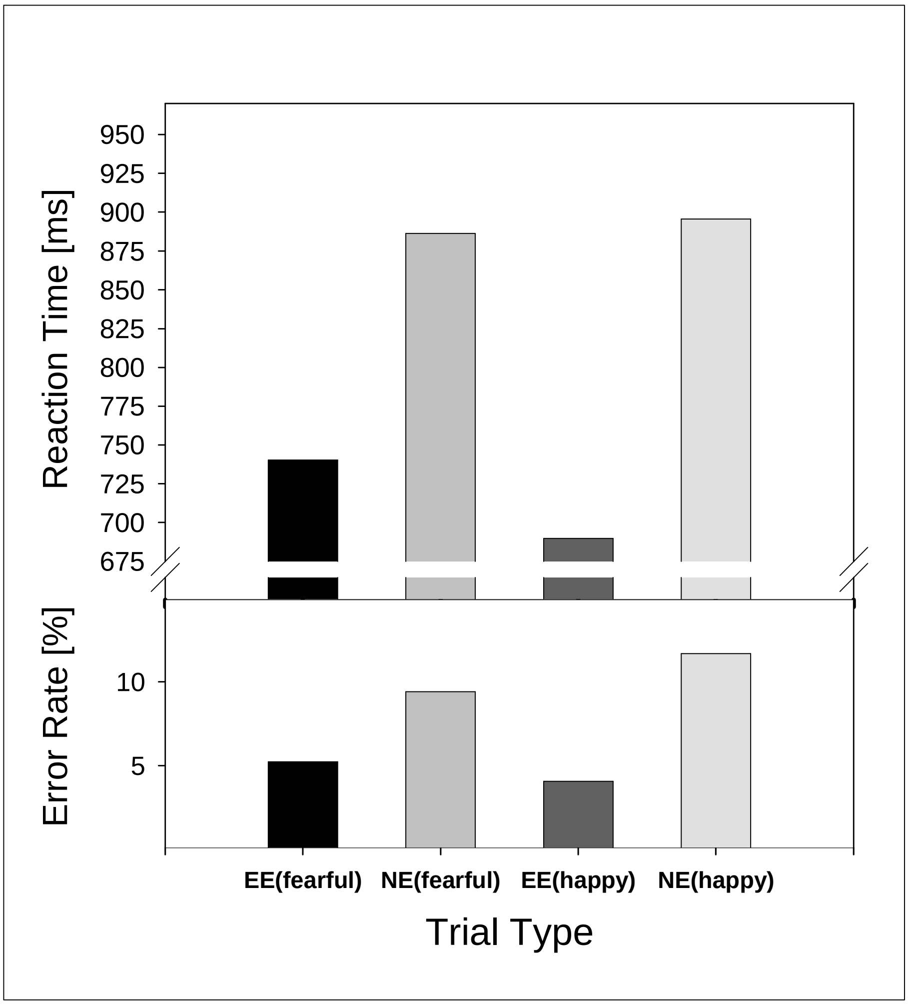

Figure 4-4. Reaction time and accuracy for EE(fearful), NE(fearful), EE(happy) and NE(happy) trials for the faces condition.

4.3.1.2 Individual Differences in Emotional Attention Set-Shifting Ability

To test whether trait anxiety moderates emotional switch costs, four regressions were performed where each type of switch cost (i.e. FN, HN, NF, NH) served as the predictor and trait-anxiety score served as the criterion variable. Table 4-1 summarises the results from these analyses.

Table 4-1. Four regressions for switch costs on the faces condition with trait anxiety as the criterion variable in each case.

Regression	Predictor Variable	Criterion Variable	*b*	*SE b*	t-value (d.f. = 30)	p-value
1	FN Switch Cost	Trait Anxiety	-0.499	1.630	0.31	0.762
2	HN Switch Cost	Trait Anxiety	-0.337	1.701	0.20	0.844
3	NF Switch Cost	Trait Anxiety	-3.476	1.457	2.39	0.024*
4	NH Switch Cost	Trait Anxiety	0.309	1.909	0.16	0.873

N.B. FN = fearful→neutral(fearful); HN = happy→neutral(happy); NF = neutral(fearful)→fearful; NH = neutral(happy)→happy. For each regression, n = 32. Significant predictors are indicated with an asterisk.

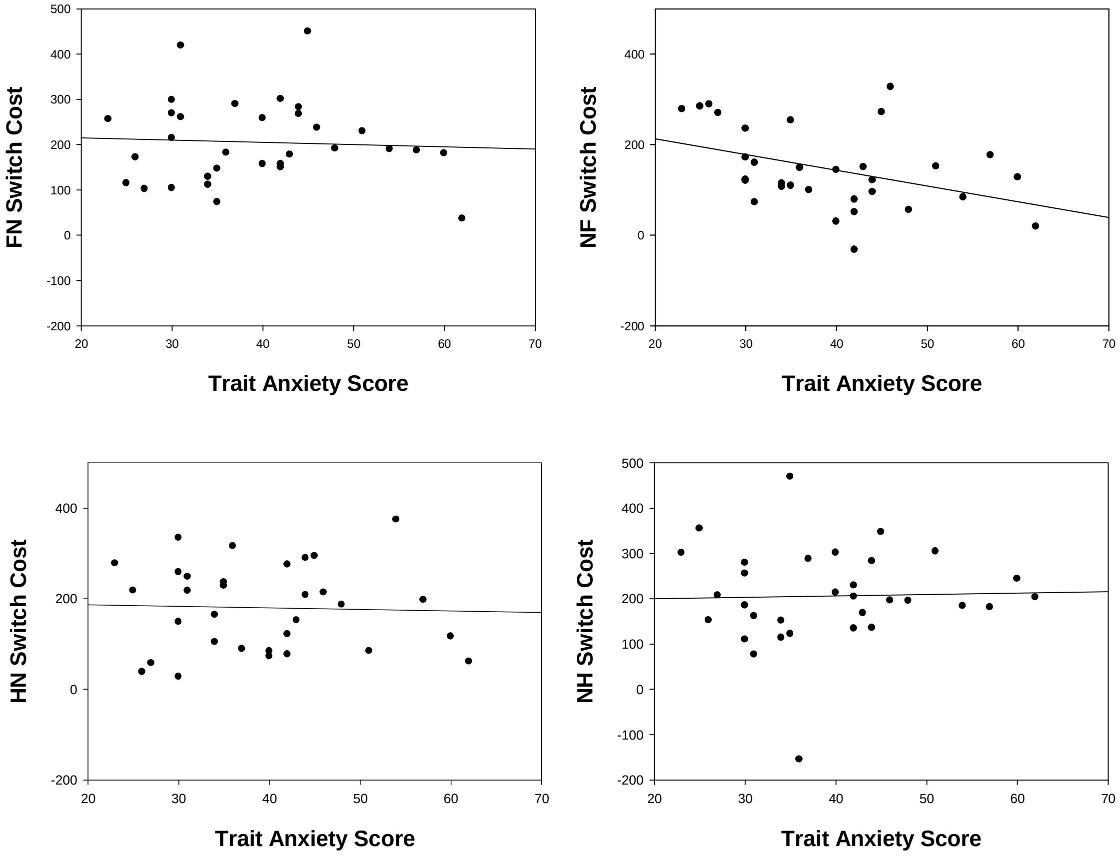

Figure 4-5. Regression analyses for the faces condition with FN (top left), NF (top right), HN (bottom left) and NH (bottom right) switch costs as predictor variables and trait anxiety as the criterion variable in each case.

4.3.1.2.1 Fearful Switch Costs

As the results from Table 4-1 suggest, trait anxiety significantly moderated the NF switch cost so that those higher in trait anxiety had an increased ability to switch from a neutral mental set to a fearful mental set (see Figure 4-5, regression line is plotted). However, the FN switch cost was not significantly moderated by trait anxiety.

4.3.1.3 Happy Switch Costs

Neither HN nor NH switch costs were moderated by trait anxiety (c.f. Table 2-1, Figure 4-5). This indicates that trait anxiety could not account for the cost of switching attention between happy and neutral mental sets.

4.3.2 IAPS

4.3.2.1 Emotional Attention Switch Costs

Analogous tests were performed on the IAPS data set. A repeated measures ANOVA on RT with the variable trial type (EE, NN, NE and EN) revealed a significant effect, $F(3, 93) = 60.46$, $p < .0001$. Planned contrasts revealed a significant NE switch cost ($M = 163$ ms; i.e., NE minus EE trials), $F(1, 31) = 122.73$, $p < .0001$, and a significant EN switch cost ($M = 160$ ms; i.e., EN minus NN trials), $F(1, 31) = 89.57$, $p < .0001$. As Figure 4-6 shows, a speed-accuracy trade-off cannot explain these results, faster RTs were associated with lower error rates. A repeated measures ANOVA with the variable switch cost (NE, EN) revealed that there was no significant difference between switch costs when either switching from an emotional set to a neutral set or switching from a neutral set to an emotional set, $F < 1$.

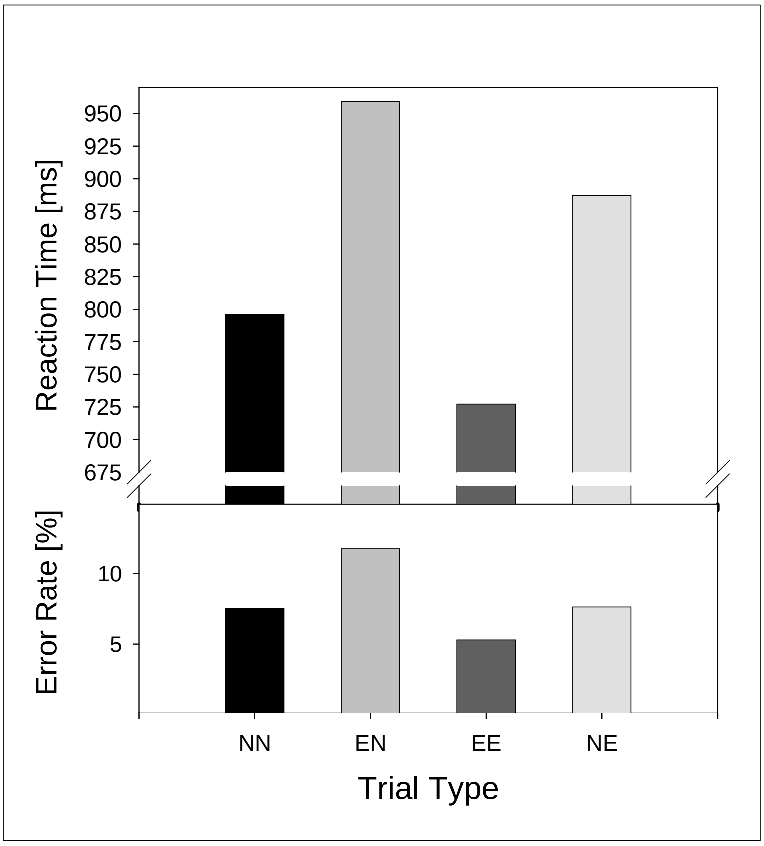

Figure 4-6. Reaction time and accuracy for NN, EN, EE and NE trials for the IAPS condition.

4.3.2.1.1 Switching from an Emotional Set to a Neutral Set

A repeated measures ANOVA on RT with variable trial type (EN(negative), NN(negative), EN(positive), and NN(positive)) revealed a significant main effect, F(3, 93) = 39.72, *p*<.0001. Planned contrasts revealed a significant NegN switch cost when switching from a negative trial to a neutral trial (*M* = 159 ms; i.e., EN(negative) minus NN(negative) trials), *F*(1, 31) = 36.49, *p* < .0001, and a significant PosN switch cost when switching from a positive trial to a neutral trial (*M* = 204 ms; i.e., EN(positive) minus NN(positive) trials), *F*(1, 31) = 60.26, *p* < .0001. As Figure 4-7 shows, a speed-accuracy trade-off cannot explain these results as faster RTs were associated with lower error rates. A repeated measures ANOVA with the variable switch cost (NNeg, NPos) revealed that the switch cost associated with switching from a negative emotional task set to a neutral set was significantly smaller than the switch cost associated with switching from a positive set to a neutral set (*M* = 45 ms), *F*(1, 31) = 4.62, *p* < .05. This provides evidence that disengaging a negative set and engaging a neutral set was less demanding on attentional control processes than when disengaging from a positive emotional set to engage in a neutral set.

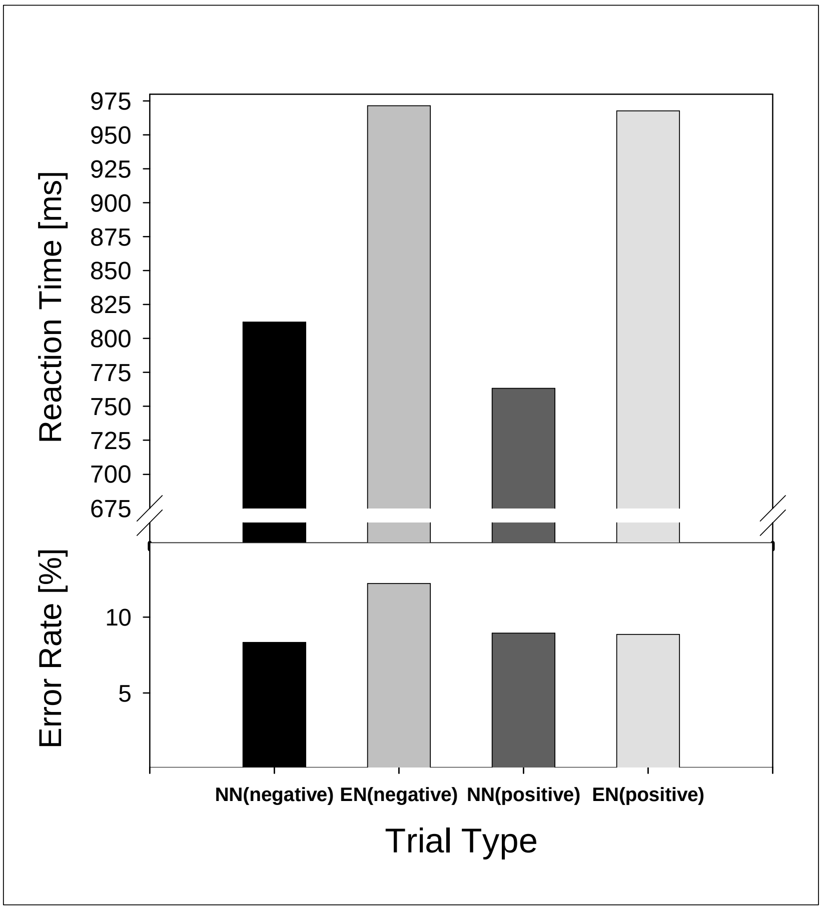

Figure 4-7. Reaction time and accuracy for NN(negative), EN(negative), NN(positive) and NE(positive) trials for the IAPS condition.

4.3.2.1.2 Switching from a Neutral Set to an Emotional Set

A repeated measures ANOVA on RT with variable trial type (NE(negative), EE(negative), NE(positive), and EE(positive)) revealed a significant main effect, *F*(3, 93) = 39.95, *p* < .0001. Planned contrasts revealed a significant NNeg switch cost when switching from a neutral trial to a negative trial (*M* = 181 ms; i.e., NE(negative) minus EE(negative) trials), *F*(1, 31) = 79.67, *p* < .0001, and a significant NPos switch cost when switching from a neutral trial to a positive trial (M = 164 ms; i.e., NE(positive) minus EE(positive) trials), *F*(1, 31) = 77.85, *p* < .0001. As Figure 4-8 shows, a speed-accuracy trade-off cannot explain these results as faster RTs were associated with higher accuracy rates. A repeated measures ANOVA with the variable switch cost (NNeg, NPos) revealed that there was no significant difference between switch costs when either switching from an neutral set to a negative set or switching from a neutral set to a positive set, *F* < 1.

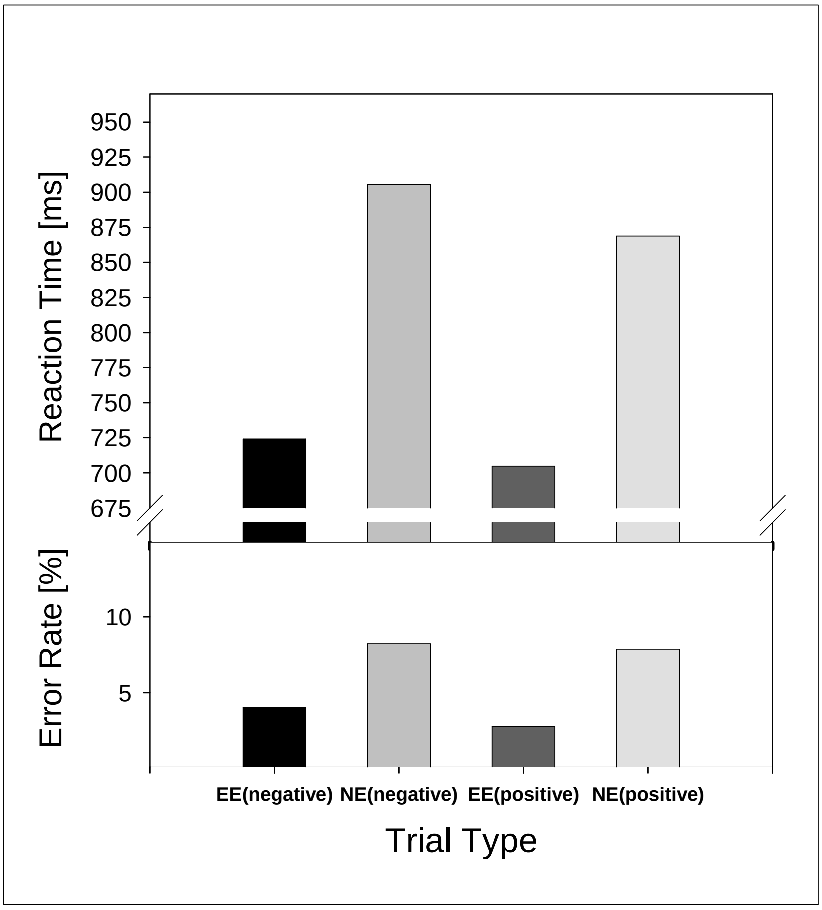

Figure 4-8. Reaction time and accuracy for EE(negative), NE(negative), EE(positive) and NE(positive) trials for the IAPS condition.

4.3.2.2 Individual Differences in Emotional Attention Set-Shifting Ability

To test whether trait anxiety moderates emotional switch costs, four regressions were performed where each type of switch cost (i.e. EN, NE, NegN, PosN, NNeg, NPos) served as the predictor and trait-anxiety score served as the criterion variable. Table 4-2 summarises the results from these analyses.

Table 4-2. Four regressions for switch costs on the IAPS condition with trait anxiety as the criterion variable in each case.

Regression	Predictor Variable	Criterion Variable	*b*	*SE b*	t-value (d.f. = 30)	p-value
1	NegN Switch Cost	Trait Anxiety	-3.994	2.567	1.56	0.130
2	PosN Switch Cost	Trait Anxiety	-5.876	2.435	2.41	0.022*
3	NNeg Switch Cost	Trait Anxiety	-2.851	1.986	1.44	0.161
4	NPos Switch Cost	Trait Anxiety	-2.129	1.839	1.16	0.256

N.B. NegN = negative→neutral(negative); PosN = positive→neutral(positive); NNeg = neutral(negative)→negative; NPos = neutral(positive)→positive. For each regression, n = 32. Significant predictors are indicated with an asterisk.

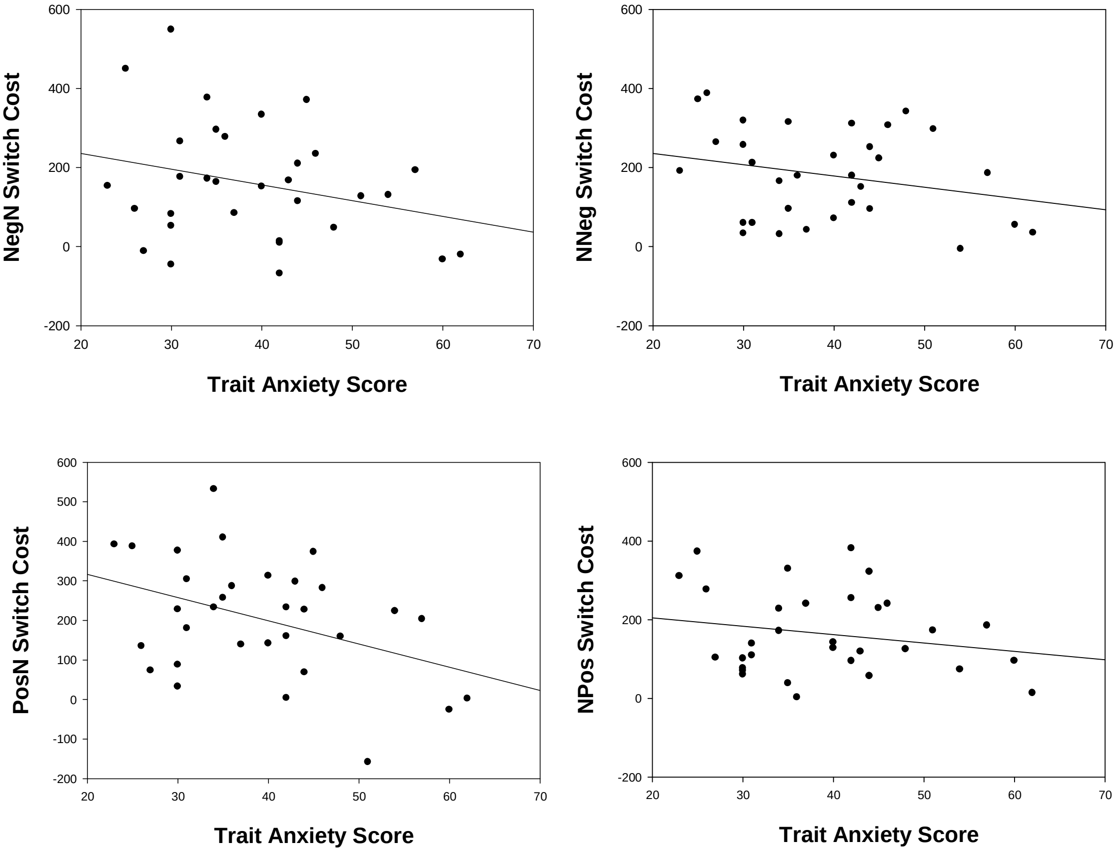

Figure 4-9. Regression analyses for the IAPS condition with NegN (top left), NNeg (top right), PosN (bottom left) and NPos (bottom right) switch costs as predictor variables and trait anxiety as the criterion variable in each case.

4.3.2.2.1 Negative Switch Costs

Neither NegN nor NNeg switch costs were moderated by trait anxiety (c.f. Table 4-2, Figure 4-9). This indicates that trait anxiety could not account for the cost of switching attention between negative and neutral mental sets.

4.3.2.2.2 Positive Switch Costs

As the results from Table 4-2 suggest, trait anxiety significantly moderated the PosN switch cost so that those higher in trait anxiety had an increased ability to switch from a positive mental set to a neutral mental set (see Figure 4-9). However, the NPos switch cost was not significantly moderated by trait anxiety.

4.4 Discussion

The main interest of the current investigation was the effect of anxiety on cognitive control processes involved in the attentional deployment of emotional information. A variant of the classic task-switching paradigm, the ACCE task (Johnson, in press), was used to study emotional attention set-shifting ability. Johnson (2009) previously reported individual variation in attentional control capacity for emotion using this task. The current goal was firstly to try to replicate the findings of Johnson (2009), and secondly, yet more crucially, to extend these findings to look at valence-specific effects on emotional attention set-shifting. Significant emotional to neutral and neutral to emotional switch costs were observed for both the faces and IAPS data sets, which is rest-assuring that control processes were engaged when task requirements were changed. However, unlike Johnson (2009), the switch cost associated with the emotional task (i.e. the faces and IAPS tasks) was non-distinguishable from the switch cost associated with the emotionally neutral task (i.e. the word task). Therefore, the data suggest that the attentional control demands were similar on both switch tasks. These data clearly suggest that the asymmetry reported by Johnson (2009) reflect the attentional control demands imposed by the task design rather than emotional attention set-shifting ability. Concerning the second aim, however, investigation into emotional attention set-shifting for valence-specific material revealed significant modulatory effects by trait anxiety, which will be addressed in more detail below.

The most important finding was that for face stimuli those higher in trait anxiety were faster to switch from a neutral to a threatening mental set. Nevertheless, this finding connecting ACCE and anxiety is directly relevant to theories of anxiety acknowledging a hypervigilance to threat (e.g., Mathews & Mackintosh, 1998; Mogg & Bradley, 1998; Williams, Watts, MacLeod, & Mathews, 1997). Attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007) predicts that individuals high in anxiety should exhibit a generalized switching deficit due to the increased distractibility of the stimulus-driven attentional system interfering with goal-directed attention. However, the theory also recognises that anxiety typically reduces attentional focus on the current task unless it involves threatening stimuli. To my knowledge, this is the first empirical demonstration of an anxiety-related advantage to the central executive process of switching to a threatening mental set.

Related reports of faster attentional orienting towards threatening stimuli with increasing levels of anxiety have been documented in the context of the visual probe task using a range of stimulus types, such as threat-related words, faces and scenes (Bradley, Mogg, Falla, & Hamilton, 1998; Broadbent & Broadbent, 1988; Mogg & Bradley, 1998; Mogg et al., 2000). One possible explanation for this robust finding may be that a faster attentional orienting towards threat would likely increase chances of survival. Thus, it logically follows that threat stimuli should be detected rapidly by both high and low anxious individuals albeit at varying degrees. Indeed, an anxiety-independent threat-related attentional bias has been reported in the literature (i.e., Öhman & Mineka, 2001). In the present context, there was a general pattern across all participants for a reduced switch cost when switching from a neutral to a fearful versus happy mental set, which seems to support the notion that the attentional bias to threat is a general adaptation.

Anxiety is suggested to have an adaptive function that enables rapid detection of threat to impel a speedy reaction (Fox, Russo, Bowles, & Dutton, 2001) however this bias may be heightened to a suboptimal level infringing upon current task goals when a perceived source of threat commands attention. The disadvantage of an overly responsive threat-sensitive attentional system becomes all the more apparent when we consider that anxious patients are more likely to interpret ambiguous stimuli as threatening than less anxious, or non-anxious, patients. However, the present study shows that the processing bias associated with elevated levels of anxiety may prove to be advantageous in some contexts, particularly when the task demands emotional attention set-shifting from a neutral to a fearful mental set.

The attentional bias to threat in anxiety was only apparent for emotional faces and not affective scenes, despite the fact that pictures depicting aversive threat scenes were used (e.g., violence, mutilation). Failing to generalise the attentional bias across stimulus types would seem to suggest that social significance, in addition to emotional value, is an important feature of attentionally engaging stimuli. These data provide compelling evidence that stimulus type is an important factor to consider when investigating emotion-cognition interactions and caution must be taken when comparing emotion-specific effects across studies using different stimulus types.

A second important finding was that switch costs were reduced when diverting attention away from threatening IAPS pictures and towards the neutral words task as compared to a positive to neutral switch. Following the assumption of attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007) that anxiety increases the allocation of attention to threat-related stimuli, anxiety should also enhance attentional focus on a current task that involves threatening stimuli, thus impairing attentional shifting mechanisms away from this stimulus. The idea that anxiety selectively modulates cognitive control processes involved with the disengage component of attention is in line with other theories that address the relationship between anxiety and attentional bias (Fox, Russo, Bowles, & Dutton, 2001; Mathews & MacLeod, 2005) and has received some empirical support (Fox, Russo, Bowles, & Dutton, 2001; Paulitzki, Risko, Oakman, & Stolz, 2008). However, the present study did not find any evidence to support this hypothesis. In contrast, evidence of reduced switch costs when diverting attention away from threatening IAPS pictures and towards the neutral words task was thought to reflect avoidance of threat and/or the tendency to disengage attention away from threat. However, this attentional bias was not modulated by trait-anxiety and therefore was not consistent with Sibrava and Borkovec's (2006) cognitive avoidance theory of anxiety presupposing an avoidance strategy for self-preservation. It has been proposed that such cognitive biases are characteristic of people vulnerable to anxiety disorders, nevertheless the data suggest that the ability to disengage a negative emotional set may be a general adaption for regulating emotional state.

The present study also revealed that trait anxiety was related to an anxiety-related attentional bias for positive IAPS pictures, such that the positive to neutral switch cost was reduced with increasing levels of trait anxiety implicating an attentional avoidance of positive IAPS pictures. Although cognitive avoidance theory (Sibrava & Borkovec, 2006) does not make specific predictions regarding the processing of positive information, this result seems counter-intuitive given that positive information is considered non-anxiety evoking. However, diverting attention away from relatively innocuous stimuli in search of possible sources of threat could be interpreted as a behaviour contributing to maintaining the experience of anxiety, but there are other possible explanations. Using non-threatening distractor stimuli, Graydon and Eysenck (1989) reported greater distraction for high trait-anxious individuals with increasing processing demands. The authors concluded that since high anxious individuals have less residual working memory (e.g. see Darke, 1988) they have less processing capacity to prevent distracting stimuli from interfering with task performance. Therefore, reduced working memory capacity at the cost of increased distractibility may have contributed to the improved flexibility when switching to the emotional neutral task from the positive IAPS task. However, one would expect trait anxiety to modulate both positive and negative emotional switch costs, for both the IAPS and faces data sets, if the limited working memory capacity explanation was valid. The fact that differential effects were observed for the faces and IAPS sets would seem to suggest that selective attentional biases were responsible for the observed modulations by anxiety.

Johnson (2009) points out that each switch cost represents a combination of all the executive processes required to disengage a previous mental set and engage a new mental set. Therefore, ambiguity lies in the interpretation of which component processes are driving the observed switch costs. An attentional bias for threat-related information in anxiety would predict that speeded shifting or accelerated engagement is largely considered the main contributor to the observed reduced switch cost for threatening stimuli, although it is equally viable that anxious individuals disengage more quickly from neutral stimuli (in this case the words) in order to detect more threatening stimuli more quickly. Despite this ambiguity, the present work demonstrates most importantly a threat-related processing bias, which affects task-switching processes. Future research is necessary to disambiguate the executive processes contributing to the observed switch cost reduction for neutral to threat-related task-set switching.

Chapter 5 The Metaphorical Representation of Affect Pervades Sensorimotor Behaviour

5.1 Introduction

Popular figures of speech often use metaphor to link affect with perceptual experience (Kovecses, 2000). One particularly pervasive and productive metaphor is the vertical position metaphor, which underlies the understanding of the relatively abstract concept of affect. Objects located ‘high’ or ‘above’ are generally considered to be positive and objects positioned ‘low’ or ‘down’ are generally evaluated negatively. This metaphor is perhaps most famously utilised in biblical accounts of heaven representing all that is good as located ‘above’ and its counterpart, hell, ‘below’. Metaphor can also be an important communication tool. For example, the association of spatial location with positive mood state is expressed in the phrase “things are looking up”, whereas “feeling down” reflects a negative affective state. Even a lowered head tilt can be judged to be symptomatic of a more depressive state (Waxer, 1974a, 1976; Waxer, 1974b).

Many examples can be offered to highlight the ubiquity of the pairing of affect with a metaphorical physical construct. Such abstract thoughts Piaget and Inhelder (1969) propose are built upon our earliest sensorimotor experiences. According to this view, children inextricably associate physical sensations with cognitive representations. For example, pleasant sensory experiences are held with a positive regard. This pairing between environmental feedback and abstract conceptual construction, they suggest, provides the foundation for future representations. In this sense we can trace the origins of describing something invoking a negative feeling state as literally ‘leaving a bad taste in the mouth’.

Interaction with the physical world introduces biased associations between affect and vertical location. The earliest social (e.g. smiling) and physical (e.g. light and food) rewards an infant receives comes from above, therefore it makes perfect evolutionary sense that a positive cognitive bias continues to exert subtle influences on spatial representation. Consider that we typically make a thumbs up gesture to signify a positive evaluation, while the converse is true of a thumbs down response. The spatial metaphor clearly permeates our conceptualization of the abstract notion of affect, allowing us to communicate our cognitive experiences intelligibly. However, as Lakoff and Johnson (1999) have suggested, metaphoric representation may not solely serve as a communicative aid but may above all else reflect our cognitive constructs of abstract concepts routed in perceptual-conceptual associations acquired in infancy (see Meier & Robinson, 2005). Thus, it is of interest to explore empirically the spatial location metaphor as a consistent cognitive bias in the representation of the abstract concept of affect.

Based on the ideas expressed in Lakoff and Johnson (1999), Meier and Robinson (2005) identify three areas of exploration: the encoding and representation of affective stimuli based on spatial metaphor; sensorimotor production under affective bias; and the automaticity of these processes. Existing findings provide convincing evidence that people represent affective stimuli in a metaphor-consistent way (i.e. up=good; down=bad). In one investigation (Lundholm, 1921), individuals were asked to visually depict positive and negative affective word stimuli in line-form as they saw fit. Although metaphoric construct was not of primary concern in this study, words such as *merry* and *cheerful* were associated with lines having an upwards directional tendency and words such as *sad* and *mournful* with downward directional lines. In testing the proposition that the spatial representation of affect biases stimulus encoding, Crawford et al. (2006) reported a vertical location bias in affective stimulus recall, where after stimulus presentation participants reported to have seen positively valenced images higher (and negative lower) than their original location. These findings point to a relatively implicit activation of vertical metaphor when evaluating affective stimuli.

In a series of studies, Meier and Robinson (2004) sought to determine whether the associations between valence and vertical position are obligatory rather than voluntary. To test this prediction, evaluation latencies of positive and negative words were assessed in a task where vertical position was irrelevant and positive and negative words were randomly located in either upper or lower visual positions. Evaluations of positive words were faster when presented in the upper vertical position and conversely negative in the lower vertical position, in comparison to incongruent vertical metaphor locations. In a second study, positive or negative evaluations of centrally presented affective words were found to activate selective attention mechanisms in a metaphor-consistent manner. Responses were faster to non-affective target stimuli presented above relative to below fixation following evaluation of a centrally-positioned positive word, as were responses to stimuli presented below relative to above fixation faster following a negative word evaluation. The fact that vertical metaphor associations were necessarily retrieved in parallel to mental operations related to affective material suggests that metaphors linking affect and vertical direction are obligatory in nature. However, a third study further examined perceptual-conceptual associations by reversing the sequence of event in the second study. Participants first responded to an upper or lower spatial probe and subsequently evaluated centrally presented words. The results from these studies showed that while affective evaluations biased visual perception (i.e. ‘bad’ activates ‘down’; study 2), the activation of areas of visual space was not sufficient to induce affective associations (i.e. ‘down’ does not activate ‘bad’; study 3). On the basis of these results, Meier and colleagues were able to confirm Lakoff and Johnson’s (1999; see also Piaget & Inhelder, 1969) arguments concerning the development of abstract thought being established upon concrete experience and conceptual thought. In summary, it appears that valence, and spatial location associations are unidirectional in nature and as such, affective metaphors may only be activated following affective judgements.

Although people appear to represent affect automatically on the basis of verticality, the extent to which this affective bias pervades sensorimotor behaviour has received relatively little investigation. Contemporary theories of emotion (Davidson, Saron, Senulis, Ekman, & Friesen, 1990; Elliot & Covington, 2001 for a review; Lang, 2000) contend that emotion drives our basic motivational systems. Approach versus avoidance motivation systems are thought to direct our behavioural response to affective stimuli. The defensive reflex of blinking is an example of primitive avoidance behaviour that reflects an unpleasant reaction response (Bradley, Codispoti, Cuthbert, & Lang, 2001). Lang and colleagues (1990) reported that negative stimuli were associated with a greater blink reflex than positive stimuli. Extending from this, approach- and avoidance- related active motor movements appear to be strongly represented by spatial-affective associations, even when affective evaluations are not explicitly involved (Chen & Bargh, 1999); Approach responses (a ‘pull’ flexor motor movement) to positive stimuli and avoidant responses (a ‘push’ extensor motor movement) to negative stimuli are faster in comparison to incompatible conditions (Solarz, 1960). In the vertical domain, Cacioppo et al. (1993) reported that participants’ like-dislike preferences of Chinese ideographs were biased as a function of their presentation during arm flexion (pushing up against a hard surface) or extension (pushing down on a hard surface). Liking for stimuli was automatically influenced by the metaphorically consistent approach-avoidance response. Based on these findings, the motor-process hypothesis (Cacioppo, Priester, & Berntson, 1993) proposes that sensorimotor responses can influence attitude development, with arm flexion, in contrast to extension, associated with an approach motivational orientation. Extrapolating from this finding and the ideas expressed in the developmental theories (Lakoff & Johnson, 1980, 1999; Piaget & Inhelder, 1969), it is proposed that metaphors related to the verticality of affect (i.e., up=good; down=bad) could manifest in approach/avoidance motor behaviours along the relative directions ‘up’ and ‘down’ respectively, when engaged in an affective experience.

Forster and Strack (1996) propose a conceptual-motor compatibility model to explain how avoidance/approach motor behaviours could influence cognitive processes in this manner. Cognitive constructs, they contend, store compatible motor-action and evaluative concepts. When compatible combinations of motoric and conceptual tasks are performed, cognitive capacity is facilitated, whereas incompatible combinations inhibit. Accordingly, vertical metaphor-related stimulus-motoric pairings should systematically modulate the efficiency of the behavioural response to affective material. This mechanism, however, only appears to manifest when evaluative judgments in an affective dimension are given (Cacioppo, Priester, & Berntson, 1993; Forster & Strack, 1996), as such affective metaphors do not appear to be activated from sensory experience alone, rather they require an active engagement of the stimulus.

5.1.1 Overview of Studies

If affect is represented on the basis of a vertical metaphor, then an affective experience should activate the sensorimotor processes linked to the metaphor, in accordance with the second testable prediction of Meier and Robinson (2004). Forster and Strack (1996) make similar predictions in their conceptual-motor compatibility model. According to the model, one should expect facilitation of response when compatible combinations of motor-action and conceptual task are performed (i.e. ‘up’ and ‘positive’). If a conceptual framework exists, linking compatible motoric and evaluative concepts, and is implicitly active, then compatible responses should be faster than incompatible responses.

Here two studies are presented which directly test these predictions. Both are lexical decision tasks (modified from the classic Simon task) concerned with vertical position, emotional valence and reaction time response as recorded via an up/down finger movement sensor. In the first experiment, participants made emotional valence categorization judgements (using a vertical movement sensor) on positive and negative affective lexical stimuli presented on a vertical axis (above versus below a central fixation cross). It is important to note that participants would be consciously and intentionally evaluating word stimuli so any conceptual-motor compatibility effects, which might be observed cannot be said to be automatic under this procedure. To test whether conceptual-motor compatibility is non-conscious, Experiment 2 was designed to remove the conscious evaluation of the word stimulus, thus if the predicted conceptual-motor compatibility effect was observed in this case, it could be conclude that automatic evaluation of word stimuli in turn automatically predisposes linking of compatible motoric and evaluative concepts.

In the second experiment, participants were required to make colour categorization judgements (using the same vertical movement sensor) on positive and negative lexical stimuli presented on a vertical axis (above versus below a central fixation cross). It was predicted that metaphor-consistent activation of sensorimotor behaviour would only become apparent following an affective judgement (i.e., Experiment 1), in line with the findings of Meier et al (2004; studies 2 and 3) and the predictions made by Lakoff and Johnson (1999) and also Piaget and Inhelder (1969) concerning the development of perceptual-conceptual associations.

Additionally, Experiment 2 extends on previous work by Meier et al. (2004), who showed that associations between valence and vertical position are obligatory when affective judgements are made, by examining whether this association persists in the absence of valence evaluations. It is expected that if affective metaphor bias is implicitly accessed, then the task-irrelevant factor, that is emotional valence (positive or negative), should influence response times in a metaphorically consistent manner; positive words would be responded to more quickly when in the higher (vs. lower) vertical position, whereas the opposite would be true for negative words. Experiment 1 allows one to test whether Meier et al.'s (2004) findings can be replicated when participants must once again perform affective judgements.

In both experiments, stimulus position was irrelevant to the task but if a conceptual framework exists, integrating stimulus location and response mappings, and is implicitly active, then congruent[8] upward responses to top positioned stimuli and downward responses to bottom positioned stimuli should produce faster reaction times than incongruent upward responses with bottom positioned stimuli and downwards responses to top positioned stimuli. This type of stimulus-response spatial congruency is referred to as the Simon effect and is a robust effect reported in many studies. Therefore, it was predicted that a Simon effect would be observed in both Experiments 1 and 2.

5.1.1.1 Influence of anxiety on conceptual-motor compatibility

A secondary aim was to investigate the concept of metaphor-consistent cognitive constructs, linking affect and vertical location, being modulated by anxiety.

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[8] Congruency will be used to describe the accordance between stimulus and response locations, while the term compatibility will be used to differentiate the accordance of conceptual and response locations.

Models of anxiety focus on attentional processes because one function of anxiety is to facilitate the detection of threat, to enable a fast response. In accordance with the predictions of the cognitive theories (e.g., Bower, 1981; Bower, 1987; Williams, Watts, MacLeod, & Mathews, 1997; Williams, Watts, Macleod, & Matthews, 1988), high levels of anxiety are associated with selective attentional biases of negative information. Selectivity for threat-related words in persons with a variety of anxiety disorders (e.g. post-traumatic stress, panic disorder, social phobia, GAD) have been documented with the modified Stroop task (e.g., Mathews & Macleod, 1985; McNally, Riemann, Louro, Lukach, & Kim, 1992; Mogg, Mathews, & Weinman, 1989). Most notably the reported colour-naming interference does not appear to rely on conscious attention; interference from subliminally presented threatening stimuli has been reported in four studies (Macleod & Hagan, 1992; Macleod & Rutherford, 1992; Mogg, Bradley, Williams, & Mathews, 1993; Mogg, Kentish, & Bradley, 1993). Experiment 2 was a modified version of the emotional Stroop task, specifically, participants were asked to name the ink colour of the words (using upwards/downwards finger responses), disregarding their semantic content. Thus, it was hypothesised that an attentional bias in anxiety would be demonstrated in longer responses to name the colour of negatively valenced words. Furthermore, since one would expect highly anxious individuals to be distracted by the emotional content of the words, if there exists a conceptual-motor compatibility bias, facilitating responses when compatible combinations of motor-action and conceptual task are performed (i.e. ‘down’ and ‘negative), then heightened anxiety would be associated with an increased effort necessary to emit an incompatible behaviour, particularly with negatively valenced stimuli.

5.2 Method

5.2.1 Participants

Thirty-four students were pre-selected based on their score on the trait version of the State-Trait Anxiety Inventory (STAI; Spielberger, 1983) from a sample of 48 University of Glasgow undergraduate students. The sample comprised of 22 females and 12 males, between the ages of 18 to 28 years, who were right-handed native English speakers. All participants had normal or corrected-to-normal vision and without neurological disease. The study was approved by the Glasgow University Research Ethics Committee and performed in appliance with their guidelines. Participation was voluntary and paid. Participants were naïve to the full purpose of the study and gave consent on the basis of receiving a full debriefing on completion.

A median split (median = 41) was performed on the scores of the trait version of the State-Trait Anxiety Inventory (Spielberger, 1983) , excluding participants scoring in the range of 39-43. On this basis, two groups of 17 participants were created: the high anxiety group (HTA) and the low anxiety group (LTA). Group characteristics are reported in Table 5-1. Participants completed both the trait and state versions of the STAI before the ERP session. *t*-tests showed that the two groups were significantly different in trait-anxiety scores ($t(32) = 11.56$, $p < .0001$) and in state-anxiety scores ($t(32) = 11.56$, $p < .0001$) with the high-anxious group scoring higher than the low-anxious group on both measures. Participants' state anxiety scores ranged from 20 to 56 ($M = 33.85$, SD = 8.98). Participant's trait anxiety scores ranged from 24 to 66 ($M = 40.97$, SD = 11.53). These scores are similar to the published norms for college students (*M*(state) = 37.61, SD, 10.98; *M*(trait) = 39.35, SD, 9.66) (Spielberger, 1983). Participants also completed the Beck depression inventory (Beck, Steer, & Brown, 1996). Using the cut-off scores as recommended by Furlanetto et al., (2005), 19 of the participants were defined as having no or minimal depression, 13 as having mild to moderate depression and 2 with scores in the moderate to severe bracket. Of the 15 participants with scores indicating clinical levels of depression, 12 of these belonged to the HTA group, including both participants with scores in the severe bracket.[9] A *t*-test of group differences in depression scores was significant ($t(32) = 4.68$, $p < .0001$); the HTA group scoring higher as one might expect.

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[9] Total scores on the BDI less than 10 indicate the absence of depression or very minimal depression. Scores equal to and above 10 are considered to be indicative of clinical levels; 10-18 for mild to moderate depression, 19-28 for moderate to severe depression and 29 and above for severe depression (Furlanetto, Mendlowicz, & Bueno, 2005). *N.B.* The two reported cases belonging to the moderate to severe category scored a total of 22 and 25 each on the BDI.

Table 5-1. Means and standard deviations (in brackets) for scores on the Trait and State versions of the STAI and BDI. Statistics are provided for high and low anxiety groups.

	High	**Low**
N	17	17
Age (years)	23.3 (5.2)	25.6 (6.3)
T-Anxiety	48.95 (8.6)	30.76 (4.5)
S-Anxiety	37.79 (8.4)	28.41 (6.8)
BDI	12.71(5.7)	4.53 (4.4)

5.2.2 Stimuli

Two word sets were employed, that is the original word set used by Meier and Robinson (2004) and a second set compiled from the Affective Norms for English Words (ANEW) database (Bradley & Lang, 1999). The Meier and Robinson (2004) set consisted of 100 words, half with positive meaning (e.g. baby) and half with negative meaning (e.g. diseased) (see Appendix B). The number of letters was similar for positive ($M = 6.26$) and negative words ($M = 6.04$), $F < 1$ (Meier & Robinson, 2004). In their study, 7 participants rated the valence of each of these words (1=extremely negative, 5=neutral, 9=extremely positive). Mean valence scores for the positive ($M = 7.46$) and negative ($M = 2.42$) word groups were significantly different on this rating, $F(1, 98) = 1040.44$, $p < .0001$, and the absolute difference between the valence rating of each word and the neutral midpoint was equal for positive and negative words, $F < 1$ (Meier & Robinson, 2004). The authors provided no norms regarding arousal or word frequency, therefore the arousal and valence values were determined for the words included in the Affective Norms for English Words (ANEW) database (Bradley & Lang, 1999). In the ANEW dataset, valence is rated on a 1-9 scale (1 = negative to 9 = positive) and words are only included on the list if they have a valence standard deviation ≤ 2. Arousal is calculated relative to valence via a median split, excluding the middle 50 words since few words could be labelled as arousing and neutral or non-arousing and positive or negative. Each word has an arousal rating on a 9-point scale (1 = low to 9 = high).

Average valence and arousal values for the 20 positive words included in the ANEW database were 7.38 and 5.29 and for the 23 negative words 2.92 and 5.64, respectively. Median valence scores are very similar to those reported in Meier and Robinson (2004) for the entire word set (M(positive) = 7.46; M(negative) =

2.42). *t*-tests showed that there was a significant difference in emotional valence between the positive and negative word sets (7.38 vs. 2.92), *t*(41) = 18.85, *p* < .0001, and that the arousal values of these sets did not significantly differ (5.63 vs. 5.29), *t*(41) = 1.22, *p* > .05.

A supplementary word set (see Appendix B) was created from the ANEW database (Bradley & Lang, 1999) that excluded any of the words included in the original set of Meier and Robinson (2004). Using the CELEX Lexical Database (Baayen, Piepenbrock, & van Rijn, 1993), word frequencies per million were determined for this set of positive and negative words; 25 low frequency (LF; 9.64) positive words, 25 high frequency (HF; 52.6) positive words, 25 LF negative words (9.0) and 25 HF negative words (50.36). Word valence and arousal values for positive words were 7.98 and 6.68. Word valence and arousal values for negative words were 2.22 and 6.51, respectively. Positive words were rated as significantly more positive than the negative words (7.98 vs. 2.22), *t*(98) = 62.52, *p* < .0001, although they did not differ in respect to arousal (6.67 vs. 6.46), *t*(98) = 1.46, *p* > .05.

5.2.3 Procedure

On arrival, participants were invited to sit in front of a computer and to read the statements on-screen and decide how closely these statements described the way they felt, indicating their response in the spreadsheet. It was emphasised that they should answer as quickly and accurately as possible and that there was no right or wrong answer. They completed three spreadsheet templates measuring state anxiety, trait anxiety, and depression in order.

Following this, participants were shown into the testing booth, a moderately sound-proofed room with ambulant lighting, and asked to sit in front of a 21” Samsung monitor, at a viewing distance of about 80 cm, with their chin placed on a chin-rest. Word stimuli were presented in coloured (greenish and bluish) 20-point Helvetica font on a black background above or below fixation at a distance of 3° of visual angle from the centre of the screen. Approximately three characters subtended 1˚ of visual angle. Participants responded to word stimuli on the screen by using their right index finger to operate a response force key, which was mounted on a board. A leaf spring (55×20×2 mm) was held by an adjustable clamp at one end, while the other end remained free. Strain gauges were attached near the fixed end of the leaf spring. The fingertip was located in an adjustable thimble-like holder fixed at the free end. The force key allowed for near-isometric recordings of index finger flexion (downward) and extension (upward). A response was registered as soon as force output exceeded a criterion of 60 cN (1 cN is about 1 gram) from the baseline force level in either the downward or upward force direction. The right forearm and palm rested comfortably on the board, such that any body movements other than right index finger movements were minimized. Reaction times were measured with millisecond resolution. Participants were encouraged to make rapid responses but also to respond accurately and feedback was given on these measures after each trial.

Participants were instructed to read on-screen instructions as to how to move their finger in response to what they saw on-screen as quickly and as accurately as possible. Their understanding of the task was reinforced by the experimenter before each experimental task and by appropriate paper ‘map’ reminders on how to complete the task that remained with them throughout the experiment. The experiment was controlled by the Experimental Run Time System (ERTS) software (Dutta, 1995).

When participants were ready, the experimenter pressed a key to begin each experimental task. This would clear the on-screen instructions and the first block of trials would begin. At the start of each trial, a fixation cross was shown in the centre of the screen for 700 ms. Following this, a word appeared either above or below fixation until response onset. Participants were told to evaluate each word as quickly as possible and as accurately as they could by performing the appropriate force key response. After word offset a blank interval of 500 ms duration followed before the next trial started with the presentation of the fixation cue.

Participants completed both an affective judgement task (Experiment 1) and a colour judgement task (Experiment 2). Tasks were counterbalanced and participants randomly assigned to task orders to prevent order effects. Practice trials with performance feedback were also included to facilitate learning of the task and counteract practice effects. To eliminate any effects resulting from allocation of response keys to word valence, the S-R mapping was balanced across participants.

The affective judgment task started with a practice block consisting of 48 trials in which the words ‘positive’ and ‘negative’ were presented randomly above or below fixation and participants were asked to judge the valence of the word by responding with the appropriate response, ‘positive’ or ‘negative’. The practice and experimental stimuli were randomly presented in greenish or bluish colour. Then followed two blocks of 100 experimental trials each, one in which the words used by Meier and Robinson (2004) were presented and one in which the affective words of the new word set were displayed. Each block contained 50 positive and 50 negative words that were presented in random order above or below fixation. Participants were asked to judge the valence of the word by responding either ‘positive’ or ‘negative’. In the so-called compatible condition, positive words were assigned with an upward (extension) movement and negative words with a downward (flexion) movement. In the incompatible condition, this S-R assignment was reversed and positive words demanded downward (flexion) movement whereas negative words demanded upward (extension) movement. Word colour was task irrelevant. Participants performed one block using the compatible mapping and the other block using the incongruent mapping. The order of compatible and incompatible blocks was balanced across participants.

In the colour task, participants were asked to decide whether the word was displayed in greenish or bluish colour, that is, word valence (positive or negative) was task-irrelevant. Participants were asked to judge the colour of the displayed stimulus and to respond according to instructions with the appropriate force key response. On one block of experimental trials participants responded with an upwards motion for greenish targets and a downwards motion for bluish targets, and vice versa for the second block. The order of this mapping was balanced across participants. The experiment started with a practice block of 48 trials in which one stimulus of a set of three (HHHHHHHH, SSSSSSSS, XXXXXXXX) was randomly presented in greenish or bluish colour above or below fixation. Then followed two blocks of 100 experimental trials each, one in which the words used by Meier and Robinson (2004) were presented and one in which the affective words of the new word set were displayed. After the first block of 100 trials, there was a brief break. Each block contained 50 positive and 50 negative words that were presented in random order above or below fixation and the colour of the word stimulus was randomized.

Half of the participants commenced with the affective judgment task and then performed the colour judgment task, whereas the other half of the participants performed the two tasks in reverse order. The order in which word lists were presented in the two tasks was balanced across participants. On completion of the experiments, each participant was then debriefed as to the purpose of the experiment and asked to complete the consent form to confirm this.

5.2.4 Data analysis

Repeated measures ANOVAs were performed on the reaction time latencies and percentage error scores for both tasks and a 5% significance level was adopted for all analyses. Both the affective judgement and the colour judgement tasks employed a factorial 2x2x2x2 ANOVA with anxiety group (HTA vs. LTA) as a between-subjects factor and target location (top vs. bottom position relative to central fixation), response (upwards vs. downwards finger movement) and valence (positive vs. negative word) as within-subjects factors. The first four trials of each experimental block were considered warm-up trials and excluded from data analysis, as were incorrect response trials and those with RT < 100 ms (anticipations) and RT > 2,000 ms (misses). Analogous analyses were performed on the mean error percent rates.

5.3 Results

5.3.1 Experiment 1

Mean RT and mean error rate are depicted in Figure 5-1.

5.3.1.1 RT Analysis

A main effect of valence indicated that participants were faster to respond to positively valenced words relative to negatively valenced words (888 vs. 911 ms), $F(1,32) = 10.22$, $p < .01$. The ANOVA revealed a significant Target Location

× Response interaction, *F*(1, 32) = 7.47, $p < .05$ (cf. Figure 5-1). Planned contrasts revealed that responses were significantly faster when an upwards response rather than a downwards response was made to stimuli located above fixation, (886 vs. 909 ms), *F*(1, 32) = 8.31, $p < .01$, and similarly downwards rather than upwards responses were faster for stimuli presented below fixation (893 vs. 910 ms), *F*(1, 32) = 7.68, p < .01. A significant Valence x Response interaction was observed, *F*(1, 32) = 5.19, $p < .05$. Planned contrasts revealed that participants' responses were significantly faster when an upwards rather than a downwards response was made to positive stimuli (871 vs. 905 ms), *F*(1, 32) = 4.29, $p < .05$. There was a strong trend for faster responses when a downwards rather than an upwards response was made to negative stimuli (896 vs. 926 ms), *F*(1, 32) = 4.06, $p = .05$. There was a trend for the HTA group to respond slower overall in comparison to the LTA group (936 vs. 862 ms), *F*(1, 32) = 3.00, $p = .09$. No other effects were significant (all Fs < 2.89, *p*s > .05).

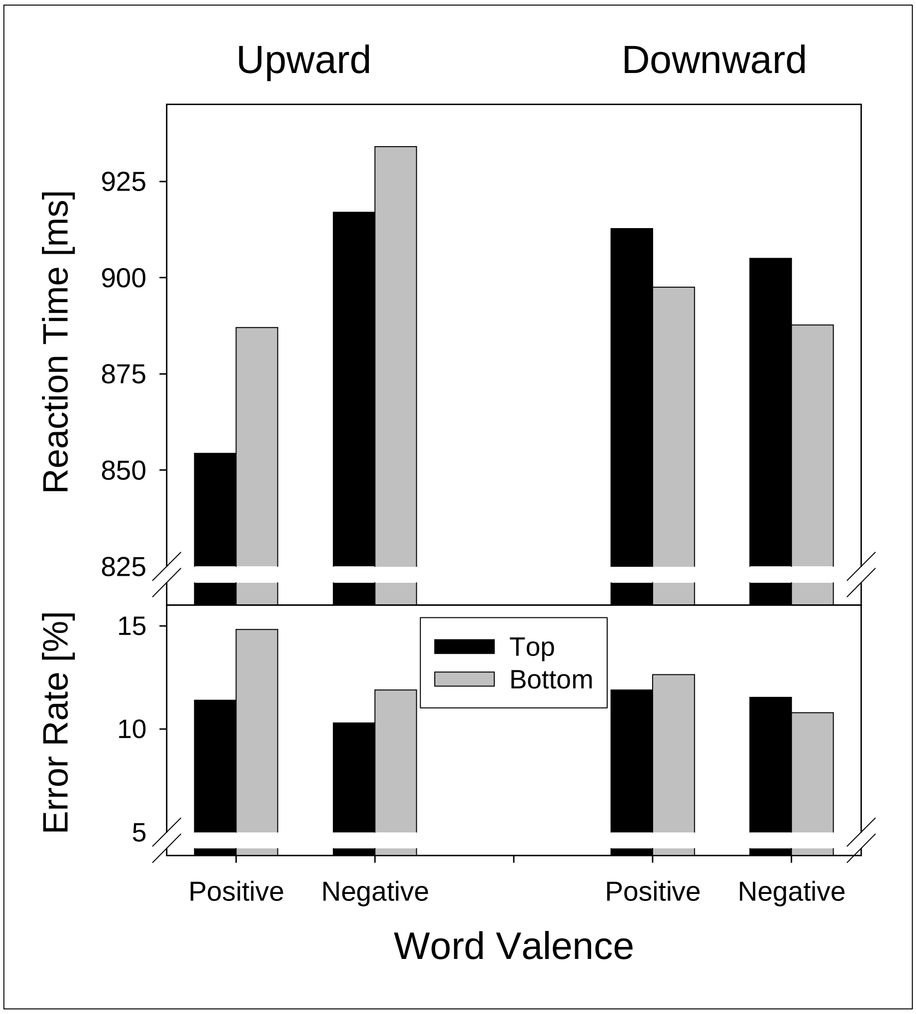

Figure 5-1. Mean reaction times and percentage error rates across the entire sample population in the affective judgement task.

5.3.1.2 Error Analysis

Error rates were subjected to comparable ANOVAs performed on the RT data. There was a significant Target Location × Response interaction, $F(1, 32) = 4.35$, $p < .05$. However, planned comparisons revealed that there was no significant difference in error rate when either an upwards or downwards response was required for targets presented above fixation (10.8 vs. 11.7 %), $F(1,32) = 0.43$, $p > .05$. Neither was there a significant difference in error rate between upwards and downwards response trials when targets were presented below fixation (13.3 vs. 11.7 %), $F(1,32) = 2.07$, $p > .05$, which indicates that the stimulus-response congruency effect observed in the RT data was not compromised by a speed accuracy trade-off. All other effects were insignificant (all *F*s < 2.92).

5.3.1.3 Regression Analyses

Additional regression analyses were used to evaluate the predictive utility of trait-anxiety scores on the observed conceptual-motor compatibility effect for both positive and negative word stimuli. The conceptual-motor compatibility effect was defined as a difference in RTs between compatible and incompatible trials (i.e. incompatible – compatible)[10], which was calculated separately for both positive and negative word stimuli. Positive scores reflect the fact that participants were faster on compatible trials, whereas negative scores reflect the fact that participants were faster on incompatible trials. However, the conceptual-motor compatibility effect was not significantly moderated by trait anxiety for either positive, $ß(32) = 0.97$, $p = .53$, or negative word stimuli, $ß(32) = 0.12$, $p = .93$. Plots of the fitted least squares regression lines are shown in Figure 5-2 and Figure 5-3 for positive and negative word stimuli, respectively. As the figures and the analyses indicate, trait-anxiety level was not a reliable predictor of the conceptual-motor compatibility effect for either positive or negative word stimuli.

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[10] Regression analyses with trait anxiety as the criterion variable and conceptual-motor compatibility as the predictor variable were performed only for Experiment 1 since the conceptual-motor compatibility effect was not observed in Experiment 2.

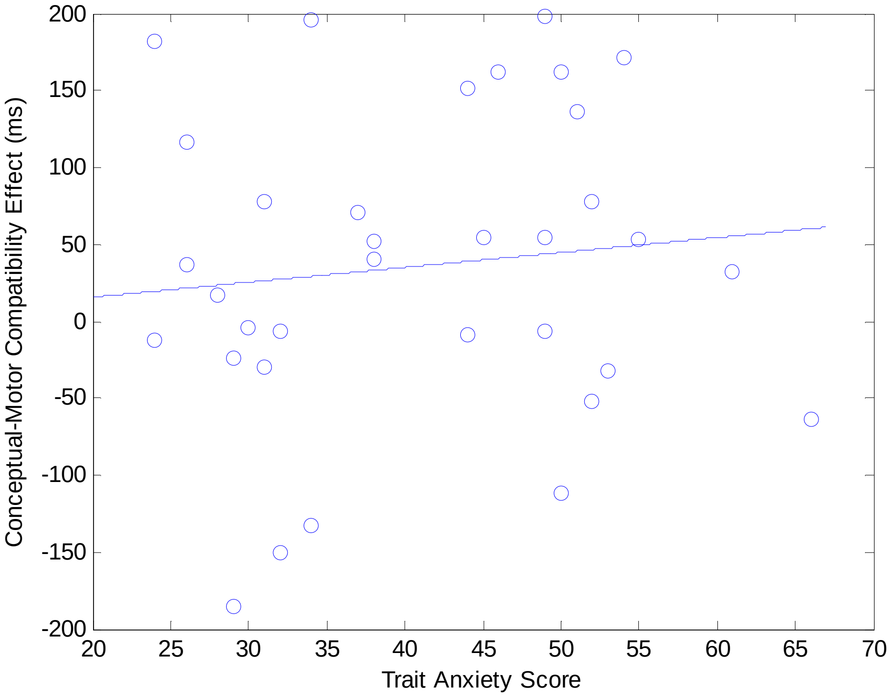

Figure 5-2. Conceptual-motor compatibility effect for positive word stimuli (i.e., 'incompatible RT'-'compatible RT') plotted against trait-anxiety scores on the STAI along with the fitted least squares linear regression line.

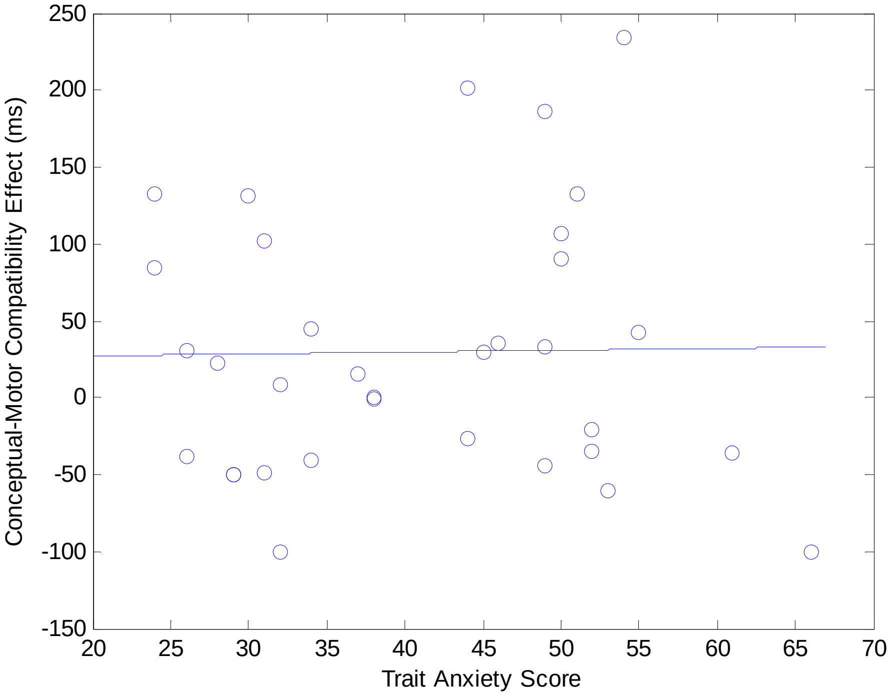

Figure 5-3. Conceptual-motor compatibility effect for negative word stimuli (i.e., 'incompatible RT'-'compatible RT') plotted against trait-anxiety scores on the STAI along with the fitted least squares linear regression line.

5.3.1.4 Discussion

Metaphor-compatible directional movements were demonstrated to facilitate response latencies; participants were relatively faster to make upward responses to positive words and downward responses to negative words than to metaphor-incompatible stimulus-response mappings. These findings suggest that a conceptual framework exists, linking compatible motoric and evaluative concepts, thus reconfirming the predictions of Meier et al. (2004), that the association between valence and verticality is obligatory rather than voluntary.

The regression analyses intending to investigate the relationship between the conceptual-motor compatibility effect for both positive and negative stimuli and trait anxiety sores did not reveal self-reported anxiety to be a reliable predictor of the metaphoric motor bias to affective stimuli. This result is perhaps surprising in light of the anxiety literature reporting increased attentional distractibility in the face of environmental threat (Eysenck, 1988). Although whilst the word stimuli used in this experiment were controlled for valence and arousal, it is possible that stimuli with a greater biological significance (e.g. IAPS; Lang, Bradley, & Cuthbert, 2008), or specifically threat-related stimuli, may evoke greater attentional biases than that observed and particularly in those with heightened anxiety. Indeed, Williams, Mathews, and MacLeod (1996) found that Stroop interference for emotional words was related to the degree to which words are semantically related to the schema in any specific disorder. For example, specific biases were reported for social phobia and specific phobia.

Reaction times were faster when response movement direction and stimulus location corresponded (i.e. top stimulus/upwards response, bottom stimulus/downwards response) rather than not, clearly demonstrative of the classic Simon effect. It refers to the fact that stimulus-response mappings where the location of the stimulus (up or down) matches the location of the response (up or down) are easier to perform than otherwise incongruent mappings. Even though stimulus location is an irrelevant factor it cannot be ignored and interferes with response selection. There appears to be a comparable congruency between the spatial codes of the response and the task-irrelevant spatial codes of the stimulus (sensory driven versus metaphorical) producing the Simon and conceptual-motor compatibility effects. It was reasoned that if the conceptual-motor compatibility effect originated from a spatial representation that shared circuitry with the spatial codes that produce the Simon effect, the two effects would show interactivity. The fact that these effects combined additively leads one to speculate that distinct processes are contributing to these RT effects.

Overall, participants responded faster to positive words than negative words. This finding mirrors previous studies reporting faster categorization of positively toned words than negatively toned words (e.g. Feyereisen, Verbekedewitte, & Seron, 1986; Stenberg, Wiking, & Dahl, 1998), thus supporting the possibility that the cognitive system is biased for positive signals. However, unlike the studies of Meier et al. (2004) the present study did not find that positive words were responded to more quickly when in the higher (vs. lower) vertical position, or vice versa for negative words. Therefore, the present findings do not support the proposition that associations between valence and vertical position are obligatory.

5.3.2 Experiment 2

The goal of the second experiment was to extend the findings from Experiment 1 to test the automaticity of the conceptual-motor compatibility effect. For this purpose, word valence was task-irrelevant and participants had to respond instead to the colour of the words. Mean RT and mean error rate are depicted in Figure 5-4.

5.3.2.1 RT Analysis

The effect of group failed to reach significance, as did all other main effects (All *F*s < 1.48). However, a significant Target Location × Response interaction was present, *F*(1, 32) = 45.43, *p* < .0001 (cf. Figure 5-4). Planned contrasts revealed that responses were significantly faster when an upwards response rather than a downwards response was made to stimuli located above fixation, (675 vs. 720 ms), *F*(1, 32) = 26.88, *p* < .0001, and similarly downwards rather than upwards responses were faster to stimuli presented below fixation (671 vs. 720 ms), *F*(1, 32) = 13.54, p < .001. All other interaction effects were non-significant (All *F*s < 1.98).

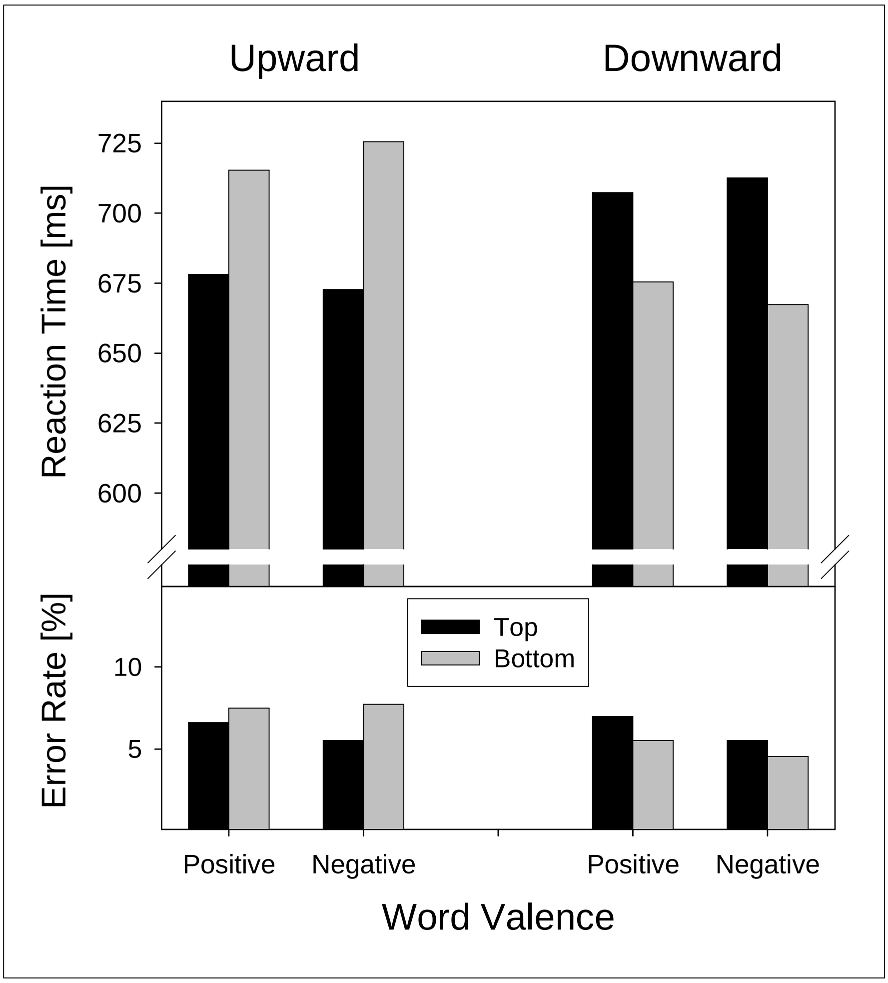

Figure 5-4. Mean reaction times and percentage error rates across the entire sample population in the colour task.

5.3.2.2 Error Analysis

The Target Location × Response interaction was significant, *F*(1, 32) = 4.43, p < .05. However, planned comparisons revealed that there was no significant difference in error rate between upwards and downwards response trials when targets were presented above fixation (6.7 vs. 6.3 %), *F*(1,32) = .03, *p* > .05. Neither was there a significant difference in error rate between upwards and downwards response trials when targets were presented below fixation (7.6 vs. 5.0 %), *F*(1,32) = 3.61, *p* > .05. Therefore, the stimulus-response congruency effect observed in the RT data does not appear to be a corollary of a speed-accuracy trade-off. All other main effects and interactions failed to reach significance (all *F*s < 2.24).

5.3.2.3 Discussion

In the second experiment, participants were asked to make upwards or downwards finger responses determined by the colour of affective word stimuli; the emotional valence of the word was task irrelevant, as was target location. The irrelevant dimension of word valence did not significantly influence responses in this task unlike for the affective judgement task, thus the data support the notion that the encoding and representation of affective stimuli based on spatial metaphor does not occur automatically - it requires active engagement with the affective stimulus (as in Experiment 1).

As predicted, an independent Simon effect was observed; responses were faster when stimulus and response locations were congruent than when they were incongruent.

5.4 General Discussion

Two experiments sought to determine whether metaphorical representation of affective evaluations pervades action responses. Only when affective judgements of the word stimuli were made did the association between vertical space and the mental representation of affect become apparent. The evidence supports the view that obligatory activation of the vertical-metaphor is contingent upon the semantic evaluation of affective words and is manifest in metaphor-consistent motor facilitation.

As demonstrated in Experiment 1, explicit affective judgments were a necessity for metaphor-consistent behaviour to emerge. Metaphor-compatible directional movements were demonstrated to facilitate response latencies; participants were relatively faster to make upward responses to positive words and downward responses to negative words than to metaphor-incompatible stimulus-response mappings. These findings suggest that a conceptual framework exists, linking compatible motoric and evaluative concepts, and is implicitly active, thus reconfirming the predictions of Meier et al. (2004), that the association between valence and verticality is obligatory rather than voluntary. Extending from the studies of Meier et al. (2004), the current findings suggest that this association is only activated following valence evaluations, therefore is does not appear to be fully automatic. In the current investigation, the spatial metaphor did not influence verticality per se, but rather directional movements along the vertical axis specifically. Unlike the studies of Meier et al. (2004) the current investigation did not find that positive words were responded to more quickly when in the higher (vs. lower) vertical position, or vice versa for negative words. Nonetheless, the results are demonstrative of an obligatory metaphorical representation of affect along the vertical domain pervading sensorimotor responses.

The results from Experiment 1 are consistent with the conceptual-compatibility model proposed by Forster and Strack (1996), whereby stimulus and response incompatibility (either perceptual-motor as is the case of the Simon effect or conceptual-motor incompatibility) affects execution of specific behaviours. Behaviours that are closely associated with abstract spatial representation of affect are more easily elicited than by antagonistic behaviours. Building upon the foundations set by Forster and Strack's (1996) model, a possible mechanism for the observed phenomenon can be put forward. On the basis of these findings, affective judgements may have influenced sensorimotor performance by taxing cognitive capacity in the execution of finger movements. For example, it may be easier to make an upwards finger movement when we evaluate a positive stimulus than when we are required to make a downwards movement. The increased effort necessary to emit an incompatible behaviour may reflect the greater interference on incompatible trials, which must be overcome before an appropriate response is executed. Indeed, cognitive interference stemming from spatial-affective associations does not appear to have been an issue in Experiment 2 when the valence of the word stimuli was irrelevant, giving weight to this claim.

Neumann and Strack (2000) suggest that motor movement processing is facilitated by affective processing in order to serve evolutionary beneficial goals of approach and avoidance. In fitting with this account, Experiment 1 showed that finger extension to produce an upwards movement was facilitated in response to positive words, whereas a downwards flexion enhanced response rates to negative words. In this context, extension can be interpreted as an approach response and flexion as avoidance. Forster and Strack's (1996) conceptual-motor compatibility model proposes that cognitive constructs store compatible motor action and evaluative concepts that when accessed facilitate performance, while incompatible combinations inhibit. However, the problem of ambiguity of response reported in the literature (Forster & Strack, 1996; Puca, Rinkenauer, & Breidenstein, 2006) is not fully explained by this model. This concept refers to the fact that movement towards the self can be interpreted as both approach or withdrawal, depending on the context and can be accordingly induced by manipulating the active frame of reference (e.g. Seibt, Neumann, Nussinson, & Strack, 2008). In contrast to the present study, Cacioppo and his co-workers (1993) found effects indicative of a self-related frame of reference; isometric arm flexion in an upwards movement towards the self was associated with approach and a downwards arm extension with avoidance. While the contrasting findings of Cacioppo and colleagues (1993) and the present study highlight the dissociation of approach/avoidance from motor flexion/extension along the vertical dimension, they also raise the possibility that metaphorical representation of affect can induce the selected frame of reference to influence behaviour in a metaphor-consistent way. For example, positive = up and negative = down, therefore any motor response (flexion or extension) which is in accordance with this metaphor is viable and facilitated in comparison to antagonistic motor actions. However, additional experimentation is necessary to test empirically this prediction.

Attentional biases with respect to aversive stimuli have been demonstrated in individuals with heightened anxiety. Higher levels of anxiety are associated with a greater tendency for attentional capture of threat-related stimuli (Öhman & Mineka, 2001) and also with more difficulty disengaging attention from these stimuli (Fox, Russo, & Dutton, 2002). A consequence of this attentional bias for negative valence is that aversive stimuli tend to elicit slower responses in individuals with elevated anxiety on a range of cognitive tasks. Such propensity has been demonstrated by means of the emotional Stroop task, i.e. delayed responses when presented with threat-related words, and the dot-probe task where slower responses are observed for targets replacing neutral stimuli, presumably due to slow disengagement from threat stimuli. Furthermore, the bias reportedly persists under masked conditions suggesting that it is an automatic, pre-attentive process. Unfortunately, the current findings do not contribute to the attentional-bias to threat hypothesis. Stroop-like interference effects were not observed for either the high or low anxiety groups in Experiment 2. The high trait anxiety group tended to respond slower (to both positive and negative valence words) than the low anxiety group only under conditions of elaborate conscious processing of word valence (Experiment 1), which is more indicative of a general attentional bias to task-relevant emotional information, irrespective of valence. Moreover, this attentional bias to emotional information in the HTA appears to be restricted to the disengage component of attention, since the effect only became apparent when affective judgements had to be made on the stimulus. Thus, the data do not support an attentional orienting bias towards emotional information for heightened anxiety.

5.4.1 Outlook

Response-slowing following negative stimulus presentation is a common finding in cognitive tasks. This behavioural pattern has been linked to an instinctual freezing response in the face of danger. Evolutionary theorists would argue that one of the benefits of immobilization is that most predatory animals respond more readily to visual movement than to other cues. Consistent with this proposal, the delayed responses to negative word stimuli in the affective judgement task suggest that negative stimuli cause a generalized motor suppression. Difficulty disengaging attention from negative information is thought to be responsible for the observed slowing (Fox, Russo, Bowles, & Dutton, 2001; Yiend & Mathews, 2001). If one also considers the results on the colour task where word valence was task-irrelevant and reaction times were not modulated by valence, the combined findings support the delayed disengagement explanation. Although it cannot be stated conclusively, automatic vigilance for emotional information in this task seems unlikely given that attention had to be directed towards the emotionality of the word stimulus before any modulatory effects of valence were observed. However, the current results do support the notion that negative words arrest attentional resources once they are engaged in processing, resulting in slower responses on tasks where word valence is response-relevant.

In summary, the findings strongly imply that the semantic processing of affective words can invoke a metaphorical representation of affect in the spatial domain, where positive equates with ‘upwards’ and negative with ‘downwards’. Although the data suggest that the metaphorical representation of affect is obligatory, it does not appear to be automatic since a semantic evaluation of the stimulus was required to induce this effect. According to Kornblum et al., (1990) physical or conceptual overlap between the stimulus and response dimensions is essential for S-R compatibility effects. The current investigation provides an account that is consistent with the spatial representation of affect facilitating compatible directional movements. However, this conceptual-motor compatibility effect was not modulated by anxiety, therefore one can interpret this as evidence of a general response bias under the influence of the affective metaphor. Thus, the findings suggest that popular use of linguistic metaphors depicting spatial representation of affect may reflect our underlying cognitive construct of the abstract concept of valence.

Chapter 6 General Discussion

6.1 Overview

This chapter will state, summarise, and discuss the conclusions that can be drawn from the work presented in this thesis. In addition, some possible extensions of this work will be considered. This thesis concerns the study of the emotion-cognition interaction as it relates to subclinical anxiety. The questions addressed include: the attentional mechanisms underlying the threat-related bias in anxiety (Chapters 2 and 3), executive control processes in anxiety (Chapter 4), and the mental representation of affect (Chapter 5). Before discussing the results in a wider context, a brief overview of the main findings will be provided.

To answer the question of automaticity of the threat-related processing bias in anxiety, Chapter 2 sought to elucidate whether facilitated processing of threat, evidenced by emotion-related ERP modulations, would occur rapidly and preattentively. The rationale of the experiment was driven by the studies of Bishop et al. (2004), who reported that threat-related stimuli can evoke amygdala activity without attentional engagement or conscious awareness in high-anxious but not low-anxious participants, and Eimer et al. (2003), who reported emotional expression processing, as reflected by ERP modulations, to be gated by spatial attention. Eimer et al. (2003) recognised that the activity measured in ERP and fMRI studies of attention and emotion processing are likely indicative of different stages of information processing, and concluded that ERP measures of affective processing may be attention-dependent. In light of the anxiety-specific amygdala response to unattended threat reported in the Bishop et al. (2004) study, Chapter 2 investigated whether such preattentive processing of threat in anxiety would modulate ERP measures of affective processing. Spatial attention was manipulated using a similar paradigm as Vuilleumier et al. (2001) and Holmes et al. (2003), although participants were instructed to match two peripheral faces or two peripheral Landolt squares. The results from the experiment reported in Chapter 2 do not offer support to the claim that differences in individual anxiety levels are important predictors of emotion-specific ERP responses during unattended conditions, and instead questions whether an attention-independent processing bias for emotional faces is specific to heightened anxiety. This is based on the finding of an enhanced LPP response for threat/happy versus neutral faces and an enhanced slow wave for threat versus neutral faces, neither modulated by the focus of attention for both high and low anxiety groups.

The ERP technique was once again implemented in Chapter 3 to investigate whether threat-related information sustains visual attention as postulated by the delayed disengagement hypothesis (Fox, Russo, Bowles, & Dutton, 2001). Participants made an orientation judgement of a letter stimulus presented to the left or right of a central affective image. Given the usefulness of the ERP technique as a tool for investigating the mental chronometry of attentional deployment, it was hypothesised that if threat-related stimuli are able to prolong attentional processing, N2pc onset should be delayed relative to the neutral condition. Notably, no emotion-specific modulations of the N2pc latency were observed, thus failing to support the delayed disengagement hypothesis. However, since LPP latency has been held to index stimulus evaluation time (Donchin & Coles, 1988), delayed LPP latency for negative relative to neutral IAPS pictures implies that information with a negative emotional value can prolong analysis and evaluative processes. Moreover, a longer LRP-R interval for threatening faces compared to neutral and happy is consistent with the view that motor responses freeze in face of threat. Thus, it appears that the negativity bias may operate at evaluative and motor-response stages of processing.

Chapter 4 investigated whether emotional attention set-shifting – a proposed stage of information processing when one switches between emotional and neutral mental sets- revealed significant modulatory effects by trait anxiety. Using a variant of the classic task-switching paradigm, which incorporates emotional mental set representations, the results on the ACCE task (Johnson, in press) showed that participants scoring higher in trait anxiety were faster to switch from a neutral to a threatening mental set. This finding connecting ACCE and anxiety is directly relevant to theories of anxiety acknowledging a hypervigilance to threat (e.g., Mathews & Mackintosh, 1998; Mogg & Bradley, 1998; Williams, Watts, MacLeod, & Mathews, 1997). However, this processing bias for threat in anxiety was only apparent for emotional faces and not affective scenes, despite the fact that pictures depicting aversive threat scenes were used (e.g., violence, mutilation).

In a series of experiments, Chapter 5 investigated the notion that affect is represented along a metaphorical vertical axis, such that ‘good’ equates with ‘up’ and ‘bad’ with ‘down’. Within the affective judgement task (Experiment 1, Chapter 5), participants made emotional valence categorization judgements (using a vertical movement sensor) on positive and negative affective lexical stimuli presented on a vertical axis. According to Forster and Strack’s (1996) conceptual-motor compatibility model, if a conceptual framework exists, linking compatible motoric and evaluative concepts, and is implicitly active, then compatible responses should be faster (i.e. ‘up’ and ‘positive’) than incompatible responses (i.e. ‘up’ and ‘negative’). To test whether conceptual-motor compatibility is automatic, word valence was an irrelevant stimulus dimension in the colour judgement task (Experiment 2, Chapter 5) and participants were required to make colour categorization judgements (using the same vertical movement sensor) on positive and negative lexical stimuli presented on a vertical axis. The findings from these experiments suggest that the vertical representation of affect facilitates compatible directional movements, however, the representation of affect based on spatial metaphor does not occur automatically, rather it requires active engagement with the affective stimulus.

6.2 The Role of Attention in Emotion Processing

Behavioural studies demonstrating preferential attentional engagement of threat-related stimuli suggest that we possess a tendency to prioritise threatening stimuli, perhaps as a result of a preattentive, parallel search for immediate signals of threat (Hansen & Hansen, 1988). Researchers have reported an amygdala response to threatening stimuli under conditions where the focus of attention was diverted away from the stimulus (i.e. Vuilleumier, Armony, Driver, & Dolan, 2001). In addition, a study investigating object-based attention while keeping spatial attention constant reported similar activation of the amygdala to both attended and unattended fearful and neutral faces (Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003). Chapter 2 investigated the role of attention in the processing of emotional facial expression by studying the impact of directing attention towards or away from faces on emotion-induced modulations of the ERP waveform. Emotional (both fearful and happy) faces elicited a late enhanced positivity (LPP) occurring around 500 - 700 ms post-stimulus, similar to the results from our other ERP studies (e.g. Eimer & Holmes, 2002; Krolak-Salmon, Fischer, Vighetto, & Mauguiere, 2001; Williams, Palmer, Liddell, Song, & Gordon, 2006), and the enhanced positivity for fearful versus neutral faces persisted throughout the 700-1,000 ms time range. The observed ERP modulations sensitive to emotional facial expression were unaffected by spatial attention. These results provide good evidence that the processing of emotional information is automatic and can occur independently of attention.

In contrast, previous ERP studies have demonstrated that emotion-specific ERP modulations are strongly dependent on spatial attention (Eimer, Holmes, & McGlone, 2003; Holmes, Vuilleumier, & Eimer, 2003). Attended emotional faces reportedly triggered an enhanced positivity relative to neutral faces, with an early frontocentral effect and a subsequent more broadly distributed sustained emotional positivity. In Chapter 2, emotional faces did not modulate an early frontocentral negativity as reported in these ERP studies, perhaps because by comparison emotional expression was task-irrelevant in the faces-attended task (participants performed an identity judgement task). Thus, the attention manipulation may not provide the sole explanation for the observed modulation of the ERP waveform. It is possible that this early frontocentral positivity is evoked by an evaluative stage of affective processing. Failure to observe this emotion effect when participants performed the alternative non-emotional task lends support to this hypothesis.

It has been suggested that the concept of attentional load can explain the discrepancies among the studies (Lavie, 1995; Pessoa, Kastner, & Ungerleider, 2003). Studies reporting that the processing of emotional stimuli is gated by attention may have employed tasks, which place a greater demand on attentional load. In comparison, the studies reporting little or no effect of attention could have utilised less attentional consuming tasks, with redundant processing capacity being used for task-irrelevant or unattended stimuli. The study in Chapter 2 and Holmes et al.’s (2003) study used the same spatial-orienting paradigm but with different non-face tasks. The faces-unattended task in the Holmes et al. (2003) study required participants to compare two houses, while in Chapter 2 a comparison of two Landolt squares was performed. Therefore, it is possible that the reported contradictory conclusions regarding the role of attention in affective processing was due to this manipulation. However, Chapter 2 reports that while LPP and slow wave responses to attended and unattended emotional faces were the same, earlier EPN responses to emotionally faces were, by comparison, gated by spatial attention. The fact that the emotion-specific EPN component was strongly dependant upon spatial attention supports the notion that the attentional load of the Landolt squares task was sufficient to consume most, if not all, of the attentional resources, which could have been used for the processing of unattended faces. These observations suggest that subsequent stages in emotional face processing (i.e. the processing stages underlying the LPP and slow wave responses) are fully processed, regardless of other current task demands.

6.3 Reflections on Chapter 3 and Future Research

There is considerable evidence that highly anxious individuals are sensitive to threat-related stimuli. However, the temporal course of this threat-related bias is still unclear. It has been proposed that difficulty in disengaging from threatening material may be implicated (Fox, Russo, Bowles, & Dutton, 2001). Notably, in Chapter 3 no emotion-specific modulations of the N2pc latency were observed, for either high or low anxious individuals, thus failing to support the delayed disengagement hypothesis. Posner and colleagues (Posner, 1980; Posner & Petersen, 1990) have identified three operations when attending to a new stimulus: an initial orienting of attention to the stimulus; active engagement of the stimulus; and lastly, disengaging attention from the stimulus. However in Chapter 3, the central affective image was task-irrelevant, therefore participants were not required to engage with the stimulus. Since participants were instructed to initiate attention to the central location, it was assumed that participants would be engaging attention with the affective stimulus prior to averting attention to the peripheral target. This might explain the failure to observe emotional modulation of N2pc latency. Therefore, a future study could investigate delayed attention effects on N2pc latency following active engagement with the affective stimulus, for example, by means of an affective judgement task.

6.4 Cognitive Avoidance of Threat

From stimulus onset to overt response, the reaction time period can be partitioned into at least two stages of information processing; psychological processing and response output. The interval between stimulus onset and the onset of the S-LRP is related to the duration of pre-motor processes (i.e., stimulus identification and response selection processes). The R-LRP interval is related to the duration of reaction readiness. Chapter 3 revealed that while RTs were consistent across emotional conditions, the response-locked LRP interval was longest for fearful faces and the complementary S-LRP shortest for fearful faces.

Therefore, the speed of stimulus-related information processing as indicated by shorter S-LRP latencies for threatening than happy faces indicates that affective faces effectively modulate early perceptual and cognitive stages of information processing and can be interpreted to reflect subsequent cognitive avoidance of threat after initial orienting. Such a ‘vigilant–avoidant’ pattern of processing would be compatible with recent cognitive models of fear and anxiety (e.g. Mogg & Bradley, 1998; Öhman, 1996). However, this pattern of attentional deployment was not modulated by anxiety. Thus, the data does not support a vigilance-avoidance pattern of processing as contributing to the maintenance of anxious states.

A longer LRP-R interval for threatening stimuli is consistent with the view that motor responses freeze in face of threat (Fox et al., 2001). Therefore, it might seem paradoxical that cognitive avoidance of threat is not followed by a higher reaction readiness to remove the source of threat. Nevertheless, the findings from the experiment in Chapter 3 imply that both psychological processes and reaction readiness periods of the information processing stream are involved in the negativity bias. However, further research is necessary to disentangle their individual contributions to the threat-related processing bias.

6.5 Affective Modulation of the Visual P1 Component

In emotion research the P1 component is generally of interest because of its relation to spatial attention and sensory processing (Batty & Taylor, 2003; Hillyard & Anllo-Vento, 1998). In Chapter 3, affective images (faces and IAPS) were found to modulate P1 amplitudes, which implies that sensory processes were influenced by the emotional property of irrelevant stimuli. Thus, this study provides additional evidence for the notion that there is very rapid attentional orienting towards emotional information. In contrast, Chapter 2 found no evidence of a greater deployment of processing resources to emotional faces (fearful or happy) relative to neutral faces within the P1 time range. This inconsistency is perhaps strange given that the same facial stimuli (i.e. selected from the CAFE database) were used in both experiments. However, in Chapter 2, pairs of faces were presented laterally, whereas single faces were presented foveally at fixation in Chapter 3. These observations suggest that there are important differences in the impact of spatial location on cortical stages of emotional processing. When affective stimuli are presented at fixation, an initial rapid detection of their emotional value (as reflected by early emotional expression effects on P1 amplitudes) takes place. In contrast, no evidence for emotional expression processing within the P1 time range can be found when faces are presented peripherally.

Anxiety-related enhancement of the occipital P1 component for negative as compared with neutral or happy faces has also been reported in the literature; with the magnitude of this effect being significantly enhanced for the high-anxiety group in comparison with the low-anxiety group (e.g. Holmes, Kragh Nielsen, & Green, 2008; Li, Zinbarg, Boehm, & Paller, 2008). This is consistent with increased levels of trait anxiety potentiating attentional vigilance for threat-related material. However, Chapter 2 did not report anxiety-related modulations of the P1 component, consistent with previous studies (Fox, Derakshan, & Shoker, 2008; Moser, Huppert, Duval, & Simons, 2008; Rossignol, Philippot, Douilliez, Crommelinck, & Campanella, 2005).

6.6 Facilitated Emotional Processing: Evidence from the EPN component

An early posterior negativity (EPN) as an index of early emotion discrimination and both ERP experiments in Chapters 2 and 3 reported an enhanced EPN to emotional compared with neutral faces around 200-300 ms post-stimulus. When the emotional valence of the face stimuli was task relevant (Chapter 2) enhanced EPN amplitudes were observed for both fearful and happy relative to neutral faces. However, when emotional expression was task-irrelevant (Chapter 3), the EPN was enhanced for fearful relative to neutral faces but an EPN for happy relative to neutral faces was not observed. Both studies utilised the same stimulus set (i.e., the CAFE database), therefore it is possible that this difference in the EPN response is due to variations in experimental manipulation rather than stimulus-driven factors. However, different participants took part in these two experiments, which could also explain this inconsistency.

The EPN component reflects facilitated processing of emotional images and has been found to be sensitive to both fearful faces (e.g., Eimer, Holmes, & McGlone, 2003; Sato, Kochiyama, Yoshikawa, & Matsumura, 2001; Schupp, Ohman et al., 2004) and happy faces (e.g., Marinkovic & Halgren, 1998; Schacht & Sommer, 2009) relative to neutral faces. However, the fact that fearful faces continued to evoke an EPN when task-irrelevant, unlike the happy faces, implies that fearful stimuli demonstrate successful bottom-up attentional control. However, the EPN effect for fearful (and happy) faces was absent when attention was diverted away from the faces (Chapter 2). Therefore, it does not appear that that the attentional capture of threatening facial expression is a fully automatic response.

The emotion-linked EPN was not present for IAPS pictures (Chapter 3). This is perhaps surprising given the literature reporting emotion-related EPN effects with both positive and negative IAPS pictures (Herrmann et al., 2009). However, previous studies using IAPS stimuli have reported that the amplitude of the EPN was most pronounced for stimuli of high evolutionary significance, i.e. erotic images and pictures of mutilations (Junghofer, Bradley, Elbert, & Lang, 2001; Schupp et al., 2003). The IAPS stimuli in Chapter 3 were selected to be of high emotional arousal, which included pictures of mutilations in the negative set. However, as mentioned previously, the affective images were task-irrelevant and so the IAPS pictures (particularly the negative set) may not have been of sufficient threat-value to induce an EPN response such as that observed for the fearful faces. Facial stimuli have, in comparison to IAPS pictures, a high social and evolutionary significance, therefore perhaps negative facial expressions are also more attentionally engaging than scenes of a negative tone.

6.7 N170 and Emotional Face Processing

The renowned face recognition model of Bruce and Young (1986) differentiates between facial identity and facial expression processes. This model is supported by event-related potential studies linking the N170 component with the structural encoding of faces (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2000), a process proposed to operate in parallel with facial expression discrimination (Eimer & Holmes, 2002). The results from experimental Chapters 2 and 3 are accordance with this model and previous studies (e.g. Eimer & Holmes, 2002), showing that the N170 was insensitive to facial expressions, while other ERP components were modulated by affect. Thus, Chapters 2 and 3 demonstrate that facial configuration processing occurred independently of affective encoding.

In Chapter 2 only post-N170 components were affected by emotional expression, however in Chapter 3, the preceding P1 was modulated by emotion. Thus, the data are in conflict with regards to the time course of facial structural analysis and facial expression processes. The results from Chapter 2 suggest that the affective property of face stimuli is processed only once initial face configuration and identification is complete, while Chapter 3 implies that the structural encoding of faces can operate in parallel with facial expression discrimination. However, both studies agree that the N170 reflects only basic structural encoding of facial information and is insensitive to affective properties of faces.

6.8 Executive Control in Anxiety

In Chapter 4, the most important finding was that those higher in trait anxiety were faster to switch from a neutral to a threatening mental set. This improved ability to switch attention to the emotional judgement task when threatening faces are presented is in accordance with a hypervigilance theory of anxiety. The argument follows that facilitated attentional orienting to threat is a causal factor in anxiety disorders (Mathews & Macleod, 1994). However, it is also assumed that priority threat processing is a *'normal adaptive mechanism'* (Yiend & Mathews, 2001) for survival purposes.

Attentional capture by threat is suggested to be governed by a decision threshold that permits interruption of goal-directed behaviour when a potential threat risk exceeds a certain level (Mathews & Mackintosh, 1998). It is hypothesised that individual variation in anxiety is related to response threshold differences. Therefore, highly threatening stimuli should surpass this threshold and capture the attention of everyone, while less threatening stimuli should only surpass a relatively low threshold as in anxiety-prone individuals (see Mathews & Mackintosh, 1998; Mogg & Bradley, 1998). Therefore, the result reported in Chapter 4 shows that while fearful faces were sufficient to elicit a vigilant response across all participants (in part because they were task-relevant), reduced switch costs associated with increasing anxiety could be interpreted as arising from variations in this threshold level.

6.9 The Vertical Metaphor: Embodied Cognition versus Evaluative Response Coding

The experiments of Chapter 5 revealed that metaphor-compatible directional movements were demonstrated to facilitate response latencies, such that participants were relatively faster to make upward responses to positively-evaluated words and downward responses to negatively-evaluated words than to metaphor-incompatible stimulus-response mappings. These findings suggest that a conceptual framework exists, linking compatible motoric and evaluative concepts. But what are the means by which this is achieved? Lakoff and Johnson (1999) argue that the nature of human cognition, including conceptual thought, is shaped by aspects of the body. This sentiment encapsulates an embodied mind theory of cognition which has historical roots in Kant's philosophical view of the mind-body problem.

The understanding of emotional valence in terms of a vertical metaphor appears to be implicit. For example, Meier and colleagues (2007) reported that people encode God-related concepts faster if presented in a high versus low vertical position. The authors claim to have shown that vertical perceptions are invoked when the abstract dualistic concept of "good and evil" is accessed. Further, it has been hypothesised that the mapping between conceptual domains, in this case, understanding valence in terms of directionality, corresponds to neural mappings in the brain (see Feldman & Narayanan, 2004).

George Lakoff and Mark Johnson's book, *Metaphors We Live By* (1980), explains how conceptual metaphors shape our understanding of abstract concepts and aid in communication. However, these metaphors are not only linguistic tools, they shape our thoughts and perceptions and consequently our actions. For example, a thumbs up sign is a visual way to express the way you feel. Similarly, the experiments in chapter 5 imply that the vertical metaphor is not only a communicative aid, but has a deeper mode of concept representation-we implicitly act in accordance with this metaphor.

The embodied cognition interpretation of the findings in Chapter 5, however, rests on the following assumption; that affective evaluation of emotional stimuli assigns affective codes to motor responses on a metaphorical level. That is, if there exists an implicit vertical-metaphor representation of affect, a behavioural response to positive-affect stimuli should invoke an *upwards* response coding, while a behavioural response to negative-affect stimuli should invoke a *downwards* response coding. Forster and Strack's (1996) conceptual-compatibility model explains this affective S-R compatibility principle as such; behaviours that are closely associated with abstract spatial representation of affect are more easily elicited than by antagonistic behaviours. However, this leaves open the possibility that different conceptualisations of affective-mapping between affective stimuli and lever movements could similarly induce behaviours that match or mismatch the valence of the invoking stimuli. Indeed, a series of experiments showed that the response label assignment significantly predicted approach and avoidance related movements to positive and negative valenced words (Eder & Rothermund, 2008). Participants performed identical arm-bending pull and arm-extension push movements of a lever that were labelled as either *towards* and *away* or *upwards* and *downwards*. Lever movements labelled *upwards* and *downwards* reversed the standard affective mapping affects obtained with *towards* and *away* lever labels despite the execution of identical motor movements.

If the vertical representation of affect is embodied in cognition then metaphor-consistent movements should not depend upon the evaluative meaning of response labels that are used in the task instructions. In Chapter 5, the response labels *upwards-downwards* were applied to vertical movements of a finger sensor. Therefore, an embodied cognition account would be supported if this study could be replicated using response labels *towards* and *away* to label finger flexions and extensions, respectively.

6.10 Concluding Remarks

In summary, this thesis combined behavioural and electrophysiological approaches to the study of the emotion-cognition interaction as it relates to individual variation in trait-anxiety. The attentional bias to threat was investigated in Chapters 2, 3 and 4. While the studies in Chapters 2 and 3 showed that threatening stimuli can prioritise processing resources, there was no evidence for an anxiety-related bias in either the preattentive stage of processing (Chapter2) or in the disengage component of attention (Chapter3). However, using a task-switching paradigm, Chapter 4 showed that trait anxiety predicts a hypervigilance for threat, mirroring the findings from previous studies reporting a threat-related bias in the orienting component of visual attention. Finally, Chapter 5 investigated how affect is mentally represented. The data suggest that the vertical position metaphor underlies our understanding of the relatively abstract concept of affect. Although it is less clear whether the vertical representation of affect advocates an embodied view of conceptual structure (see Lakoff & Johnson, 1980) or an evaluative response-coding view (see Eder & Rothermund, 2008). Future research is necessary to help clarify this issue.

Appendix A: Stimuli from Chapter 4 Experiment

The real word sets were compiled from the Affective Norms for English Words (ANEW) database (Bradley & Lang, 1999).

V = Valence Mean; A = Arousal Mean; W = Word Length; F = Frequency.

F = word frequencies per million (CELEX Lexical Database; Baayen, Piepenbrock, & Gulikers, 1995).

Real-Word Set 1

	V	**A**	**W**	**F**
frog	5.71	4.54	4	1
icebox	5.00	4.84	6	3
limber	5.45	4.85	6	2
ketchup	5.68	4.52	7	1
mystic	6.00	4.84	6	3
lighthouse	5.89	4.41	10	2
repentant	5.86	5.05	9	1
appliance	5.10	4.05	9	5
nonchalant	4.74	3.12	9	1
rattle	5.03	4.36	6	5
swamp	4.90	4.40	5	5
trumpet	5.70	4.80	7	7
salute	5.92	5.31	6	3
scissors	5.05	4.47	8	1
thermometer	4.37	3.79	11	2
clumsy	4.00	5.18	6	6
hawk	5.88	4.39	4	14
cane	4.00	4.20	4	12
boxer	5.51	5.12	5	1
pamphlet	4.79	3.62	8	3
hairdryer	4.84	3.71	9	2

sphere	5.33	3.88	6	22
lantern	5.57	4.05	7	13
tamper	4.10	4.95	6	1
basket	5.45	3.63	6	17
mushroom	5.78	4.72	8	2
reserved	4.88	3.27	8	27
patent	5.29	3.50	6	35
hide	4.32	5.28	4	22
avenue	5.50	4.12	6	46
consoled	5.78	4.53	8	2
glacier	5.50	4.24	7	1
nonsense	4.61	4.17	8	13
absurd	4.26	4.36	6	17
bench	4.61	3.59	5	35
alley	4.48	4.91	5	8
runner	5.67	4.76	6	1
stove	4.98	4.51	5	15
gender	5.73	4.38	6	2
golfer	5.61	3.73	6	3
Average	**5.17**	**4.35**	**6.6**	**9.62**

Real-Word Set 2

	V	**A**	**W**	**F**
headlight	5.24	3.81	9	7
locker	5.19	3.38	6	9
windmill	5.6	3.74	8	1
salad	5.74	3.81	5	9
errand	4.58	3.85	6	7
utensil	5.14	3.57	7	2
jelly	5.66	3.7	5	3
context	5.2	4.22	7	2
kettle	5.22	3.22	6	3
hairpin	5.26	3.27	7	1
owl	5.8	3.98	3	2

mantel	4.93	3.27	6	3
inhabitant	5.05	3.95	10	2
activate	5.46	4.86	8	2
banner	5.4	3.83	6	8
fork	5.29	3.96	4	14
violin	5.43	3.49	6	11
wagon	5.37	3.98	5	55
bland	4.1	3.29	5	3
humble	5.86	3.74	6	18
vanity	4.29	5	6	7
radiator	4.67	4.02	8	4
sentiment	5.98	4.41	9	23
muddy	4.44	4.13	5	10
coarse	4.55	4.21	6	10
trunk	5.09	4.18	5	8
sheltered	5.75	4.28	9	4
highway	5.92	5.16	7	40
insect	4.07	4.07	6	14
spray	5.45	4.14	5	16
privacy	5.88	4.12	7	12
hammer	4.88	4.58	6	9
lump	4.16	4.8	4	7
whistle	5.81	4.69	7	4
truck	5.47	4.84	5	57
quart	5.39	3.59	5	3
alien	5.6	5.45	5	16
custom	5.85	4.66	6	14
nursery	5.73	4.04	7	13
invest	5.93	5.12	6	3
Average	**5.26**	**4.11**	**6.22**	**11.49**

Pseudo-Word Sets 1 and 2

N.B. W = Word Length

Set 1	**W**	**Set 2**	**W**
nesterilly	10	chelesing	9
splath	6	jootine	7
noradly	7	dusious	7
tabanol	7	occle	5
durate	6	nyson	5
ammolodate	10	clorious	8
andesker	8	clife	5
rebration	9	plining	7
camboliate	10	plembiator	10
clife	5	blaptious	9
sharb	5	prumptious	10
thriney	7	zocker	6
fotion	6	facsiliate	10
strimple	8	calidorate	10
momberment	10	numbial	7
pammel	6	harch	5
tury	4	chunts	6
nisk	4	stip	4
uttle	5	drit	4
excemming	9	plounch	7
moller	6	cuttal	6
crobment	8	illarin	7
slamperic	9	sleck	5
flines	6	bequette	8
tallow	6	plude	5
snafe	5	blonce	6
bidiment	8	bareming	8
givest	6	plaction	8
berrow	6	diberate	8
yender	6	gond	4
caborial	8	ploon	5

occle	5	thumfiate	9
bleth	5	fupple	6
hethlem	7	quone	5
faner	5	harin	5
lindermy	8	quannet	7
drack	5	wollen	6
blacken	7	glat	4
thoungle	8	naughder	8
factam	6	stime	5
Average	**6.80**		**6.65**

Appendix B: Stimuli from Chapter 5 Experiment

Word List from Meier and Robinson (2004)

V = Valence Mean; A = Arousal Mean; W = Word Length

Positive

	V	A	W
active			7
agile			5
ambitious			9
baby	8.22	5.53	4
brave	7.15	6.15	5
candy	6.54	4.58	5
champion	8.44	5.85	8
clean			5
cordially			9
devotion			7
dream	6.73	4.53	5
earnest			7
ethical			7
faith			5
festival			8
garden	6.71	4.39	6
generous			8
genius			6
gentle	7.31	3.21	6
gracious			8
heaven	7.30	5.61	6
hero			4
justice	7.78	5.47	7
kiss	8.26	7.32	4
leisure			7
love	8.72	6.44	4

Negative

	V	A	W
aimless			7
argue			5
beggar	3.22	4.91	6
bitter			6
cancer	1.5	6.42	6
cheat			5
clumsy	4	5.18	6
crime	2.89	5.41	5
critical			8
crooked			7
crude	3.12	5.07	5
cruel	1.97	5.86	5
danger	2.95	7.32	6
dead	1.94	5.73	4
defeat			6
delay			5
devil	2.21	6.07	5
diseased			8
divorce	2.22	6.33	7
enemy			5
fickle			6
foolish			7
fraud	2.67	5.75	5
greedy			6
hostile	2.73	6.44	7
insane	2.85	5.83	6

loyal	7.55	5.16	5	insolent	4.35	5.38	8
mature			6	liar			4
mercy			5	mediocre			8
neat			4	mosquito	2.80	4.78	8
nurse	6.08	4.84	5	nasty	3.58	4.89	5
polite			6	neurotic	4.45	5.13	8
power	6.54	6.67	5	obnoxious	3.50	4.74	9
pretty	7.75	6.03	6	poison	1.98	6.05	6
prompt			6	pompous			7
radiant	6.73	5.39	7	profane			7
reliable			8	rude	2.50	6.31	4
righteous			9	sarcastic			9
satisfying			10	shallow			7
sensible			8	sloppy			6
sincere			7	sour	3.93	5.10	4
sleep	7.20	2.80	5	spider	3.33	5.71	6
studious			8	steal			5
sweet			5	stingy			6
talented			8	theft			5
trust	6.68	5.30	5	touchy			6
truthful			8	ugly	2.43	5.38	4
victory	8.32	6.63	7	unfair			6
wise	7.52	3.91	4	vain			4
witty			5	vulgar			6
Average	**7.38**	**5.29**	**6.28**		**2.92**	**5.63**	**6.04**

New Word List

Words selected from the ANEW database (Bradley & Lang, 1999).

V = Valence Mean; A = Arousal Mean; W = Word Length; F = Frequency.

F = word frequencies per million (CELEX Lexical Database; Baayen, Piepenbrock, & Gulikers, 1995).

Low Frequency Words

Positive	**V**	**A**	**W**	**F**	**Negative**	**V**	**A**	**W**	**F**
admired	7.74	6.11	7	20	abuse	1.8	6.83	5	14
aroused	7.97	6.63	7	15	annoy	2.74	6.49	5	4
birthday	7.84	6.68	8	20	betray	1.68	7.24	6	8
cheer	8.10	6.12	5	11	brutal	2.80	6.60	5	13
dazzle	7.29	6.33	6	1	demon	2.11	6.76	5	6
ecstasy	7.98	7.38	7	6	detest	2.17	6.06	6	4
elated	7.45	6.21	6	3	disloyal	1.93	6.56	8	2
erotic	7.43	7.24	6	9	foul	2.81	4.93	4	9
fame	7.93	6.55	4	10	hatred	1.98	6.66	6	21
flirt	7.52	6.91	5	1	infection	1.66	5.03	8	18
glory	7.55	6.02	5	22	insult	2.29	6	6	13
graduate	8.19	7.25	8	8	killer	1.89	7.86	6	11
hug	8.00	5.35	3	6	leprosy	2.09	6.29	7	1
lust	7.12	6.88	4	10	lice	2.31	5	4	2
miracle	8.60	7.65	7	15	nightmare	1.91	7.59	9	13
nude	6.82	6.41	4	6	rotten	2.26	4.53	6	12
orgasm	8.32	8.10	6	9	slap	2.95	6.46	4	7
rainbow	8.14	4.64	7	6	slaughter	1.64	6.77	9	12
rescue	7.70	6.53	6	20	suffocate	1.56	6.03	9	1
riches	7.70	6.17	6	6	surgery	2.86	6.35	7	12
sexy	8.02	7.36	4	4	terrified	1.72	7.86	9	15
terrific	8.16	6.23	8	12	torture	1.56	6.10	7	15
thrill	8.05	8.02	6	5	toxic	2.10	6.40	5	6
treasure	8.27	6.75	8	9	tumour	2.36	6.51	6	2
triumphant	8.82	6.78	10	7	venom	2.68	6.08	5	3
Average	**7.87**	**6.65**	**6.12**	**9.64**		**2.15**	**6.36**	**6.28**	**8.96**

High Frequency Words

Positive					**Negative**				
	V	**A**	**W**	**F**		**V**	**A**	**W**	**F**
affection	8.39	6.21	9	24	accident	2.05	6.26	8	49
cash	8.37	7.37	4	54	afraid	2.00	6.67	6	112
confident	7.98	6.22	8	28	anger	2.34	7.63	5	74
desire	7.69	7.35	6	65	assault	2.03	7.51	7	21
engaged	8.00	6.77	7	35	bloody	2.90	6.41	6	64
excitement	7.50	7.67	9	37	bomb	2.10	7.15	4	32
fun	8.37	7.22	3	46	confused	3.21	6.03	8	27
gift	7.77	6.14	4	31	crash	2.31	6.95	5	19
happy	8.21	6.49	5	135	destroy	2.64	6.83	7	44
holiday	7.55	6.59	7	58	disaster	1.73	6.33	8	33
humour	8.56	5.50	6	27	funeral	1.39	4.94	7	22
joke	8.10	6.74	4	33	guilty	2.63	6.04	6	51
joy	8.60	7.22	3	40	hate	2.12	6.95	4	55
laughter	8.45	6.75	8	48	hell	2.24	5.38	4	94
leader	7.63	6.27	6	68	horror	2.76	7.21	6	30
lucky	8.17	6.53	5	47	nervous	3.29	6.59	7	48
passion	8.03	7.26	7	31	pain	2.13	6.50	4	75
pleasure	8.28	5.74	8	83	pressure	3.38	6.07	8	106
progress	7.73	6.02	8	73	rape	1.25	6.81	4	19
promotion	8.20	6.44	9	15	rejected	1.50	6.37	8	35
romantic	8.32	7.59	8	32	stress	2.09	7.45	5	35
sex	8.05	7.36	3	124	tragedy	1.78	6.24	6	19
success	8.29	6.11	7	102	trouble	3.03	6.85	7	146
sunlight	7.76	6.10	8	22	victim	2.18	6.06	6	28
win	8.38	7.72	3	58	violent	2.29	6.89	7	39
Average	**8.09**	**6.69**	**6.2**	**52.64**		**2.29**	**6.57**	**6.12**	**51.08**

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