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The Effect of Anxiety on Hemispheric Attention

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Philosophy
in Psychology

by

Caroline Michelle Crump

2012

ABSTRACT OF THE DISSERTATION

The Effects of Anxiety on Hemispheric Attention

By

Caroline Michelle Crump
Doctor of Philosophy in Psychology
University of California, Los Angeles, 2012
Professor Eran Zaidel, Chair

Anxiety is often associated with changes in visual attention, particularly toward emotional or threatening stimuli (MacLeod, *et al*, 1986). However, common clinical tests of the attention bias present an inconclusive picture of attention in anxiety: it is often difficult to reproduce the results of one test across different samples of participants, individuals with high anxiety do not consistently focus on threat stimuli in particular, and paradigms show different effects depending on the aspect of attention measured. This dissertation takes a basic cognitive neuroscience approach to investigate the attention bias observed in anxiety. Specifically, we examined the independent contributions of the two cerebral hemispheres to the observed effect in order to verify whether differences in hemispheric specialization in different tasks could account for the difficulty replicating results. This series of experiments establishes that the effects of anxiety on attention 1) are strongly tied to typical right hemisphere specialization, 2) are selective to orienting of spatial attention, and 3) are not exclusive to the presence of threatening stimuli.

The dissertation of Caroline Michelle Crump is approved.

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2012

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McCaa, M., Crump, C., & Zaidel, E. (2012). Hemispheric attention networks. Poster presented at the Psychology Undergraduate Research Conference, Los Angeles, CA.

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Gobrial, M., Crump, C. M ., & Zaidel, E. (2010). The effects of anxiety on Inhibition of Return. Poster presented at the Psychology Undergraduate Research Conference, Los Angeles, CA.

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Crump, C. M. & Zaidel, E. (2009). Anxiety affects luminance discrimination in the right hemisphere. Poster presented at the Cognitive Neuroscience Society Annual Meeting, San Francisco, CA.

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I. Introduction

1. Anxiety

Anxiety disorders affect 18.1% of the population of the United States in a given year (NIMH, 2009). However, scientific, medical, and lay understanding of anxiety remains incomplete. Because attention is well-characterized both conceptually and neuroscientifically in normal populations, it provides a useful background for the study of cognition in individuals with high anxiety. Thus, research has focused on the effects of long-term (trait) anxiety on attention. The right hemisphere has been strongly linked to both attention and emotional processing in normal samples. Changes in attention in anxiety may be due to a change in right hemisphere attention selectively. Understanding the nature of this change will help identify clinical markers of high anxiety which can be targeted for treatment and prevention. This series of studies investigated attention in anxiety using clinical, basic neuroscience, and neurophysiological measures. Results were followed-up by an investigation of individual differences that are associated with individuals with high anxiety. Specifically, we sought to address three major questions: 1) what is the hemispheric basis of attention changes in high anxiety? 2) which aspects of attention are modulated by high anxiety? and 3) are the effects of high anxiety on attention selective to the presence of threatening stimuli?

1.1 Conceptualization of Anxiety

The term “anxiety” refers to a hugely diverse class of disorders which encompasses specific fears, panic attacks, repetitive compulsive behaviors, and uncontrolled worry (Brown, 2002). However, despite the variety of anxiety classifications, both clinical and nonclinical presentations of all types of anxiety share specific cognitive and physiological traits. Cognitive traits include two categories of negative feelings commonly identified by individuals with high anxiety (Scherer, 2002). The first includes transient emotional responses which dissipate rapidly following removal of the triggering stimulus. This is usually identified as the feeling of *fear*, a cognitive and biological readiness to respond to immediate threat (Nitschke, Heller, & Miller, 2002). The second category of negative feelings includes more general and persistent negative disposition, often occurring in the absence of a discrete triggering stimulus. This is usually identified as the feeling of *anxiety*, primarily cognitive preparations for possible future threat (Nitschke, *et al*, 2002).

Physiological traits include changes in arousal in individuals with high anxiety, even in the absence of any discrete, objective threat (Freeman & DiTomasso, 2002). Interestingly, the physical manifestations of this response vary: for example, anxiety is often thought to require increased autonomic arousal, yet patients with GAD and participants with high trait anxiety often exhibit decreased autonomic arousal. It seems equally possible that this is due to the nature of the anxiety (Sapolsky, 2004, p. 41), or is the result of suppression or exhaustion following excessive sympathetic nervous system activation (Brown, 2002; De Pascalis, Strippoli, Riccardi, & Vergari, 2002).

1.2 Quantifying Anxiety in General Populations

Anxiety has been operationally defined in ways which apply generally to both non-psychiatric and psychiatric populations. Consonant with the separation between transient fear and lasting anxiety, Spielberger et al. (1983) introduced the idea of state versus trait anxiety. State anxiety is fear or worry about an immediate or discrete threat; trait anxiety is a stable, persistent experience of negative emotions and interpretations of the world. Trait anxiety is considered a valid measure of the same anxiety experienced in GAD, and places this type of anxiety on a continuum between nonclinical and clinical anxiety. Trait anxiety is commonly measured using the Spielberger State-Trait Anxiety Inventory, Trait Anxiety version (STAI-TA). The STAI-TA uses a four-point Likert scale on which participants indicate agreement with 20 statements of general mood. Scores on the STAI may range from 20-80, with a score of 40 is a common median and modal score. Most studies utilizing this measure in nonclinical samples define “high anxiety” by median split of the range of scores for that sample (see Fisher & Durham, 1999 for discussion of the STAI-TA in clinical research).

While the STAI-TA is commonly used, there are questions as to its content validity. Psychometric analysis has shown that the STAI may measure overall negative affect better than anxiety, and may also measure depression better than anxiety (Bieling, Antony, & Swinson, 1998). Factor analyses of the STAI have broken it into three subscales which separately measure anxiety, depression, and general distress. We have conducted exploratory analyses which confirmed that the depression subscale has a higher correlation with overall score than the anxiety subscale does ($r = 0.93$ vs. $r = 0.84$). However, our ANOVAs using the anxiety subscale scores of the STAI-TA reveal the same results as those analyses using the overall STAI-TA scores. We therefore conclude that the overall STAI remains a valid measure of anxiety despite also measuring depression. Furthermore, this measurement of anxiety may be more ecologically valid with clinical diagnoses of anxiety because anxiety and depression are highly comorbid (e.g., Kessler, Gruber, Hettema, Hwang, Sampson, & Yonkers, 2008). Thus, the STAI-TA provides an excellent model of natural presentations of clinical anxiety.

2. Orienting and Conflict in Selective Attention

Using a definition of anxiety which spans both clinical and nonclinical presentations, we can begin to look at cognitive and biological markers of high anxiety. Physiological arousal is difficult to measure as a biomarker because it is not consistent across all presentations of anxiety (see Sapolsky, 2004 chapter 15). Knowing that anxiety is commonly associated with fear about immediate environmental threat, one may predict that an anxious person is constantly expecting and searching for threat. The search for threat should preferentially direct attention to threatening stimuli or situations in the environment (e.g., Hypervigilance Theory; Eysenck 1992, chapter 3). By examining the nature of attention allocation in both low and high anxious individuals, we can identify the differences in basic attention processes between these individuals. This can be done both in terms of behavioral responding and in terms of cortical resources recruited for attention.

Behavioral responding is assessed through performance measures of accuracy and reaction time on a given task. The influence of emotional stimuli on basic attention can be seen by presenting emotional stimuli (e.g., facial expressions, emotional words) followed by emotionally neutral target stimuli (e.g., arrows, asterisks). Participants respond to the emotionally neutral target stimuli. In this case, attention is measured by task performance. Performance differences which depend on the preceding emotional stimuli are typically observed. These reflect emotional processing effects on attention. Higher accuracy and faster response times (increase in performance) reflect “better” attention to the task stimuli. Lower accuracy and slower response times (decrease in performance) reflect “worse” attention to the task stimuli.

Cortical resources and underlying brain activity can be measured using event-related potentials (ERPs) determined from scalp electroencephalogram (EEG). EEG is known for excellent temporal resolution (on the order of milliseconds), and thus EEG and ERP methods are ideal for measuring immediate/early differences in attentional and emotional processing between individuals with high anxiety and individuals with low anxiety. ERPs are measured by subtracting ongoing cortical EEG activity from the EEG activity following a stimulus event. The activity for each event is then averaged across all trials with the same stimulus event. This results in waveforms which represent neuronal activity evoked by the stimulus, known as ERPs or event-related potentials. Positive and negative deflections in the waveform (components) are named by their polarity and the order in which they occur (see Figure 1.1). For example, the third positive deflection in the waveform is named the P3.

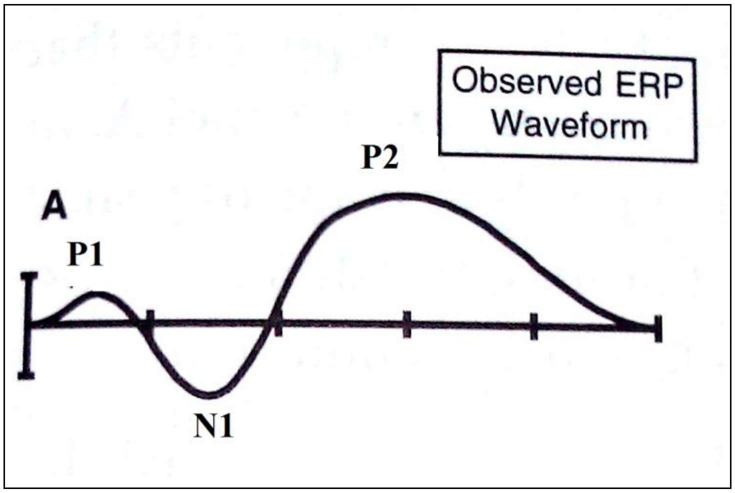


Figure 1.1. Sample ERP waveform. Adapted from Luck, 2005, Figure 2.1.

These general measures of attention inferred through performance and cortical processing can be applied to major aspects of attention: spatial orienting and executive conflict resolution (response conflict).

2.1 Spatial Orienting

Spatial orienting occurs when attention is drawn to a specific location in space either by an internally-guided stimulus (e.g., wanting to look there) or by an externally-guided stimulus (e.g., a startling sound). Internally-guided orienting is often called endogenous or *controlled* orienting, whereas externally-guided orienting is often called exogenous or *automatic* orienting

(Posner, 1980). In both cases, when the stimulus signals a significant event, it is known as a *cue*. The significant event following the cue is known as the *target*. When attention is to be moved from the cue to the target, attention is disengaged from the cue, shifted to the target, and re-engaged to the target.

Orienting can occur either overtly or covertly (Posner, 1980). *Overt orienting* occurs when an individual guides attention by moving his or her eyes, head, or body toward the desired spatial location. *Covert orienting* occurs when an individual guides attention independently of eye, head, or body movements. Both overt and covert orienting consist of two main phenomena (Posner & Cohen, 1984). The first phenomenon is facilitation, which refers to the speeding of stimulus detection when the stimulus appears in the same location as the cue (a valid cue; see Figure 1.2). This reflects attention deployment at the location of the cue.

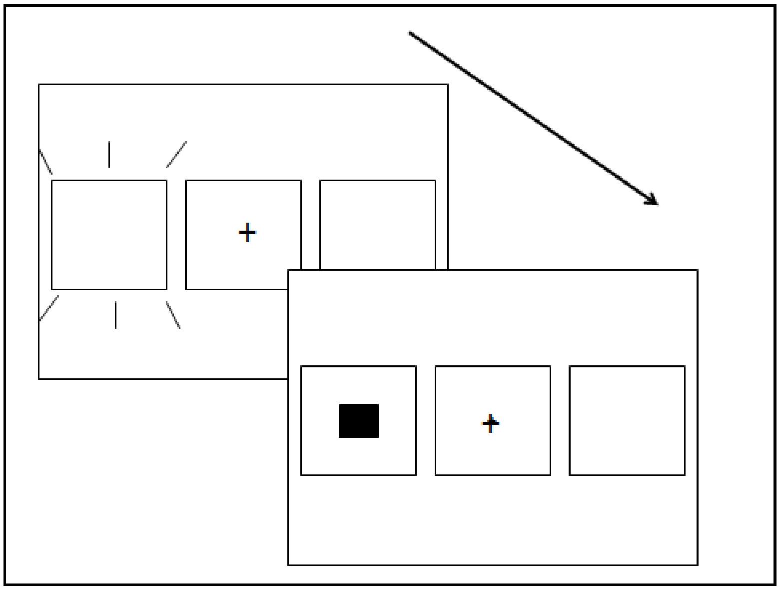


Figure 1.2. Valid cue, cf. Posner & Cohen, 1984. Arrow represents time.

The second phenomenon is inhibition, which refers to the decreased attention deployed at uncued locations when the stimulus appears in a different location from the cue (an invalid cue; see Figure 1.3).

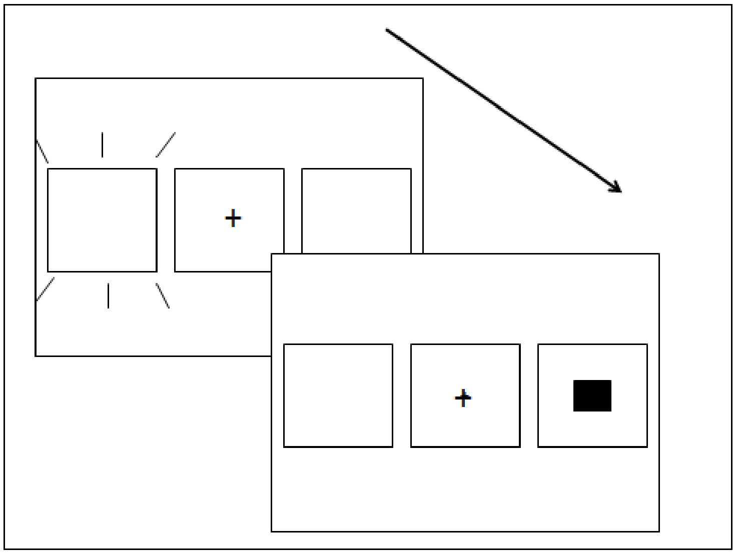


Figure 1.3. An invalid cue, cf. Posner & Cohen, 1984. Arrow represents time.

Together these phenomena focus attention in cued locations. Facilitation is measured by the decrease in response latencies following a valid cue, compared to an invalid cue. This is reflected by an enhancement of the P1 and N1 event-related potentials (ERPs) at posterior electrode sites (Eimer, 1993). Inhibition is measured by the increase in response latencies following an invalid cue, compared to a valid cue. This is reflected by an enhancement of the N2 ERP component at posterior electrodes (Eimer, 1993). This pattern of fast responses to a valid cue and slow responses to an invalid cue is known as the cue validity effect (see Figure 1.4). When facilitation and inhibition are both large, attention is presumably deployed to the cued location.

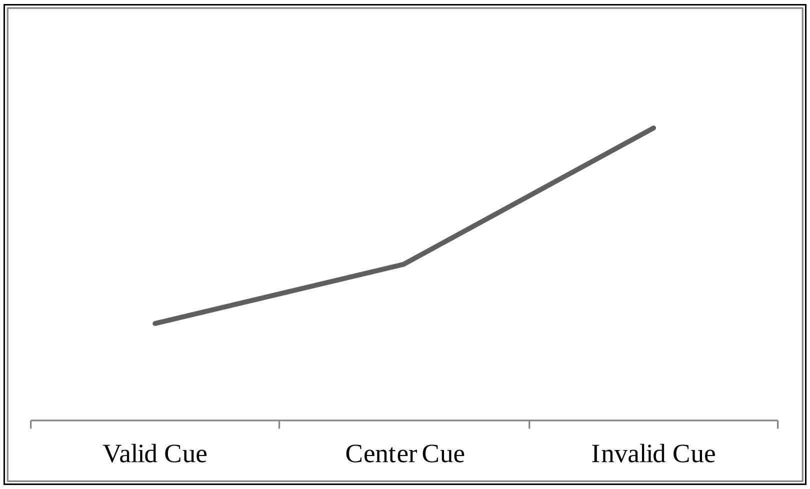


Figure 1.4. Pattern of response times typical of the cue validity effect.

Interestingly, experimental manipulations of the cue validity effect reveal that this effect occurs only when the delay between the onset of the cue and the onset of the target (the Stimulus Onset Asynchrony, or SOA*)* is less than 300ms. After this point, the cue validity effect reverses: targets preceded by an invalid cue elicit faster response times than targets preceded by a valid cue (see Figure 1.5). This effect is known as Inhibition of Return (IOR; Klein, 2000). This effect continues for up to 3000ms, during which any target stimuli presented in the cued location elicit slower responses than target stimuli presented in the opposite location. Event-related potential studies have shown that the amplitude of the visual P3 component increases over a long cue-to-target interval, likely reflecting IOR (i.e., Tian & Yao, 2008).

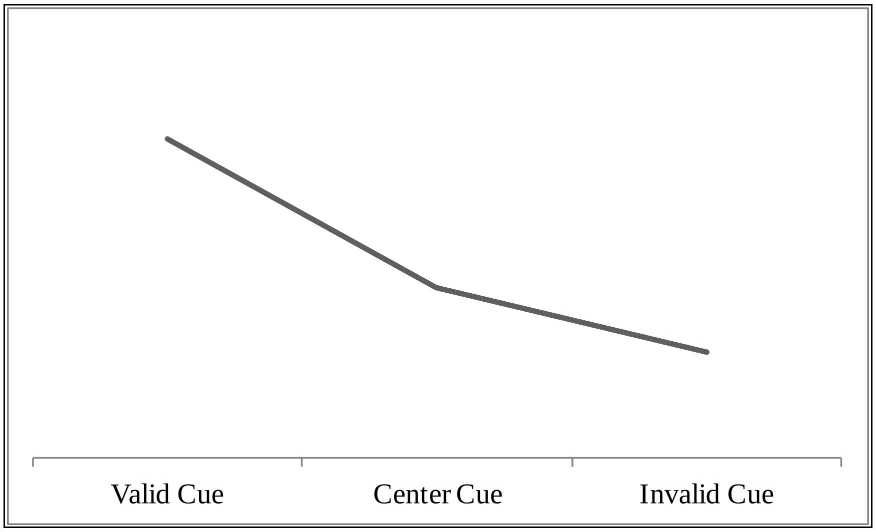


Figure 1.5. Pattern of response times typical of Inhibition of Return.

2.2 Conflict

Conflict occurs when one aspect of a target stimulus influences attention to another aspect of the stimulus (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003). A classic example of this is the Stroop task, in which the meaning of a color word interferes with the identification of the color ink in which the word is printed (Stroop, 1935). This conflict is particularly large when the meaning of the word does not match the color ink (incongruent condition). The conflict is reduced when the meaning of the word is the same as the color ink (congruent condition). The resolution of this conflict depends on the ability to suppress responding to the distracting information. The selective attention necessary for resolving conflict involves more conscious effort than spatial orienting does, and likely occurs at a later level of processing than orienting. Conflict is typically measured by subtracting reaction times to the congruent stimulus from reaction times to the incongruent stimulus. In ERP studies, conflict in selective attention may be measured by the N2pc component (Kiss, Van Velzen, & Eimer, 2008).

3. Attention in Anxiety: The Attention Bias to Threat

Threatening stimuli are thought to preferentially capture attention in people with low levels of anxiety as well as people with high levels of anxiety. Visual search studies have utilized stimulus arrays with a threatening target and non-threatening distracters, and measured reaction times in finding the threatening target (e.g. Öhman, Flykt, & Esteves, 2001). Results show that participants of all anxiety levels easily find the threatening target. Conversely, all participants have a more difficult time finding a non-threatening target in an array of threatening distracters. Intuitively, one would expect that any person would show faster orienting to threat in the immediate environment, because this quick orienting allows organisms to prepare for threat. However, further research suggests that this type of orienting may become maladaptive if this search is a consistent strategy (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002). The increase in vigilance for threatening stimuli may be interpreted as a mechanism of maintaining anxiety in high anxious participants.

Accordingly, researchers have investigated the attention bias as a primary method of intervention and means of understanding anxiety in general. The attention bias has been a fruitful area of research due to its discriminant validity between 1) anxiety and mood disorders, and 2) individuals with and without a diagnosis of clinical anxiety. Very little evidence supports the existence of an attention bias in depression (Dalgleish & Watts, 1990). In addition, some studies of attention in low anxiety participants have found that, rather than a reduced bias to *threatening* stimuli, there is instead a bias toward *happy* stimuli (Waters, Nitz, Craske, & Johnson, 2007). This bias was explained as attentional avoidance of unpleasant or threatening stimuli. Yet the attention bias retains the power to measure anxiety on a continuum: it has been found both in participants with high trait anxiety (Li, Zinbarg, & Paller, 2007; Salemink, van den Hout, & Kindt, 2006; Koster, Crombez, Verschuere, Van Damme, & Wiersema, 2006) and in participants with GAD (Bradley, Mogg, White, Groom, & de Bono, 1999). Thus, modifying the attention bias away from threat is a current target for the treatment of GAD (MacLeod, *et al*, 2002).

3.1 Components of the Attention Bias

3.1.1 Hypervigilance for Threat.

Hypervigilance can be conceptualized as a lowered threshold for threat identification, i.e. threatening stimuli have greater ability to attract attention than positive or neutral stimuli. This is conceptually similar to the shift component of spatial orienting. Thus, threat stimuli are identified more quickly regardless of distracters or location of covert attention. Although intuitively it seems that facilitation of threat detection should occur at all possible locations, hypervigilance is typically measured by facilitation due to a valid or spatially congruent threat cue. The latency of early event-related potentials (ERPs), including the occipital P1 and N1, are typically shown to be sped up in individuals with high anxiety, reflecting hypervigilance (Bar-Haim, Laimy, & Glickman, 2005; Holmes, Nielsen, & Green, 2008).

3.1.2 Difficulty Disengaging from Threat.

Difficulty disengaging from threat can be conceptualized as enhanced attention at the location of a threatening stimulus, i.e., threat stimuli hold attention longer than positive or neutral stimuli. In this case, threat stimuli inhibit responding to a later stimulus if that stimulus requires a shift in attention. This is conceptually similar to the disengage component of spatial orienting. Accordingly, most measures of disengagement measure inhibition associated with attention shifting rather than disengagement directly. Event-related potentials may measure difficulty disengaging by increased amplitudes, which reflect enhanced processing due to additional engagement with the stimuli. Increased amplitudes of early visual processing components have been shown for threatening stimuli (Kollassa, Musial, Kollassa, & Miltner, 2006; Fox, Derakshan, & Shoker, 2008; Santesso, Meuret, Hofmann, Mueller, Ratner, Roesch, *et al*, 2008). By contrast, processing of happy stimuli is reflected in reduced amplitudes of early visual components (Santesso, *et al*, 2008). Increased amplitudes may also result in longer latencies for the onset of late visual components such as the P3. Thus, difficulty disengaging may be reflected in the latency of the P3 as well.

3.2 Measures of the Attention Bias

3.2.1 Common Clinical Tests

Visual Probe Task. The Visual Probe task was originally theorized to measure attention in anxiety by MacLeod and colleagues (1986). In the task, participants are presented with two stimuli simultaneously, one above and one below fixation (see Figure 1.6). One of these stimuli is always emotionally neutral, the other is either emotional or emotionally neutral. Immediately following these stimuli, a dot appears either in the same location as the emotional stimulus (congruent condition) or in the same location as the neutral stimulus, i.e., the location opposite the emotional stimulus (incongruent condition). Usually one observes faster reaction times to the congruent dot compared to the incongruent dot resulting in a *spatial* bias of attention. Presumably, the affinity between the emotional stimulus and the emotional state/trait of the participant orients him/her to the stimulus and thereby creates an *emotional* (attentional) bias to the position of the target in space. Thus, the bias due to threat in anxious individuals may be measured by the differences in spatial bias between threat stimuli and neutral stimuli, or between threat stimuli and happy stimuli.

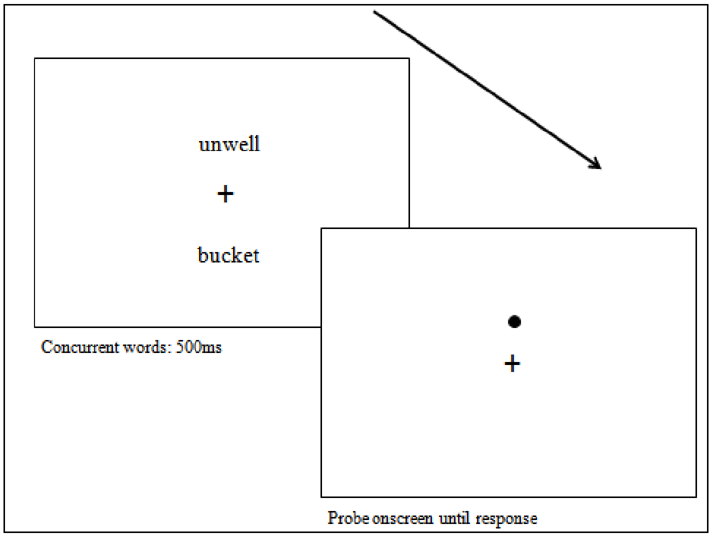


Figure 1.6. *Visual Probe trial with probe in position congruent to emotional word (cf. MacLeod & Mathews, 1985). Arrow represents time.*

In the case of anxiety, the dot probe task effectively measures both the hypervigilance and the disengagement components of the attention bias separately, and together these components measure overall attention or fixation on the emotional stimulus. Specifically, hypervigilance is evidenced by faster responding to a target spatially congruent with a threat stimulus (threat stimulus paired with a neutral stimulus) than to a target preceded by two neutral stimuli (neutral stimulus paired with a neutral stimulus). Disengagement is evidenced by slower responding to a target spatially incongruent with a threat stimulus (threat stimulus paired with a neutral stimulus) than to a target preceded by two neutral stimuli (neutral stimulus paired with neutral stimulus). Overall attention or fixation can be measured by comparing reaction times to targets preceded by a congruent emotional stimulus with reaction times to targets preceded by an incongruent emotional stimulus (known as the Attention Bias Index).

Emotional Stroop Task. The Emotional Stroop task is similar to the traditional Stroop task in that participants are presented with words in different ink colors, and participants are to name the ink colors (see Figure 1.7). The difference is the type of words presented to participants: whereas in the traditional Stroop task the words are color names, in the Emotional Stroop task the words are emotional (see Williams, Mathews, & MacLeod, 1996 for a review). When the emotional words are congruent with the participant’s emotional state, or are otherwise personally meaningful, the participant has a more difficult time suppressing the automatic reading of the word and processing of its meaning, and thus has a more difficult time with the main task of color naming. Response times are thereby slower when the words are threatening to someone with high anxiety. The response interference seen in the Emotional Stroop task presumably occurs due to the increased processing necessary to disengage from the emotional words (Phaf & Kan, 2006). Therefore, the Emotional Stroop task is thought to measure disengagement of attention. There is no complementary measure of hypervigilance in the Emotional Stroop task.

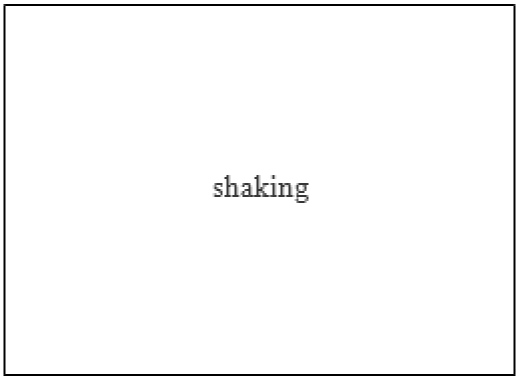


Figure 1.7. Emotional Stroop task, cf. Mathews & Klug, 1993.

3.2.2 Basic Attention Tests of Visuospatial Attention

Covert Orienting of Spatial Attention. Spatial orienting tasks measure both facilitation and inhibition during covert orienting of spatial attention (Fox, Russo, Bowles, & Dutton, 2001). A single cue is presented on one side of central fixation (often to the left or to the right). After a brief delay, a target stimulus is presented either in the same location (valid cue) or in the opposite location (invalid cue; see Figures 1.2 and 1.3). The task for participants is either simple detection of the target or discrimination of some aspect of the target, e.g., identifying the direction of an arrow. Within spatial orienting tasks, hypervigilance is measured by decreased response latency to targets appearing in the same location as an emotional cue (valid cue; facilitation), and difficulty disengaging is measured by increased response latency to targets appearing in the opposite location as an emotional cue (invalid cue; inhibition).

Inhibition of Return (IOR). IOR is measured using a covert orienting of spatial attention paradigm with a long cue-to-target interval (stimulus onset asynchrony; SOA). Typically an SOA of 500ms is used, although some manipulations of SOA have extended to several seconds. IOR is commonly thought to require disengagement of attention from the cued location (Posner & Cohen, 1984; Klein, 2000). Previous studies have shown that individuals with high trait anxiety exhibit reduced IOR (decreased disengagement) relative to individuals with low trait anxiety. This effect is usually assumed to be restricted to threatening stimuli (Fox, Russo, & Dutton, 2002; Perez-Dueñas, Acosta, & Lupiáñez, 2009).

Flanker Task. The Eriksen Flanker Task presents a stimulus array of five arrows (Eriksen & Eriksen, 1974). The central arrow is the target; the other four arrows are distracters. The distracter arrows may point in either the same direction as the target arrow (congruent condition) or the opposite direction as the target arrow (incongruent condition; see Figure 1.8).

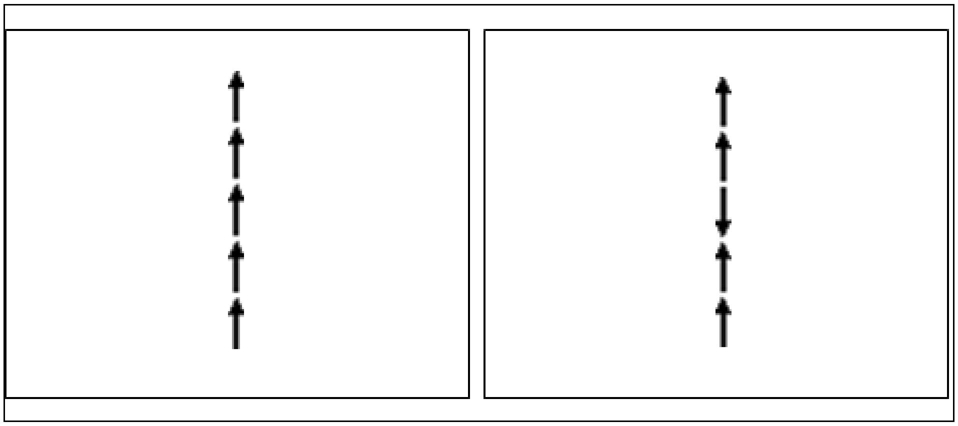


Figure 1.8. Congruent (left) and incongruent (right) flankers in the Eriksen flanker task.

Reaction times are typically slowed for incongruent flankers compared to congruent flankers. This response interference is presumably due to difficulties suppressing the distracting information. The magnitude of this difference is a measure of executive Conflict resolution, or selective attention. This measure of conflict is similar to the traditional Stroop because the incongruity of the target stimulus is objectively apparent and requires selective attention to resolve the incongruity. Although this task does not typically include an emotional manipulation of the stimulus array, the effects of anxiety and emotional context on Conflict resolution have been examined following presentation of emotional cues. A threatening context, created by presentation of a fearful or neutral face cue, is followed by increased Conflict in participants with high anxiety selectively (Reinholdt-Dunne, Mogg, & Bradley, 2009; Dennis, Chen, & McCandliss, 2007). Interestingly, a positive context, created by listening to enjoyable music, also increased Conflict in all participants (Rowe, Hirsh, & Anderson, 2006).

3.3 Validity of the Attention Bias Measurements

The results of studies using the Visual Probe and the Emotional Stroop are often null or conflicting (Schmukle, 2002). Furthermore, the effect size of the attention bias in both clinical tasks is rather small (.38; Bar-Haim, Laimy, Pergamin, Bakermans-Kranenburg, & van

Ijzendoon, 2007). This may be due in part to the specificity of the attention bias for threatening stimuli. Threat stimuli are defined by presenting either a general physical or social threat. However, these general threat stimuli may not affect individuals with specific fears and worries (e.g., Amir, Beard, Taylor, Klumpp, Elias, *et al*, 2009). Instead, threat stimuli specific to each individual may be more effective in eliciting the attention bias in anxiety.

Furthermore, some results suggest that highly anxious participants have developed a coping strategy of redirecting attention to happy stimuli because such stimuli are more likely to signal safety than threat (Derryberry & Reed, 2002; Eysenck, Derakshan, Santos, & Calvo, 2007). Additionally, Rutherford & Raymond (2009) also found a reduction in IOR for emotionally neutral faces, albeit smaller than the reduction for threatening faces.

In summary, an increase in attention to threatening stimuli is one of the major correlates of high anxiety. The exact mechanism of this increase remains clouded by conflicting results from the major paradigms used to measure attention in anxiety. Two major mechanisms, increased hypervigilance for threat and decreased ability to disengage from threat, have been proposed and supported by much of the research. Although most orienting and conflict tasks support difficulty disengaging more than hypervigilance, hypervigilance does occur, as seen in the visual search tasks and possibly also in decreased latencies of visual processing ERP components. Unfortunately, these are not easily separable and do not identify major components of normal attention that are dysfunctional in high anxiety. Future research should incorporate discrete measures of the different components of attention so that we can better ascertain which components are 1) affected in high anxiety, and 2) affected by threatening stimuli preferentially. Ideally, this paradigm will include discrete measures of different components of attention which have been previously studied and validated in normal populations.

3.4 Attention Network Task.

The Attention Network Task measures three components of automatic covert attention independently (Fan, McCandliss, Sommer, Raz, & Posner, 2002). These components include spatial Orienting, executive Conflict resolution, and Alerting. The Attention Network Task has been shown to be a reliable and internally valid measure of attention, and has been suggested as a clinical tool for assessing attention problems in psychiatric disorders (Fan, *et al*, 2002).

The ANT consists of both a covert orienting of spatial attention paradigm and a flanker paradigm (see Figure 1.9). Orienting and Alerting are measured based on responses following different spatial cues. Conflict is measured based on responses to the flanker task. This task can therefore be applied to the study of basic attention processes in anxiety in order to identify which of the three networks of attention is most affected by anxiety. Emotional modifications of this task may additionally ascertain whether the different networks are affected by different emotions.

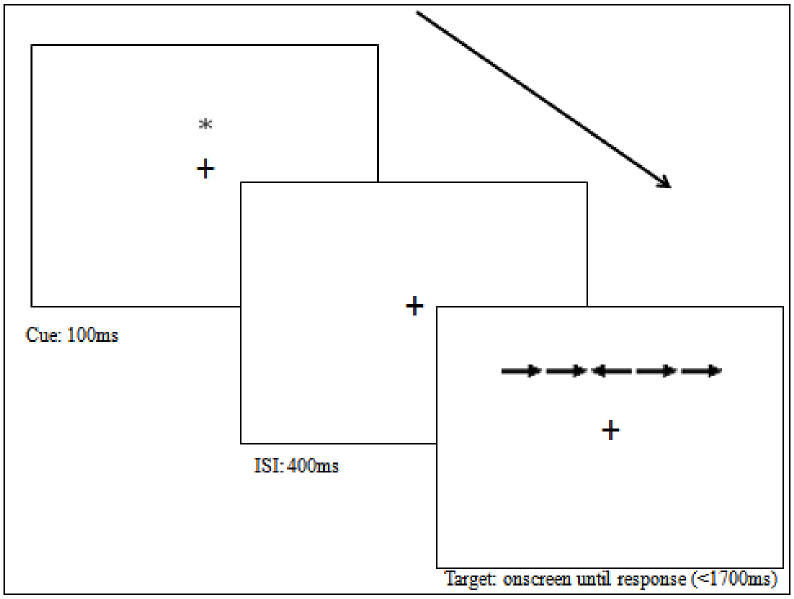


Figure 1.9. Sequence of trial events in the Attention Network Task (cf. Fan, McCandliss, Sommer, Raz, & Posner 2002).

4. The Role of the Cerebral Hemispheres

The right hemisphere is specialized for negative emotions (see Silberman & Weingartner, 1986), and for attention (Heilman & Van Den Abell, 1980). Therefore, separating the hemispheric contributions to emotional experience, emotional stimulus processing, and attention to threat is a germane method of investigating attention in anxiety. There is by now compelling evidence that the two cerebral hemispheres constitute two separate cognitive systems that can process diverse stimuli in many perceptual-motor-cognitive tasks (e.g., Zaidel, Clarke, & Suyenobu, 1990). The hemispheres furthermore share processing resources and mutually inhibit each other during periods of dominant activation (Zaidel, *et al*, 1990). By studying the hemispheres' contributions to emotional processing and attention in anxiety, we may begin to understand the biology underlying the experience of anxiety and how this can develop into maladaptive experience.

4.1 Measuring Hemispheric Dominance in Neurologically Intact Individuals

There are two main methods by which researchers can infer hemispheric specialization or dominance in experimental conditions. The first is known as the behavioral (visual) laterality technique. This technique infers hemispheric dominance from reaction time to visual stimuli presented in either the left visual field or the right visual field.

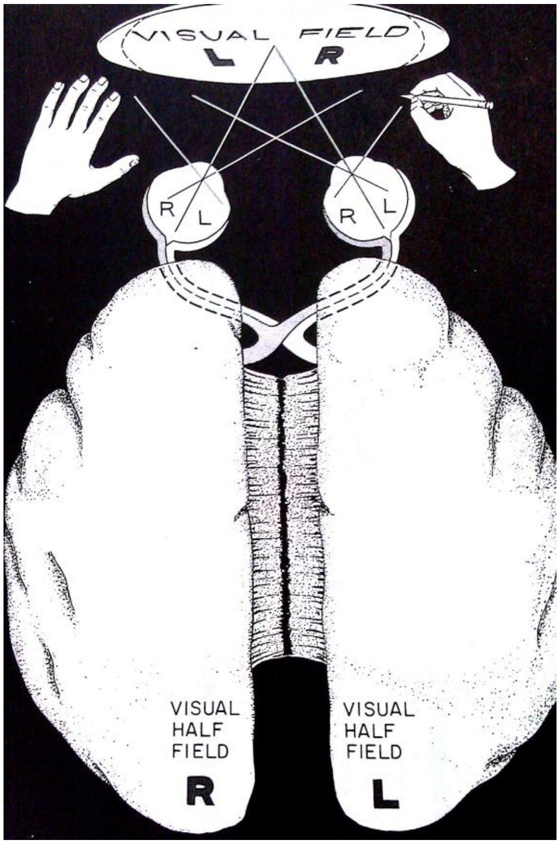


Figure 1.10. Schematic representation of visual system, from visual field to cortex (adapted from Figure 2 from Sperry, 1985, p 13).

In this case, target stimuli are flashed several degrees of the visual angle to the left or to the right of a central fixation point for less than 220 milliseconds (ms). Thus, stimuli appear in the periphery of vision (in one visual field) and disappear quickly enough that the participant’s eyes cannot saccade to the stimulus location. This technique takes advantage of the anatomical organization of the visual system (see Figure 1.10), such that stimuli presented in the periphery of the left visual field are initially processed by the right hemisphere only, and stimuli presented in the periphery of the right visual field are initially processed by the left hemisphere only. This technique ensures that only one hemisphere will initially receive and process the stimulus information. Zaidel (1983) has confirmed that responding to stimuli presented in one visual field is a reliable measure of the contralateral hemisphere’s proficiency at a given task. For example, word-reading tasks typically show a right visual field advantage (Zaidel, 1985). We believe that lateralized presentations best tap the limits of independent competence of the two cerebral hemispheres in a given task (Zaidel, Iacoboni, Zaidel, & Bogen, 2003). This is in contrast to central presentations which may involve variable degrees of interhemispheric interactions.

The second technique for inferring hemispheric specialization uses physiological measures of cortical activity, including electroencephalogram (EEG) and event-related potentials (ERPs). Although behavioral data are important for a broad examination of hemispheric responding, they are limited by the fact that we must infer cognitive processing, attention allocation, and hemispheric activation from measures of reaction time and accuracy. Stronger evidence of hemispheric processing is provided by electrophysiological measures of stimulus-evoked brain activity. Activity in specific brain structures, such as the right hemisphere, during this processing is more difficult to infer due to the inverse problem associated with source localization of ERPs (Luck, 2005). However, inferring hemispheric activity is somewhat more accurate if the data include information from a broad array of electrodes, including those over both the left and the right hemisphere.

4.2 Individual Differences in Laterality

The behavioral laterality method takes advantage of regularities in hemispheric organization and processing. However, not all brains are organized the same. In particular, men are more lateralized than women. This means that in women, certain cognitive functions such as language are more likely to recruit both hemispheres rather than the left hemisphere alone (Lewis & Diamond, 1996; Bradshaw & Nettleton, 1983, chapter 11). Similarly, left-handers are less lateralized than right-handers (Bradshaw & Nettleton, 1983, chapter 10). In rare cases, left-handers exhibit reversed laterality (productive language in the right hemisphere rather than the left). It should be noted that the effects of gender and handedness are not guaranteed to interact additively: that is, left-handed women are not necessarily the least lateralized. Thus, it is important to consider gender and handedness in a thorough assessment of the laterality of an effect.

5. Emotions and the Right Hemisphere

5.1 Theories on Specialization for Emotion

There are three distinct theories on the role of the hemispheres in emotional stimulus processing and the experience of emotions (see Demaree, Everhart, Youngstrom, & Harrison, 2005 for a review). The first theory is the Right Hemisphere Hypothesis, which states that the right hemisphere is responsible for perception of emotional stimuli and the experience of all emotions, irrespective of valence. The basis of this theory lies in the right hemisphere’s superiority at expressing and interpreting facial emotions (Borod, 1993). Furthermore, specialization for negative emotions is possibly due to preferential right hemisphere control over the autonomic nervous system (Hugdahl, 1996; Spence, Shapiro, & Zaidel, 1995). Yet whereas negative emotional states such as anxiety are associated with relatively greater right hemisphere function as measured by decreased alpha waves using electroencephalogram (EEG; Metzger, Paige, Carson, Lasko, Paulus, *et al,* 2004; Aftanas & Pavlov, 2005), there is unfortunately little evidence to support this theory in its entirety. For example, whereas right hemisphere activation increases with self-reported emotional experience, right hemisphere activation does not always covary between emotional and neutral stimulus perception (Hagemann, Hewig, Naumann, Seifert, & Bartussek, 2005; but see Kayser, Tenke, Nordby, Hammerborg, Hugdahl, & Erdmann, 1997).

The Valence Hypothesis is the second major theory on hemispheric specialization for emotions. This theory attempts to explain differences in emotional perception and processing by assigning negative emotions to the right hemisphere, and positive emotions to the left hemisphere. This theory is based on the finding that patients with left hemisphere lesions display a catastrophically sad reaction, whereas patients with right hemisphere lesions are inappropriately happy (Gainotti, 1972). While most physiological evidence points to null responses to threatening stimuli as evidence of a positivity bias (e.g., Davidson, Mednick, Moss, & Saron, 1987), there is a lot of evidence to support this hypothesis in the attention, behavioral, and neuropsychological literature. The most interesting support for this theory comes from the fact that there appears to be a preconscious association between valence and space such that the left visual field is negative and the right visual field is positive (Walters, Harrison, Williamson, & Foster, 2006; Heller, 1993).

The Valence Hypothesis has been reformulated in terms of Gray's (1987) motivational theory of emotions: the Approach/Withdrawal theory. In this theory, the right hemisphere is responsible for emotional and behavioral withdrawal or behavior inhibition (BIS), and the left hemisphere is responsible for emotional and behavioral approach or behavior activation (BAS). Specifically, the frontal cortices of the hemispheres are responsible for these motivational functions (Davidson, 1992; Maxwell & Davidson, 2007). This theory reinterprets the traditional emotional responses following unilateral brain damage. The catastrophic reaction associated with left hemisphere damage reflects a lack of approach instead of negative emotionality. The inappropriate happiness or mania following right hemisphere damage reflects a lack of inhibitory control. Davidson (1996) has found that this theory is supported by resting hemispheric asymmetry as measured by alpha waves in normal participants: participants with greater right hemisphere activation at rest tend to show a disposition to engage in behaviors less often, whereas participants with greater left hemisphere activation at rest tend to show a disposition to engage in behaviors more often. This baseline asymmetry may therefore reflect trait emotional dispositions.

In all three theories, the right hemisphere is associated with negative emotions. Several studies show that right hemisphere activation increases during the experience of both state (Hagemann, *et al*, 2005) and trait (Davidson, 1996) anxiety. It is therefore possible that people with trait anxiety and anxiety disorders are experiencing disproportionately strong right hemisphere activation. The role of the right hemisphere in attention would then additionally mediate the attention changes toward negative stimuli seen in anxiety.

5.2 The Right Hemisphere and Biased Attention

While it is generally true that the left hemisphere attends to the right half of space and the right hemisphere attends to the left half of space, it is also possible that either the right hemisphere (Heilman & Van Den Abell, 1980) or the hemisphere more active at rest (Spencer & Banich, 2005) exerts preferential control over both sides of visual space. Furthermore, the right hemisphere has been shown to be superior to the left hemisphere in not only spatial attention, but also object-based attention (Valsangkar-Smyth, Donovan, Sinnett, Dawson, & Kingstone, 2004). This type of attention is important in tracking stimuli as well as attending to biologically relevant stimuli, such as emotional stimuli. Assuming that the right hemisphere is more active in participants with high anxiety, we would expect that these participants will show right hemisphere facilitation in tasks measuring hypervigilance for threatening stimuli, and will show right hemisphere interference in tasks measuring disengagement from threatening stimuli. In fact, words presented to the right hemisphere of participants with high anxiety elicit greater interference for color-naming in the Emotional Stroop task than do words presented to the left hemisphere of individuals with high anxiety, regardless of valence (Van Strien & Valstar, 2004; Richards, French, & Dowd, 1995).

Many studies using the Visual Probe and covert orienting of spatial attention paradigms present stimuli to the left and right of fixation. Researchers then draw conclusions about hemispheric processing based on reaction time or ERP measures differing between right and left presentations (e.g. Mogg & Bradley, 2002). Although this method of interpretation usually leads to support for the right hemisphere’s role in the attention bias and anxiety, these interpretations are severely limited. First, the duration of stimulus presentation is typically 500ms. During 500ms presentations, it is very easy for participants to make microsaccades away from fixation. Any shift in eye position will immediately change the visual input, and thus the lateralization, of the stimuli. Second, although degrees of the visual angle are not always reported, stimulus sizes tend to be large and participants are seated either very near to the screen (~30cm) or rather far from the screen (~70cm). The visual field of presentation is therefore not well-controlled such that visual stimulus information may be present in both visual fields at once. Third, studies which evaluate the effects of one stimulus material risk confounding their results with hemispheric specialization for stimulus material (Kinsbourne, 1970). Any task which utilizes words only may elicit a left hemisphere bias; any task which utilizes faces only may elicit a right hemisphere bias. For example, the emotional stimuli presented in the dot probe experiment are usually restricted to either words or faces with differing results. Studies using words alone (Salemink, *et al*, 2007) or faces alone (Koster, Crombez, Verschuere, & de Hower, 2003; Bradley, Mogg, & Millar, 2000) do generally show evidence of the attention bias in high anxiety, but not universally (Schmukle, 2005). The inconsistency may be due to the fact that the location of the target is confounded with the hemisphere that is specialized for processing the material: the right hemisphere is often thought to be specialized for face stimuli, whereas the left hemisphere is specialized for word stimuli.

Taken together, conclusions on laterality drawn from these studies are likely not reflecting true hemispheric specialization. The attentional bias measured in terms of spatial orienting may originate from two different sources: first, the affinity between the emotional stimulus and the emotional state of the participant (greater affinity resulting in greater orienting), and second, the inherent hemispheric specialization for the emotional material, with greater orienting for specialized material (words vs. faces). Consequently, it is important to control the visual field of the stimulus in order to explicitly measure these different contributions. Further studies investigating hemispheric specialization must be conducted, controlling the stimulus presentation so that it reliably occurs in one visual field at a time.

5.3 Lateralized Attention Network Task

From the previous discussion, we know that an ideal test of the attention bias measures several attention networks simultaneously. Based on the proposed importance of the cerebral hemispheres to the effect of attention in anxiety, we expect a more ideal test would measure attention networks in each hemisphere separately. Greene and colleagues (2007) developed the Lateralized Attention Network Task, which measures the components of the original ANT (Fan, *et al*, 2002; see section 3.4) separately and independently within each cerebral hemisphere. This version of the Attention Network Task rotates stimuli to be presented to the left and right of central fixation. Stimuli are flashed (<200ms duration) to avoid saccades from fixation. Additionally, the LANT separates spatial Orienting into separate measures of Orienting Benefit (response facilitation; OB) and Orienting Cost (response inhibition; OC). OB measures response facilitation to a validly-cued location, as visuospatial attention is already in the expected location of the target. This is the measure of hypervigilance and facilitation in the previously mentioned paradigms. OC measures response inhibition to an invalidly-cued location, as visuospatial attention remains in the previously-cued location and requires an additional attention shift away from the cued location. This is the measure of difficulty disengaging and inhibition in the previously mentioned paradigms. Data in normal populations show that this is a valid and reliable version of the Attention Network Task. Data also reveal that each hemisphere has its own separate, independent attention networks which respond to different stimuli at different times. This is a promising paradigm which may be used to probe the attention bias in anxiety.

6. Summary

Individuals with high anxiety show an attention bias to threatening stimuli (MacLeod, *et al.*, 1986). The bias is moderately reliable across different testing sessions (d = 0.38; Bar-Haim, *et al*, 2007) and occurs in both clinical and subclinical samples (Bradley, *et al.*, 1999). The bias is thought to consist of two components: an initial hypervigilance toward threatening stimuli and a subsequent difficulty disengaging from threatening stimuli (Fox, *et al.*, 2001). By contrast, individuals with low anxiety sometimes show a selective bias away from threatening stimuli (Waters, *et al*, 2007). However, it is difficult to study the attention bias using paradigms that are not designed to measure basic attention processes. Furthermore, many studies show similar effects of threatening, positive, and even emotionally neutral stimuli on attention in anxiety.

The changes in attention seen with high anxiety may be due to summed activation of the right hemisphere for the experience of negative emotions, the activation of the autonomic nervous system, and orienting of spatial attention. However, the precise role of the right hemisphere in emotional processing and experience remains unclear. It is important to properly evaluate the role of the right hemisphere in the attention bias. This requires replication of previous paradigms and utilization of a more thorough paradigm that is designed to probe attention. Behavioral results should be bolstered by physiological data examining the laterality and stages of cognitive processing involved in both attending to the stimulus and processing stimulus valence.

6.1 General Overview

The experiments delineated here are designed to investigate three major questions. First, what is the role of the right hemisphere in attention in anxiety? Second, what aspect of attention (orienting or conflict) is most affected by anxiety? Third, are individuals with high anxiety more or less sensitive to stimuli of a particular valence (positive vs. threatening)?

Lateralized versions of the attention bias paradigms are necessary to investigate the right hemisphere's contribution to attention in high anxiety. These paradigms are different from other versions of the same paradigms in that they include 1) lateralized presentations of stimuli, with tightly controlled stimulus sizes and viewing distances, 2) tachistoscopic presentations of the stimuli, in which the stimuli are flashed to participants in order to avoid saccades which would inadvertently present the stimulus to both visual fields, and 3) comparisons of both verbal and nonverbal stimuli directly manipulated to account for hemispheric specialization for the materials.

Studies of both orienting and executive conflict resolution have shown some evidence of the attention bias, but no paradigm stands out as the best measure of attention in anxiety. Direct comparison of the paradigms used to measure the attention bias requires using similar participant populations, similar criteria for differentiating high anxious participants from low anxious participants, and similar stimuli in all paradigms. Control over these variables will provide more reliable results which may then be used to decide not only which aspect of attention is most affected by anxiety, but also which paradigm is the best measure of attention in anxiety. Thorough comparison of the effects measured by each paradigm requires investigation not only of behavioral responses, such as reaction time, but also of neural responses, such as event-related potential measures of cognitive processing.

Lastly, the attention bias seen in individuals with high trait anxiety is, by definition, toward threatening stimuli. However, there is some evidence suggesting that attention to threatening stimuli and attention to positive stimuli recruit different processing resources with varying time scales in the brain (Mogg, Bradley, de Bono, & Painter, 1997; Cooper & Langton, 2006). For example, threat stimuli may immediately recruit processing resources (before 300ms), whereas positive stimuli may recruit processing resources later (closer to 500ms). While this should be evident in delayed response times to positive stimuli compared to negative stimuli, these may also be neural processes which enhance visual attention to threat in a way that does not affect response programming. ERPs are a natural method of investigating this possibility.

6.2 Overview of Methods

To examine the three major questions, seven separate experiments are presented here which record either behavioral measures alone or both behavioral and physiological measures. All experiments were run on undergraduates who were predominantly unselected for anxiety level on the basis of pretesting. Trait anxiety was measured using the trait portion of the State-Trait Anxiety Inventory (STAI-TA; Spielberger, *et al*, 1983). Anxiety level was predominantly defined by median split. Given that the STAI-TA is positively correlated with clinical diagnoses, and given that the medians of our samples typically fall at the population median (a score of 40 out of possible 80), we posit that our high anxiety participants do have higher levels of anxiety than average, and that our low anxiety participants have lower levels of anxiety than average. Furthermore, studies of the attention bias in anxiety predominantly use median split methods rather than either cutoff scores or clinical diagnoses. We therefore argue that the use of median split is both conceptually valid and is high in construct validity.

In addition to the STAI-TA, each participant also completed a modified version of the Edinburgh Handedness Questionnaire (Oldfield, 1971) to assess handedness, neurological history, color vision (for the Emotional Stroop), and English language fluency (for the verbal versions of the Visual Probe and the Emotional Stroop tasks). Handedness and neurological history were assessed to determine typical or atypical patterns of hemispheric specialization. We did not include any participants with a history of neurological problems for any study. We did not include participants who were color blind for the Emotional Stroop, and we did not include participants who were not fluent in English for either the Visual Probe or the Emotional Stroop, due to the verbal stimuli employed in those tasks. While a small portion of left-handers are included in the behavioral experiments, ERP experiments include data from right-handers exclusively. Left-handers were included in behavioral studies to increase sample size and ecological validity.

The experiments here first attempt to replicate two major measures of hypervigilance and disengagement in the attention bias literature: the Visual Probe task and the Emotional Stroop task. These paradigms were lateralized and presented with both verbal and nonverbal stimuli to properly assess hemispheric specialization in each task. Following these tasks, two basic attention paradigms were applied to assess 1) networks of attention in each hemisphere, 2) their sensitivity to positive vs. threatening stimuli, and 3) the general effects of high anxiety compared to low anxiety. A test of visual perimetry complemented these basic attention tasks with measurements of basic visual sensitivity and response bias in an emotionally neutral context. Next, two attention tasks (the Visual Probe and a covert orienting of spatial attention task) were replicated using a neurophysiological paradigm to assess general brain activity evoked by task stimuli over time. Finally, individual differences in gender, handedness, and personality were used to sharpen the conclusions drawn from the basic cognitive neuroscience tests of covert orienting of spatial attention. Together, these experiments attempt to delineate 1) the hemispheric basis of attention in anxiety, 2) the specific effects of anxiety on attention, and 3) the salience of different emotional stimuli to attention in anxiety.

II. Common Clinical Tests of Attention in Anxiety

Experiment 1: Lateralized Visual Probe

The attention bias in anxiety is often measured using the Visual Probe task. However, results from this paradigm are not consistent across testing sessions, across participants, or across different variations on the paradigm (e.g. manipulations of stimulus material, words or faces; Schmukle, 2002). Furthermore, results do not consistently implicate the predicted bias to threat stimuli for individuals with high anxiety. We suggest that the inconsistency of the results may be due to the confounding of stimulus material with stimulus location in the visual field, i.e. words prime the left hemisphere and faces prime the right hemisphere (Kinsbourne, 1970). Thus, it is important to control the information presented to the each hemisphere in a given task. Several studies have attempted to draw conclusions about hemispheric activity in the Visual Probe task based on the fact that it sometimes includes stimulus presentations to the left and right of fixation (e.g., Mogg & Bradley, 2002). However, these conclusions may be unwarranted because the durations of stimulus presentation are typically 500ms: long enough for participants to shift their eyes and change the input to each hemisphere.

Experiment 1 compared the attention bias in response to both verbal and nonverbal stimuli using a lateralized Visual Probe paradigm. The purpose was to replicate the effect of anxiety on attention observed in the literature, assess the laterality of the observed effect, and establish the emotional specificity of the bias. Attention was measured as hypervigilance, disengagement, and overall attention to the stimulus (Attention Bias Index). In order to provide an appropriate baseline, one-third of the trials consisted of neutral-neutral stimulus pairs against which we could measure attention to both threatening and positive stimuli. Consistent with the literature on the attention bias, we predicted a selective bias to threatening stimuli in participants with high anxiety. We furthermore predicted that this bias will interact with stimulus material and visual field of presentation: face stimuli will selectively orient attention to the left visual field (right hemisphere), and that word stimuli will selectively orient attention to the right visual field (left hemisphere). This interaction will help clarify some of the contradictory results found in previous versions of the visual probe paradigm.

Methods

Participants

Nineteen undergraduates at the University of California, Los Angeles completed this experiment for course credit (1 male, 3 left-handed). All participants had normal or corrected-to-normal vision and were neurologically normal as assessed by self-report. Handedness was evaluated with a modified version of the Edinburgh Handedness Inventory (Oldfield, 1971). The modified version of this questionnaire asked additional questions related to participant eligibility (e.g. “Do you have normal vision?”). Anxiety level was measured with the trait portion of the State-Trait Anxiety Inventory (Spielberger, *et al*, 1983). STAI-TA scores ranged from 26 to 53 with a median score of 40. Participants were classified as high or low anxiety by median split.

Materials

Stimuli were programmed using E-Prime version 1.1 (Psychology Software Tools, 2002) on an IBM-compatible PC. Stimuli were presented on a 17” Dell LCD monitor with a refresh rate of 75Hz and a screen resolution of 1280 x 1024 pixels/inch. Participants were seated so that their eyes would be exactly 57cm from the central fixation presented on the monitor. Participants responded to target stimuli with a keypress of “5” with their left index finger simultaneous with a keypress of “8” with their right index finger.

Visual Probe Task. A central fixation cross subtending 1° of the visual angle was present throughout the experiment. Each trial began with a warning signal for 180ms. This signal changed the fixation cross to two black asterisks printed in size 16 Courier New font. The warning signal was followed by presentation of the emotional stimuli for 180ms. Emotional stimuli were presented either in the right or the left visual field simultaneously with an emotionally neutral stimulus in the opposite visual field. Presentation of the target followed immediately and lasted for 100ms. The target appeared either in the same location as the emotional stimulus (within the same visual field) or in the opposite location as the emotional stimulus (between visual fields). Participants were then given 1000ms to respond. See Figure 2.1 for sample trial.

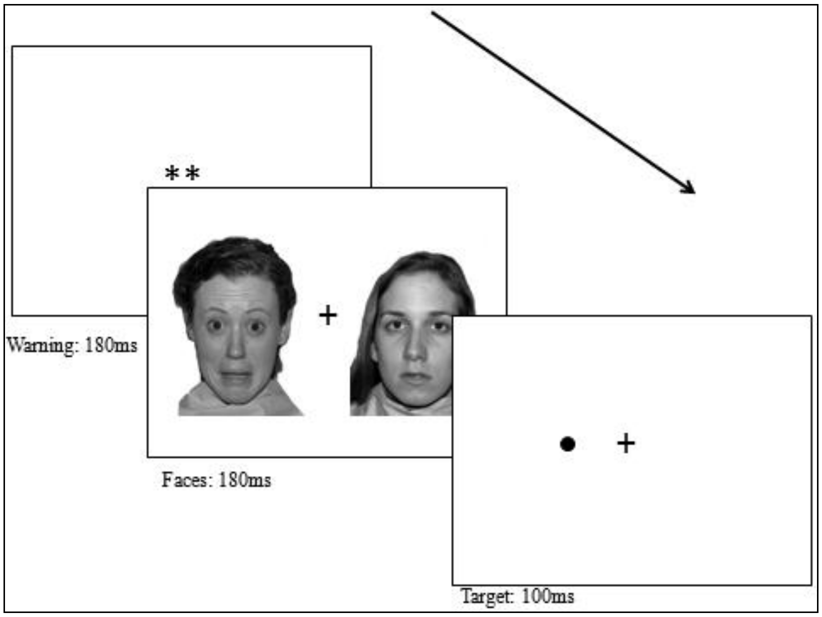


Figure 2.1. Illustration of trial events in Lateralized Visual Probe.

Emotional word stimuli were 5-7 letters long and printed in 12-point black Courier New font. These were presented 2 degrees to the right and left of the central fixation, and ranged from

2-4 degrees wide. We sampled 10 words from each of 5 different emotional categories: sad (e.g., “bleak”, “despair”), neutral (e.g. “bucket”, “carpet”), physically threatening (e.g. “funeral”, “lethal”), socially threatening (e.g., “foolish”, “idiotic”), and positive (e.g. “harmony”, “praise”). Words were chosen from a pretested list and matched for ratings of arousal. Sad and socially threatening words were included to investigate a separate hypothesis and were not analyzed for this study.

Emotional face stimuli were 100 pixels square, full-color images selected from the NimStim facial stimulus set (www.macbrain.org; Tottenham, Tanaka, Leon, McCarry, Nurse, Hare, *et al*, 2009). These were presented 2 degrees to the right and left of the central fixation, and were approximately 2.5 degrees of the visual angle. We sampled 10 unique faces (5 male, 20% Asian, 80% Caucasian: 02, 03, 07, 10, 19, 22, 23, 25, 27, 45) which displayed each of 5 expressions: sad, neutral, fearful, disgusted, and happy. Sad and disgusted faces were included to investigate a separate hypothesis and were not analyzed for this study. A separate set of 10 faces were used for the neutral face appearing in the opposite visual field (01, 05, 06, 09, 15, 20, 21, 24, 26, 34). Faces present on the same trial were always matched by gender and ethnicity.

Target stimuli consisted of a period (dot) printed in 24-point, black Courier New font (0.5 degrees). The dot was presented 3 degrees to either the right or the left of the central fixation. On one-third of the trials, the dot was not present at all (catch trials).

There were two versions of the experiment: one with all word stimuli, and the other with all face stimuli. The experiments were identical in every aspect other than the stimuli presented.

For each version of the experiment, there was one practice block and four experimental blocks. The practice block consisted of 12 trials and provided feedback with accuracy and reaction time for each trial. Each experimental block consisted of 150 trials. Each block was separated by a break, the length of which was determined by the participant.

Procedure

Following informed consent, participants completed the Edinburgh Handedness questionnaire and the STAI-TA. Participants were then taken to the experimenting room, where they were seated with their heads fixed in a chinrest situated 57cm from the computer monitor. Participants were instructed to keep their eyes on the fixation cross at all times, and to detect the target as quickly and accurately as possible. Half the participants were randomly assigned to perform the experiment with face stimuli first; the other half were assigned to perform the experiment with word stimuli first. All participants responded with a bimanual keypress of the letters “5” and “8” at the top of the keyboard.

In order to evaluate the effects of the emotional stimuli on the attention bias in anxiety, we calculated the Attention Bias Index (ABI; *cf.* MacLeod & Mathews, 1985). We did this by subtracting reaction times to targets within the same visual field as the emotional stimulus from reaction times to targets appearing in the opposite visual field. Positive ABI scores (more rapid RTs to congruent targets) reflect attentional engagement, and negative ABI scores (more rapid RTs to incongruent targets) reflect attentional avoidance.

Treatment of the Data

One participant was excluded due to excessively long reaction times (>3 *SD* longer than the overall mean). Overall accuracy for the 18 remaining participants was 99% (*SD* = 0.8%). The remaining participants were predominantly right-handed females (1 male, 1 left-handed). The median STAI-TA score was 40 (9 high anxiety).

We analyzed reaction time of accurate trials only, and excluded catch trials from analysis. The analysis was restricted to threatening, neutral, and positive stimuli. All results were Greenhouse-Geisser corrected for violations of sphericity. All post-hoc paired comparisons for interactions were performed with t-tests, Bonferroni corrected to maintain $p < 0.05$.

Results

Attention Bias Index

We performed a 2 (Material: Face, Word) x 2 (Emotion Visual Field: Left, Right) x 3 (Valence: Positive, Neutral, Threatening) x 2 (Anxiety Level: Low, High) mixed ANOVA with the Attention Bias Index as the dependent variable, and with Anxiety Level as a between-subjects factor. This analysis yielded a significant interaction between Material, Emotion Visual Field, and Anxiety Level, $F(1,16) = 9.61$, $MSE = 278.99$, $p = 0.007$, and a significant interaction between Material, Emotion Visual Field, and Valence, $F(2,32) = 3.94$, $MSE = 385.46$, $p = 0.03$. We predicted significant interactions involving various combinations of Emotion Visual Field, Valence, and Anxiety. Consequently, we ran ANOVAs involving those three variables for face stimuli and for word stimuli separately.

ABI for Faces

The 2 (Emotion Visual Field: Left, Right) x 3 (Valence: Positive, Neutral, Threatening) x 2 (Anxiety Level: Low, High) mixed ANOVA for face stimuli showed a significant interaction between Emotion Visual Field and Anxiety, $F(1,16) = 5.06$, $MSE = 383.91$, $p = 0.04$ (see Figure 2.2). However, the contrasts between visual fields and between anxiety levels were not significant.

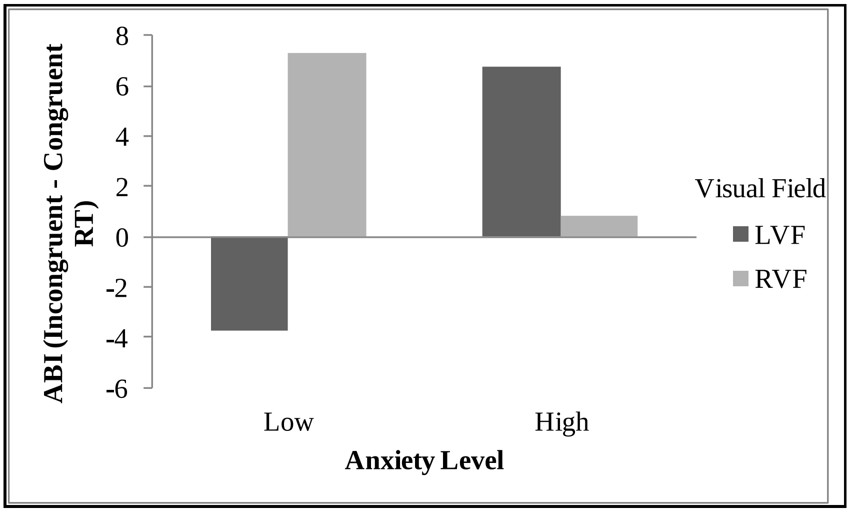


Figure 2.2. VF x Anxiety Level interaction for Face stimuli, using the Attention Bias Index (interaction significant p < 0.05).

ABI for Words

The 2 (Emotion Visual Field: Left, Right) x 3 (Valence: Positive, Neutral, Threatening) x 2 (Anxiety Level: Low, High) mixed ANOVA for word stimuli showed a significant interaction between Emotion Visual Field and Valence, *F*(2,32) = 3.65, *MSE* = 195.60, *p* = 0.04 (see Figure 2.3). However, the differences between visual fields and between valences were not significant.

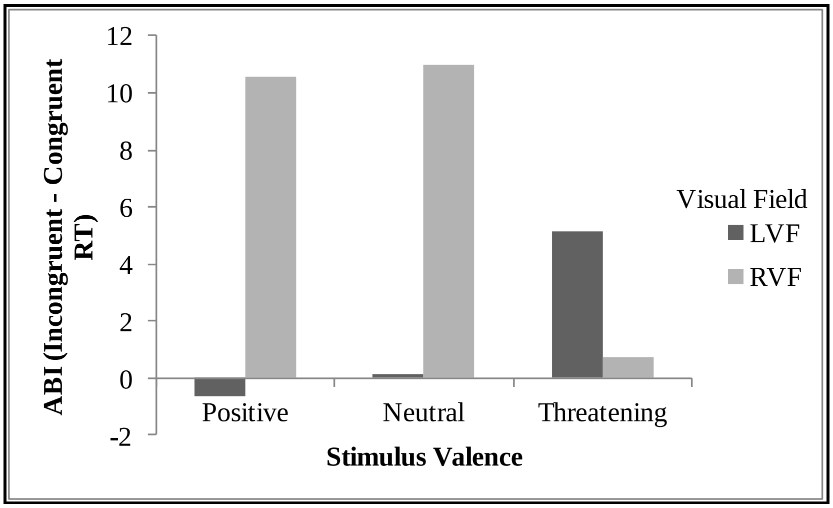


Figure 2.3. Emotion Visual Field x Stimulus Valence interaction for Word stimuli, using the Attention Bias Index (interaction significant p < 0.05).

Hypervigilance (Congruent Trials Only)

To investigate the effects of anxiety on hypervigilance and disengagement respectively, we ran separate ANOVAs for congruent and incongruent trials with response latency as the dependent variable.

The 2 (Material: Faces, Words) x 2 (Emotion Visual Field: Left, Right) x 3 (Valence: Neutral Threat, Positive) x 2 (Anxiety Level: High, Low) mixed ANOVA on congruent trials showed a significant main effect of Material: word stimuli (M = 326.28ms, SD = 2.00) elicited significantly faster reaction times than did face stimuli (M = 337.70ms, SD = 1.88), $F(1,16)$ = 7.86, MSE = 557.90, p = 0.01. There was a significant interaction between Material and Valence, $F(2,15)$ = 5.13, MSE = 107.13, p = 0.020. There were also significant interactions between Material, Emotion Visual Field, and Anxiety, $F(1,16)$ = 5.18, MSE = 100.25, p = 0.04, and between Material, Emotion Visual Field, and Valence, $F(1,16)$ = 4.77, MSE = 75.05, p = 0.02.

To investigate the three-way interactions, we ran separate ANOVAs for the data with face stimuli and the data with word stimuli. The 2 (Emotion Visual Field: Left, Right) x 3

(Valence: Neutral Threat, Positive) x 2 (Anxiety Level: High, Low) mixed ANOVA on congruent trials with face stimuli showed a main effect of Valence, *F*(2, 32) = 3.16, *MSE* = 305.38, *p* = 0.05. Neutral faces (*M* = 340.54ms, *SD* = 2.63) and fearful faces (*M* = 340.83, *SD* = 1.80) did not elicit significantly different reaction times (*p* = 1.00), but fearful faces elicited significantly slower reaction times than did happy faces (*M* = 331.72ms, *SD* = 1.46), *t*(17) = 3.88, *p* = 0.005. There was also a main effect of Anxiety Level, as participants with high anxiety had significantly slower reaction times (*M* = 350.09ms, *SD* = 2.66) than did participants with low anxiety, (*M* = 325.31ms, *SD* = 2.66), *F*(1,16) = 4.34, *MSE* = 3822.91, *p* = 0.05. There were no other main effects or interactions.

The 2 (Emotion Visual Field: Left, Right) x 3 (Valence: Neutral Threat, Positive) x 2 (Anxiety Level: High, Low) mixed ANOVA on congruent trials with word stimuli showed a significant interaction between Emotion Visual Field and Anxiety Level, *F*(1,16) = 5.72, *MSE* = 108.12, *p* = 0.03. However, participants with high anxiety did not differ from participants with low anxiety in either visual field (*p* > .1).

Disengagement (Incongruent Trials Only)

The 2 (Material: Faces, Words) x 2 (Emotion Visual Field: Left, Right) x 3 (Valence: Neutral, Threat, Positive) x 2 (Anxiety Level: High, Low) mixed ANOVA on the data for incongruent trials showed a significant main effect of Material: word stimuli (*M* = 330.76ms, *SD* = 2.10) elicited significantly faster reaction times than did face stimuli (*M* = 340.57ms, *SD* = 1.74), *F*(1,16) = 6.00, *MSE* = 865.39, *p* = 0.03. We also found a significant interaction between Material, Emotion Visual Field, and Valence, *F*(2,15) = 3.93, *MSE* = 175.37, *p* = 0.03.

To investigate this three-way interaction, we ran separate ANOVAs for face stimuli and for word stimuli. The 2 (Emotion Visual Field: Left, Right) x 3 (Valence: Neutral Threat, Positive) x 2 (Anxiety Level: High, Low) mixed ANOVA on incongruent trials with face stimuli showed a significant main effect of Anxiety Level, as participants with high anxiety exhibited significantly slower reaction times (*M* = 355.07ms, *SD* = 2.45) than did participants with low anxiety (*M* = 326.07ms, *SD* = 2.45), *F*(1,16) = 6.98, *MSE* = 3254.58, *p* = 0.02.

The 2 (Emotion Visual Field: Left, Right) x 3 (Valence: Neutral Threat, Positive) x 2 (Anxiety Level: High, Low) mixed ANOVA on incongruent trials with word stimuli showed a significant main effect of Emotion Visual Field, as emotional words presented to the left visual field elicited significantly faster reaction times (*M* = 328.77ms, *SD* = 2.24) than did emotional words presented to the right visual field (*M* = 332.76ms, *SD* = 2.00), *F*(1,16) = 4.68, *MSE* = 91.93, *p* = 0.05. This analysis also showed a significant interaction between Emotion Visual Field and Valence, *F*(2,32) = 4.56, *MSE* = 88.31, *p* = 0.02, but no difference in the effect of valence between visual fields ($p > 0.05$).

Discussion

We predicted a threat-specific bias in attention for participants with high anxiety. We also predicted that this bias would interact with stimulus material (words and faces) and visual field of presentation. We examined these predictions using three dependent variables: 1) overall orienting of attention to the emotional stimuli, 2) hypervigilance toward the spatial location occupied by an emotional stimulus, and 3) difficulty disengaging from the spatial location occupied by an emotional stimulus. We expected that word stimuli would elicit stronger orienting in the left hemisphere, and that face stimuli would elicit stronger orienting in the right hemisphere. We found instead that both types of materials selectively engaged the right hemisphere, although under different conditions: right hemisphere processing of words interacted with stimulus valence, whereas right hemisphere processing of faces interacted with participant anxiety level. Because our results were similar for all three measures of attention (the Attention Bias Index, hypervigilance, and disengagement) we focus the discussion on the more general measure of the Attention Bias Index (ABI).

Individuals with high anxiety did not show the expected attention bias to threatening stimuli. The ABI showed an interaction between anxiety and visual field with all *face* stimuli: faces elicited stronger orienting in the left visual field (right hemisphere) of participants with high anxiety, whereas faces elicited stronger orienting in the right visual field (left hemisphere) of participants with low anxiety. This was reflected by a significant effect of anxiety in both hypervigilance and disengagement. The ABI also showed an interaction between valence and visual field with *word* stimuli: threatening words elicited stronger orienting in the right hemisphere than in the left, whereas positive and neutral words elicited stronger orienting in left hemisphere than in the right. This was reflected by a significant effect of valence for disengagement only. Taking the results for face and word stimuli together, we note that participant anxiety level never interacted with stimulus valence, although both participant anxiety level and stimulus valence separately interacted with visual field of presentation.

Our results show that the right hemisphere is selectively engaged in the task when the participants are highly anxious and when the stimuli are negative, depending on whether the stimulus material consisted of faces or words respectively. However, contrary to our predictions, the right hemisphere was not significantly more engaged when a high anxious participant viewed a negative stimulus. Instead, the bias to threat in the right hemisphere occurred independently of participant anxiety level. This suggests that the experience of anxiety and the perception of a threatening stimulus draw from independent resources. This helps to explain why experimenters often do not observe the attention bias to threat in participants with high anxiety: the experience of anxiety and the selective perception of threatening stimuli are independent.

It should be noted that our threat stimuli were probably not equivalent across words and faces. One would expect an angry face to have a different effect than a threatening word (see Bradley, Mogg, Millar, Bonham-Carter, Fergusson, Jenkins, *et al*, 1997). However, an actual physical threat should elicit an active fear response, but passive viewing of fearful faces may not elicit the same degree of fear response. This difference should be reflected in measures of attention because attention is said to be oriented in preparation for action (Rizzolatti, Riggio, Dascola, & Umiltá, 1987). Given that anxiety was more sensitive to facial stimuli, it is more likely that we would have observed the expected attention bias in highly anxious individuals with angry faces, rather than with the fearful faces used in this study.

Our results may be limited by relatively high variance. That may explain why our data show significant interactions and interesting trends but sometimes do not show significant contrasts between conditions. High variance may be due to both the unreliability of the ABI and our relatively small sample size. Historically, the reliability of the ABI was calculated using several difference measures, and test-retest correlations were consistently low (r = 0.38; Schmukle, 2005). Moreover, a high cross-correlation between the components (RTs to congruent and incongruent probes) is likely to yield an unreliable difference measure. However, the raw reaction time components of the ABI are stable in the emotional Stroop, and are assumed to be equally stable in the Visual Probe task as well (Eide, Kemp, Silberstein, & Nathan, 2002). Therefore, our reaction time measures of the two components of the ABI are most likely reliable. This is indeed reflected in the significant contrasts found in the separate analyses for hypervigilance (congruent trials) and disengagement (incongruent trials).

Our sample did have a relatively small number of participants (19). However, we had a total of 40 trials per condition (left vs. right visual field presentations of threat vs. happy vs. neutral stimuli, faces vs. words) per participant. In order to observe an attention bias to threat with an effect size of 0.38 (Bar-Haim, *et al*, 2007), we need a total 20 participants for power = 0.95. Therefore, our sample size should be sufficient to detect the attention bias to threat. This power does decrease for contrasts between conditions using t-tests due to a smaller number of trials. This may contribute to the absence of significant contrasts in our significant interactions. However, this does not detract from the important conclusion that valence and anxiety reflect independent mechanisms for modulating attention, and thus behavior.

Conclusions

In sum, our data show that face stimuli differentiate between levels of anxiety, and that word stimuli differentiate between positive and negative valence. Both these effects interacted with visual field of presentation, showing right hemisphere selectivity for experiencing negative emotions and for perceiving negative stimuli. None of our measures of attention showed the expected interaction between anxiety level and valence, suggesting that the experience of anxiety and the perception of threatening stimuli are not interdependent, as previously thought. Although the right hemisphere seems to be responsible for negative emotions, the mechanism it engages for the *experience* of negative emotions is apparently different from those engaged for the *perception* of a negative emotion.

Experiment 2: Lateralized Emotional Stroop

The results from the Visual Probe did not show the expected bias to threat in individuals with high anxiety. However, the Visual Probe measures attention differently from the other common test of the attention bias, the Emotional Stroop task: whereas the Visual Probe measures spatial allocation of attention, the Emotional Stroop task measures selective attention to stimulus properties while suppressing stimulus meaning. Attention in the Emotional Stroop may be more sensitive to the effects of anxiety because of the additional top-down inhibition required for performance (see Fox, 1994 for discussion of inhibitory control in anxiety disorders).

The Lateralized Emotional Stroop is already well-established in the literature, revealing robust right hemisphere interference in naming the color of both positive and threatening words (Richards, *et al*, 1995; Van Strien & Valstar, 2004). However, the Lateralized Emotional Stroop paradigms have not compared the effects of emotional words and emotional faces. In this task, we utilized schematic emotional faces as well as emotional words. The simple words used in Experiment 1 appeared to be perceptible to the right hemisphere, although the faces did not show an effect in the left hemisphere of our participants. Thus, we chose to use a set of faces that are more likely to be equally perceived in both hemispheres (Yashar, Herzberg, Fourney, Sopfe, Sin, Elperin, *et al,* 2008). Just as simple words are perceptible to both hemispheres, highly schematic faces should be perceptible to both hemispheres. This avoids any potential confound by stimulus material.

We also replaced fearful faces with angry faces. This was done because fearful faces may signal an impending environmental threat but not pose a direct threat to the participant (see p42). Experiment 1 showed a dissociation between the perception of threat stimuli and the experience of anxiety, but the introduction of a direct threat may capture attention more strongly in individuals with high anxiety than indirect threat.

We ran a Lateralized Emotional Stroop comparing emotional words and schematic emotional faces both to replicate previous findings in the literature on the attention bias in anxiety and to compare results for words and faces. The Lateralized Emotional Stroop is thought to measure disengagement of attention by speed and accuracy of color-naming. We predicted that speed and accuracy would decrease for stimuli presented in the left visual field (right hemisphere) of individuals with high anxiety, consistent with a right hemisphere bias in attention. Stimuli of positive, neutral, and threatening valences were included to assess the specificity of the bias.

Methods

Participants

Forty-five undergraduates participated in this study for psychology course credit (5 males, 37 strongly right-handed). STAI-TA scores ranged from 24 to 55 with a median score of 37. Due to the low median, we defined our high anxiety participants as those with a score of 40 or higher, and our low anxiety participants as those with a score of 39 or lower. This resulted in 17 high anxious participants, as measured by the STAI-TA.

Materials

Participants completed the task on an IBM-compatible personal computer using E-Prime 1.1 experimenting software (Psychology Software Tools, 2002). Stimuli were presented on a 17" Dell monitor with a refresh rate of 60Hz and a resolution of 1280 x 800 pixels/inch. The monitor was situated 57cm away from the participant's eyes, and each participant's head was fixed in a chinrest. Participants indicated the color of each stimulus by pressing "5" with the left index finger or “8” with the right index finger for the color red, pressing “4” with the left middle finger or “9” with the right middle finger for the color green, and by pressing “3” with the left ring finger or “0” with the right ring finger for the color blue.

A central fixation cross subtending 1° of the visual angle was present throughout the experiment. Each trial began with a fixation period which lasted 750ms. This was followed by presentation of the target stimuli for 200ms. Target stimuli were presented equally often in the right or the left visual field. Participants were then given 1200ms to indicate the color of the stimulus. See Figure 2.4 for sample trial stimulus.

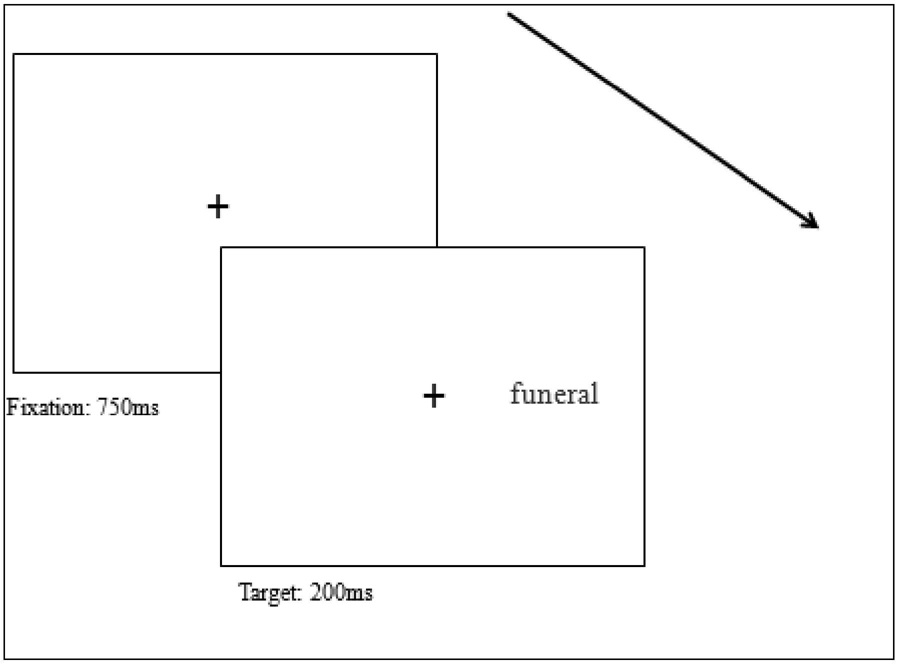


Figure 2.4. Sequence of trial events in Lateralized Emotional Stroop.

Stimuli consisted of either words or schematic faces. Word stimuli were 5-7 letters long and printed in 12-point Courier New font. These were presented 2 degrees to the right and left of the central fixation, and ranged from 2-4 degrees wide. We sampled 10 words from each of 3 different emotional categories: positive (e.g. “harmony”, “praise”), neutral (e.g. “bucket”, “carpet”), and physically threatening (e.g. “funeral”, “lethal”). Words were chosen from a pretested list and matched for ratings of arousal.

Face stimuli were presented at 100 x 100 pixels square. Each face conveyed one of three emotions: happy, neutral, or angry (*cf*. Öhman, Lundqvist, & Esteves, 2001). The inner features (eyes, nose, and mouth) were traced in red, green, or blue to match the hues of the words. The outline of the head overall was presented in black.

Word stimuli and face stimuli were presented to participants as separate tasks (one consisting of all word stimuli and the other consisting of all face stimuli). The presentation of these tasks was counterbalanced between participants. Each task included one practice block and four trial blocks. Practice blocks consisted of 16 trials, with the visual field of presentation for the first trial always counterbalanced between participants to avoid any confounding bias for stimuli in one visual field. Practice trials included feedback for response time and accuracy to ensure that participants understood the task. Trial blocks consisted of 36 trials presented in random order.

Procedure

Participants completed the handedness questionnaire, the STAI-TA, and the BIS/BAS prior to completing the Emotional Stroop task. Each participant was randomly assigned to perform the task with word stimuli first or with face stimuli first. Within these assignments, participants were randomly assigned to begin responding with their right hand or with their left hand. Participants were told to name the color of the stimulus as quickly and accurately as possible. Participants were told to maintain central fixation and move their attention to the left or right. Fixation was monitored by an experimenter throughout the experiment. Response hand alternated between each block. Accuracy and reaction time measures were recorded.

Treatment of the Data

Three participants were excluded due to extremely low accuracy (>2.5 SD from the mean of 92%). Following exclusion, there were two males, four left-handers, and seventeen participants with high anxiety. Only accurate response times were included for the analysis. All post-hoc comparisons were performed with t-tests using Bonferroni corrections for multiple comparisons.

Results

Response Time

We ran a 2 (Visual Field: Left, Right) x 2 (Material: Word, Face) x 3 (Valence: Positive, Neutral, Threatening) x 2 (Anxiety Level: High, Low) mixed ANOVA on the response time data. The between-subjects variable was Anxiety Level. We found a main effect of Material, such that Word stimuli elicited faster response times than did Face stimuli, $F(1,40) = 2.50$, $MSE = 4169.13$, $p = 0.02$. We also found an interaction between Material, Visual Field, Valence, and Anxiety Level, $F(2,80) = 3.07$, $MSE = 909.09$, $p = 0.05$. To further investigate the four-way interaction, we ran separate ANOVAs on the response time data for word stimuli and for face stimuli.

Words Only

We ran a 2 (Visual Field: Left, Right) x 3 (Valence: Positive, Neutral, Threatening) x 2 (Anxiety Level: High, Low) mixed ANOVA on the response time data for Word stimuli only. We found an interaction between Visual Field, Valence, and Anxiety Level, $F(2, 80) = 3.37$, $MSE = 828.87$, $p = 0.04$.

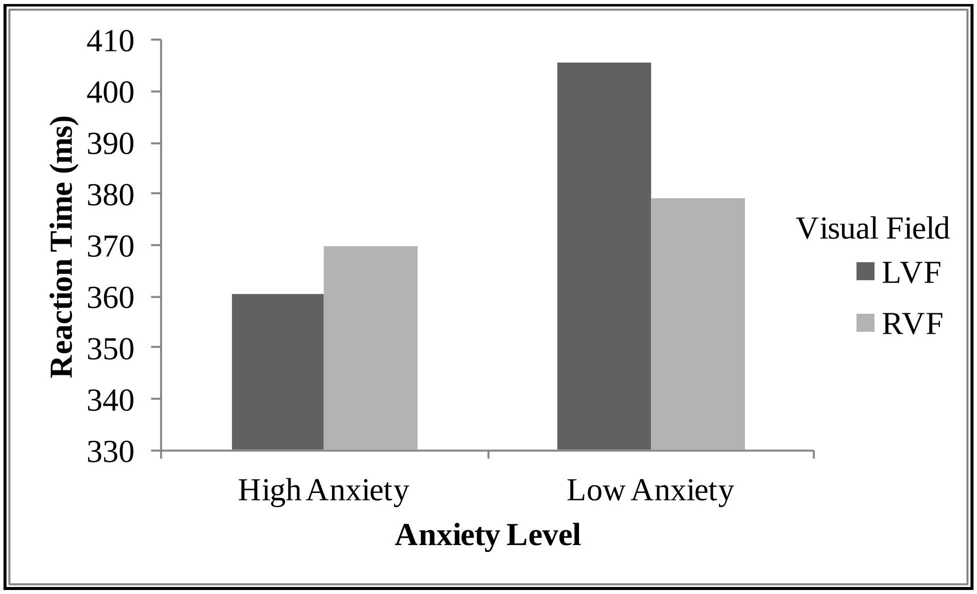


Figure 2.5. Latency to name the ink color of positive words in each visual field for participants with low anxiety and participants with high anxiety. Interaction for positive words is significant at p < .05.

Posthoc comparisons were performed to compare performance for each Anxiety Level for each Valence between Visual Fields. Although no contrasts showed significance, we did observe a large difference in naming the ink of positive words presented to the left visual field between high and low anxious participants. To test the significance of the interaction between Visual Field and Anxiety Level, we ran a separate 2 (Visual Field: Left, Right) x 2 (STAI-TA Anxiety Level: High, Low) mixed ANOVA on the response time data for positive words only. This interaction between Visual Field and Anxiety Level was significant, $F(1,40) = 6.74$, $MSE = 966.49$, $p = 0.01$ (see Figure 2.5).

Faces Only

We ran a 2 (Visual Field: Left, Right) x 3 (Valence: Positive, Neutral, Threatening) x 2 (STAI-TA Anxiety Level: High, Low) mixed ANOVA on the response time data for Face stimuli only. There were no significant main effects or interactions.

Discussion

We predicted that the attention bias in anxiety would manifest for left visual field presentations of emotional stimuli, particularly negative stimuli. We found no evidence of greater engagement with negative stimuli either overall or in either visual field in participants with high anxiety. Instead, participants with high anxiety showed faster reaction times (less interference) to positive words presented to the right hemisphere. This directly contrasted with performance by participants with low anxiety, who showed slowed reaction times (more interference) to positive words presented to the right hemisphere. The Emotional Stroop measures inhibition of semantic processing. Thus, faster response times reflect less processing of the stimulus. These results suggest that individuals with high anxiety are less engaged with positive stimuli, rather than more engaged with negative stimuli. This effect is mediated by the right hemisphere. Thus, the attention bias as measured by the Emotional Stroop is more sensitive to positive stimuli rather than threat stimuli. These results contrast with results in Experiment 1 by showing an interaction between anxiety and stimulus valence, and by showing this interaction for word stimuli rather than face stimuli. The face stimuli used here may have required less semantic processing than the words because they were simple, schematic, and highly repetitive. Thus, faces here were easier to ignore in order to focus on the color of the features.

Decreased sensitivity to positive stimuli is typically associated with depression rather than anxiety (Gotlib, Ranganath, & Rosenfeld, 1998). Given that the STAI-TA measures depression as well as anxiety, this suggests that the present results are more strongly influenced by depression than anxiety. However, independent analysis using the anxiety subscale of the STAI-TA (Bieling, *et al*, 2002) showed similar results to those reported here. Thus, these effects are likely due to anxiety.

Experiment 1 showed no interaction between valence and anxiety, and furthermore showed an effect of anxiety on facial stimuli, and valence on word stimuli, both in the right hemisphere. By contrast, Experiment 2 showed an interaction between valence and anxiety but only for word stimuli in the right hemisphere. It should be noted that these word stimuli are identical to those used in Experiment 1. Taken together, the right hemisphere shows the effects of anxiety independently of stimulus material, yet the specific interaction between anxiety level and sensitivity to emotional stimuli remains inconsistent across tasks. It may be idiosyncratic to other personality variables within the sample (e.g. Amir, *et al*, 2009). Alternately, it may be idiosyncratic to the aspects of attention measured by each paradigm (bottom-up attention in the Lateralized Visual Probe; top-down attention control in the Lateralized Emotional Stroop). Future studies including more specific measures of basic attention processes, such as spatial orienting, could incorporate emotional stimuli to assess the effect of anxiety on attention to emotional stimuli. Understanding which aspects of attention are specifically measured may help elucidate the emotional specificity of attention in anxiety.

Conclusions

The Lateralized Emotional Stroop showed that individuals with high anxiety process positive stimuli less than individuals with low anxiety. This effect is selective to the right hemisphere. These results inform psychotherapeutic techniques such as Attention Bias Modification Training by proposing that therapies target positive stimuli in the left visual field selectively.

Experiments 1 and 2: General Discussion

Experiments 1 and 2 attempted to replicate and clarify the attention bias to threat often observed in individuals with high anxiety. This was done by carefully manipulating both the hemisphere processing stimuli and controlling the response, and the stimulus material (verbal or non-verbal). Neither the Lateralized Visual Probe nor the Lateralized Emotional Stroop replicated the bias to threat. Instead, the Lateralized Visual Probe showed a dissociation between threat stimuli and participant anxiety based on stimulus material: threatening stimuli affected responses to words, whereas high anxiety affected responses to faces. This dissociation was apparent for right hemisphere cue presentations selectively. The Lateralized Emotional Stroop also showed an effect of anxiety on stimuli presented to the right hemisphere. However, the Lateralized Emotional Stroop found an effect of anxiety on facilitating responses to positive words. Taken together, our lateralized versions of clinical tests of attention in anxiety showed a selective effect of anxiety on right hemisphere attention. However, the nature of the effect on attention varied depending on the task, the stimulus material, and the stimulus valence.

In general, the Visual Probe measures allocation of spatial attention whereas the Emotional Stroop measures engagement with the meaning of a stimulus. However, neither of these paradigms measures a well-defined aspect of attention. The general consensus in the literature is that specific aspects of attention are affected by high anxiety. It is possible that the clinical paradigms do not have the appropriate specificity to accurately measure attention in anxiety because they do not measure the particular aspects of attention most affected by anxiety. To further investigate this possibility, we conducted several tests developed from the cognitive neuroscience perspective of attention to measure three main aspects of attention and the effect of anxiety on them.

III. Basic Cognitive Neuroscience Tests of Visuospatial Attention

Experiment 3: Emotional Lateralized Attention Network Test

The lateralized clinical tests of the attention bias showed somewhat inconsistent results. While there was a consistent effect of anxiety on attention in the right hemisphere, the exact nature of the effect varied for word and face stimuli, and also for emotional and non-emotional stimuli. Furthermore, both tests measured attention differently yet both found an effect of anxiety. It is clear from these results that a more systematic investigation of attention in anxiety is necessary. For this purpose, we utilized the Lateralized Attention Network Task (LANT). The LANT measures spatial Orienting (both Benefit and Cost), Alerting, and executive Conflict resolution separately in each hemisphere. With this task, we can identify the effect of anxiety on each aspect of attention. Furthermore, we can identify the interaction between participant anxiety level and valence of the stimulus presented in order to examine the specificity of the attention bias (to threat, to emotional stimuli in general, or overall) in each network.

In this experiment, participants with high and low anxiety were given one of three versions of the LANT using happy, neutral, or angry faces as implicit spatial cues. The facial affects (angry, happy, neutral) were expressed in schematic cartoons, which should be equally perceptible to both hemispheres (Yashar, *et al*, 2008). The literature on the attention bias in anxious individuals leads to the prediction that angry face cues would increase OB and increase OC in participants with high anxiety relative to participants with low anxiety and relative to neutral faces in either group. This reflects both hypervigilance and difficulty disengaging attention, respectively. At the same time, we measured two other aspects of spatial attention which may be affected by anxiety, namely, Conflict Resolution and Alerting. Furthermore, we manipulated the valence of the stimulus (positive, negative, and emotionally neutral) and the visual field of presentation (lateralized, tachistoscopic presentations). Due to the right hemisphere's known role in both negative emotions and spatial attention (see Chapter 1), we predicted that effects of anxiety on attention will be selective to the right hemisphere.

Methods

Participants

One hundred fifteen undergraduates (54 males) at the University of California, Los Angeles participated in the experiment as part of a class assignment. Anxiety level was measured with the trait portion of the State-Trait Anxiety Inventory (Spielberger, Gorsuch, & Lushene, 1983). Anxiety scores ranged from 24-69, with a median score of 41.

Apparatus

The experiment was performed on an IBM-compatible personal computer using E-Prime 1.1 presentation software (Psychology Software Tools, 2002). Stimuli were presented on a 17" Dell monitor with a refresh rate of 60Hz and a resolution of 1280 x 800 pixels/inch. The monitor was situated 57cm away from the participant's eyes. Participants made unimanual responses using a two-button computer mouse held in front of the participant at the midline. The mouse was rotated 90° (placed on its side) so that pressing a button with the index finger indicated the response "up", and pressing a button with the middle finger indicated the response "down".

Stimuli

Lateralized Attention Network Task (LANT). Targets consisted of a vertical arrow, pointing up or down, that appeared one degree to the left or right of fixation. Targets were flanked by two arrows above and two arrows below pointing in the same (congruent) or opposite (incongruent) direction and appearing equally often in the left visual field (LVF; 2° to the left of fixation at the closest edge) and in the right visual field (RVF; 2° to the right of fixation at the closest edge). The complete target stimulus (one central arrow plus four flankers) subtended a total of 3.09° of visual angle vertically and 0.57° horizontally.

An emotional cue preceded each target and consisted of a schematic happy, neutral, or angry face (*cf.* Öhman, Lundqvist, & Esteves, 2001). There were three versions of the test, each including cues of one valence type. Within each version of the test, the cues appeared equally often in one of three locations: at the same location as the target (valid cue), in the opposite visual field as the target (invalid cue), or at fixation (central, spatially neutral cue). There was also a fourth condition in which the cue did not appear at all (no cue). The cues subtended 1° of the visual angle vertically and horizontally. The neutral face cue in the central location constituted the baseline condition for this experiment: both spatially and emotionally neutral.

Each trial began with a fixation cross projected for either 400ms or 1600ms, varying randomly by trial. The temporal jitter was manipulated to avoid temporal expectation of cue presentations and thus pre-programming of the response. The fixation cross was followed by a 180ms cue, in which one of the emotional faces or no cue was presented. The cue was followed by a 150ms interstimulus interval, after which the target and flanker arrows were presented for 170ms. Participants had up to 1000ms to make a response after the target and flankers had disappeared from the screen, and their reaction times and accuracy were recorded. The fixation cross appeared unchanged throughout all trials and intervals. See Figure 3.1 for an illustration of trial events.

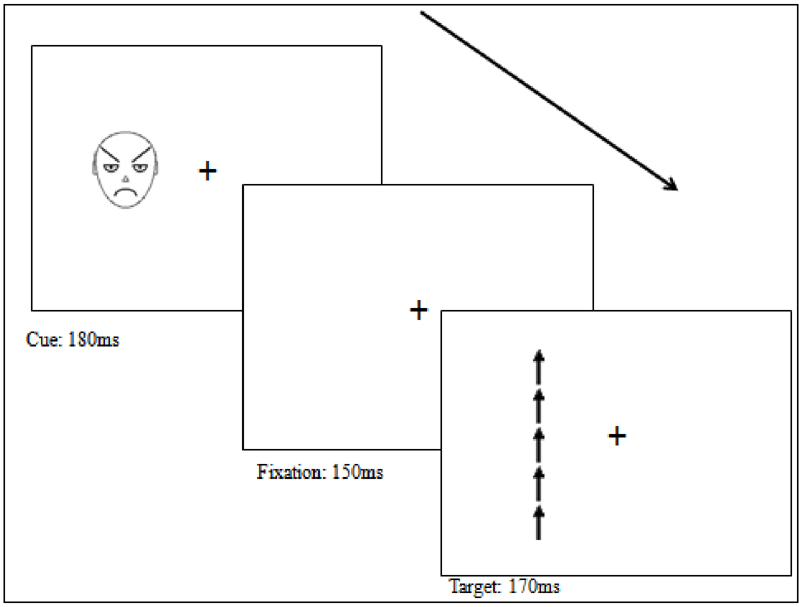


Figure 3.1. Schematic progression of the LANT experiment. Arrow represents progression of time.

Procedure

Participants were randomly assigned to one of the three versions of the task: one with happy faces only, one with angry faces only, or one with neutral faces only. Cue Valence was a between subjects variable to limit the experiment to a practical length (approximately 35 minutes) and avoid the effects of fatigue. Each participant was first given a 20-trial practice block during which participants were given feedback on their accuracy and reaction time on each trial. This was followed by the two experimental blocks presented without feedback, separated by breaks after each run of 160 trials. Each block took approximately ten minutes. The length of each break was determined by the individual participant.

Participants were instructed to keep their eyes on the fixation cross at all times and to indicate the direction of the target arrow as quickly and accurately as possible. Participants clicked the mouse with either their left or right index finger if the target pointed up and they clicked the mouse with either their right or left middle finger if the target pointed down.

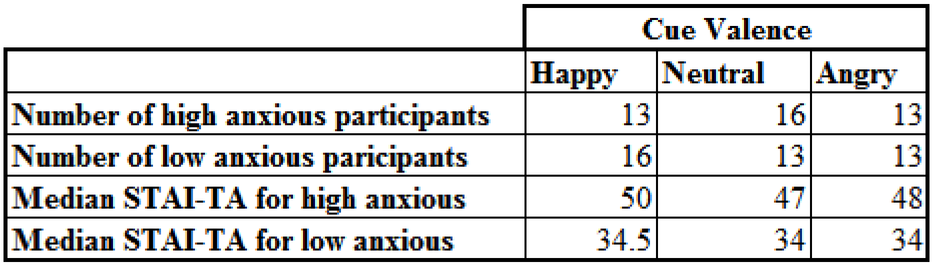
Response hand alternated after each block, counterbalanced between subjects. The practice block and first trial block always used the same hand to respond. Response hand was included as a within-subjects variable in the experiment. However, the results showed no main effects or interactions involving Response Hand, Visual Field, Anxiety Level, or Valence. Consequently, Response Hand was excluded from further analysis.

The Orienting Benefit (OB) network was determined by subtracting response times to targets preceded by valid cues from response times to targets preceded by central cues. The Orienting Cost (OC) network was determined by subtracting response times to targets preceded by central cues from response times to targets preceded by invalid cues. The Conflict (C) network was determined by subtracting response times to targets with congruent flankers from response times to targets with incongruent flankers. The Alerting (A) network was determined by subtracting response times to targets preceded by a central cue from response times to targets preceded by no cue.

Treatment of the Data

Seventeen participants were removed from analysis because they failed to complete the State-Trait Anxiety Inventory. Overall accuracy for the LANT was 89% (*SD* = 19%). Participants who met any of the following criteria were excluded: 1) response times greater than two standard deviations from the mean of response times, 2) overall accuracy less than two standard deviations away from chance (50%) using the normal approximation to the binomial guessing distribution ($z < 1.96$, $p > 0.05$), or 3) large discrepancy in performance between congruent and incongruent flanker conditions (i.e., 90% or greater accuracy for congruent conditions, but 50% or less accuracy for incongruent conditions), showing that they could not do the task. This resulted in additional exclusion of 15 participants (12% of total). Eighty-four participants remained after exclusion (39 male).

Of the 84 remaining participants, 42 were categorized as high anxiety by median split on STAI-TA scores of the remaining participants (anxiety score > 40). See Table 3.1 for distribution of high and low anxiety in each participant group.



	Cue Valence		
	Happy	Neutral	Angry
Number of high anxious participants	13	16	13
Number of low anxious paricipants	16	13	13
Median STAI-TA for high anxious	50	47	48
Median STAI-TA for low anxious	34.5	34	34

Table 3.1. Distribution of STAI-TA scores for each participant group and each cue valence.

Handedness scores were not available for the participants in this experiment. However, the pattern of results in the LANT that involved hemispheric differences in each of the attention networks was similar in this class to previous academic terms, during which the Oldfield handedness questionnaire was administered and 7% of participants were non-consistent right-handers. Moreover, there were no effects or interactions with response hand. Taken together, we take the results in this experiment to represent the pattern expected from a representative population of right-handed participants.

Only reaction times for correct responses were included in the analysis. Response times below 100ms were considered errors of anticipation and were removed from analysis. Response times above 1000ms were considered lapses of attention and were not recorded in the experiment. All main effects and interactions were Greenhouse-Geisser corrected for violations of sphericity where appropriate.

Results

Initial Analysis

We first performed a 2 (Flanker Congruity: Congruent, Incongruent) x 4 (Cue Position: Valid, Invalid, Central, None) x 2 (Target Visual Field: Left, Right) x 3 (Cue Valence: Happy, Neutral, Angry) x 2 (Anxiety Level: High, Low) mixed ANOVA with three repeated measures. Cue Valence and Anxiety Level were between-subjects factors. The dependent variable was reaction time (RT) measured in milliseconds (ms).

There was a significant main effect of Flanker Congruity showing that congruent targets (*M* = 323.67ms, *SD* = 1.75) were processed more quickly than incongruent targets (*M* = 401.43ms, *SD* = 2.24), *F*(1, 78) = 566.62, *MSE* = 3551.51, *p* = .000. There was a main effect of Cue Position, *F*(2.61, 203.25) = 141.73, *MSE* = 998.44, *p* = .000, showing that targets preceded by valid cues (*M* = 341.08ms, *SD* = 2.09) were identified more rapidly than those with central, spatially neutral cues (*M* = 353.95ms, *SD* = 1.99; *t*(83) = 5.83, *p* = .000, significant OB), which in turn were identified more rapidly than targets preceded by invalid cues (*M* = 365.60ms, *SD* = 2.16; *t*(83) = 5.91, *p* = .000, significant OC). Targets preceded by either cue, valid or invalid, were identified more rapidly than when there were no cues (*M* = 389.59ms, *SD* = 1.89). Cue Position also interacted with Target Visual Field, *F*(2.68, 209.36) = 5.89, *MSE* = 608.90, *p* = .001 (see Figure 3.2), suggesting larger OC as well as OB in the right visual field (left hemisphere) than in the left visual field (right hemisphere).

There was no main effect of Anxiety Level, reflecting no systematic differences between the two participant groups, *F*(1,78) = 2.33, *MSE* = 500062.17, *p* = .131. However, Anxiety

Level did interact with Target Visual Field, *F*(1, 78) = 5.76, *MSE* = 1547.34, *p* = .017. This showed no difference between responses to targets in either visual field in individuals with high anxiety. This is distinct from a pattern of increased reaction times to right visual field targets in individuals with low anxiety.

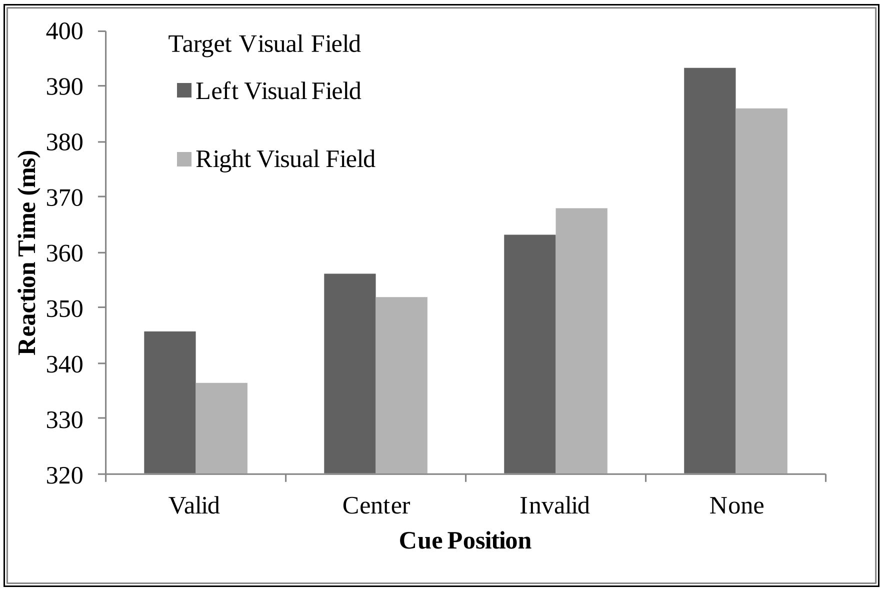


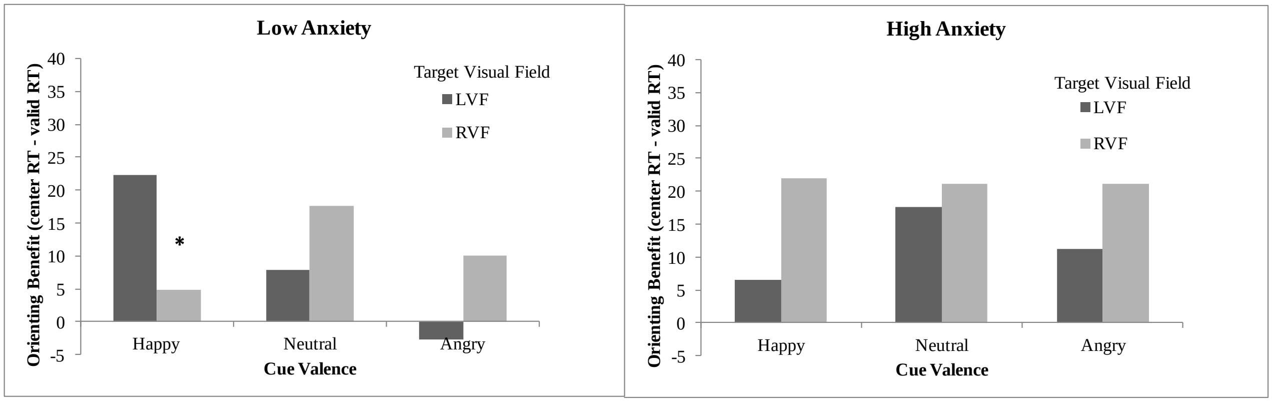
Figure 3.2. Cue Position x Target Visual Field interaction in initial analysis, significant at p < .05.

There was a significant interaction between Flanker Congruity and Cue Position, *F*(2.79, 217.74) = 35.54, *MSE* = 685.61, *p* = .000. Given 1) our a priori predictions about the independent effect of anxiety on the separate attention networks in each hemisphere, 2) the observed interaction between Cue Position and Visual Field, and 3) the observed interaction between Anxiety Level and Visual Field, separate ANOVAs were carried out to investigate each of the four attention networks in each hemisphere.

Orienting Benefit

We used OB (i.e., response times to targets preceded by central cues minus response times to targets preceded by valid cues) as the dependent variable for this analysis. The critical interaction between Target Visual Field, Anxiety Level, and Cue Valence was significant, $F(2,78) = 4.27$, $MSE = 433.10$, $p = .017$ (see Figure 3.3). There were no other significant main effects or interactions.

Planned comparisons for the three-way interaction were Bonferroni corrected to maintain $p < .05$. There was one significant contrast: in participants with low anxiety, happy faces presented to the left visual field ($M = 22.32$, $SD = 18.27$) elicited significantly higher OB than did happy faces presented to the right visual field ($M = 4.91$, $SD = 13.51$), $t(15) = 3.07$, $p < .05$. Importantly, this pattern is reversed in participants with high anxiety. Those participants showed higher OB to happy faces presented to the RVF ($M = 21.96$, $SD = 21.62$) than to the LVF ($M = 6.58$, $SD = 21.77$).



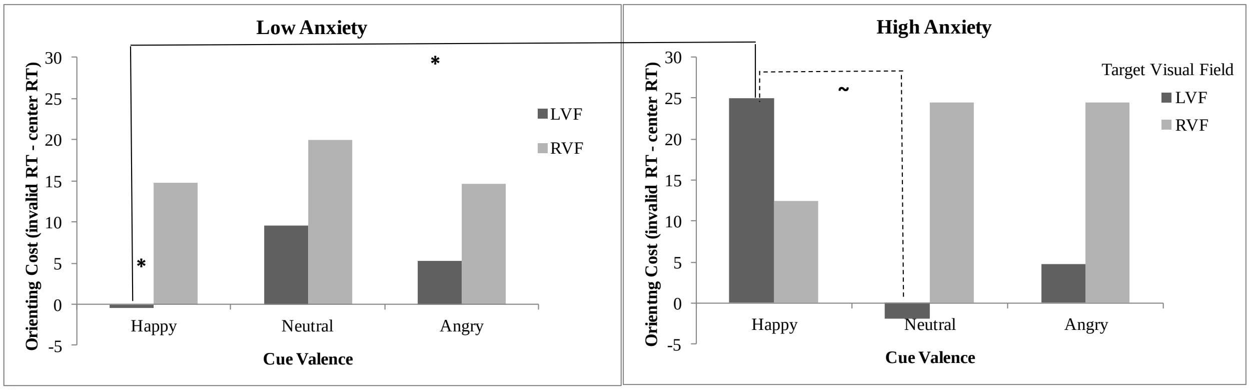
*** = $p < .05$**

Figure 3.3. Target Visual Field x Anxiety Level x Valence interaction for OB. Interaction significant at p < .05

Orienting Cost

We used OC (i.e., response times to targets preceded by invalid cues minus reaction times minus response times targets preceded by central cues) as the dependent variable for this analysis. There was a significant difference in OC between the left and right visual fields overall, $F(1,78) = 6.70$, $MSE = 532.91$, $p = .011$. OC was lower in the LVF ($M = 7.03$, $SD = .73$) than in the RVF (*M* = 16.29, *SD* = .94). The critical interaction between Target Visual Field, Anxiety Level, and Cue Valence was again significant, *F*(3,78) = 2.23, *MSE* = 532.91, *p* = .045 (see Figure 3.4). There were no other significant main effects or interactions.

Planned comparisons for the three-way interaction were Bonferroni corrected to maintain *p* < .05. There were two significant effects: 1) Happy faces presented to the LVF of participants with low anxiety elicited significantly smaller OC (*M* = -.41, *SD* = 16.67) than did happy faces presented to the RVF (*M* = 14.80, *SD* = 18.62), *t*(15) = 3.28, *p* < .05. 2) Happy faces presented to the LVF of participants with low anxiety elicited significantly smaller OC (*M* = -.92, *SD* = 12.31) than did happy faces presented to the LVF of participants with high anxiety (*M* = 24.96, *SD* = 21.76), *t*(12) = 5.15, *p* < .05. There was also a near-significant difference in participants with high anxiety between OC to happy faces (*M* = 24.96, *SD* = 21.76) versus neutral faces (*M* = -2.88, *SD* = 20.94) presented to the LVF, *t*(12) = 3.16, *p* = .06.



*** = *p* < .05**
~ = *p* < .06

Figure 3.4. *Target Visual Field x Anxiety Level x Valence interaction for OC. Interaction significant at p < .05.*

Alerting

We used Alerting (i.e., response times to targets preceded by no cues minus response times to targets preceded by central cues) as the dependent variable for this analysis. Alerting also showed the critical interaction between Target Visual Field, Anxiety Level, and Cue Valence, $F(2,78) = 3.21$, $MSE = 643.67$, $p = .046$. There were no other significant main effects or interactions.

Planned comparisons for the three-way interaction were Bonferroni corrected to maintain $p < .05$. Left visual field targets preceded by happy, central face cues showed a trend for eliciting greater Alerting in participants with high anxiety than in participants with low anxiety. However, there were no significant contrasts.

Conflict

We used Conflict (i.e., response times to targets with incongruent flankers minus response times to targets with congruent flankers) as the dependent variable for this analysis. Conflict showed no significant main effects or interactions.

Correlations with STAI-TA scores

The use of median split procedures to define participant groups simplifies the data in an attempt to enhance group differences, but is accompanied by a decrease in statistical power. Consequently, we correlated STAI-TA scores with OB and OC in each visual field to confirm the results of our ANOVAs. We furthermore compared these correlations for positive stimuli and for threatening stimuli. The only significant correlation following Bonferroni correction was between STAI-TA score and OC in the LVF for happy faces, $r = .616$, $p = .000$.

Reliability of the Neutral Condition

Targets preceded by central cues served as the spatially neutral condition, and therefore expected to have reaction times between those for targets preceded by the valid and invalid cues.

Similarly, targets preceded by neutral face cues served as the emotionally neutral condition, and therefore expected to have reaction times between those for targets preceded by angry and happy face cues. The centrally presented cues satisfied this criterion for both high and low participants (see Figure 3.5). However, the emotionally neutral face cue did not satisfy this criterion separately for each participant group. In particular, the neutral face cue did not serve as an emotional neutral for participants with high anxiety (see Figure 3.6). This may be because participants with high anxiety interpreted the neutral face cue in a threatening way (Lee, Kang, Park, Kim & An, 2008).

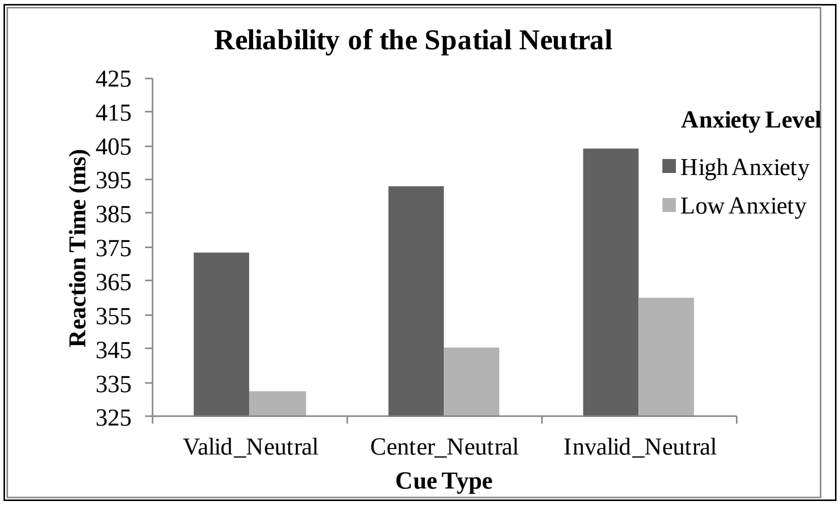


Figure 3.5. Reliability of the spatial neutral.

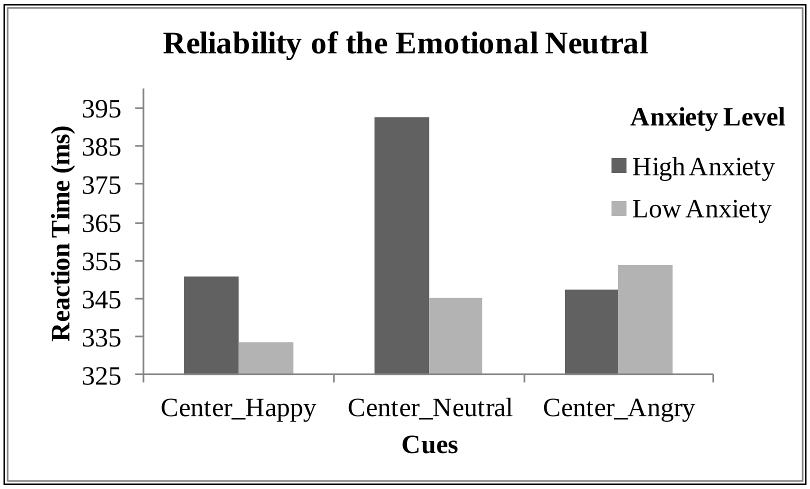


Figure 3.6. Reliability of the emotional neutral.

Discussion

The goals of this study were to examine 1) the separate contributions of the three networks of selective spatial attention to the attention bias to threat in high anxiety discussed in the literature, 2) the separate contributions of each hemisphere to the attention bias, and 3) the differential effects of positive and negative stimuli on attention in anxiety. We determined that anxiety selectively affects spatial Orienting (including both OB and OC) compared to Alerting or Conflict. Only Orienting was explicitly sensitive to target visual field, valence, and anxiety level simultaneously. Based on traditional measures of the attention bias and on the traditional views of hemispheric specialization for emotional stimuli, we predicted that in anxious participants both hypervigilance (OB) and difficulty disengaging (OC) would be higher for angry cues than for nonthreatening cues and larger in the left visual field (LVF) than in the right visual field (RVF). We confirmed that sensitivity to emotional stimuli is selective to targets projecting to the LVF, i.e., the right hemisphere: targets projected to the right hemisphere showed differential effects depending on the cue valence for both OB and OC. By contrast, RVF cues elicited stable effects across cue valence. However, we found that the right hemisphere was specifically responsive to *happy* face cues rather than to *angry* face cues. Thus, participants with low anxiety showed overall response *facilitation* when happy cues were presented to the LVF (OB increased, OC decreased). This is in agreement with several studies which have shown that low anxious participants are more sensitive to positive stimuli (e.g. Waters, *et al*, 2007; Bar-Haim, Laimy, *et al,* 2007; MacLeod, *et al*, 1986). By contrast, participants with high anxiety showed overall response *inhibition* when happy cues were presented to the LVF (OB decreased, OC increased). In sum, happy faces helped right hemisphere spatial Orienting in participants with low anxiety and hurt right hemisphere spatial Orienting in participants with high anxiety. Neither Alerting nor Conflict showed a significant effect of anxiety level with either happy or angry face cues, suggesting that neither provides as sensitive a measure of the attention bias in anxiety as does Orienting.

Attention Bias to Threatening Stimuli

Taken together, our results suggest that the effects of threatening and happy stimuli in anxiety are independent of each other. This is in direct contrast both with 1) the standard theory of attention to threat in anxiety, which would predict a primary increase in OB to threatening stimuli (as well as an increase in OC to threatening stimuli), and 2) with attentional control theory (Eysenck, *et al*, 2007), which predicts a secondary increase in OB to positive stimuli (as well as an increase in OC to positive stimuli). Instead, positive stimuli demonstrated a primary increase in OB and decrease in OC in individuals with low anxiety and a primary decrease in OB and increase in OC in individuals with high anxiety. Threatening stimuli did not differentiate individuals with high anxiety from individuals with low anxiety. Importantly, this effect was found for Orienting in the LVF selectively, highlighting the necessity to differentiate the role of the two hemispheres when examining anxiety. This may have important implications for methods of clinical intervention for anxiety by targeting anatomical structures and processes in the right hemisphere.

Hemispheric Contributions to the Attention Bias

Our data failed to show a LVF advantage for all emotional cues, thus failing to provide strong support for the Right Hemisphere Hypothesis of emotion processing. Our data also failed to show a selective LVF sensitivity for negative emotional cues together with a selective RVF sensitivity for positive emotional cues, thus failing to support the Valence Hypothesis. However, the face cues did help performance (increasing OB, decreasing OC) in the LVF, whereas there was no sensitivity to the different valences of the faces in the RVF. We take this to provide partial support for the Right Hemisphere Hypothesis. It could be argued that this LVF sensitivity may in fact be due to right hemisphere specialization for processing and identifying faces. However, the face cues consisted of highly salient schematic cartoon faces that are equally perceived in both hemispheres (Yashar, *et al*, 2008).

Generalizations and Extensions

Our results may be underestimated due to the relatively high exclusion rate. However, our sample size exhibited sufficient power to observe the predicted effects with this task. Nonetheless, these results should be replicated and extended in several ways.

Our results showed that non-emotional cartoon faces do not serve as effective neutral stimuli to distinguish between positive and negative emotional faces for individuals with high anxiety. This point is particularly interesting because it invokes the question of how non-emotional stimuli are evaluated by individuals with high anxiety and, if non-emotional stimuli are evaluated as emotional, why do individuals with high anxiety automatically classify stimuli? Consequently, future studies should explore better candidates for neutrally-valenced stimuli.

Future studies should also examine the possibility that evaluation of a non-emotional face may serve as an implicit measure of anxiety level. It is possible that our neutral faces were evaluated as emotional in some way, compared to angry and happy faces. One possibility is to test neutral faces alone to avoid effects of emotional context.

Lastly, it is important to consider the role that individual differences play in our results. This includes more explicit measures of handedness which distinguish strong right-handers from non-consistent right-handers and from strong left-handers, with and without familial sinistrality. This also includes consideration of sex (male/female) as well as gender attribution (masculinity and femininity). Consideration of sex is particularly important given that females are more likely to develop anxiety disorders than males (National Institutes of Mental Health, 2009).

Based on the present results and those found in Experiment 2, we suggest that the inability to benefit from positive experiences is an important part of the maintenance of anxiety. Studies have shown that it is possible to induce an attention bias to particular stimuli by making the stimuli predictive of target location (Frewen, Dozois, Joanisse, & Neufeld, 2007). Our results support Attention Bias Modification Training which induces an attention bias to positive stimuli in the left visual field in particular (MacLeod, *et al*, 2002). This implicit change in behavior may teach individuals with high anxiety to attend to positive stimuli and experiences in everyday life, thus overcoming the maintenance of anxiety.

Conclusions

In summary, we examined the effects of emotional valence on separate networks of attention in anxiety independently in each cerebral hemisphere. We confirmed that the mechanisms underlying the attention bias occurred selectively in the Orienting, rather than Alerting or Conflict, attention network. We demonstrated that the two hemispheres make separate and independent contributions to the effect of anxiety on attention. Our results support a form of the Right Hemisphere Hypothesis in that we found right hemisphere sensitivity to positive stimuli but not to negative stimuli. Using a novel paradigm for measuring attention in anxiety, we found that attention in anxiety is primarily and independently affected by happy cues rather than by threatening cues. Thus, happy cues helped LVF performance in participants with low anxiety. By contrast, happy cues impaired LVF performance in participants with high anxiety.

Taken together, these results show that: 1) the Orienting network of the emotional LANT is sensitive to anxiety level, 2) the effects of positive cues provide a more sensitive measure of anxiety than the effects of threatening cues, and 3) a sensitive test of anxiety should distinguish its effects in each hemisphere.

Experiment 4: Inhibition of Return and Anxiety

Experiment 3 showed that the effects of anxiety on attention are restricted to spatial Orienting. As mentioned in Chapter 1, spatial Orienting consists of two major components: an initial facilitation of attention to cued locations, followed by inhibition of attention to cued locations. Experiment 4 was designed to test the effect of anxiety on the later component of spatial Orienting, known as Inhibition of Return (IOR). IOR is often considered a measure of disengagement of attention from a particular location. Thus, increased IOR means increased, or faster, disengagement. IOR has been shown to be reduced in individuals with high anxiety (e.g. Fox, *et al*, 2002). However, the laterality of this effect has not been established. Furthermore, there is considerable evidence in the literature that this effect is specific to spatial Orienting to threatening stimuli (either cues or targets; Fox, *et al*, 2002; Perez-Dueñas, *et al*, 2009), while other evidence suggests that anxiety is associated with reduced IOR in the absence of threatening cues (Rutherford & Raymond, 2009). Our own results from Experiments 1-3 suggest that anxiety is not selectively sensitive to threat, and thus the effect of anxiety on attention may be observed even in the absence of threatening stimuli. We chose to use the same neutral faces as in Experiment 3 to assess this stimulus in a non-emotional context (see Experiment 3 discussion). Thus, Experiment 4 attempted to establish the expected reduction in IOR for individuals with high anxiety in an emotionally neutral context.

As with other measures of Orienting, IOR has been attributed to right hemisphere mechanisms (Lepsien & Pollman, 2002). It therefore seems likely that responses to targets in the two visual fields will exhibit a different magnitude or duration of IOR. Additionally, previous studies of IOR in patients with obsessive compulsive disorder (OCD) showed that IOR is significantly reduced for targets projected to the right hemisphere of patients with OCD, compared to those without OCD (Rankins, Bradshaw, Moss, & Georgiou-Karistianis, 2004; Nelson, Early, & Haller, 1994). Thus, we predicted that individuals with high anxiety would show a selective decrease in IOR in the right hemisphere, i.e., in response to left visual field targets.

Finally, in order to fully investigate the reduction in IOR, we considered “reduction” in two possible ways: first, as a reduction in the magnitude of the IOR, and second, as a reduction in the duration of IOR. IOR has been shown to occur during SOAs ranging from 300ms to 3000ms (Samuel & Kat, 2003). Therefore, in order to determine the duration of the IOR in each participant group, we sampled eight different stimulus-onset asynchronies (SOAs), ranging from 250ms to 3500ms. We predicted that individuals with high trait anxiety would show a reduction both in magnitude and in duration of IOR. Magnitude of IOR was calculated as the performance difference between responses to targets preceded by valid cues and responses to targets preceded by invalid cues (i.e., valid minus invalid).

Method

Participants

Fifty-five students at the University of California, Los Angeles, volunteered to participate in the experiment for either course credit or monetary compensation (38 for credit, 17 for money). The participants ranged in age from 18-32 years (mean age = 21). A total of 42 females and 13 males participated (28 strongly right-handed). None reported history of neurological disease or insult and all reported normal or corrected-to-normal vision.

Materials

The experiment was conducted using a 3.00 GHz Intel Pentium D personal computer, running Windows XP. Stimuli were presented via E-Prime 1.1 software (Psychology Software

Tools, 2002) on a 17-inch LCD monitor with a refresh rate of 75 Hz and a resolution of 1280 x 1024 pixels. Participants were seated at a distance of 57 cm with their chins on a chinrest and their eyes aligned with the fixation cross (“+”) in the center of the screen. All stimuli appeared on a uniform white field. The fixation cross subtended 1° of the visual field and remained on the screen throughout the trials. A schematic neutral face (*cf.* Öhman, Lundqvist, & Esteves, 2001) served as the cue in all conditions. The face appeared either replacing the central fixation cross, or 6° to the left or to the right of central fixation. Face stimuli had a width of 44 pixels and a height of 50 pixels. The target was a black, 10-point Courier New asterisk (“*”) and appeared in the exact location as the cue (valid trials), in the opposite visual field (invalid trials), or did not appear at all (catch trials). Responses were collected when participants pressed the spacebar with their designated response hand. Response hand was counterbalanced and alternated for each block to avoid a potential bias of hemispheric effects (e.g., all right-handed responses could activate the left hemisphere more so than the right hemisphere).

Each trial began with the central fixation cross presented on a blank screen for 500ms. The fixation cross stayed on the screen for the entire duration of the experimental block. The neutral face cue was presented for 250ms, and appeared equally often in one of three locations: in the center (replacing the central fixation), in the left visual field, or in the right visual field. Upon cue onset, the interval between the cue onset and the target onset (stimulus onset asynchrony, or SOA) was varied. The SOA was 300, 550, 1050, 1550, 2050, 2550, 3050 or 3550ms from the onset of the cue. Following the SOA, the target was presented for 100ms either to the right or the left of the fixation. In catch trials, a cue was presented but the target was not presented. These trials were included to ensure that participants were not automatically responding upon presentation of the cue. After target presentation, participants had 1000ms to respond before the next trial began. Figure 3.7 shows a sample valid trial.

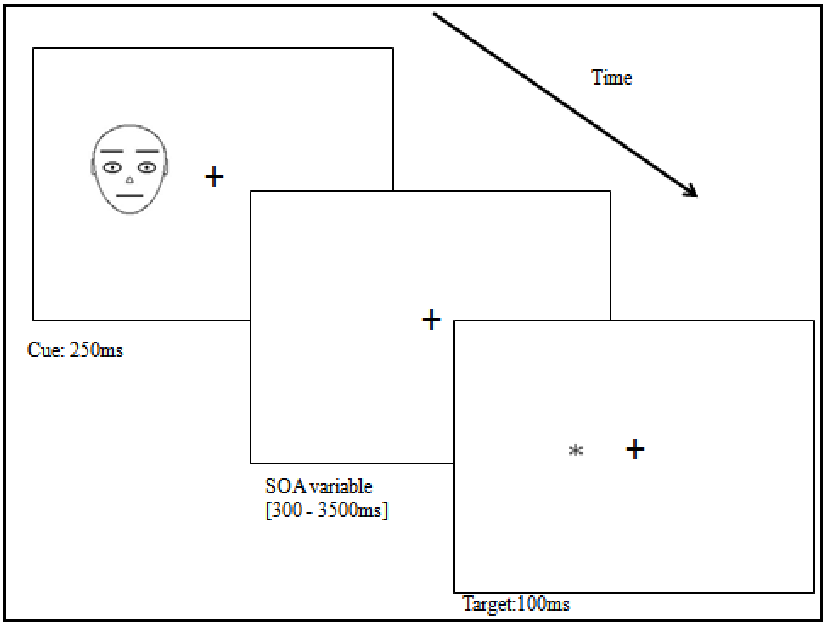


Figure 3.7. Sample of experimental valid trial

The task included one practice block of 16 trials and four experimental blocks of 64 trials each. After each trial in the practice block, participants were given feedback on their reaction time and accuracy. All trials were randomized by block. Each block was separated by a period of rest, the length of which was determined by the participant. The entire experimental session lasted approximately 20 minutes.

Several inventories were administered to each participant prior to starting the computerized task, including the trait version State-Trait Anxiety Inventory (STAI-TA: Spielberger, *et al*, 1983), the Tridimensional Personality Questionnaire (TPQ: Cloninger, 1987), and the Barratt Impulsiveness Scale (BIS: Patton, Stanford, & Barratt, 1995). The STAI-TA was administered to assess trait anxiety, the TPQ to assess novelty-seeking, and the BIS to measure impulsivity. The BIS assessed impulsivity in three separate ways: as attentional impulsivity, as motor impulsivity, and as overall impulsivity. After completion of the experiment, each inventory was scored and participants were placed in a high or low anxiety group based on a median split of STAI-TA scores. Scores ranged from 22-53 with a median score of 40.

Procedure

Before the start of the experiment, participants completed a modified version of the Edinburgh handedness survey (Oldfield, 1971) along with the personality inventories. Then participants were directed to a small, quiet experiment room where they were seated 57cm from the computer screen and instructed to place their chin on the chinrest. All participants were instructed to keep their eyes fixated on the central fixation cross throughout the experiment. Participants were also instructed to press the spacebar as quickly and accurately as possible with their right or left hand (depending on the block) whenever they saw the target. The experimenter stayed with the participant throughout the experiment in order to watch the participant's eyes and to ensure that the participant followed directions properly.

Treatment of the Data

Only reaction times (RTs) for accurate trials were analyzed. Trials with RTs less than 100 ms were excluded as these were assumed to be errors of anticipation. RTs longer than 1000ms were automatically cut off. All main effects of Cue or SOA and interactions with Cue or SOA were Greenhouse-Geisser corrected for violations of sphericity where appropriate. All post-hoc analyses and correlations were Bonferroni corrected for multiple comparisons to maintain $p < .05$.

In order to make the effects of laterality more incisive, we excluded the left-handed participants from our analyses. There remained 27 participants (median handedness score: +14; 2

males). Participants were defined as high anxiety or low anxiety by median split. The median score for the STAI-TA remained at 40 following exclusion of left-handers (13 high anxiety, 14 low anxiety).

Because half of our right-handed participants were paid for their participation and half received course credit, we examined method of compensation as a between-subjects variable to see if these differences affected the results. There were no significant differences related to this variable using either raw RT data or IOR data.

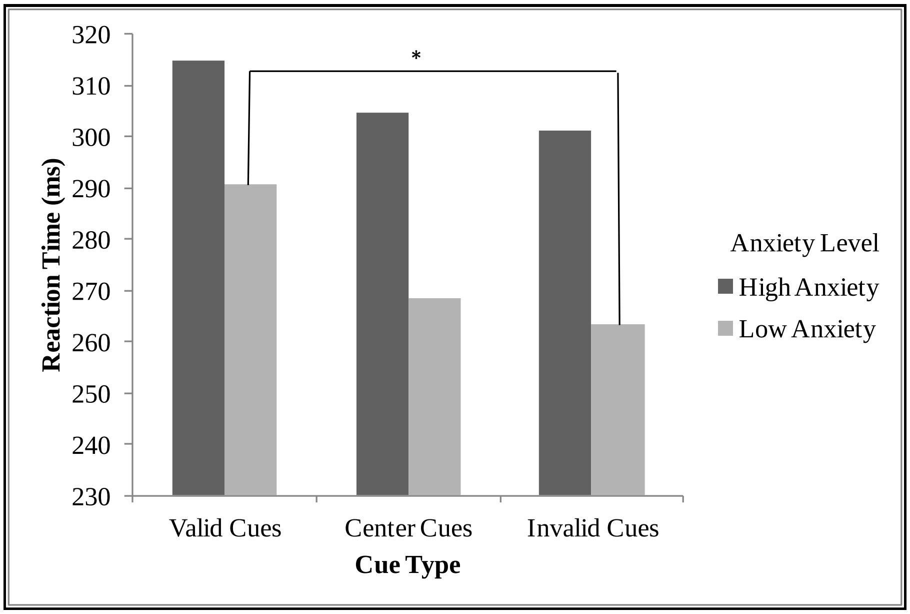
Results

Reaction Times

We performed a 3 (Cue: Valid, Invalid, Center) x 2 (Target Visual Field: Right, Left) x 8 (SOA: 300, 550, 1050, 1550, 2050, 2550, 3050, 3550 ms) x 2 (Anxiety Level: Low, High) mixed ANOVA with a between-subjects factor of Anxiety Level. The dependent variable was median RT. There was a significant main effect of Cue, *F*(1.58, 41.05) = 39.79, *MSE* = 1645.38, *p* = .000. Relative to the center cue, RTs were slightly faster for invalidly cued targets (*M* = 282.35ms, *SD* = 36.51ms) and slower for validly cued targets (*M* = 302.75ms, *SD* = 36.93ms) relative to targets preceded by a central cue (*M* = 286.72ms, *SD* = 36.04ms). There was also a significant main effect of SOA, *F*(3.452, 89.747) = 13.60, *MSE* = 1420.72, *p* =.000. In general, RT was slowest for short SOAs and faster for increasingly long SOAs. All participants responded more slowly at the 300 ms SOA (*M* = 306.10ms, *SD* = 37.73ms) than at the 3500ms SOA (*M* = 287.86, *SD* = 43.44ms).

We found main effects of Target Visual Field (TVF), *F*(1, 26) = 5.11, *MSE* = 1428.30, *p* =.032, and of Anxiety Level, *F*(1, 26) = 5.89, *MSE* = 61318.22, *p* =.022. Participants responded faster when cues were presented in left visual field (LVF; *M* = 288.28ms, *SD* = 35.08ms) compared to the right visual field (RVF; *M* = 292.93ms, *SD* = 37.20ms). Individuals with high anxiety responded more slowly (*M* = 307.00ms, *SD* = 50.53ms) than individuals with low anxiety (*M* = 274.21ms, *SD* = 50.53ms).

We found a Cue x Anxiety Level interaction, *F*(1.58, 41.05) = 4.62, *MSE* = 1645.38, *p* = .022. This showed that participants with high anxiety had no significant differences in their responses to valid, invalid, or center cues, suggesting no effect of IOR overall, whereas participants with low anxiety significantly differed in their responses to valid and invalid cues, *t*(13) = 9.81, *p* = .000; see Figure 3.8.



*** = *p* < .05**

Figure 3.8. Anxiety x Cue interaction for reaction time. Interaction significant at p < .05

We also found a Cue x SOA interaction, *F*(8.61, 223.94) = 2.14, *MSE* = 1481.47, *p* = .029. An inspection of Figure 3.9 suggests that at long SOAs (>300ms), invalid cues are facilitatory and valid cues are inhibitory, indicating that IOR was occurring, as we expected. In order to test this formally, we ran an ANOVA with IOR as the dependent variable.

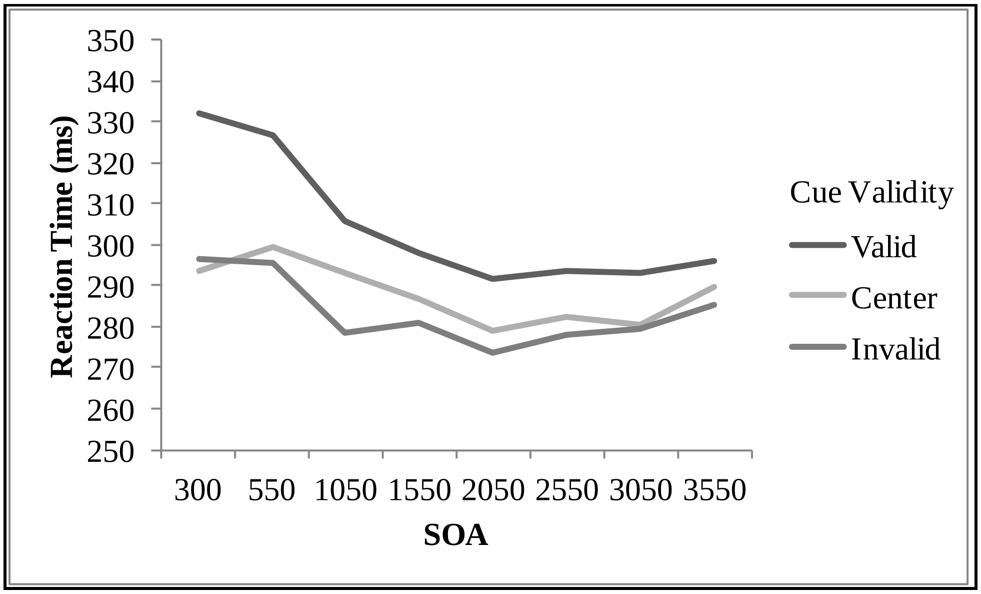


Figure 3.9. Cue x SOA interaction for raw reaction time data. Interaction significant at p < .05

IOR

We performed a 2 (TVF: Right, Left) x 8 (SOA: 300, 550, 1050, 1550, 2050, 2550, 3050, 3550 ms) x 2 (Anxiety Level: Low, High) mixed ANOVA with a between subjects-factor of Anxiety Level. The dependent variable was IOR magnitude, calculated as the difference between reaction times to targets preceded by valid cues and targets preceded by invalid cues. This analysis showed a main effect of SOA *F*(7, 182) = 2.72, *MSE* = 1613.20, *p* =.010. As seen in Figure 3.10, participants showed the greatest magnitude of IOR at the 300 ms SOA, which decreased rapidly from that point and then stabilized at the 1550 ms SOA. At approximately 2500ms, IOR magnitude decreased again until it finally tapered off at an SOA of 3550ms.

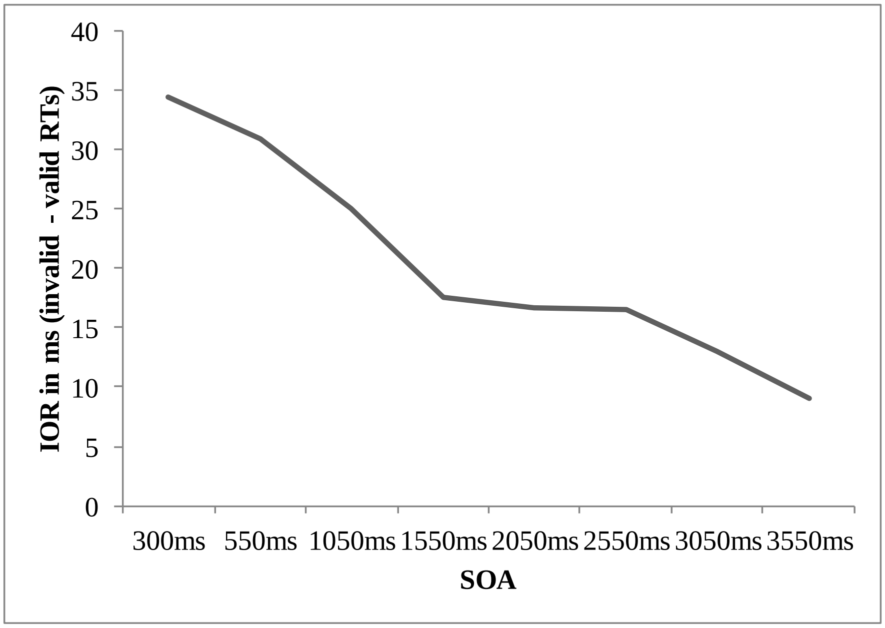


Figure 3.10. IOR decreases over time for approximately 1500ms, and then plateaus before decreasing again after approximately 2500ms. Main effect significant at p < .05

There was also a main effect of Anxiety Level, *F*(1,26) = 6.83, *MSE* = 2931.62, *p* = .015. In general, individuals with high anxiety showed decreased IOR compared to individuals with low anxiety (high anxiety: *M* = 13.72ms, *SD* = 19.16ms; low anxiety: *M* = 27.09ms, *SD* = 19.16ms; see Figure 3.11).

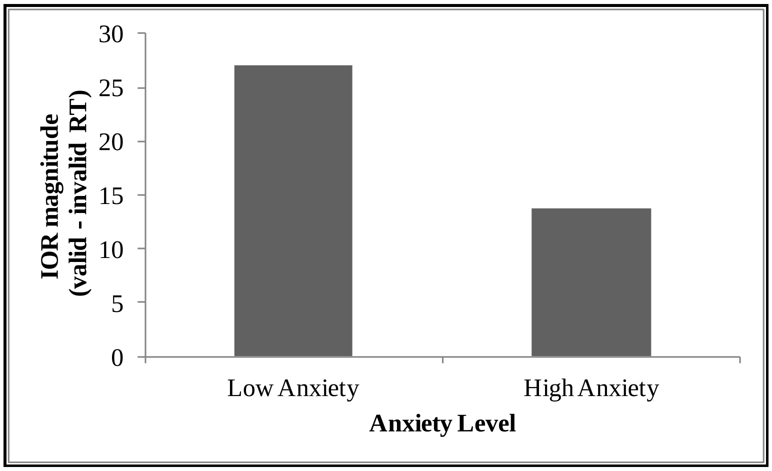


Figure 3.11. Main effect of Anxiety Level when examining IOR magnitude, significant at p < .05

Valid Cues, Invalid Cues, and Center Cues Separately

We examined performance for valid, invalid, and central cues separately to fully investigate the Cue x Anxiety Level interaction found in the reaction time data. For each analysis, we found a main effect of SOA, showing that RTs decreased as SOA increased: valid cues, *F*(7,182) = 16.33, *MSE* = 924.07, *p* = .000; invalid cues, SOA, *F*(7,182) = 4.00, *MSE* = 1058.39, *p* = .000; and center cues, SOA, *F*(4.11,102.86) = 2.45, *MSE* = 1923.22, *p* = .05.

Valid Cues. In addition to the main effect of SOA, there was an interaction between SOA and Anxiety Level, *F*(7,182) = 2.57, *MSE* = 924.07, *p* = .015. This showed that participants with high anxiety were generally slower to respond to targets following valid cues than were participants with low anxiety. The main difference occurred at the last SOA (3550ms), when RTs from participants with high anxiety increased whereas RTs from participants with low anxiety decreased. However, this difference is not significant (*p* = .09). There was no main effect of Anxiety Level (*p* = .09).

Invalid Cues. In addition to the main effect of SOA, there was a main effect of Target Visual Field, *F*(1,26) = 6.68, *MSE* = 1059.68, *p* = .016. These results were consistent with the overall

RT results, showing that responses to LVF targets were faster than responses to RVF targets. We also found a main effect of Anxiety Level, *F*(1,26) = 7.48, *MSE* = 21342.56, *p* = .011. Individuals with high anxiety were slower (*M* = 301.22ms, *SD* = 51.65ms) than individuals with low anxiety (*M* = 263.47ms, *SD* = 51.65ms) following invalid cues.

Center Cues. In addition to the main effect of SOA, there was a main effect of Anxiety Level, *F*(1,25) = 7.86, *MSE* = 20755.28, *p* = .01. This again showed that participants with high anxiety responded more slowly (*M* = 307.51ms, *SD* = 52.86ms) than participants with low anxiety (*M* = 268.61ms, *SD* = 50.96ms) following center cues.

Correlations

The use of median split procedures to define groups does not take full advantage of the continuous nature of the measures of novelty-seeking and anxiety. This reduction of data reduces statistical power. Consequently, we examined the correlation between STAI-TA scores and overall IOR magnitude in order to measure the association between anxiety and IOR. We also examined the correlation between anxiety and IOR magnitude in the LVF and the RVF separately in order to consider possible differential hemispheric contributions. All correlations were Bonferroni corrected for multiple correlations to maintain $p < .05$. STAI-TA scores significantly correlated with IOR in the RVF only, $r = -.457$, $p < .05$. This negative correlation shows that as anxiety level increases, IOR decreases but only in the left hemisphere. This relationship was not significant for LVF targets, $r = -.234$, $p > .2$.

Discussion

This study tested three main predictions: 1) IOR decreases as anxiety level increases, 2) changes in attention due to anxiety are not limited to threatening contexts, and 3) the decrease in

IOR for individuals with high anxiety selectively occurs when targets appear in the left visual field.

We found a significant decrease in IOR magnitude in individuals with high anxiety compared to individuals with low anxiety. This effect occurred in a non-threatening experimental context. The decrease in IOR for individuals with high anxiety appears to have been related to slowed responses to invalid cues compared to valid cues, resulting in similar response times following both cue types. Thus, we interpret our results to reflect the difficulty disengaging attention from a cued location observed in the literature. The decrease was not significantly affected by visual field of target presentation, although STAI-TA was negatively correlated with IOR for right visual field targets (left hemisphere IOR). Anxiety did not affect the duration of IOR.

Attention in Anxiety

There is evidence that the changes in attention due to anxiety may occur independently of the presence of threatening stimuli (Rutherford & Raymond, 2009). This study successfully replicated the result that anxiety is associated with changes in attention even in an emotionally neutral context. We therefore confirmed that IOR reflects attention changes in anxiety. Importantly, IOR reflects these changes in attention due to anxiety even in an emotionally neutral context. However, we cannot exclude the possibility that the effects of anxiety on attention may be accentuated by emotional stimuli, both positive and negative.

It may be argued that these results do not reflect a fundamental difference in attention due to anxiety, but rather reflect a general cognitive slowing in high anxiety. However, if this account were correct, we would expect that individuals with high anxiety would still show changes in responding to targets following valid cues compared to targets following invalid cues, and the difference between these conditions should still be nearly equivalent to the differences for individuals with low anxiety. This was not the case: we instead found that individuals with high anxiety had significantly smaller differences among the target conditions than did individuals with low anxiety. Therefore, although individuals with high anxiety are indeed slower, this slowing does not account for the observed patterns of results.

How Neutral is the Neutral Context?

The use of emotionally neutral faces as spatial orienting cues with general trait anxiety is controversial because neutral faces are often perceived as emoting a particular valence. This perception occurs more often in individuals with high anxiety (Russell & Fehr, 1987; Yoon & Zinbarg, 2007). Therefore, the context may in fact be implicitly more threatening to individuals high in anxiety than to low anxiety. Alternately, because neutral faces are ambiguous, they are more threatening (Somerville, Kim, Johnstone, Alexander, & Whalen, 2004). This would increase engagement with the face and thus decrease IOR. However, a third option is that ambiguity could lead to the attribution of environmental threat and increase scanning, thus increasing disengagement (Stoyanova, Pratt, & Anderson, 2007). Further studies must validate and delimit the specific attribution of threat to neutral face stimuli and its effects on attention in particular and on cognition in general.

Hemispheric Effects

Although the ANOVA showed no effects of hemisphere, we did find a significant negative correlation between IOR magnitude in the left hemisphere and anxiety level. This is different from most results with generalized anxiety which implicate a right hemisphere mechanism (Richards, French, & Dowd, 1994; Van Strien & Valstar, 2004). However, these results complement the findings in individuals with OCD, which show a right hemisphere deficit in (and consequently left hemisphere control of) the disengagement of attention (Rankins, *et al*, 2004; Nelson, *et al*, 1994). OCD is sometimes associated with left hemisphere dysfunction (see Khanna, 1988 for a review), yet exhibits a deficit in IOR in the right hemisphere. Similarly, high trait anxiety is sometimes associated with right hemisphere dysfunction, but exhibits a deficit in IOR in the left hemisphere. Due to the long SOAs employed in these studies, the reversal in hemispheric relations may reflect mixed contributions of both hemispheres, or later dominance of the left hemisphere (in high anxiety) following interhemispheric transfer. Future studies are needed to examine this potential hemispheric transfer in later stages of orienting.

Conclusions

Experiment 4 showed that attention is influenced by anxiety in later aspects of orienting as well as early aspects of orienting. However, these effects appear to be mediated by the left hemisphere rather than the right hemisphere. This is possibly due to interhemispheric transfer occurring during later stages of orienting. These results were obtained in an emotionally neutral context, suggesting that the effects of anxiety on hemispheric attention occur independently of the presence of emotional stimuli.

Experiment 5. Peripheral Vision and Anxiety

Experiments 1-4 show that high anxiety is associated with changes in spatial Orienting of attention. We examined whether changes in attention observed in anxiety may reflect changes in basic visual processes, such as peripheral vision acuity. Peripheral vision acuity is measured clinically using a test of visual perimetry. This test maps out the boundaries of the visual field for each eye. Thus, measures of hemispheric sensitivity to the periphery are included in typical clinical tests. Assessment of peripheral vision complements the findings in orienting of spatial attention and will deepen understanding of how attention is affected by high anxiety.

Eysenck (1992) proposed that in the absence of threatening stimuli, individuals with high anxiety would show increased scanning of the environment and a greater sensitivity to peripheral stimuli because of hypervigilance. However, when threat stimuli are introduced, individuals with high anxiety would focus their attention on these stimuli and have difficulty disengaging from them (Hypervigilance Theory). Thus, by this theory, individuals with high anxiety should show increased sensitivity to the periphery of the visual field.

Several studies have examined individuals' performance on clinical perimetry tests under conditions of stress. Williams & Anderson (1997) found that athletes who had many stressful life events were more likely to have peripheral narrowing during demanding tasks than those with fewer stressful life events, possibly making the former more prone to injury (see also Williams, Tonymon, & Andersen, 1990). These results contrast with the predictions made by Hypervigilance Theory. However, these studies focused exclusively on state anxiety, which is similar to transient stress and measures anxiety as a mood or state. We seek to expand these findings to trait anxiety, which is similar to clinical diagnoses of anxiety and measures anxiety as a personality trait. This will increase our existing knowledge of the cognitive correlates of high anxiety.

To assess the effect of high anxiety on basic peripheral vision, we created a modified version of the clinical static perimetry task. Participants completed the task and accuracy, sensitivity, and response criterion were calculated as measures of peripheral vision.

Methods

Participants

Forty undergraduates at the University of California, Los Angeles participated in this study for monetary compensation (7 males, all strongly right-handed). Participants were recruited in one of two ways: 1) preselected for anxiety level from a large sample of introductory psychology students, or 2) found via an advertisement posted on bulletin boards throughout the university campus. Anxiety was measured by the trait portion of the State-Trait Anxiety Inventory (STAI-TA; Spielberger, Gorsuch, & Lushene, 1983). Participants who scored between 38 and 45 did not complete the experiment so that we could compare vision in high and low (not intermediate) anxiety only. STAI-TA scores ranged from 24-62, with a median score of 40. All participants had normal or corrected-to-normal vision and were neurologically normal as assessed by self-report.

Materials

Stimuli were presented using E-Prime software (Psychology Software Tools, 2002) on a 3GHz Pentium D personal computer running Windows XP. Stimuli were presented on a 17-inch Samsung monitor with a 75Hz refresh rate. The stimuli matched standard Goldmann size III (0.43° in diameter). The brightness of the stimuli was 13 cd/ m^2. The locations at which the stimuli would appear were systematically chosen in the following manner: four concentric circles were drawn 8°, 14°, 20°, and 26° of the visual angle from the center of the fixation cross. Diameter lines were drawn through all of these circles at 30°, 45°, 60°, 120°, 135°, and 150° of the visual angle from the vertical meridian. The intersections between the circles and the diameter lines defined possible locations where stimuli would be presented. There were a total of 48 possible locations for the experimental trials (12 per quadrant of the total visual field). The points at 0°, 90°, 180°, and 270° were not used because they do not fall into one of the four quadrants of space, and thus could not be analyzed. See Figure 3.12 for an example of the possible points.

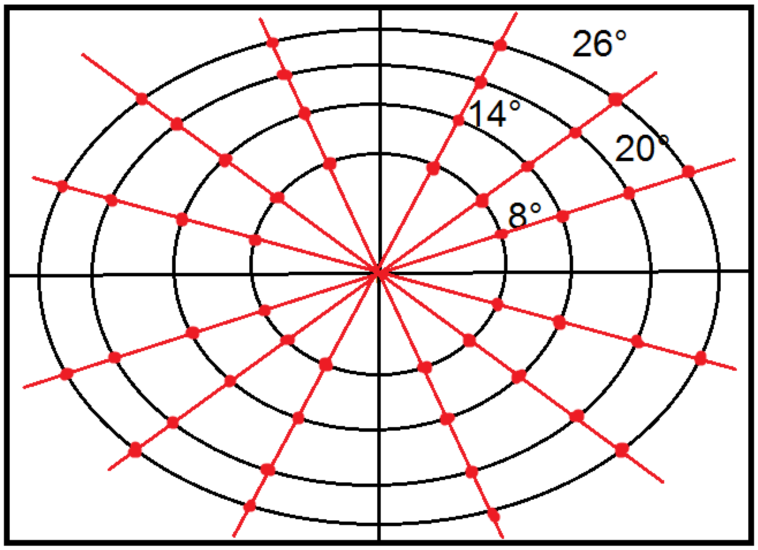


Figure 3.12. All possible stimulus locations at each eccentricity.

Calculation of the Just-Noticeable Difference for Brightness

We completed a preliminary task to finding the just-noticeable difference (JND) between the stimuli and the background. To do this, we created 7 different brightness levels for the stimuli. These levels were brighter than the background in 1 cd/m^2 increments (11-17 cd/ m^2). Using only the points that were 14° diagonally from fixation and 45° and 135° from the horizontal, we presented the stimuli at each of the four possible locations, seven possible brightness levels, and three possible intertrial intervals (100ms, 300ms, and 500ms). The intertrial interval varied to avoid response preparation prior to stimulus detection. Thus, we had a total of 84 experimental trials, and added 16 catch trials to make 100 total experimental trials for this task. Eight randomly selected participants volunteered for the preliminary task. The results showed that the JND was 13 cd/ m^2 (against the 10 cd/ m^2 background) so stimuli for the peripheral vision experiment were given this brightness level.

Peripheral Vision Task

Each experimental trial was preceded by a gray background (10 cd/ m^2) with a black fixation cross at the center. The test stimuli were then presented for 150 ms at a pseudorandom location (see Figure 3.12). Test stimuli consisted of a dot presented at the luminance determined in the preliminary task (13 cd/ m^2). Each dot was presented at each location on the four concentric circles at each of the three intertrial intervals (100 ms, 500 ms, and 800 ms) once per block. Following dot presentation, participants had 1000ms to respond. Detection of the dot was indicated by pressing the spacebar. There were 180 trials per block, including 36 catch trials per block, and 4 blocks total.

Procedure

Each participant completed the STAI-TA at one of two times depending on how they were recruited. Participants who were preselected by anxiety level completed the STAI-TA prior to coming in to the lab. Participants who were recruited by advertisements completed the experiment in two sessions, the first session for completing the STAI-TA to confirm eligibility. When participants came in to complete the experiment trials, each participant gave informed consent and filled out a revised version of the Edinburgh Handedness Inventory (Oldfield, 1971). This version of the inventory evaluates handedness and additionally asks questions related to participant eligibility (e.g. “Do you have normal or corrected-to-normal vision?”).

Participants were instructed to position their chin on a chin rest with a viewing distance of 30 cm in front of a computer monitor in a dimly lit room. Participants were told to fix their eyes on the fixation cross and shift their attention only to the different locations in the periphery. Participants were instructed to respond to the dots of light with a keypress as quickly and accurately as possible. Participants were not to respond when they did not detect the dots of light.

Each experiment began with a block of 11 practice trials including feedback for reaction time and accuracy. The first practice trial counterbalanced the quadrant in which the stimuli first appear between participants. This was done to eliminate attention or response biases toward this quadrant. Participants then competed the experimental blocks. Participants responded using one hand at a time, alternating the response hand before the start of each block. Response hand was counterbalanced between participants. Accuracy and reaction time was recorded for each trial.

To calculate each participant’s sensitivity to the dots of light at each possible location, we performed a signal detection analysis on the accuracy data.

Treatment of the Data

We chose not to include data from the most eccentric points (26 degrees) because overall accuracy was nearly 0% at these points. Two participants were excluded due to excessively low accuracy at the most central position (more than 2 standard deviations from the mean; <65%

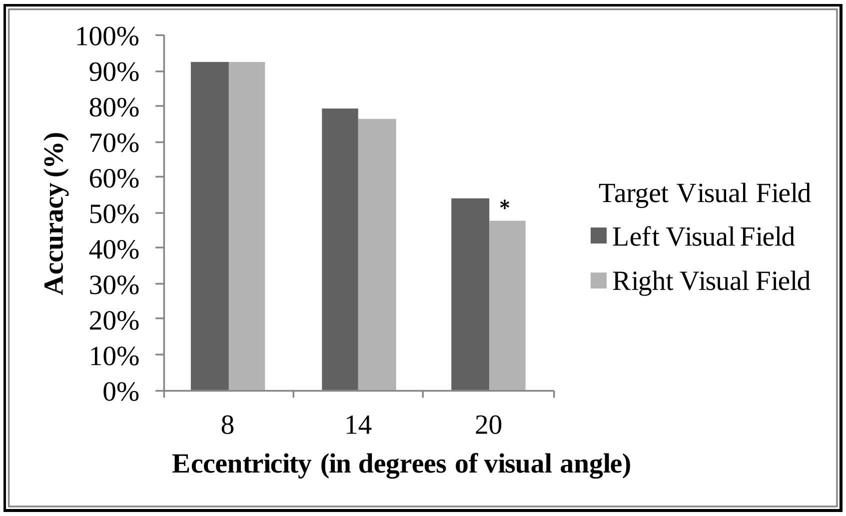
accuracy). Four additional participants were excluded due to technical difficulties. Overall accuracy was 75% for the remaining 35 participants (17 high anxiety). All values are Greenhouse-Geisser and Bonferroni corrected where appropriate.

Results

Accuracy

We ran a 2 (Visual Field: Left, Right) x 3 (Eccentricity: 8, 14, 20 degrees) x 2 (Anxiety Level: High, Low) mixed ANOVA with Anxiety Level as the between-subjects variable and accuracy as the dependent variable. We found a main effect of Visual Field, $F(1,32) = 9.10$, $MSE = .011$, $p = 0.005$, $\eta_p^2 = .216$. Overall accuracy was greater in the left visual field ($M = 0.75$, $SD = 0.12$) than in the right visual field ($M = 0.72$, $SD = 0.12$). We also found a main effect of Eccentricity, $F(2,64) = 180.38$, $MSE = .047$, $p = 0.000$, $\eta_p^2 = .845$. Accuracy was greatest at the most central locations ($M = 0.93$, $SD = 0.06$), significantly decreasing at 14 degrees ($M = 0.78$, $SD = 0.14$), and decreasing to chance level at 20 degrees ($M = 0.51$, $SD = 0.18$). There was also a significant interaction between Target Visual Field and Eccentricity, $F(2,62) = 4.93$, $MSE = .007$, $p = .011$, $\eta_p^2 = .130$. There were no interactions with Anxiety Level ($p > .1$).

Post-hoc comparisons of the interaction between Target Visual Field and Eccentricity showed that the significant decrease in accuracy at each eccentricity is significant in each visual field (all $p < .001$). However, the only significant difference in performance between the two visual fields occurred at the greatest eccentricity (20 degrees), $t(34) = 3.30$, $p < .05$. Consistent with the main effect of Visual Field, accuracy at the greatest peripheral location was greater in the left visual field ($M = .54$, $SD = .188$) than in the right visual field ($M = .48$, $SD = .183$; see Figure 3.13).



*** = *p* < .05**

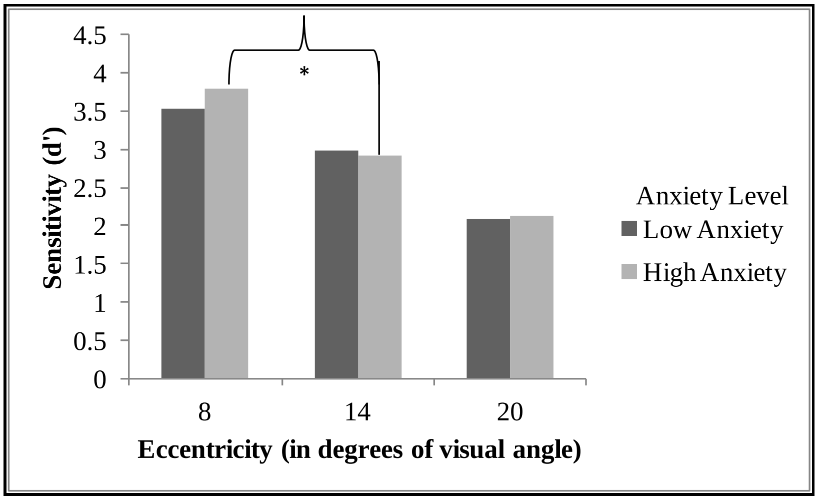
Figure 3.13. Interaction between Visual Field and Peripheral Eccentricity on response accuracy. Interaction significant at p < .05

Sensitivity

Although accuracy did not show an effect of Anxiety Level, we reasoned that a more subtle measure of perception may differentiate between high and low anxiety. We measured sensitivity, the ability of each participant to detect the stimuli, using the d-prime measure in signal detection analysis (ratio of hit rate to false alarm rate). We performed a 2 (Visual Field: Left, Right) x 3 (Eccentricity: 8, 14, 20 degrees) x 2 (Anxiety Level: High, Low) mixed ANOVA with Anxiety Level as the between-subjects variable and d-prime as the dependent variable. Results were largely consistent with the accuracy data: we found a main effect of Visual Field, $F(1,33) = 5.59$, $MSE = 0.74$, $p = 0.024$, $\eta_p^2 = .145$. Sensitivity was greater in the left visual field ($M = 2.95$, $SD = 0.59$) than in the right visual field ($M = 2.86$, $SD = 0.59$). We also found a main effect of Eccentricity, $F(2,66) = 283.97$, $MSE = 0.18$, $p = 0.000$, $\eta_p^2 = .896$. Sensitivity was greatest at the most central locations ($M = 3.67$, $SD = 0.68$), decreased significantly at 14 degrees ($M = 2.95$, $SD = 0.69$), and decreased significantly again at 20 degrees ($M = 2.10$, $SD = 0.59$). Eccentricity interacted with Visual Field, $F(2,66) = 3.52$, $MSE = 0.051$, $p = 0.035$, $\eta_p^2 = .096$. As with the

Eccentricity x Target Visual Field interaction with accuracy, post-hoc comparisons revealed that the decrease in sensitivity at each eccentricity was significant in each visual field. However, sensitivity in the two visual fields differed at the greatest eccentricity (20 degrees), $t(34) = 3.49$, $p < .05$. Sensitivity at the greatest peripheral location was greater in the left visual field ($M = 2.20$, $SD = .61$) than in the right visual field ($M = 2.01$, $SD = .58$).

Importantly, we also found a significant interaction between Eccentricity and Anxiety Level, $F(2,66) = 3.64$, $MSE = 0.18$, $p = 0.04$, $\eta_p^2 = .099$. As seen in Figure 3.14, people with high anxiety had slightly greater sensitivity in the center of their vision compared to individuals with low anxiety. While post hoc comparisons showed no significant differences between sensitivity for individuals with high anxiety and individuals with low anxiety at each eccentricity ($p > .31$), we also compared the magnitude of decrease in sensitivity between the central location and next peripheral location between individuals with high anxiety and those with low anxiety. The decrease between the most central points and the medium periphery points was greater for individuals with high anxiety than individuals with low anxiety, $t(16) = 2.48$, $p < .05$. Therefore, while individuals with high anxiety were not significantly more sensitive in the center of vision compared to individuals with low anxiety, their decline in sensitivity at more peripheral locations was much greater.



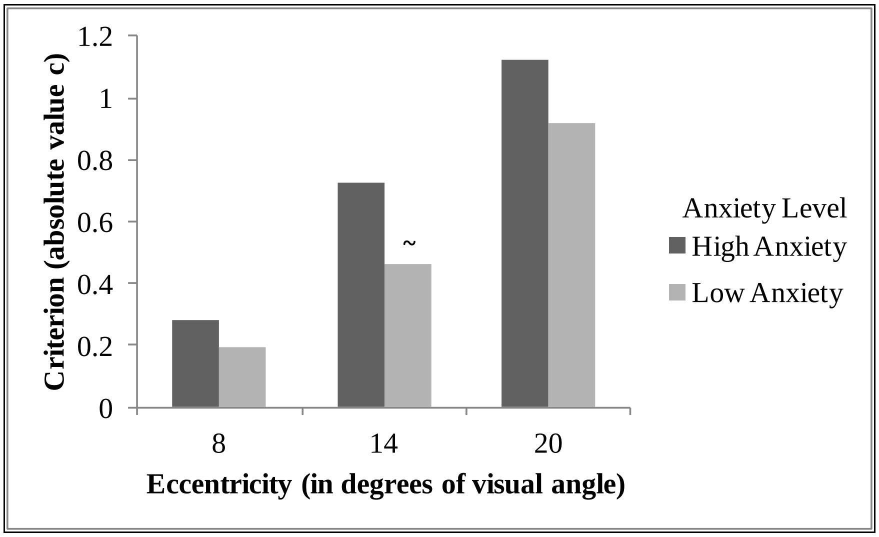
*** = $p < .05$**

Figure 3.14. Interaction between Anxiety Level and Peripheral Eccentricity on visual sensitivity. Interaction significant at $p < .05$

Criterion

To test whether participants varied in their response bias to report that they did not detect the stimulus, we calculated each participant's criterion (derived from the ratio of hits to false alarms; MacMillan & Creelman, 2004). We performed a 2 (Visual Field: Left, Right) x 3 (Eccentricity: 8, 14, 20 degrees) x 2 (Anxiety Level: High, Low) mixed ANOVA with Anxiety Level as the between-subjects variable and the absolute value of the criterion as the dependent variable. We found a main effect of Visual Field, $F(1,33) = 5.59$, $MSE = 0.18$, $p = 0.024$, $\eta_p^2 = .145$. Sensitivity was greater in the left visual field ($M = 2.95$, $SD = 0.59$) than in the right visual field ($M = 2.86$, $SD = 0.59$). We also found a main effect of Eccentricity, $F(2,66) = 283.97$, $MSE = 0.05$, $p = 0.000$, $\eta_p^2 = .896$. Sensitivity was greatest at the most central locations ($M = 3.67$, $SD = 0.68$), decreased significantly at 14 degrees ($M = 2.95$, $SD = 0.69$), and decreased significantly again at 20 degrees ($M = 2.10$, $SD = 0.59$). Eccentricity interacted with Visual Field, $F(2,66) = 3.52$, $MSE = 0.051$, $p = 0.035$, $\eta_p^2 = .096$. Post hoc comparisons of this interaction again showed that the greatest difference in response criterion between the two visual fields was at the greatest periphery (20 degrees), $t(34) = 3.49$, $p < .05$.

We again found a significant interaction between Eccentricity and Anxiety Level, $F(2,66) = 3.64$, $MSE = 0.18$, $p = 0.04$, $\eta_p^2 = .099$. Post hoc comparisons of this interaction again showed no significant differences between individuals with high anxiety and individuals with low anxiety (see Figure 3.15). However, individuals with high anxiety showed a trend toward a higher criterion than individuals with low anxiety at the second peripheral location (14 degrees), $t(16) = 1.99$, $p = .06$. This suggests that while individuals with high anxiety are equally sensitive to individuals with low anxiety at a medium peripheral location, these individuals are less likely to respond that they did detect the stimulus.



~ = $p < .06$

Figure 3.15. Interaction between Anxiety Level and Peripheral Eccentricity on the absolute value of criterion as a measure of response bias. Interaction significant at $p < .05$

Discussion

We examined peripheral vision acuity in individuals with high anxiety and individuals with low anxiety in order to assess the effect of anxiety on peripheral vision. Further investigation of peripheral vision in anxiety expands the results of spatial orienting by assessing awareness in the periphery as well as environmental scanning. We found that while anxiety does not significantly affect accuracy, anxiety does affect sensitivity to the stimuli and response bias in the task. Specifically, we found that individuals with anxiety show a greater decrease in sensitivity from central to peripheral locations compared to individuals with low anxiety. This decrease is accompanied by a slightly greater response bias at the mid-peripheral location. Taken together, these results support Williams (1990; 1997) previous findings of peripheral narrowing in individuals with high anxiety. As with Experiment 4, these results occurred in the absence of emotional stimuli in the environment. This contrasts with the predictions made by Hypervigilance Theory, which predicts peripheral broadening in the absence of threat. This may be due to task differences: Hypervigilance Theory is based on search tasks, rather than assessment of basic visual sensitivity.

Asymmetries of Luminance Detection

Overall, we found that performance on this modified perimetry task was greater in the left visual field compared to the right visual field. This was particularly true at the most peripheral eccentricity we analyzed (20 degrees). This is consistent with the literature that posits right hemisphere dominance in both spatial attention and luminance perception (Heilman & Van Den Abell, 2006; Okubo & Nicholls, 2006). However, this asymmetry was not significantly accentuated by anxiety as we predicted. Rather, it was true of all participants regardless of their anxiety level. This is most likely due to the fact that this task did not measure orienting of spatial attention. Thus, anxiety affects orienting of spatial attention in the right hemisphere selectively, whereas anxiety affects peripheral vision in each hemisphere. Alternately, it is possible that this result is due to the lack of emotional stimuli in the environment (*cf.* Eysenck, 1992, chapter 3), and that if the task was to detect a stimulus that was emotional in some way, the predicted effect of anxiety would be observed. Future studies should manipulate the emotionality of the stimulus either by changing it to an inherently emotional stimulus or associating it with an emotional experience.

Anxiety and Luminance Detection

Our results show that anxiety enhances acuity in the center of vision compared to the periphery. While there is not a significant decrease in sensitivity at the near-periphery of vision compared to individuals with low anxiety, the significant decrease relative to center can be considered a narrowing of peripheral vision. In addition to the reduced acuity in the periphery, individuals with high anxiety are also less likely to report that they detected the stimulus. This decreased bias to respond may be due to the sharp decrease in acuity at this eccentricity. Individuals with high anxiety are known to be more sensitive to uncertainty in stimuli. Thus, the magnitude of the decrease in visual sensitivity may cause uncertainty or decreased confidence in perception. This is reflected in the increased bias to not respond to stimuli.

The combination of increased sensitivity in the center of vision and decreased sensitivity in the near-periphery of vision has important implications for what individuals with high anxiety typically attend to and perceive. For example, individuals with high anxiety may be more sensitive to immediate stimuli and less sensitive to peripheral or contextual stimuli. This relates to extinction training procedures used in the treatment of specific phobias and post-traumatic stress (PSTD): these disorders are considered conditioned fears to a specific context, thus extinction training focuses on desensitizing the individual to the context (e.g. Rougemont-

Bucking, Linnman, Zeffiro, Zeidon, Lebron-Millad, *et al*, 2010). If individuals do not adequately perceive the peripheral context, they will be unable to focus on it sufficiently for desensitization.

Conclusions

We found that individuals with high trait anxiety exhibit narrowing of peripheral vision to emotionally neutral stimuli. The current study presents a novel finding regarding basic vision changes in high trait anxiety. This study was conducted using a modified perimetry test. It would be extremely informative to attempt to replicate these results using a standard perimetry testing procedure in an optometrist's office. Regardless, these findings enhance understanding of the effects of anxiety on attention: increased engagement with focal stimuli and decreased shifting of attention occurs not only from left to right, but also from central to peripheral vision.

Experiments 3, 4, and 5: General Discussion

The Lateralized Attention Network Task (LANT) measured the effect of anxiety on spatial Orienting (both Benefit and Cost), Alerting, and executive Conflict resolution. Results primarily showed an effect of anxiety on spatial Orienting (both Benefit and Cost). There was no effect of anxiety on Conflict. As in Experiments 1 and 2, the effect of anxiety was selective to attention in the right hemisphere. As in Experiment 2, the effect of anxiety was selective to positive stimuli.

To further investigate the effect of anxiety on spatial Orienting, Experiment 4 investigated Inhibition of Return (IOR). This showed that anxiety decreased IOR overall, and that anxiety level had a significant negative correlation with IOR in the left hemisphere. Thus, while the effect of anxiety on early spatial Orienting is mediated by the right hemisphere, later Orienting appears to be related to left hemisphere mechanisms instead.

Taken together, both the LANT and the IOR study showed that the effect of anxiety on attention is selective to spatial Orienting. As Orienting Benefit is considered a measure of hypervigilance and both Orienting Cost and IOR are considered measures of disengagement, the results from Experiments 3 and 4 support the disengagement mechanism in the attention bias. Orienting Benefit (hypervigilance) decreased with happy cues, whereas Orienting Cost (difficulty disengaging) increased, and IOR (a measure of ease of disengagement) decreased. Furthermore, Experiment 5 showed that the effect of anxiety on attention may be related to narrowing of the peripheral field. Peripheral narrowing is also consistent with the idea of difficulty disengaging from central stimuli in high anxiety. Thus, the effects of anxiety on attention are selective to Orienting of spatial attention, and affect the disengagement component of spatial orienting more than the search/detection (hypervigilance) component. However, both components may show the effects of anxiety depending on task demands.

Experiment 3 again showed that the effect of anxiety on attention is not specific to threat. Experiments 4 and 5 showed that the effect of anxiety is not specific to emotional stimuli at all. The question remains as to whether individuals with high anxiety and individuals with low anxiety perceive and process emotional material differently in some way that is not reflected in responses. A more subtle measure of covert processing such as Event-Related Potentials (ERPs) may illuminate this issue. Additionally, consideration of the scalp localization of ERPs for both early and late Orienting may further establish the right hemisphere as the locus of attention changes in high anxiety.

IV. Event-Related Potentials and The Attention Bias

Experiment 6: ERPs in the Lateralized Visual Probe

Experiments 3 and 4 clearly show that covert Orienting of spatial attention in the right hemisphere is selectively affected by high anxiety. Experiments 1-5 show that this change in attention is not dependent on the presence of threatening stimuli. These results contrast with a broad literature on a threat-specific bias in attention in individuals with high trait anxiety. This discrepancy may be due to the fact that different paradigms emphasize different stages of processing. Stages of processing may differ in sensitivity to positive and negative emotional stimuli. The following experiments use event-related potentials (ERPs) to examine the interaction between anxiety and stimulus valence at different stages of processing. We examined both a clinical test of attention (Lateralized Visual Probe) and a basic test of attention (covert orienting of spatial attention including inhibition of return) to examine neural processing of emotional faces in anxiety. We chose to examine the electrophysiological underpinnings of the Lateralized Visual Probe rather than the Lateralized Emotional Stroop primarily because it is more likely to measure orienting of attention. Although the Visual Probe and covert orienting of spatial attention tasks are different, they each speak to the same aspect of attention.

These experiments addressed two of the major questions raised in the dissertation. First, what is the laterality of attention in anxiety? Second, do individuals with high anxiety preferentially direct attention to stimuli of a particular valence? The first question may be answered using ERP methods by examining interactions between the visual field of target presentation and the side of the electrode (over the left hemisphere or over the right hemisphere). Two patterns of activity in particular have been distinguished (Zaidel, *et al,* 1990). The first pattern is “direct access,” where each hemisphere is able to process the information directly presented to it. This is evidenced by stronger activation in the hemisphere contralateral to the stimulus presentation (i.e., left visual field stimuli elicit the greatest ERP amplitude over a right than a left hemisphere electrode). The second pattern is “callosal relay,” where one hemisphere is specialized for the stimulus/task. When the stimuli are presented to the unspecialized hemisphere, the information must transfer via corpus callosum to the specialized hemisphere. This would lead to stronger activation in one hemisphere (electrode) regardless of stimulus visual field.

The behavioral results from the Lateralized Visual Probe suggest that the perception and the experience of negative emotions evoke independent processes within the same right hemisphere. However, anxiety may affect processing of threat in a way that is not reflected in behavioral responses. Consequently, we ran the Lateralized Visual Probe in a second group of participants, focusing on ERPs as a measure of neural processing. To reduce the number of experimental conditions so as to maximize reliability of the waveforms for each participant, we considered only face stimuli. These stimuli showed the greatest influence of anxiety in the behavioral test (Experiment 1). As in Experiment 2, we included angry faces, rather than fearful faces, because angry faces may elicit a greater response in individuals with high anxiety than that elicited by fearful faces.

Methods

Participants

30 undergraduates (5 males) at the University of California, Los Angeles participated in this experiment for course credit. All participants were over the age of 18, had normal or corrected-to-normal vision, and had no history of neurological disease or insult as assessed by self-report. All participants were strongly right-handed (score of +12 or greater), as measured by

the Edinburgh Handedness Inventory (Oldfield, 1971). Participants were categorized as high anxiety if they scored 41 or higher on the STAI-TA (10 total; 1 male); all other participants were categorized as low anxiety (21 total; 4 males).

Materials

Stimuli were presented by an Intel Core2Duo computer with a 2.60 GHz processor using E-Prime 1.1 software (Psychology Software Tools, 2002). Stimuli were presented on a 17” CRT computer monitor at 1024 x 768 pixel resolution, with a refresh rate of 85.074 Hz. Electroencephalogram activity was recorded using a 64-channel Neuroscan Quickcap following International 10-20 electrode placements. Data were amplified through Neuroscan’s SynAmps and stored for offline analysis. All impedances were kept below 10kΩ. Eye movements were recorded from four electrodes placed one centimeter above and below the left eye, and one centimeter from the outer corner of each eye. ERP triggers occurred at the onset of each target dot. ERP codes indicated the visual field of the target, congruity with the emotional face, and the emotionality of each face.

Facial stimuli were taken from the NimStim facial stimulus set (www.macbrain.org; Tottenham, Tanaka, Leon, McCarry, Nurse, Hare, *et al*, 2009). Faces were selected to equally represent each gender. Only Caucasian faces were selected for this experiment to avoid potential interactions with ethnic identity.

The experiment began with a 750ms fixation period, followed by a bilateral presentation of two faces as cues. Faces were 100 x 100 pixels in full color presented 1 degree to the left and right of fixation. The faces were from two different people of the same gender. One face was always emotionally neutral (models 05, 07, 24, and 27); the other face could be angry, happy, or neutral (models 02, 10, 23, 25). Faces were presented for 150ms. Directly after this presentation, a dot appeared on 2/3 of the trials for 100ms. When the dot did not appear, the screen was blank for 100ms. The dot appeared equally often in the left and right visual fields, in a location congruent or incongruent to the location of the emotional face. Because the dot appeared in the center of location where the face was present, the dot was approximately 2 degrees from fixation. Following presentation of the dot, participants were given 1000ms to respond. A black central fixation cross subtending x degrees was present throughout the experiment. See Figure 4.1 for a sample trial.

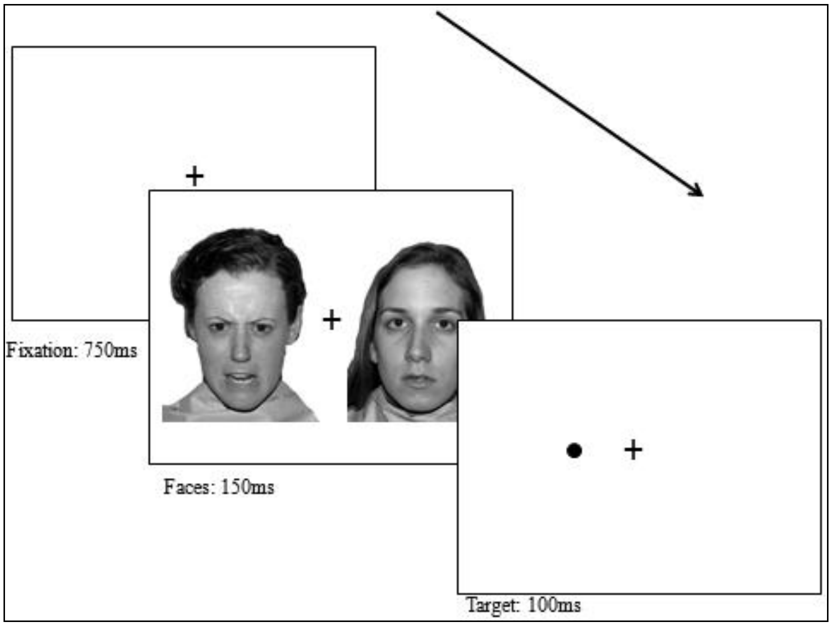


Figure 4.1. Sample congruent trial in Visual Probe paradigm utilized for Event-Related Potentials.

Each condition was repeated 26 times, yielding 10 blocks of 72 trials each. Each block took approximately 3 minutes to complete and was followed by a break. Starting response hand was counterbalanced between subjects and response hand alternated between blocks.

Participants completed three inventories of their emotions and personality: the trait portion of the State-Trait Anxiety Inventory to assess trait anxiety (STAI-TA; Spielberger, Gorsuch, & Lushene, 1983), the Behavioral Inhibition and Behavioral Approach Scales as an alternate assessment of trait anxiety (BIS/BAS; Carver & White, 1994), and the Center for Epedimiologic Studies Depression Scale (CES-D; Ratloff, 1977). The BIS/BAS and CES-D scales were administered to assess similarities to the STAI-TA but were not included in the overall ANOVA.

Procedure

Participants gave informed consent and completed a modified version of the Edinburgh Handedness questionnaire which includes questions from the original version as well as questions relating to participants' eligibility (e.g. "Have you ever had a history of neurological disease?"). Eligibility was confirmed prior to administration of the three emotional inventories. Participants were instructed to answer each question about how they feel in general. Participants were then taken to the experimenting room for cap application. Following cap set-up, participants were instructed to remain still throughout the experiment and to keep their eyes on the central fixation cross. Although head movements were not restrained, experimenters remained in the experimenting room to monitor head and eye movements. Participants were told that this was a test of attention. They would see a face in each visual field, after which they may or may not see a dot in one of the two previously cued locations. If they see the dot, they are to press the spacebar. If they do not see the dot, they do not press anything. Participants were instructed to respond as quickly and accurately as possible.

Treatment of the Data

A minimized set of 22-electrode EEG files were imported into Matlab and analyzed using the EEGLab and ERPLab plug-ins for Matlab (Delorme & Makeig, 2004; F1/2, FC5/6, P1/2/5/6/7/8, PO5/6/7/8, O1/2, FZ, PZ, OZ, M1/2, and HEO/VEO). Each participant's data file was referenced to the average of 22 electrodes plus the two mastoid electrodes, and then band-pass filtered between .1Hz and 40Hz. Eye movement artifacts were detected and removed using Independent Component Analysis. Continuous data were then epoched between 500ms prior to target dot onset and 1000ms following target onset. Muscle and electrical artifacts were visually identified for each participant and removed prior to calculation of weighted averages for each condition.

PO7 and PO8 were visually identified as the locations of strong, clean waveforms that varied with Valence and Probe Location. The N1 component was identified between 100 and 175ms. The P2 component was identified between 175 and 300ms. The N2 component was identified between 300 and 400ms. Mean amplitude and peak latency measurements were taken from the ERPs at PO7 and PO8.

Exclusions

Data from one participant were removed from analysis due to long reaction times (>2 SDs from the mean of reaction times). Data from one additional participant were removed from analysis due to low accuracy (>2 SDs from the mean of accuracy; 84%). Data from two additional participants were removed due to technical errors with data collection. There remained 26 participants following exclusions (10 high anxiety; median STAI-TA score 36).

All results were Greenhouse-Geisser corrected for violations of sphericity where appropriate. Post hoc tests were Bonferroni corrected for multiple comparisons. All results were considered significant at $p < .05$. For brevity and clarity, only interactions with Electrode and Valence or Anxiety Level are reported for the ERP analyses.

Results

N1 Component

Mean Amplitude. We conducted a 3 (Valence: Happy, Neutral, Angry) x 3 (Probe Location: Congruent, Incongruent, Absent) x 2 (Visual Field of Emotional Face: Left, Right) x 2 (Electrode: Left, Right) x 2 (Anxiety Level: High, Low) mixed ANOVA on the mean amplitude measurement of the N1 component. This showed a significant interaction between Valence, Anxiety Level, and Electrode, $F(1.99, 25.81) = 7.01$, $MSE = .216$, $p = .004$, $\eta_p^2 = .350$. A post hoc 3 (Valence) x 2 (Anxiety Level) ANOVA on each electrode separately showed a significant Valence x Anxiety Level interaction in the right hemisphere (right electrode) only, $F(1.60, 26) = 3.82$, $MSE = .082$, $p = .047$ (see Figure 4.2). This showed that the amplitude of the N1 in individuals with high anxiety was overall the same across valences, whereas the amplitude of the N1 was smaller for neutral faces relative to happy and angry faces for individuals with low anxiety. However, no pairwise comparisons showed significant differences. Thus, the N1 measured over the right hemisphere in individuals with high anxiety was slightly greater for neutral faces than that measured in individuals with low anxiety. Individuals with low anxiety showed a lesser response to neutral faces, whereas individuals with high anxiety showed the same response to neutral faces as to emotional faces.

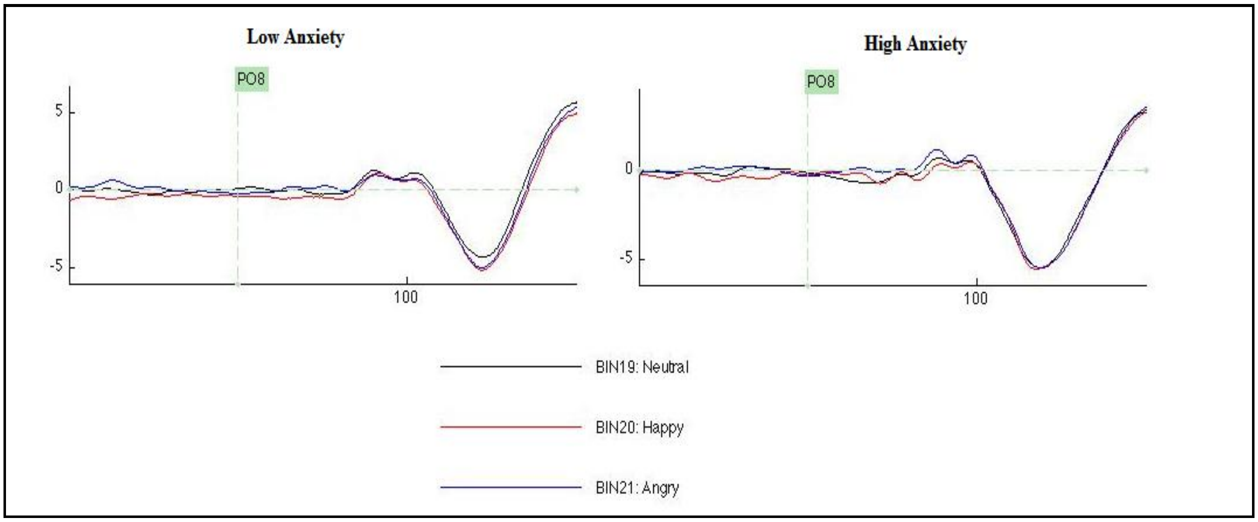


Figure 4.2. N1 waveform evoked by probes following each face valence, shown for each anxiety group over PO8 (Right Hemisphere).

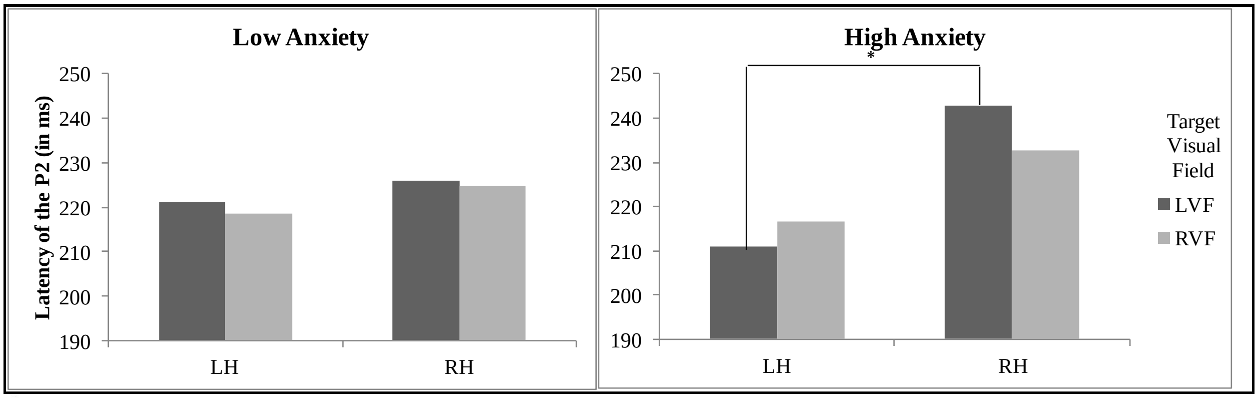
Peak Latency. We conducted a 3 (Valence: Happy, Neutral, Angry) x 3 (Probe Location: Congruent, Incongruent, Absent) x 2 (Visual Field of Emotional Face: Left, Right) x 2 (Electrode: Left, Right) x 2 (Anxiety Level: High, Low) mixed ANOVA on the peak latency measurement of the N1 component. This showed no significant effects of Anxiety Level or Valence.

P2 Component

Mean Amplitude. We conducted a 3 (Valence: Happy, Neutral, Angry) x 3 (Probe Location: Congruent, Incongruent, Absent) x 2 (Visual Field of Emotional Face: Left, Right) x 2 (Electrode: Left, Right) x 2 (Anxiety Level: High, Low) mixed ANOVA on the mean amplitude measurement of the P2 component. This showed a significant main effect of Valence, *F*(1.72, 22.31) = 8.81, *MSE* = .271 *p* = .002, η_p^2 = .404. Post hoc comparisons of this main effect showed that Neutral faces elicited a significantly greater P2 amplitude compared to Happy (*t*(14) = 3.18, $p < .05$) or Angry (*t*(14) = 3.59, $p < .05$) faces. There was also a significant interaction between Probe Location, Anxiety Level, Visual Field, and Electrode, *F*(1.71, 22.28) = 3.61, *MSE* = .224, *p* = .05, η_p^2 = .217. Post hoc comparisons between individuals with high anxiety and individuals with low anxiety showed no significant differences between conditions (Probe Location x Visual Field x Electrode).

Peak Latency. We conducted a 3 (Valence: Happy, Neutral, Angry) x 3 (Probe Location: Congruent, Incongruent, Absent) x 2 (Visual Field of Emotional Face: Left, Right) x 2 (Electrode: Left, Right) x 2 (Anxiety Level: High, Low) mixed ANOVA on the peak latency measurement of the P2 component. This showed a significant interaction between Valence, Probe Location, and Electrode, *F*(2.58, 33.57) = 3.84, *MSE* = 736.52, *p* = .023, η_p^2 = .228. Post hoc comparisons between the right and left hemisphere electrodes showed no significant differences between conditions (Valence x Probe Location).

There was also a significant interaction between Anxiety Level, Visual Field, and Electrode, *F*(1, 13) = 6.56, *MSE* = 243.69, *p* = .008, η_p^2 = .433 (see Figure 4.3). Post hoc comparisons showed that while there was no difference in the latency of the P2 depending on Target Visual Field and Electrode for individuals with low anxiety, there was a significant difference in the latency of the P2 for individuals with high anxiety between left hemisphere and right hemisphere electrodes when targets were presented in the left visual field, *t*(5) = 9.10, *p* < .01. Specifically, left visual field targets elicited a faster onset of the P2 in the left hemisphere than in the right hemisphere. This is indicative of a direct access pattern for the right hemisphere specifically.



*** = *p* < .05**

Figure 4.3. Anxiety x Target Visual Field x Electrode interaction on the latency of the P2 component. LH = PO7, RH = PO8. Interaction significant at p < .05

N2 Component

Mean Amplitude. We conducted a 3 (Valence: Happy, Neutral, Angry) x 3 (Probe Location: Congruent, Incongruent, Absent) x 2 (Visual Field of Emotional Face: Left, Right) x 2

(Electrode: Left, Right) x 2 (Anxiety Level: High, Low) mixed ANOVA on the mean amplitude measurement of the N2 component. This showed a significant interaction between Valence, Probe Position, Anxiety Level, Visual Field, and Electrode $F(3.28, 42.59) = 3.018$, $MSE = .279$, $p = .036$, $\eta_p^2 = .188$. To further investigate this five-way interaction, we conducted separate ANOVAs for each condition (Probe Position, Anxiety Level, and Visual Field) at PO7 and PO8 separately. However, these ANOVAs revealed no other significant effects of Valence or Anxiety Level.

Peak Latency. We conducted a 3 (Valence: Happy, Neutral, Angry) x 3 (Probe Location: Congruent, Incongruent, Absent) x 2 (Visual Field of Emotional Face: Left, Right) x 2 (Electrode: Left, Right) x 2 (Anxiety Level: High, Low) mixed ANOVA on the peak latency measurement of the N2 component. There were no significant effects involving Electrode and Valence or Anxiety Level.

Discussion

This study was designed to measure first the laterality of attention in anxiety, and second the emotional specificity of the observed attention bias. The significant interaction between anxiety, emotion visual field, and electrode observed for the peak latency of the P2 component showed a greater “direct access” pattern in individuals with high anxiety than for individuals with low anxiety (see Figure 4.4). Specifically, in individuals with high anxiety, targets presented in the left visual field elicited a shorter latency of the P2 over left hemisphere sites but a much longer latency of the P2 over right hemisphere sites. By contrast, in individuals with low anxiety, the latency of the P2 was very similar regardless of visual field of target presentation and electrode. The increase in the latency of the P2 over the right hemisphere for left visual presentations remains consistent with a direct access model. In this case, “direct access” suggests that the right hemisphere of individuals with high anxiety is responsible for processing left visual field stimuli although it appears to be less competent (i.e. longer peak latencies) with stimulus processing for this task. These results support previous findings in behavior showing that impaired processing of left visual field target presentations in the right hemisphere in individuals with high anxiety is the condition that most strongly differentiates individuals with high anxiety from individuals with low anxiety.

Secondly, valence does not interact with both anxiety and probe position at the same time. This reflects the results observed in Experiment 1, where there is a dissociation between the hemispheric effects of stimulus valence and the hemispheric effects of anxiety on attention.

Anxiety does interact with stimulus valence in the amplitude of the N1. However, the primary difference between individuals with high anxiety and individuals with low anxiety is the amplitude of the N1 evoked by neutral faces. Neutral faces elicit the same amplitude of the N1 as emotional faces for individuals with high anxiety, but neutral faces elicit a smaller amplitude of the N1 than emotional faces for individuals with low anxiety. This effect of the neutral may be related to increased ambiguity of the neutral face in an emotional context (see Experiment 4). Alternately, most face pairs presented consisted of a happy or angry face with a neutral face. Thus, the neutral-neutral face pairs were less common and high anxiety may have heightened sensitivity to this novelty. This hypothesis could be supported by the presence of a larger amplitude P3 component following neutral-neutral pairs, compared to emotional-neutral pairs. However, no P3 component was observed in this data.

Future Directions

These results may be supported and extended in several ways. First, the reduction of the electrode set limited a thorough investigation. It was expected that the posterior or frontal electrodes would show the greatest differences between individuals with high anxiety and individuals with low anxiety, and between positive and threatening emotional stimuli. However, it is possible that central or temporo-parietal electrodes may have shown the effects. PO7 and PO8 electrodes are near the “underside” of the head, and thus while these electrodes revealed relevant effects, the polarity may have been inverted. This would explain why the effects of attention (probe congruity) in this task were observed for the P2 rather than the N2. This would also help to explain why no P3 was observed for this data when the P3 is typically observed following emotional stimuli. Future studies should include more central and temporo-parietal electrodes to investigate this possibility.

Second, the use of actual faces rather than schematic faces set may have biased results toward the right hemisphere. We chose to implement these faces again in order to compare results with Experiment 1. Future studies should compare the results for attention in anxiety with schematic emotional faces and with photographs of faces. This can be implemented in this paradigm by blocks of schematic face pairs interleaved with blocks of photographed face pairs.

Finally, behavioral performance on this task was recorded but showed few significant effects. This contrasts with the performance on a similar task observed in Experiment 1. The primary difference in this experiment was the introduction of the EEG cap. Participants wearing the cap are subject to increased discomfort and fatigue throughout a testing session relative to purely behavioral tasks. Furthermore, participants’ movements were restricted by the chinrest in Experiment 1, whereas their movements were restricted only by the cap apparatus and wires in Experiment 6. These procedural differences may account for the differences in results. However, it is important to note that the physiology observed here was consistent with previous behavioral results in Experiment 1. This presents a case where the behavioral performance on the task is not as sensitive to anxiety as the physiology in somewhat stressful testing environments, but the physiology remains consistent with behavioral performance in less stressful testing environments.

Conclusion

Individuals with high anxiety again differed from individuals with low anxiety in responses to left visual field targets. These results are extended by the observed interaction with electrode, such that the deficits in performance following left visual field targets can be traced to slowed right hemisphere ERP activity. Furthermore, the results from the present experiment are consistent with those found in Experiment 1, suggesting that individuals with high anxiety are not more sensitive to emotional stimuli than individuals with low anxiety. However, the exception to this is in initial processing of neutral faces: individuals with high anxiety are more sensitive to neutral faces than individuals with low anxiety. These results confirm and strengthen the foregoing conclusions from the behavioral data collected in Experiments 1-5.

Experiment 7: ERPs in Covert Orienting of Spatial Attention

Experiments 3 and 4 clearly show that both early and late covert spatial orienting processes are affected in participants with high anxiety. However, these studies showed some conflicting findings in terms of the laterality of the effects of anxiety during early vs. late orienting. Furthermore, the effects of anxiety on attention to specific emotional stimuli remain unclear. Our data from Experiment 3 suggest that, rather than enhanced processing of threatening stimuli, we see reduced processing of positive stimuli in participants with high anxiety. Yet consistent with Experiments 4-6, we predict that individuals with high anxiety may show increased reactivity to neutral faces compared to individuals with low anxiety. As in Experiment 6, the pattern of neural processing of emotional stimuli may be different from behavioral responding. The present study investigated electrophysiologically both the laterality of evoked potentials in anxiety during an attention task, and the effect of emotional and emotionally neutral stimuli on individuals with high anxiety.

We ran a covert orienting of spatial attention paradigm with schematic happy, angry, and neutral faces. We also manipulated stimulus-onset asynchrony (SOA) to assess the effects of processing positive and threatening stimuli over time. We recorded event-related potentials to both the cues and target stimuli and partitioned the results into three datasets: ERPs evoked by cues, ERPs evoked by targets at the short SOA, and ERPs evoked by targets at the long SOA.

Methods

Participants

Sixty undergraduate participants (14 males) participated in this study for psychology course credit (all strongly right-handed; score of 10+ on the handedness inventory). Participants were over the age of 18 and had no history of neurological disease or insult as assessed by self-report. STAI-TA scores ranged from 22-50 (16 high anxiety participants). High anxiety was defined as a score of 40 or greater (5 males); all other scores were defined as low anxiety (9 males).

Materials

Stimuli were presented by an Intel Core2Duo computer with a 2.81 GHz processor using E-Prime 2.0 software (Psychology Software Tools, 2002). Stimuli were presented on a 17” LCD computer monitor at 1280 x 1024 pixel resolution, with a refresh rate of 60.018 Hz. Electroencephalogram activity was recorded using BioSemi 64-channel Ag/AgCl electrode caps following International 10-20 electrode placements. To record eye movements, external electrodes were applied to the outer canthus of the left eye and just beneath the right eye. For later re-referencing, two additional external electrodes were placed on the mastoid bones behind each ear. Data for participants were recorded in six separate files of two blocks each to ensure participants took breaks.

ERP triggers occurred at the onset of each cue and at the onset of each target. Cue codes indicated the visual field of presentation, the valence of the face, and the cue validity. Target codes indicate the visual field of presentation, cue validity, and length of SOA.

Each trial began with the presentation of two 100-pixel square boxes, outlined in 2-pixel black lines. Each box appeared 1.5 degrees from central fixation and remained on the screen throughout the experiment. Pre-trial fixation duration varied from 250-750ms. Cue stimuli were presented within one of the two boxes for 150ms. Cue stimuli consisted of a schematic face conveying one of three emotions: happy, neutral, or angry (*cf*. Öhman, Lundqvist, & Esteves, 2001). Cues appeared equally often in the same location as the target (valid cues), in the opposite location from the target (invalid cues), and replacing the center fixation cross (central cues).

Valid and invalid cues appeared equally often in the left visual field and the right visual field. Following cue presentation, there was a brief delay of either 100ms or 500ms. Target stimuli consisted of brightening of the outline of either the left box or the right box for 100ms. Target stimuli occurred equally often in the left box and the right box. The brightening was accomplished by replacing the black outline with a lighter grey outline. Targets were equally often present or absent. Participants indicated that they detected the target by pressing the spacebar with their index finger. See Figure 4.4 for a sample trial.

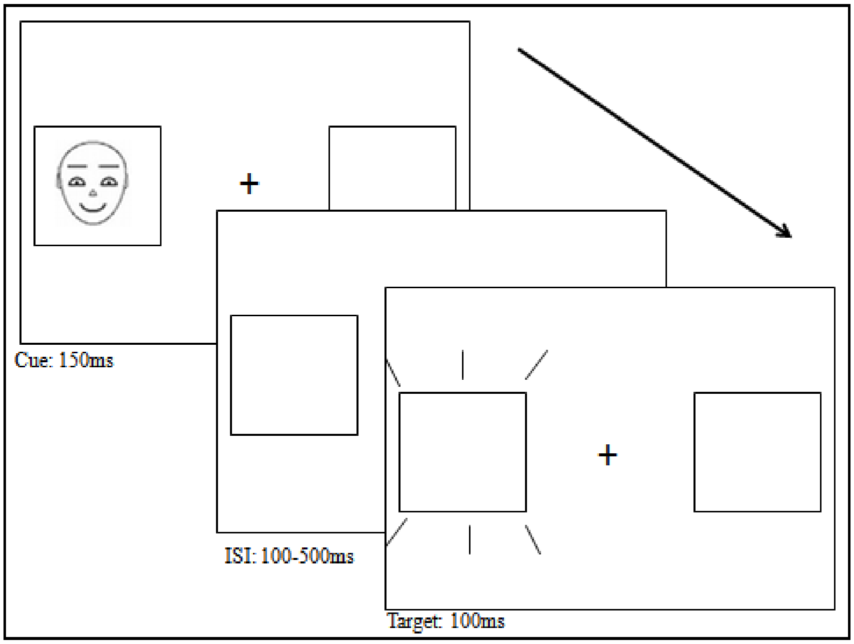


Figure 4.4. Sample valid trial for covert orienting of spatial attention paradigm for Event-Related Potentials.

Procedure

Following informed consent, participants completed the Edinburgh Handedness Inventory, the STAI-TA, and the BIS/BAS scales. Participants were then led to the experimenting room where they were fitted with an EEG cap. After the cap was set up, participants were instructed to remain seated and still throughout each experimental block.

Participants were further instructed to respond to the target as quickly and accurately as possible. All participants completed one practice block of trials prior to completing the 12 blocks of experimental trials.

Treatment of the Data

Each participant's data was referenced offline to the average of 64 electrodes, plus the two mastoid electrodes. Data were band-pass filtered between 1Hz and 50Hz. Eye movement and electrical noise artifacts were removed using Independent Components Analysis. Data were epoched twice to create two separate files for averaging: once at the onset of the cue and again at the onset of the target. This was done to separately investigate the effects of the cues and the effects of the targets. Cue epochs began 500ms prior to cue onset and ended 1500ms following cue onset. Target epochs began 1000ms prior to target onset and ended 1000ms following target onset. Data were then visually inspected for muscle and electrical artifacts. These artifacts were removed prior to computing the weighted average ERP for each condition.

Data were separated into three sets of waveforms: 1) cues, to assess initial processing of faces, 2) targets at the short SOA, to assess initial orienting of attention, and 3) targets at the long SOA, to assess inhibition of return. All data were visually inspected and large, clean waveforms identified at posterior electrodes (cues: P5 and P6; short SOA targets: P3 and P4; long SOA targets: P1 and P2). Time windows for each ERP were measured as seen in Table 2. For each time window, the mean amplitude, peak amplitude, and peak latency were recorded for analysis.

	P1	**N1**	**N2**	**P2**	**P3**
Cues	100-165	165-200		200-270	
Short SOA Targets		50-150	150-250		300-600
Long SOA Targets		100-200	150-250		250-600

Table 4.1. ERP measurement windows for each data set.

Data from 15 participants were removed from analysis due to technical problems with the electrode signal quality. Two additional participants were removed from analysis due to later reports of neurological problems following screening. Two participants were removed from analysis due to excessively long reaction times during the task (>2 SDs from the average of reaction times) and one final participant was removed from analysis due to low accuracy (22%). 32 participants (15 high anxiety) remained following exclusions.

Results

All cue ERP analyses followed a 3 (Cue Valence: Happy, Neutral, Angry) x 3 (Cue Visual Field: Left, Center, Right) x 2 (Anxiety Level) x 2 (Electrode Location: Left, Right) mixed factorial design with a between-subjects variable of Anxiety Level. Target ERP analyses followed a 3 (Cue Valence: Happy, Neutral, Angry) x 2 (Target Visual Field: Left, Right) x 3 (Cue Validity: Valid, Center, Invalid) x 2 (Anxiety Level: Low, High) x 2 (Electrode: Left, Right) mixed factorial design with a between-subjects variable of Anxiety Level. For brevity and clarity, we will focus on certain variables: for cues, main effects and interactions with Anxiety Level, Valence, and Electrode; for targets at both SOAs, main effects and interactions with Anxiety Level and Electrode.

Manipulation Check

Since N2 is believed to reflect orienting of attention due to spatial cues, we predicted that valid and invalid cues would elicit a greater N2 than central cues (Eimer, 1993). This was significant for each ERP measurement (mean amplitude, peak amplitude, and peak latency; all $p < .05$). This significant result shows that the task generally measured attention as expected (see Figure 4.5).

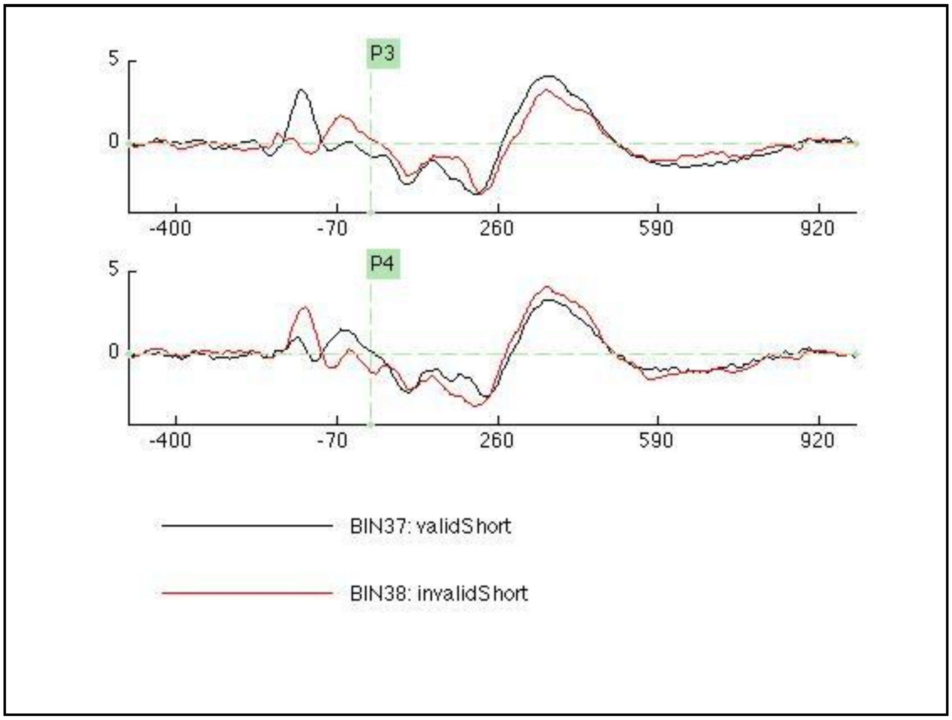


Figure 4.5. N2 evoked by targets preceded by each cue type following the short SOA. P3 = Left Hemisphere; P4 = Right Hemisphere.

Cue Effects

P1. We conducted separate ANOVAs on the mean amplitude and the peak latency of the posterior P1 component evoked by the spatial cues. There were no significant main effects or interactions with either of these dependent variables.

N1. We conducted separate ANOVAs on the mean amplitude and the peak latency of the posterior N1 component evoked by the spatial cues. For mean amplitude, there was a main effect of Cue Valence, $F(1.66, 43.05) = 4.15$, $MSE = 1.91$, $p = .029$, $\eta_p^2 = .138$. This showed that the mean amplitude of N1 tended to be larger for neutral faces compared to happy or angry faces. There was also a significant interaction between Cue Valence, Cue Visual Field, and Electrode, $F(1.81, 46.94) = 38.88$, $MSE = 1.739$, $p = .000$, $\eta_p^2 = .586$, which was qualified by an additional interaction between Cue Valence, Cue Visual Field, Electrode, and Anxiety Level, $F(1.81, 46.94) = 4.44$, $MSE = 1.739$, $p = .020$, $\eta_p^2 = .146$ (see Figure 4.6).

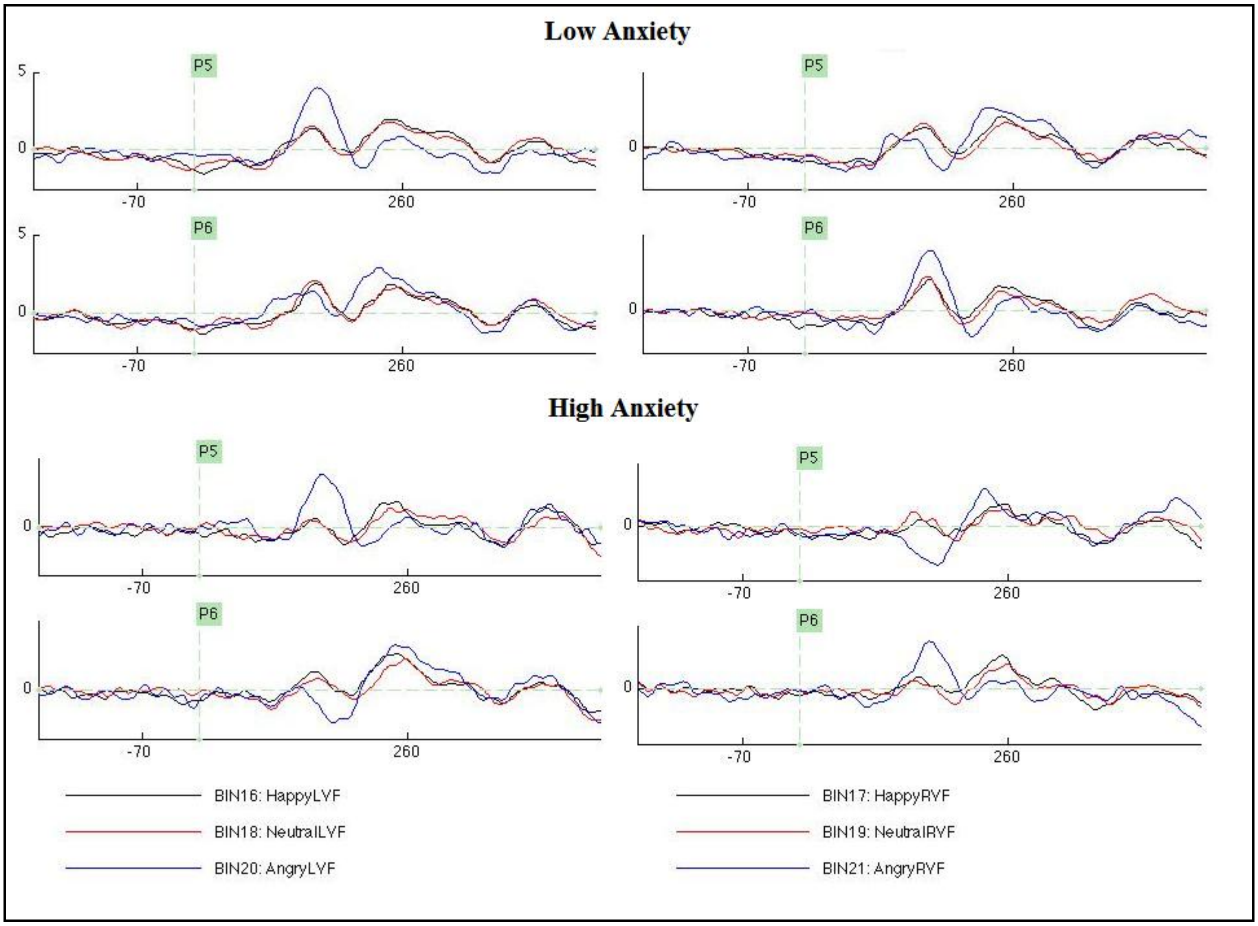


Figure 4.6. N1 waveform for Valence in each Visual Field, over P5 (Left Hemisphere) and P6 (Right Hemisphere) for high and low anxiety.

Post hoc ANOVAs were conducted to assess the effects of each valence in each hemisphere. This was done by examining Visual Field x Electrode interactions for each valence separately. There was a significant Visual Field x Electrode interaction for angry faces only for both individuals with high anxiety, $F(1.17, 11.69) = 22.60$, $MSE = 4.20$, $p = .000$, $\eta_p^2 = .693$, and individuals with low anxiety, $F(1.42, 22.82) = 17.42$, $MSE = 2.03$, $p = .000$, $\eta_p^2 = .521$. These interactions indicate direct access for angry faces for both individuals with low anxiety and individuals with high anxiety. To examine differences in this interaction, we conducted posthoc pairwise comparisons of the N1 amplitude evoked by LVF and RVF targets in each anxiety group. We found significant differences between high and low anxiety in the N1 evoked by LVF cues over the P6 electrode (right hemisphere), $t(10) = 2.50$, $p < .05$. We also found significant differences between high and low anxiety in the N1 evoked by RVF cues over the P5 electrode (left hemisphere), $t(10) = 2.56$, $p < .05$. In each case, individuals with high anxiety showed greater amplitudes. Taken together, individuals with high anxiety show increased direct access in each hemisphere for angry face cues selectively. Thus, individuals with high anxiety show greater laterality for angry face cues than individuals with low anxiety.

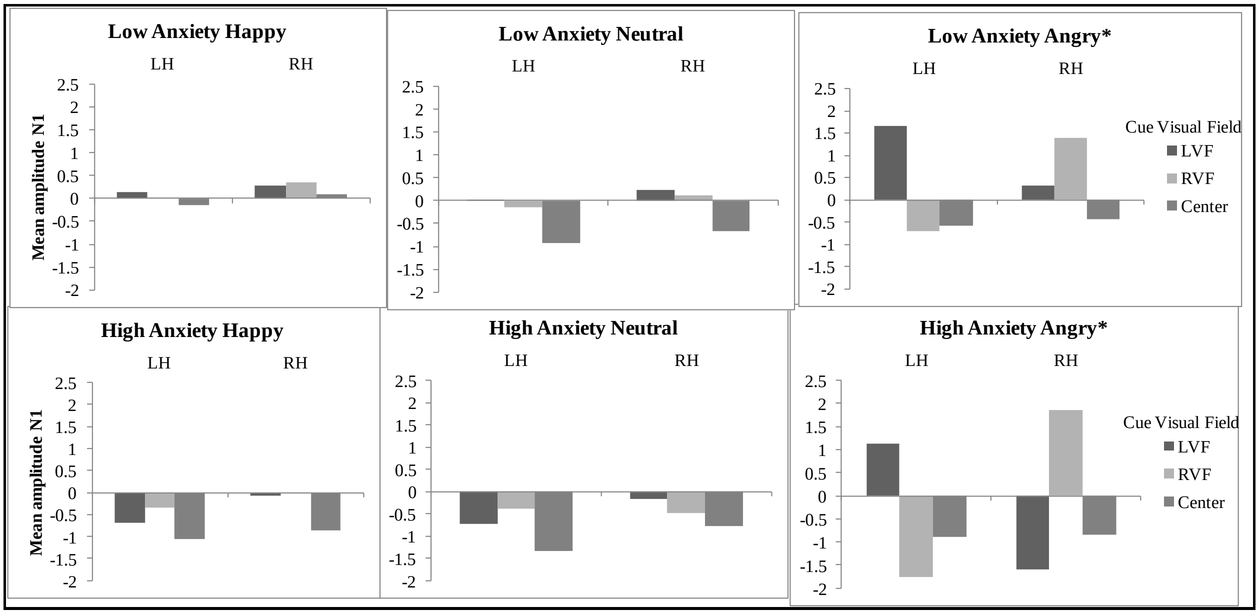


Figure 4.7. *Valence x Visual Field x Anxiety x Electrode interaction on the mean amplitude of the N1 evoked by cues. Interaction significant at p < .05. Asterisk signifies significant interaction within an individual graph. LH = P5 electrode, RH = P6 electrode.*

. For peak latency, there was a main effect of Cue Valence, $F(1.56, 40.71) = 14.75$, $MSE = 2.43$, $p = .000$, $\eta_p^2 = .362$. This showed that the onset of the N1 evoked by a happy face was significantly faster than the N1 evoked by a neutral face, $t(27) = 1.976$, $p < .05$.

P2. We conducted separate ANOVAs on the mean amplitude and the peak latency of the posterior P2 component evoked by the spatial cues. There were no significant effects of mean amplitude. For peak latency, there was a main effect of Cue Valence, $F(1.88, 48.86) = 5.26$, $MSE = 230.32$, $p = .010$, $\eta_p^2 = .168$. This showed that the peak of the P2 evoked by angry faces occurred faster than the peak of the P2 evoked by happy, $t(11) = 4.02$, $p < .05$, or neutral faces, $t(11) = 5.04$, $p < .05$. There was also a significant interaction between Cue Valence, Anxiety Level, and Electrode, $F(1.61, 41.83) = 5.34$, $MSE = 112.16$, $p = .013$, $\eta_p^2 = .170$. Inspection of Figure 4.8 shows that individuals with high anxiety have consistently longer peak latencies over the right hemisphere compared to both the left hemisphere and to individuals with low anxiety.

Pairwise comparisons showed no significant differences between individuals with high anxiety and individuals with low anxiety, or between left and right hemisphere electrodes.

Figure 4.8. Interaction between Cue Valence, Anxiety, and Electrode on the peak latency of the P2 component evoked by cues. Interaction significant at p < .05

Summary of Cue Effects. Overall, the P1, N1, and P2 components evoked by the cue presentations showed that individuals with high anxiety and individuals with low anxiety do not differ in terms of the resources allocated or the speed with which they process emotional faces. However, individuals with high anxiety differ from individuals with low anxiety in terms of laterality of evoked potentials. Individuals with high anxiety showed greater evidence of direct access (particularly for angry faces) in the amplitude of the N1. This implies less interhemispheric transfer of the information, and at a later time manifests as longer peak latencies over right hemisphere electrodes. This occurs for angry face processing selectively.

Orienting Effects, Short SOA

N1. We conducted separate ANOVAs on the mean amplitude and the peak latency of the posterior N1 component evoked by the presentation of the targets. There were no interactions between Anxiety Level and Electrode.

N2. We conducted separate ANOVAs on the mean amplitude and the peak latency of the posterior N2 component evoked by the presentation of the targets. For mean amplitude, there was a significant interaction between Cue Validity, Anxiety Level, and Electrode, *F*(1.68, 43.69) = 4.75, *MSE* = 2.23, *p* = .018, η_p^2 = .155. Post hoc comparisons of this interaction revealed no significant differences between individuals with high anxiety and individuals with low anxiety, or between left hemisphere and right hemisphere electrodes.

For peak latency, there was again a significant interaction between Cue Validity, Anxiety Level, and Electrode, *F*(1.94, 50.34) = 4.52, *MSE* = 643.72, *p* = .017, η_p^2 = .148. Post hoc comparisons of this interaction revealed no significant differences between individuals with high anxiety and individuals with low anxiety, or between left hemisphere and right hemisphere electrodes.

P3. We conducted separate ANOVAs on the mean amplitude and the peak latency of the posterior P3 component evoked by the presentation of the targets. For mean amplitude, there was a significant interaction between Cue Valence, Target Visual Field, Anxiety Level, and Electrode, *F*(1.65, 42.86) = 4.90, *MSE* = .152, *p* = .017, η_p^2 = .159 (see Figure 4.9).

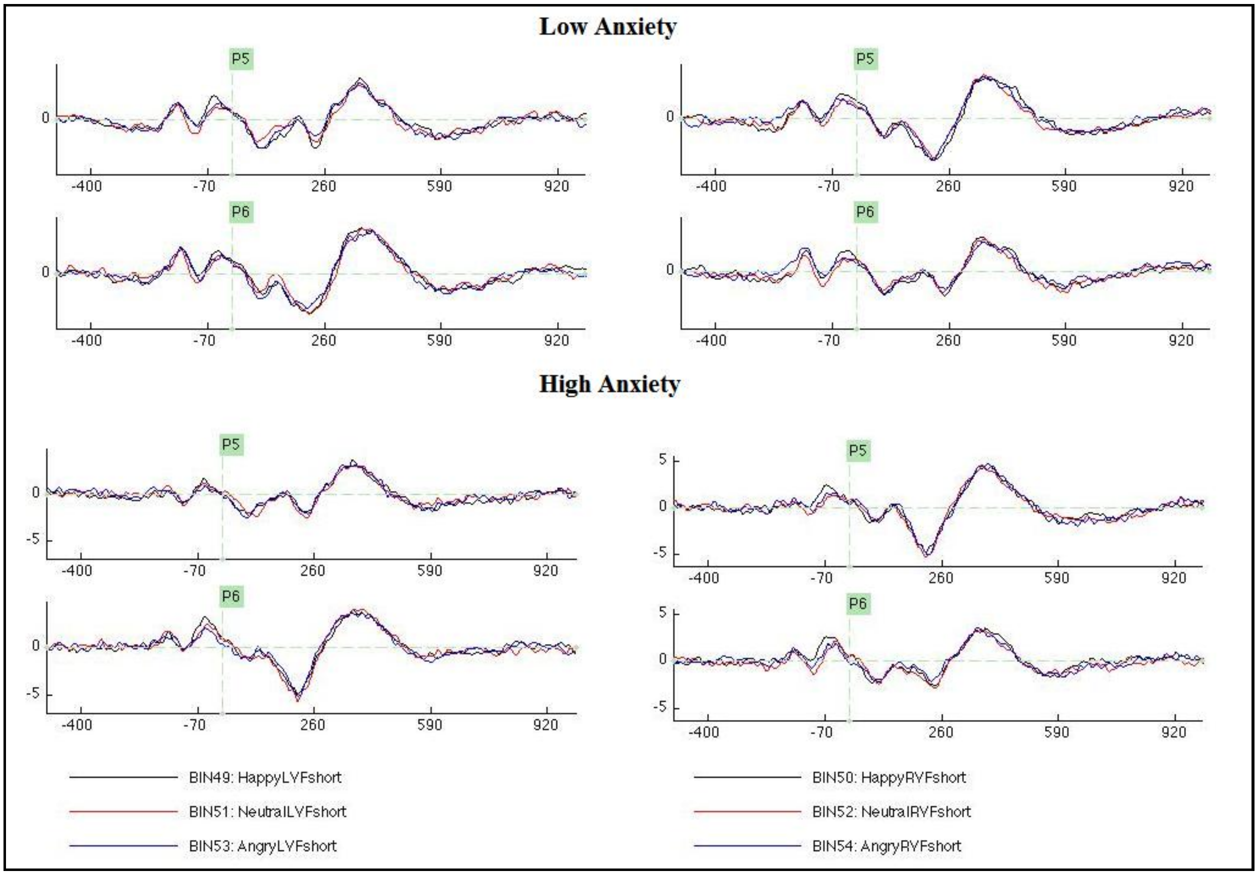


Figure 4.9. Waveform of the P3 evoked by targets showing Valence and each target Visual Field over P5 (Left Hemisphere) and P6 (Right Hemisphere) for each anxiety group.

Post hoc ANOVAs of this effect over each electrode separately showed a Valence x Anxiety Level interaction over the left hemisphere only (see Figure 4.10). Further pairwise comparisons did not reach significance. However, inspection of Figure 4.10 shows that the greatest difference between individuals with high anxiety and individuals with low anxiety occurs for neutral face cues.

There were no significant effects of peak latency.

Figure 4.10. Anxiety Level x Valence interaction on mean amplitude of the P3 over the left hemisphere. Separated by Target Visual Field. Interaction significant at p < .05

Summary of Orienting at Short SOA. Cuing effects (i.e., interactions with validity) appeared approximately 200ms following target onset. Similar to the results in Experiment 6, these effects did not interact with both Cue Valence and Anxiety Level. There was a significant interaction between Anxiety and Cue Valence, consistent with the ERPs evoked by the cues. However, following target presentation, the effects of angry cues were similar for individuals with high anxiety and individuals with low anxiety. Instead, neutral face cues evoked the largest difference in the amplitude of the P3 between anxiety groups. This occurred over the left hemisphere selectively. The P3 represents a stage of processing approximately 500ms after the onset of the cue. Because neutral faces are considered more ambiguous than happy or angry faces, individuals with high anxiety may recruit analytical processing from the left hemisphere at later stages of processing (i.e., 500ms after the cue) in an attempt to determine the emotionality of a neutral face. This effect is similar to the greater amplitude of the N1 component evoked by neutral faces in individuals with high anxiety during the Lateralized Visual Probe task. In the Lateralized Visual Probe, this increased response to neutral faces occurred over the right hemisphere, but represented earlier processing than the effect observed here (only about 200ms after the face presentation). It is possible that laterality shifts from the right hemisphere to the left hemisphere during later stages of processing and integrating task information.

Orienting, Long SOA

N1. We conducted separate ANOVAs on the mean amplitude and the peak latency of the posterior N1 component evoked by the presentation of the targets after the long SOA. For mean amplitude, there was a significant interaction between Cue Valence, Cue Validity, Anxiety Level, and Electrode, $F(2.98, 77.36) = 2.98$, $MSE = .200$, $p = .037$, $\eta_p^2 = .103$. Post hoc comparisons of this interaction showed no significant differences between conditions. For peak latency, there was a significant interaction between Anxiety Level and Electrode, $F(1, 26) = 6.94$, $MSE = 289.09$, $p = .014$, $\eta_p^2 = .211$ (see Figure 4.11). Post hoc comparisons showed a trend toward significant differences between individuals with high anxiety and individuals with low anxiety in the peak latency of the N1 component in the right hemisphere selectively, $p < .1$.

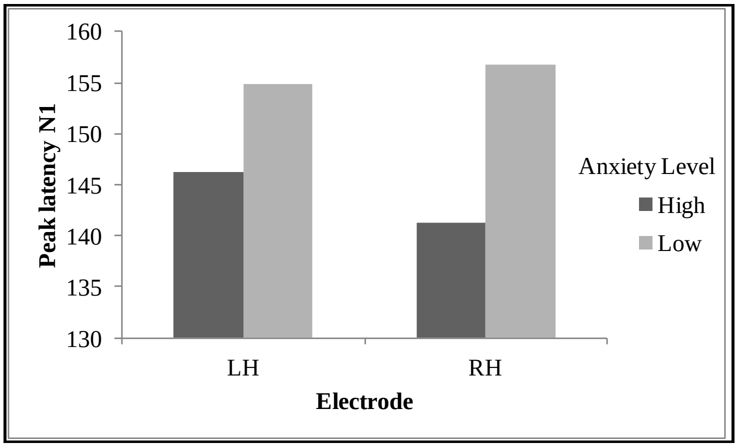


Figure 4.11. Anxiety Level x Electrode interaction on the peak latency of the N1. Interaction significant at p < .05

N2. We conducted separate ANOVAs on the mean amplitude and the peak latency of the posterior N2 component evoked by the presentation of the targets after the long SOA. For mean amplitude, there was a significant interaction between Target Visual Field, Anxiety Level, and Electrode, $F(1, 26) = 4.50$, $MSE = .753$, $p = .044$, $\eta_p^2 = .148$ (see Figure 4.12).

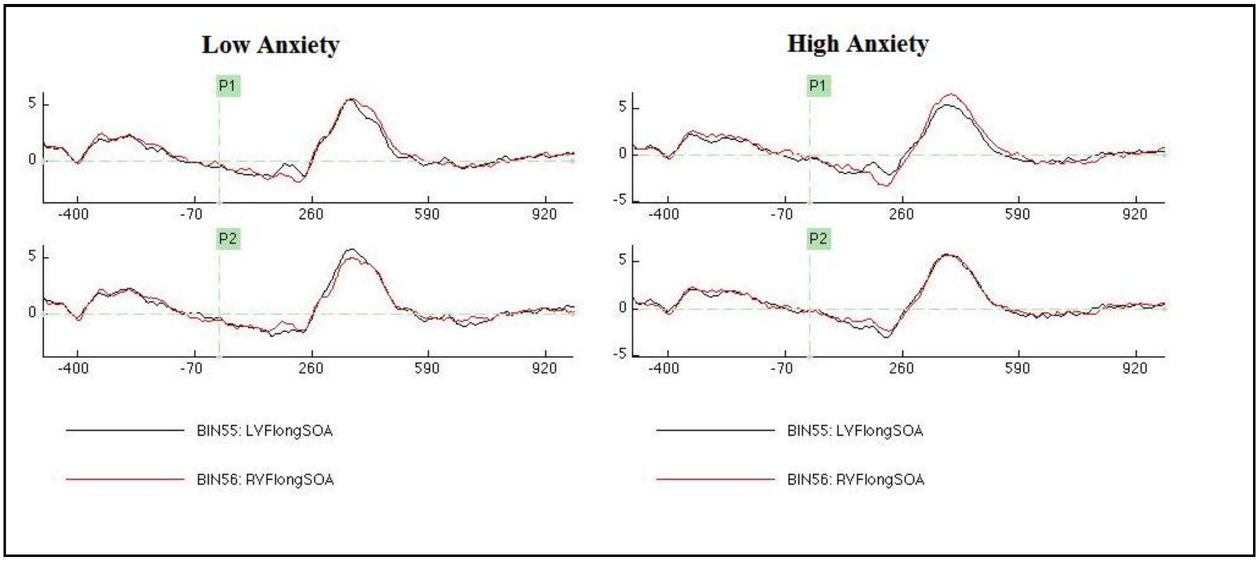
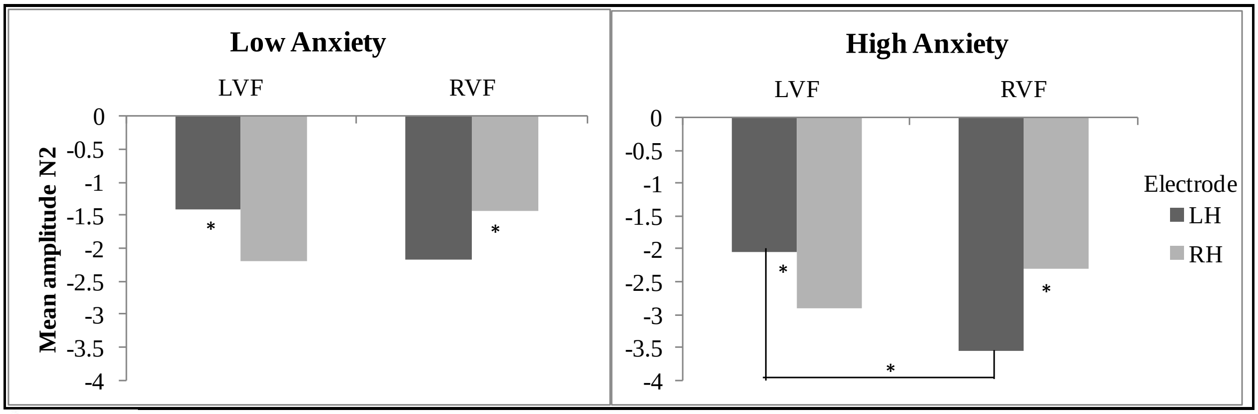


Figure 4.12. Waveform of the N2 evoked by targets at the long SOA, showing each visual field over P1 (Left Hemisphere) and P2 (Right Hemisphere) for each anxiety group.

Pairwise comparisons showed a significant difference between the mean amplitude of the N2 component in the left hemisphere for left visual field and right visual field targets. This occurred only for individuals with high anxiety, $t(10) = 6.71$, $p < .05$ (see Figure 4.13). The increased amplitude of the N2 over the left hemisphere following right visual field target presentations again shows increased direct access in individuals with high anxiety. However, this effect during late orienting (inhibition of return) shows a reversal in laterality compared to the ERPs evoked by cues: namely, cues elicited increased laterality in the right hemisphere, whereas late orienting elicited increased laterality in the left hemisphere.



*** = $p < .05$**

Figure 4.13. Anxiety Level x Target Visual Field interaction on the mean amplitude of N2 over each hemisphere. Interaction significant at p < .05

For peak latency, there was a significant interaction between Cue Valence, Anxiety Level, and Electrode, *F*(1, 26) = 4.53, *MSE* = 357.14, *p* = .043, η_p^2 = .148. Post hoc ANOVAs of Cue Valence and Anxiety Level in each hemisphere showed that the interaction was significant in the left hemisphere only, *F*(1, 26) = 6.71, *MSE* = 70.83, *p* = .016, η_p^2 = .205 (see Figure 4.14).

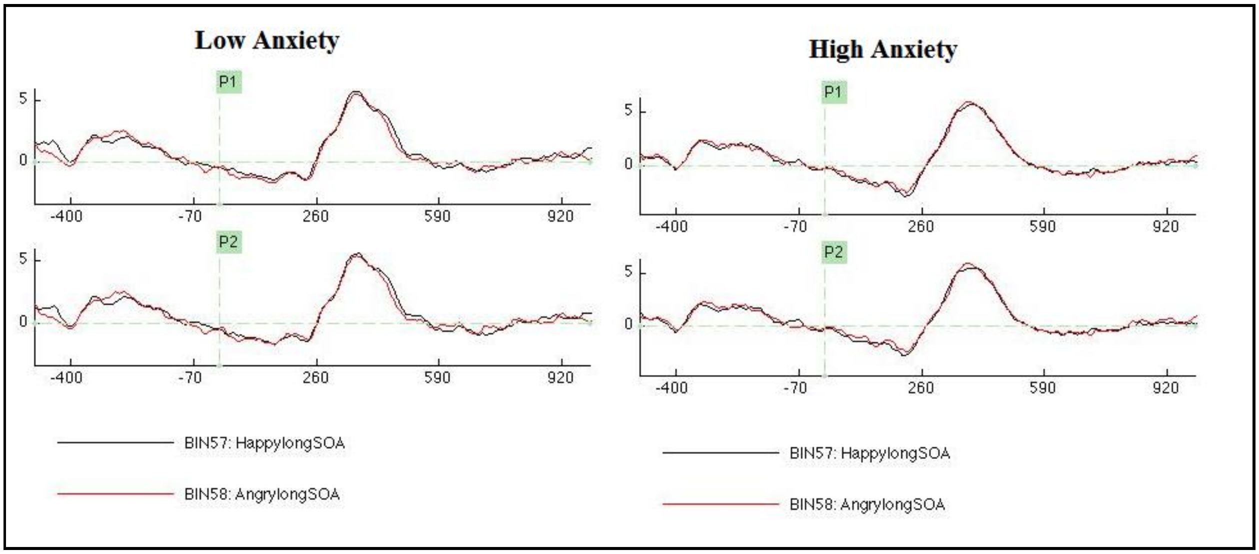


Figure 4.14. Waveform of the N2 evoked by targets at the long SOA for each Cue Valence, over P1 (Left Hemisphere) and P2 (Right Hemisphere) for each anxiety group.

Pairwise comparisons of this interaction did not reach significance. However, individuals with high anxiety had a later peak amplitude of the N2 following happy face cues, compared to individuals with low anxiety (see Figure 4.15).

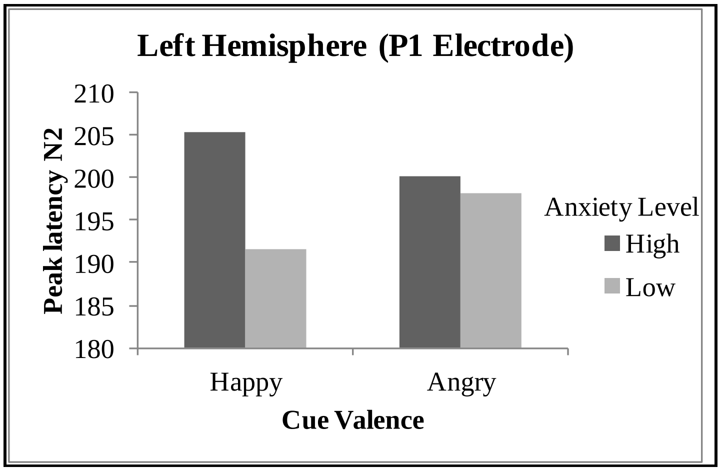


Figure 4.15. Anxiety Level x Valence interaction for the peak latency of the N2 over the left hemisphere. Interaction significant at p < .05

P3. We conducted separate ANOVAs on the mean amplitude and the peak latency of the posterior P3 component evoked by the presentation of the targets after the long SOA. There were no significant effects on the mean amplitude or peak latency of the P3.

Summary of Orienting at Long SOA. The most striking difference between the present results and the results found during cue processing is the reversal of laterality effects. Initially after the cue, the right hemisphere of individuals with high anxiety showed slower peak latencies and greater direct access, whereas at the long SOA, the left hemisphere of individuals with high anxiety shows slower peak latencies and greater direct access. This is consistent with the behavioral results found in Experiment 4.

Investigation of the neutral was not possible for this dataset, yet the results suggest that individuals with high anxiety are less sensitive to positive stimuli than to negative stimuli. This is consistent with Experiments 2 and 3, and is also consistent with literature suggesting that the effects of positive stimuli take longer to build than the effects of threatening stimuli (e.g., Mogg *et al*, 1997).

Discussion

This study aimed to investigate the laterality of orienting in anxiety as well as the emotionality of orienting in anxiety. Results from this study are meant to support and extend the findings from Experiments 3 and 4 which focused on early and late orienting, respectively. Overall, results show that individuals with high anxiety are more strongly lateralized (show greater direct access) than individuals with low anxiety. However, the side of this laterality changes between early and later orienting: the right hemisphere shows more direct access during early stages of processing, whereas the left hemisphere shows more direct access during late stages of processing. This may imply that individuals with high anxiety have greater difficulty with interhemispheric transfer than individuals with low anxiety. Alternately, the differences in laterality may simply reflect different specialization for early and late aspects of orienting.

Considering the progression of time throughout each dataset, the effects of cue valence on anxiety changed over time. Individuals with high anxiety were more sensitive to angry faces immediately following cue presentation. However, following target presentation after a short SOA, individuals with high anxiety were more sensitive to neutral faces. Finally, following target presentation after a long SOA, individuals with high anxiety were less sensitive to positive faces than individuals with low anxiety. Taken together, these results suggest that the specific responses to emotional stimuli in individuals with high anxiety will change depending on the timing of each particular task. This is consistent with prior data on the ERPs evoked by emotional stimuli (e.g., Fox, *et al*, 2007; Santesso, *et al*, 2008; Mogg, *et al*, 1997). Yet this does not explain why results for each valence differed between Experiments 3 and 4 and the present experiment. Future studies must examine alternate personality or contextual variables which may be indirectly influencing the sensitivity to each valence (e.g. Amir, *et al*, 2009).

Future Directions

This study may be extended in several ways. First, the high exclusion rate and relatively low number of trials per condition limits the power of the task. These procedures were taken to maintain a high quality of the data so that when real, significant effects occurred, they would be captured easily. Future studies must replicate these results with more participants and more observations per condition to ensure that the proper signal-to-noise ratio was maintained in this study. This can be accomplished by conducting either a two-part study incorporating separate sessions for short and long SOAs, or by conducting separate studies on each SOA.

Second, the latency of the N1 observed for targets the short SOA showed large differences between angry and happy or neutral faces. However, this was not significant in the statistical analysis. This may have occurred for two possible reasons: first, the variability between participants masked any statistical differences between conditions. Second, it is possible that the latency differences were great enough that our measurements of N1 latency overlapped with the latency of the P1. Future analyses could incorporate methods such as Independent Components Analysis (ICA) to disentangle these possible effects.

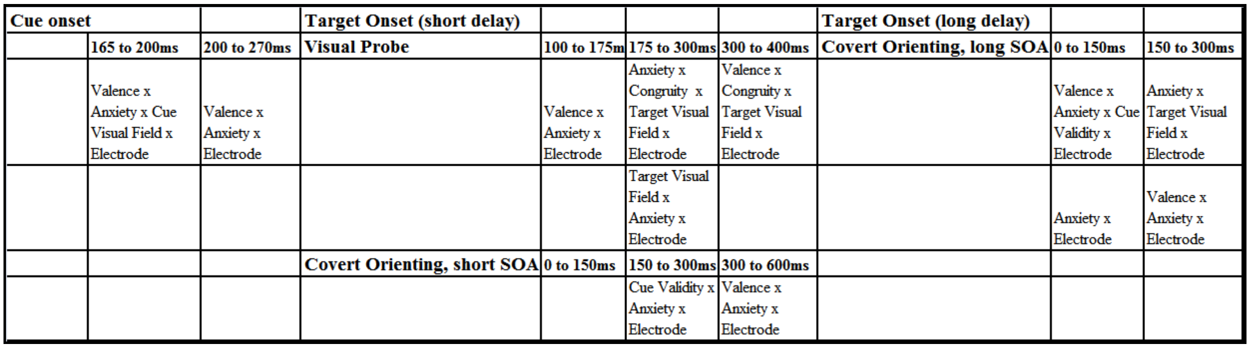
Behavioral performance was recorded during the task but, as in Experiment 6, significant results were not observed. This again points to the power of the electrophysiological measures to capture neural responding despite potentially normalizing effects of a stressful environment (see p 111). Furthermore, the results reported here are consistent with the literature on ERPs evoked by emotional stimuli. Thus, we believe that these are valid findings that accurately reflect processing of emotional stimuli in individuals with high anxiety.

Conclusions

Examination of evoked potentials in a covert orienting of spatial attention task showed results consistent with the findings in Experiment 6. Individuals with high anxiety are more strongly lateralized (show more direct access) than individuals with low anxiety. The side of this laterality shifts from the right hemisphere during early stages of processing to the left hemisphere at late stages of processing (during inhibition of return). Thus, facilitation is related to the right hemisphere and inhibition of return is related to the left hemisphere. Additionally, effects of anxiety on processing of cue valence shift over time: from increased sensitivity to threat immediately following cue presentation to increased sensitivity to neutral faces 250 ms later, to decreased sensitivity to positive faces 650ms later. These results support previous findings on the laterality of each effect in Experiments 3 and 4. However, these results show inconsistent effects of emotionality at early and late stages of orienting. Future studies are needed to delineate the specific factors involved in sensitivity to emotional stimuli in individual with high anxiety.

Experiments 6 and 7: General Discussion

Experiments 6 and 7 were designed to investigate the electrophysiological basis of the effects of anxiety on attention observed in Experiments 1-5. Specifically, these tasks were designed to assess the laterality of the observed results and the differences in processing emotional stimuli in individuals with high anxiety and individuals with low anxiety. In order to compare results from both a clinical and a basic neuroscience paradigm, we utilized the Lateralized Visual Probe and a covert orienting of spatial attention paradigm. ERPs were tied to cue onset and target onset at different times following the cue (immediately following the cue, 250ms later, and 650ms later). Significant interactions between anxiety and electrode side are summarized in Table 4.2.



Cue onset			**Target Onset (short delay)**				**Target Onset (long delay)**		
	165 to 200ms	**200 to 270ms**	**Visual Probe**	**100 to 175m**	**175 to 300ms**	**300 to 400ms**	**Covert Orienting, long SOA**	**0 to 150ms**	**150 to 300ms**
	Valence x Anxiety x Cue Visual Field x Electrode	Valence x Anxiety x Electrode		Valence x Anxiety x Electrode	Anxiety x Congruity x Target Visual Field x Electrode	Valence x Congruity x Target Visual Field x Electrode		Valence x Anxiety x Cue Validity x Electrode	Anxiety x Target Visual Field x Electrode
					Target Visual Field x Anxiety x Electrode			Anxiety x Electrode	Valence x Anxiety x Electrode
			Covert Orienting, short SOA	**0 to 150ms**	**150 to 300ms**	**300 to 600ms**			
					Cue Validity x Anxiety x Electrode	Valence x Anxiety x Electrode			

Table 4.2. Summary of significant effects of Anxiety on ERPs over time.

The results from both studies show that, for individuals with high anxiety in particular, initial processing of the cue is strongly lateralized and increased for angry cues relative to neutral or positive cues. The effect of an angry cue dissipates when the target is presented, and early orienting to the target is modulated only by the neutral face cue. This remains strongly lateralized to the right hemisphere. However, when the cue-to-target interval is long (750ms), individuals with high anxiety show decreased sensitivity following positive cues. Laterality of anxiety also shifts to the left hemisphere.

These results inform the findings in Experiments 1, 3, and 4. The effects of anxiety are strongly lateralized to the right hemisphere during early orienting (Experiments 1 and 3), yet show a shift toward the left hemisphere during inhibition of return (Experiment 4). The strong laterality observed in these results leads to the question of whether the effects of anxiety are observed in individuals with less laterality, including women and left-handers. Interestingly, both being female and being left-handed have been associated with greater levels of anxiety (e.g., Gard & Kring, 2007; Davidson & Schaffer, 1983). Specific investigation of the effects of gender and handedness on the observed effects of anxiety is necessary to fully consider the importance of laterality to these results (see Experiments 8 and 9).

The specific valence which biases attention in anxiety remains unclear. Both the behavior and the physiology of the Lateralized Visual Probe show a dissociation between the effects of cue valence and the effects of anxiety. Yet the behavior of early orienting shows decreased sensitivity to positive cues, whereas the physiology of late orienting shows decreased sensitivity to positive cues. Similarly, the behavior of late orienting shows increased sensitivity to neutral cues, whereas the physiology of early orienting shows increased sensitivity to neutral cues. Alternate personality factors may contribute to the differences in sensitivity to emotional stimuli observed in these experiments. For example, traits such as novelty-seeking and impulsivity are associated with sensitivity to reward and are known to be associated with anxiety (Taylor & Thierren, 2008; McNaughton & Corr, 2004). These traits may account for differences in sensitivity to positive stimuli observed in these experiments.

The results from Experiments 1-5 are supported by the present experiments. However, several variables relating to individual differences in laterality and personality may account for variability in the results between behavior and physiology. Thus, the remaining experiments specifically examined the contributions of gender, handedness, impulsivity, and novelty-seeking to the observed results in Experiments 3 and 4.

V. Individual Differences in Attention Bias in Anxiety

Experiment 8. Attention Bias, Anxiety, and Gender

Experiments 1-7 show that the right hemisphere is crucial to the effects of anxiety on attention. However, the right hemisphere is not specialized for the same functions in all individuals. Women and left-handers in particular are known to be less lateralized than men and right-handers, respectively (Bradshaw & Nettleton, 1983, chapters 10 and 11). Furthermore, both being female and being left-handed have been associated with increased anxiety (NIMH, 2009; Davidson & Schaffer, 1983). Therefore, it is necessary to address the differences between men and women, and between left-handers and right-handers in order to completely establish the role of the right hemisphere in anxiety. These analyses will also clarify any unintended effects of our sample characteristics. The Emotional Lateralized Attention Network Task (Experiment 3) was selected to examine the effects of gender due to the large sample size and more even representation of each gender than in other experiments. However, this sample could not be used to study the effects of handedness due to the lack of handedness scores. Instead, the Inhibition of Return task (Experiment 4) was selected to examine the effects of handedness.

The present study re-examined the results from Experiment 3 considering gender as well as anxiety level. Experiment 3 showed that individuals with high anxiety are unlikely to show the attention benefits (increased Orienting Benefit and decreased Orienting Cost) from positive stimuli presented in the left visual field. In addition to being less lateralized and more likely to be diagnosed with an anxiety disorder, women are also considered less sensitive to positive stimuli (Ward & Kring, 2007). This follow-up investigation will sharpen the conclusions drawn from Experiment 3. Because of the strong laterality of anxiety observed in Experiments 6 and 7, the laterality of the effect of anxiety may be reduced for women compared to men. However, the effect of decreased sensitivity to positive stimuli may be enhanced in female participants compared to male participants.

Methods

Methods were the same as those in Experiment 3. See Table 5.1 for number of participants of each gender and each anxiety level for each stimulus valence.

	Angry	**Happy**	**Neutral**
High Anxiety Females	5	9	10
Low Anxiety Females	11	9	4
High Anxiety Males	7	5	5
Low Anxiety Males	5	7	10
Total Females	16	18	14
Total Males	12	12	15

Figure 5.1 Table depicting number of male and female participants for each Cue Valence

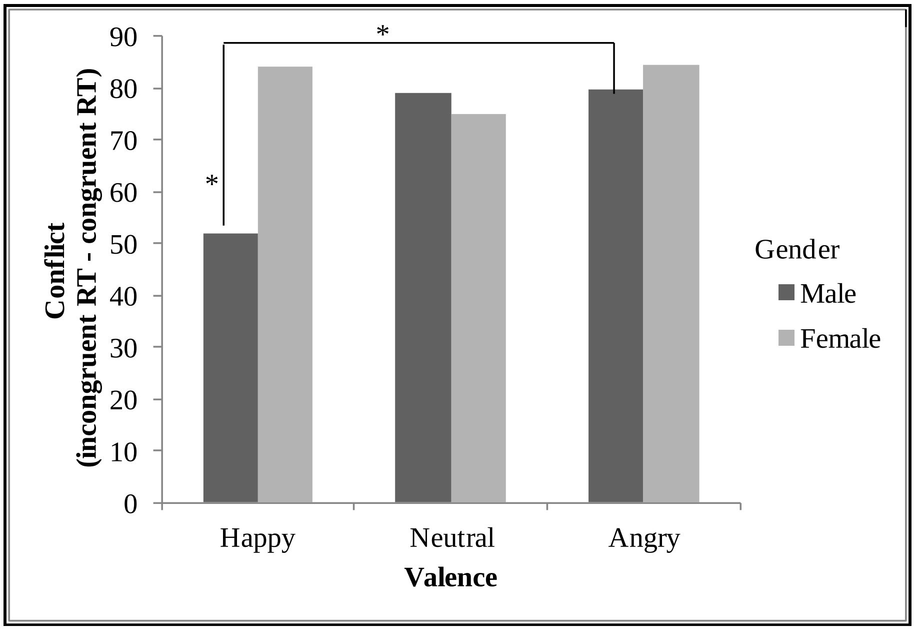
Results

Overall Analysis

We initially performed a 2 (Congruity: Congruent, Incongruent) x 4 (Cue Type: Valid, Invalid, Central, None) x 2 (Target Visual Field: Left, Right) x 3 (Valence: Happy, Angry, Neutral) x 2 (Gender: Male, Female) x 2 (Anxiety Level: High, Low) mixed ANOVA with Valence, Anxiety, and Gender as between-subjects factors. All effects remained the same as in Experiment 3, including the effects of Anxiety Level. In addition, there was a main effect of Gender, as male participants responded significantly faster (M = 340.18, SD = 2.17) than did female participants (M = 375.79, SD = 2.13), $F(1,72) = 8.83$, $p = 0.00$. There was also a significant interaction between Congruity and Gender, $F(1,90) = 3.89$, $p = 0.05$. There was a three-way interaction between Congruity, Valence, and Gender *F*(2,72) = 5.87, *p* = 0.004, and a possible four-way interaction between Congruity, Target Visual Field, Valence, and Gender *F*(2,90) = 2.93, *p* = 0.058. These results showed that Gender interacted only with Conflict, and did not interact with the Orienting or the Alerting attention networks measured by this task. Furthermore, the effects of Anxiety are not related to the effects of Gender in this task.

Conflict

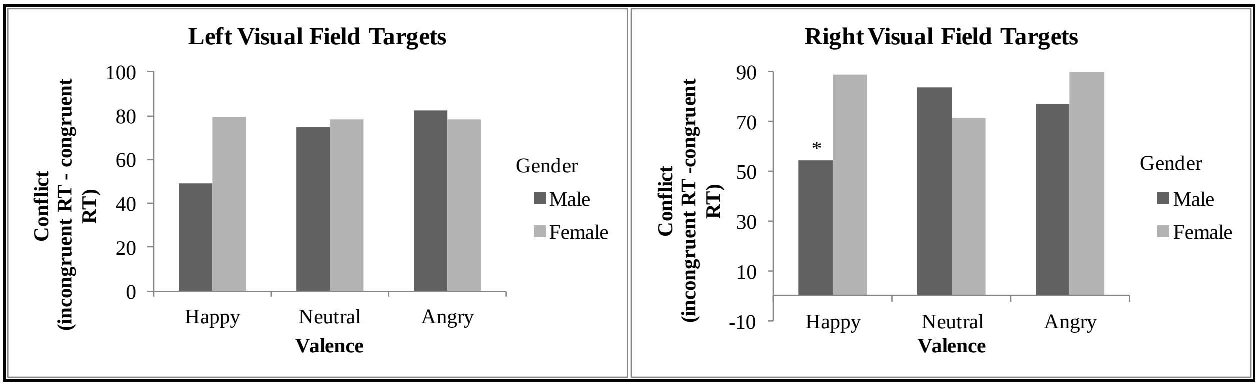
Since Gender interacted only with Congruity, we ran a separate analysis with Conflict as the dependent variable. Again we found the main effect of Gender, *F*(1,90) = 3.89, *p* = 0.05, the significant interaction between Valence and Gender *F*(2,90) = 3.92, *p* = 0.02 (see Figure 5.1), and a significant interaction between Valence, Target Visual Field, and Gender *F*(2,90) = 2.93, *p* = 0.05 (see Figure 5.2).



*** = *p* < .05**

Figure 5.1. Gender x Valence of the face cue, interaction significant at p < .05

Planned comparisons were Bonferroni corrected to maintain $p < 0.05$. Comparisons revealed that in males, angry faces elicited more Conflict ($M = 81.11$, $SD = 31.14$) than did happy faces ($M = 51.97$, $SD = 16.81$), $t(12) = 2.78$, $p < 0.05$. Furthermore, happy faces elicited less Conflict for males than for females ($M = 78.88$, $SD = 23.71$), $t(12) = 2.82$, $p < 0.05$. The difference between happy faces for male and female participants was significant specifically when targets were presented to the right visual field (Male: $M = 54.55$, $SD = 15.44$; Female: $M = 85.18$, $SD = 30.80$), $t(12) = 3.08$, $p < 0.05$. None of these were significantly different from Conflict in response to neutral faces.



*** = *p* < .05**

Figure 5.2. Gender x Valence of the face cue x Visual Field of the target, interaction significant at p < .05

Discussion

The goal of the current study was to assess the extent to which gender may have influenced the novel results obtained in Experiment 3 showing that participants with high anxiety are inhibited in spatial Orienting responses following presentation of happy stimuli in the left visual field. Because women are less lateralized, we suspected that the effects of the right hemisphere in anxiety would be reduced in women compared to men. However, because women are also more likely to be diagnosed with an anxiety disorder and less sensitive to positive stimuli, we predicted that the effect of anxiety on spatial Orienting would be enhanced for women compared to men. Instead, there were no gender differences seen in the Orienting or Alerting networks. Rather, gender differences appeared in left hemisphere Conflict resolution independently of anxiety level. Thus, two independent effects appear in this data: first, the effect of anxiety on Orienting in the right hemisphere, and second, the effect of gender on Conflict in the left hemisphere.

Conflict Resolution

We found a significant effect of emotional valence of the cues on Conflict resolution in males, who had much less Conflict in responding to targets following happy face cues than to targets following angry face cues. These valence effects were not seen in females. In addition, males had significantly less conflict when responding to happy stimuli than females, particularly for Right Visual Field (RVF) targets.

These results suggest that males are in fact sensitive to emotional faces independent of their anxiety level, and that they respond more quickly and accurately when cued with happy stimuli rather than threatening stimuli. These effects are most prominent in the RVF, suggesting that males may process positive stimuli primarily in the left hemisphere. This hemisphere may be taking advantage of its analytic processing style to resolve conflict more efficiently than the right hemisphere (Sperry, 1983). These findings draw a sharp distinction from the earlier results obtained in Experiment 3. Taken together, these results show the LANT to be capable of separating two discrete hemispheric effects. Experiment 3 showed that there is a notable difference between low- and high-anxious individuals in Orienting in the right hemisphere. In contrast, the current study shows significant gender differences in sensitivity to different emotional valences of stimulus cues, independent of anxiety level, specifically within the left hemisphere.

Experiments 3 and 8 show that both hemispheres are able to recognize and benefit from happy face cues. This contrasts with both major theories of hemispheric specialization for emotions (namely the Right Hemisphere Hypothesis and the Valence Hypothesis). We propose that this occurs because happy faces are highly familiar symbols in Western culture, particularly when they are schematic. Thus, the significant hemispheric effects observed are not due to specialization for emotions but are instead due to hemispheric specialization or each attention network (right hemisphere is related to Orienting, left hemisphere is related to Conflict; Fan, *et al*, 2002). Note that this does not invalidate the foregoing result of strong laterality in individuals with high anxiety, but it does remove hemispheric specialization for the perception of emotional stimuli from the summative factors behind the right hemisphere's role in the effects of anxiety on attention.

Women did not show strong effects of laterality in these results compared to men, consistent with the idea that women are less lateralized than men. This occurred independently of the effects of anxiety, suggesting that typical laterality may not be an important factor in the right hemisphere's role in anxiety. This suggestion can be assessed through a complementary analysis of handedness on the effect of anxiety. As in Experiment 3, a systematic assessment of handedness was not available for these results. This means that left-handers are likely included in these results, and the question remains as to whether the laterality of the results differs for left-handers compared to right-handers. Future studies must consider handedness in order to establish the right hemisphere's processing deficiencies in high anxiety.

Conclusions

These findings indicate that there is an important dissociation in the effects of emotional faces on attention networks. Experiment 3 found an effect of anxiety on Orienting in the right hemisphere, entirely independent of the effect of gender on Conflict Resolution in the left hemisphere. The latter gender difference in cognitive processing of emotional stimuli depicts males as more sensitive to emotional stimuli (particularly positive stimuli). Importantly, these results suggest that consideration of gender in the effects of anxiety is less important than previously thought. Although women are more likely to be diagnosed with high anxiety, they are not more likely to exhibit effects of anxiety.

Experiment 9. Inhibition of Return, Handedness, and Personality

Experiment 4 established that the effect of anxiety on spatial Orienting extends to later Orienting, including Inhibition of Return (IOR). In Experiments 3, 4, 6, and 7, the effect of anxiety appeared to be selective to the right hemisphere for early Orienting and selective to the left hemisphere for later Orienting. Given the strong laterality of these results, we chose to examine traits associated with less laterality in Experiment 8 and in the present experiment. Experiment 8 showed that the effect of anxiety was not specific to female participants, and thus is not affected by mixed degrees of laterality in women compared to men. Experiment 9 examines the effect of handedness on the effect of anxiety on attention. Left-handers are known for less lateralization and sometimes even reverse lateralization (Bradshaw and Nettlon, 1983, chapter 10). Experiments 1-3 considered left-handers and right-handers together, yet it is possible that the effect of anxiety is more obvious in individuals with strong lateralization. To investigate this possibility, we considered the differences in the effect of anxiety between right-handers and left-handers in this study. Because the results of Experiment 7 suggested strong laterality in individuals with high anxiety, we predicted a reduced effect of anxiety in left-handers. However, some evidence suggests that left-handers are more prone to the effects of anxiety (Davidson & Schaffer, 1983). Thus, consideration of handedness to the effect of anxiety on attention is crucial in order to establish the relationship between handedness, anxiety, and the laterality of the effects of anxiety on attention.

The results from Experiments 2 and 3 further suggested that high anxiety is associated with decreased sensitivity to positive stimuli. Sensitivity to positive stimuli is often associated with the personality traits of novelty-seeking and impulsivity, which in turn are related to anxiety. Thus, these personality traits provide a possible reason for the positive-specificity of the attention bias in high anxiety observed previously.

Novelty-seeking is the main personality trait claimed to underlie the magnitude and duration of IOR (Klein, 2000). In this view IOR should increase with novelty-seeking. This claim is motivated by the observation that IOR facilitates visual search to novel locations (Posner & Cohen, 1984). Although the novelty-seeking hypothesis is often entertained in the literature, there are as yet no studies which directly investigate the relationship between IOR and novelty-seeking as a personality trait. Our analysis allows us to directly examine this hypothesis while considering the interactions between anxiety and novelty-seeking. Other studies have already shown an effect of high anxiety on IOR, but this may be mediated by an effect of anxiety on novelty-seeking which in turn may affect the IOR. Thus, as anxiety increases, novelty-seeking should decrease (McNaughton & Corr, 2004). We inquired whether the relationship between anxiety and novelty-seeking can explain the expected reduction in IOR in individuals with high anxiety.

Anxiety has also be associated with impulsivity (Taylor & Thierren, 2008). This is particularly true of impulsivity in attention, which describes the tendency to quickly shift attention from one situation or location to another (as in Hypervigilance Theory; Eysenck, 1992, chapter 3). We decided to test the importance of reduced novelty-seeking and increased impulsivity to the effect of anxiety on IOR by including novelty-seeking and impulsivity scores in our analyses. Trait novelty-seeking was measured by the novelty-seeking subscale of the Tridimensional Personality Questionnaire (TPQ; Cloninger, 1987). Impulsivity was measured by the attentional and motor impulsivity subscales of the Barratt Impulsiveness Scales (BIS-11; Patton, Stanford & Barratt, 1995).

In sum, Experiment 9 investigated a final control for laterality (handedness) as well as alternate personality traits which may influence the effects of anxiety on hemispheric attention.

Methods

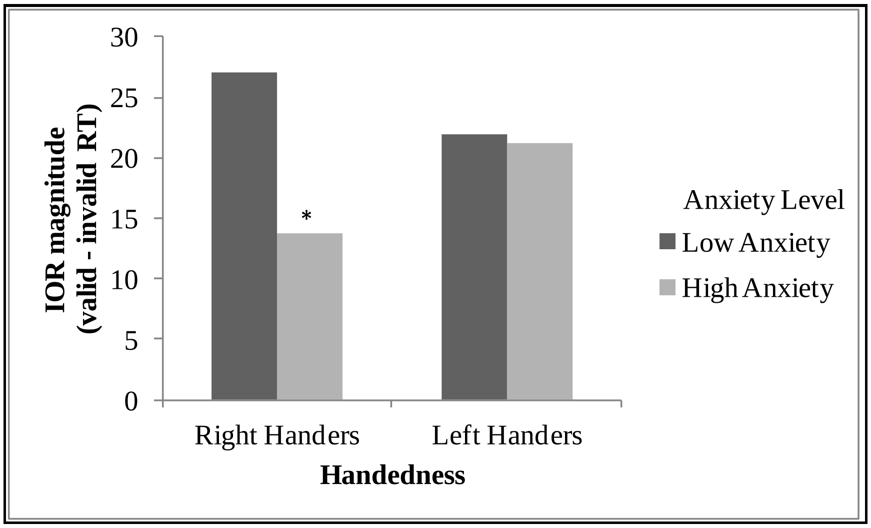
Methods were identical to Experiment 4.

Results

Left-Handedness and Anxiety

To assess the results in terms of left-handedness, we repeated our analyses from Experiment 4 with our left-handed participants only. We performed a 3 (Cue: Valid, Invalid, Center) x 2 (Target Visual Field: Right, Left) x 8 (SOA: 300, 550, 1050, 1550, 2050, 2550, 3050, 3550 ms) x 2 (Anxiety Level: Low, High) mixed ANOVA with a between-subjects factor of Anxiety Level and median reaction time as the dependent variable. This resulted in a main effect of Validity, *F*(1.95, 48.76) = 28.83, *MSE* = 1460.17, *p* = .000. RTs were slightly faster for invalidly cued targets (*M* = 271.76ms, *SD* = 27.48ms) and slower for validly cued targets (*M* = 26.35ms, *SD* = 36.93ms) relative to targets preceded by a central cue (*M* = 276.35ms, *SD* = 31.01ms). There was also a main effect of SOA, *F*(3.65, 91.18) = 9.77, *MSE* = 3497.88, *p* = .000. This showed a pattern similar to that observed in right-handers, with overall decreasing RTs as SOA increased.

To further investigate the differences in IOR between right-handers and left-handers, we calculated IOR magnitude for each left-handed participant in each condition. We performed a 2 (TVF: Right, Left) x 8 (SOA: 300, 550, 1050, 1550, 2050, 2550, 3050, 3550 ms) x 2 (Anxiety Level: Low, High) mixed ANOVA with a between subjects-factor of Anxiety Level and a dependent variable of IOR magnitude. Contrary to the results found with right-handers, there were no significant main effects or interactions for this dependent variable (see Figure 5.3 for comparison of results with left-handers and right-handers).



*** = $p < .05$**

Figure 5.3. Summary of results for Anxiety and Handedness on IOR. Interaction p = .08.

Novelty-Seeking and Anxiety

To assess the contribution of novelty-seeking to the results with anxiety, we included the TPQ novelty-seeking score as a covariate in the mixed ANOVA for right-handed participants with Anxiety Level as a between-subjects variable and median reaction time as the dependent variable. This eliminated the main effects of Target Visual Field and of SOA as well as the interaction between SOA and Cue. The interaction between Anxiety Level and Cue remained significant, *F*(1.524, 36.56) = 4.14, *MSE* = 1556.69, *p* = .033. The main effect of Anxiety Level also remained significant, *F*(1, 24) = 6.53, *MSE* = 63197.67, *p* = .017.

Impulsivity and Anxiety

To assess the contribution of impulsivity to the results with anxiety, we included the overall BIS-11 impulsivity score as a covariate in the mixed ANOVA for right-handed participants with Anxiety Level as a between-subjects variable and median reaction time as the dependent variable. This resulted in a main effect of Cue, $F(1.572, 37.72) = 4.25$, $MSE = 1574.50$, $p = .03$, and a main effect of Anxiety Level, $F(1, 24) = 7.10$, $MSE = 61715.35$, $p = .014$. There were no other significant main effects or interactions. In particular, the interaction of Anxiety Level and Cue found in the original ANOVA was no longer significant.

Effects of Personality Variables on IOR

We entered scores from the three subscales of the BIS-11 (Attentional Impulsiveness, Nonplanning, Motor Impulsiveness), the STAI-TA, the TPQ, and the Edinburgh Handedness Inventory into a stepwise linear regression with overall IOR magnitude, IOR magnitude in the LVF, and IOR magnitude in the RVF as outcome variables. STAI-TA did not significantly predict any of the IOR variables ($p > .60$). However, Attentional Impulsiveness and Nonplanning impulsiveness did significantly predict IOR magnitude in the RVF above and beyond the effects of anxiety, novelty-seeking, and handedness, Attentional: $\beta = -.564$, $t(47) = -4.25$, $p = .000$; Nonplanning: $\beta = .309$, $t(47) = 2.33$, $p = .001$. No other variables significantly accounted for the variance in IOR magnitudes.

Correlations

In order to further examine the relationships among the personality variables, we performed Pearson correlations between STAI-TA scores, BIS-11 subscale scores, TPQ scores, and handedness scores (see Table 4). All correlations were Bonferroni corrected for multiple correlations to maintain $p < .05$. The STAI was positively correlated with the attentional BIS, $r = .56$, $p = .000$, demonstrating that anxiety is related to attentional impulsiveness. The TPQ was positively correlated with the motor BIS, $r = .48$, $p = .000$ and with the nonplanning BIS, $r = .35$, p = .010, indicating that novelty seeking is related to motor impulsiveness and nonplanning in particular. No other correlations with the TPQ or the STAI-TA reached significance.

	STAI-TA	TPQ	BIS-motor	BIS-attention	BIS-nonplanning	Handedness
STAI-TA	1.0	.07	.05	**.56****	.27	-.05
TPQ		1.0	**.48****	.21	**.35***	.22
BIS-motor			1.0	**.30***	**.29***	.20
BIS-attention				1.0	**.43****	.18
BIS-nonplanning					1.0	.24
Handedness						1.0

*** = *p* < .05**

Table 4. Correlations between anxiety (STAI-TA score), novelty-seeking (TPQ novelty-seeking score), impulsivity (BIS attentional, motor, and nonplanning scores), and handedness scores.

Discussion

Effects of Handedness

We predicted that the effect of anxiety on IOR would be selective to the right cerebral hemisphere and examined both left-handed and right-handed participants to thoroughly assess the laterality of this effect. Specifically, we predicted that decreased laterality would decrease the previously observed effect. As predicted, the general effect of anxiety on IOR occurred only in right-handed participants; no effect of anxiety was observed in our left-handed participants. This result in left-handers suggests that handedness is important to consider when examining the effects of anxiety. Handedness was not correlated with impulsivity or novelty-seeking, suggesting that this effect is independent of any alternate personality trait discussed here.

Handedness was also not correlated with anxiety, showing that this result is not due to different levels of anxiety in left-handers compared to right-handers.

Contributions of Novelty-Seeking and Impulsivity to the Effect of Anxiety

High anxiety is associated with decreased novelty-seeking (McNaughton & Corr, 2004) and increased impulsivity (Taylor & Thierren, 2008). Therefore, we examined the influence of these personality traits on the reduction of IOR seen in high anxiety by including these variables as covariates in separate analyses. The critical Cue x SOA interaction, indicating IOR, was abolished when novelty-seeking was included as a covariate, revealing that novelty-seeking as a personality trait is important to the presence of IOR. However, novelty-seeking did not affect the interaction between Cue and Anxiety, which shows that the effects of anxiety on attention are independent of the effects of novelty-seeking. The lack of a correlation between TPQ scores and STAI-TA scores further reveals that these two personality traits are not necessarily related as previously assumed.

The inclusion of total impulsivity as a covariate did abolish the effects of anxiety, showing that the effects of anxiety on attention are related to changes in impulsivity with anxiety. Examination of the significant correlations suggests that the specific effect of impulsivity is related to attentional impulsivity, which showed a very high positive correlation with trait anxiety level. The regression analysis further supported the idea that decreased IOR is primarily related to attentional impulsivity. Thus, the effect of anxiety on attention is driven by attentional impulsivity. Attentional impulsivity refers to quick shifting of attention regardless of the initial locus of attention (Barratt, 1993). This quick shifting may demand a much shorter duration of IOR than that measured in this experiment. Thus it logically follows that individuals high in attentional impulsivity would exhibit a decrease in IOR. However, anxiety alone is sufficient to provoke a decrease in IOR.

Impulsivity additionally explains the interaction between Anxiety Level and Target Visual Field. Anxiety is typically associated with changes in right hemisphere attention, yet the present results implicate a left hemisphere mechanism in the decrease of IOR. Impulsivity is associated with behavioral approach and thus with the left hemisphere. Therefore it is possible that the observed results in the left hemisphere of right-handers are driven by impulsivity in anxiety rather than anxiety alone. This remains consistent with Hypervigilance Theory of attention in anxiety, which proposes that individuals with high anxiety are constantly scanning the environment for threat (Eysenck, 1992, chapter 3).

Conclusion

In sum, we found that only right-handed individuals with high anxiety have a reduction in IOR magnitude relative to individuals with low anxiety. The effect of anxiety is not due to reduced novelty-seeking, but is related to increased attentional impulsivity.

Experiments 8 and 9: General Discussion

The effect of anxiety on attention observed in Experiments 1-7 may be related to other factors. Specifically, the hemispheric effects may be related to conditions of more or less laterality, including gender differences and handedness differences in laterality, and the effects on attention may be due to novelty-seeking or impulsivity instead of anxiety alone. Furthermore, anxiety has been related to handedness. We did not control the number of men and women, or the number of left-handers and right-handers in the previous studies. Thus, Experiments 8 and 9 addressed these possibilities and strengthen the foregoing conclusions on attention in anxiety.

Experiment 8 addressed the possibility that gender confounded the results in Experiment 3 (the Emotional Lateralized Attention Network Task). The prevalence of anxiety disorders is much greater in women than in men (NIMH, 2009). Furthermore, females are known to have less laterality than males (see Lewis & Diamond, 1996). Thus, the prevalence of female participants throughout Experiments 1-7 may have influenced the result that high anxiety is associated with changes in right hemispheric attention. However, consideration of gender in Experiment 8 showed that while there is an effect of participant gender on attention to emotional stimuli, this effect is independent of the effects of anxiety. Importantly, whereas anxiety interacted with cue valence to affect spatial orienting in the right hemisphere, gender interacted with cue valence to affect executive Conflict resolution in the left hemisphere. This clear dissociation strengthens the conclusion that the effects of anxiety on attention are independent of the effects of gender. Furthermore, this suggests that while an unequal distribution of genders is not ideal, it does not significantly change the results for attention in anxiety.

Experiment 9 expanded on the conclusion from Experiment 8 by considering the effect of handedness on the observed effect of anxiety on attention. Several prior results included participants of mixed handedness. However, left-handedness is also associated with less lateralization than right-handedness. Thus it is possible that conclusions about laterality are limited by including left-handers as well as right-handers. Whereas the reduction in Inhibition of Return (IOR) was observed in right-handers, there was no effect of anxiety on IOR in left-handers. This result suggests that left-handers do not experience the same effects of anxiety on spatial attention. Thus, the results from this experiment emphasize the importance of typical laterality of the right hemisphere to observe the cognitive effects of high anxiety. Inclusion of left-handed participants may decrease the power of previous results, yet the fact that significant differences in lateralization of attention in anxiety were found in Experiment 3 suggests that the results were strong enough in right-handers to overcome the null effect in left-handers. However, this may not always be the case, and inclusion of left-handers may explain conflicting results often observed in the literature on the attention bias.

Finally, Experiment 9 included alternate personality variables in the re-analysis of Experiment 4. These showed that while the effect of anxiety on IOR is not related to novelty-seeking, it is related to attentional impulsivity. This finding supports Hypervigilance Theory (Eysenck, 1992, chapter 3), which suggests that individuals with high anxiety are more likely to scan the environment. However, this is contrary to the interpretation of IOR as disengagement of attention from a pre-cued location. We conclude that IOR may reflect both the disengage and shift components of spatial orienting, analogous to both hypervigilance and difficulty disengaging. Consistent with Experiments 1-5, we believe that difficulty disengaging explains most of the observed effects. However, this interpretation is not incompatible with the idea that individuals with high anxiety are more easily distractible and/or individuals with high anxiety scan the environment more than individuals with low anxiety prior to engaging attention with a particular stimulus.

VI. General Discussion

The current state of understanding the effects of anxiety on attention is at best unclear. The experiments in this dissertation attempted to answer three main questions about the nature of attention in anxiety: 1) what, if any, is the hemispheric basis of the effects of anxiety on attention? 2) which aspects of basic attention are most affected by high anxiety? and 3) are the changes in attention seen in anxiety specific to threatening stimuli?

Laterality of Attention in Anxiety

Throughout the experiments, the strongest differences between individuals with high anxiety and individuals with low anxiety were seen almost exclusively in the right hemisphere. Regardless of the emotional valence of the stimuli, the stimulus material, or the specific paradigm, individuals with high anxiety showed changes in attention (either increased orienting toward, or decreased orienting away from) to target stimuli in the left visual field. Furthermore, the effects of anxiety on attention were not seen in left-handers who have less typical brain laterality. This suggests that the effects of anxiety on attention are strongly tied to typical right hemisphere function. The ERP studies further showed that individuals with high anxiety show increased laterality when processing visual stimulus, compared to individuals with low anxiety. This suggests that individuals with high anxiety have increased laterality and possibly reduced interhemispheric transfer of information.

Spatial Orienting and Conflict Resolution in Anxiety

Attention in anxiety is often characterized as either increased hypervigilance toward certain stimuli or increased difficulty disengaging attention from certain stimuli. However, these general terms have not always been applied to basic attention processes known in cognitive neuroscience, such as spatial orienting, alerting, or executive conflict resolution. Thus, the second major question these experiments addressed was which basic component of attention is most affected by high anxiety. We chose to address these questions with spatial and visual tasks of the most commonly studied paradigms. In particular, we used a lateralized version of Posner's Attention Network Task (ANT). The Lateralized Attention Network Task (LANT) showed that Orienting of spatial attention is particularly affected by high anxiety. Further experiments showed effects of high anxiety can be applied to early as well as late components of Orienting of spatial attention. These findings suggest that the clinical measures of attention, particularly the Lateralized Visual Probe, likely reflect effects of spatial Orienting. Indeed, Orienting is often related to the clinical literature as hypervigilance (Orienting Benefit) and difficulty disengaging (Orienting Cost and Inhibition of Return).

These results do not explain the significant effect of anxiety on color-naming observed in the Lateralized Emotional Stroop. It has been proposed that the Lateralized Emotional Stroop measures executive Conflict resolution. The results from the LANT showed no significant effect of anxiety on Conflict. Thus, we conclude that while anxiety does not affect Conflict resolution as operationalized in the LANT (i.e., response conflict due to flanker congruity), anxiety does affect conflict as operationalized in the Emotional Stroop task (i.e., response conflict due to semantic processing of stimulus meaning). However, this effect on semantic processing conflict occurs separately from the effect on orienting of spatial attention and separately from response conflict in spatial attention.

Attention to Emotional Stimuli in Anxiety

The attention bias described in the literature typically focuses on biased attention to threat. However, our lateralized paradigms do not show the reported bias to threat. Instead, our results found nonspecific changes in spatial orienting toward positive and emotionally neutral stimuli. In fact, changes in attention between individuals with high anxiety and individuals with low anxiety occurred even in the absence of any emotional cues or contexts. These results tend to support the Right Hemisphere Hypothesis of hemispheric specialization for emotions. Namely, the right hemisphere is specialized for the experience and perception of all emotions, regardless of valence. However, it is possible that the results observed here reflect hemispheric specialization for each task rather than for a particular emotional stimulus (see Experiment 8 discussion).

	DV	**Stimuli**	**Laterality of Attention in Anxiety**	**Emotionality of Attention in Anxiety**	**Most Informative Measure**
Visual Probe	Behavior (RT, ABI)	NimStim Faces (H, F, N), words (P, T, N)	Right Hemisphere	None	ABI
Emotional Stroop	Behavior (RT)	Schematic faces (H, A, N), words (P, T, N)	Right Hemisphere	Happy	RT
Emotional LANT	Behavior (RT, OB, OC, Alerting, Conflict)	Schematic faces (H, A, N)	Right Hemisphere	Happy	OB, OC
IOR	Behavior (RT, IOR)	Schematic face (N)	Left Hemisphere	Neutral	IOR
Perimetry	Behavior (ACC, d', criterion	Spots of light	None	Neutral	d'
ERP Visual Probe	ERP (N1, P2, N2)	NimStim Faces (H, A, N)	Right Hemisphere	Neutral	N1
ERP Covert Orienting: Cues	ERP (P1, N1, P2)	Schematic faces (H, A, N)	Right hemisphere	Angry, Neutral	N1
ERP Covert Orienting: Targets, Short SOA	ERP (N1, N2, P3)	Schematic faces (H, A, N)	Right hemisphere	Neutral	P3
ERP Covert Orienting: Targets, Long SOA	ERP (N1, N2, P3)	Schematic faces (H, A)	Left Hemisphere	Happy	N1, N2

Table 6.1. Summary of effects of laterality and emotionality of the attention differences between high anxiety and low anxiety. RT = reaction time; ACC = accuracy; OB = Orienting Benefit; OC = Orienting Cost; IOR = Inhibition of Return; H = happy; A = angry; N = neutral; P = positive; T = physically threatening

All the experiments reported here varied in the specific emotion to which attention was directed in high anxiety (see Table 6.1). These results may be accounted for in one of two ways.

First, it is possible that differences in other personality traits which covary with anxiety determine which emotion will attract attention in anxiety. For example, emotions related to positive affectivity, such as novelty-seeking or impulsivity, may determine that attention will be focused on positive stimuli. However, we found that anxiety is positively correlated with impulsivity (associated with sensitivity to positive stimuli) during Inhibition of Return (IOR) in Experiment 9, yet the ERPs of IOR measured in Experiment 7 showed decreased processing of positive stimuli. The other possible account of varied results is that different paradigms measure attention at different stages of stimulus processing. Experiments 6 and 7 showed that the time course of processing stimuli differs depending on the emotional valence: first angry faces were processed, then neutral faces, then positive faces. Thus, it is more likely that the differences in sensitivity to emotional stimuli observed in different paradigms reflect the stage of processing tapped by the experimental paradigm.

There are several potential reasons that our study produced novel results. First, our findings on emotional valence in anxiety apply to implicit (i.e., task-irrelevant) cues whose effects are measured by the indirect modulation of attention. This measure therefore has the advantage of being less sensitive to strategic, conscious, and other controlled state variables, and is more likely to reflect automatic, trait variables.

Second, the effects of threatening stimuli are known to occur earlier than for other stimuli (see Bar-Haim, *et al*, 2007 for meta-analysis). This was confirmed by the time course of ERPs to emotional stimuli in Experiments 6 and 7 (N1 immediately evoked by angry face cues, N2 later evoked by neutral face cues, and P3 evoked by positive face cues even later). Therefore, it could be argued that the selective effects of happy cues in anxiety seen in Experiments 2, 3, and 8 result from slower or decreased perceptual processing of positive compared to threatening stimuli. However, the timing of the Emotional Stroop and the LANT is similar to the timing in the IOR and covert orienting of attention paradigms employed in Experiments 4 and 7. These showed effects of neutral stimuli selectively. Therefore, the effect of happy cues seen in our data cannot be attributed to the slower processing of positive stimuli compared to neutral stimuli. However, it is possible that we did not see the effect of threat because it degraded too quickly to affect behavior.

Lastly, it could be argued that we did not replicate the bias to threat because we lateralized stimulus presentations. These presentations are often considered "less natural" than other experimental paradigms. However, lateralized presentations have the advantage of being able to distinguish the lateralized cognitive processes which underlie observed behavior in natural conditions. This type of paradigm is ideal to measure the effects of anxiety on attention because the presumed component processes underlying this effect (namely, negative emotion and spatial attention) are strongly lateralized (see introduction). We believe lateralized paradigms are therefore uniquely suited to identify early implicit markers of a clinical state such as high trait anxiety.

What Characterizes Anxiety?

From these studies, we know that anxiety is characterized by selective changes in orienting of spatial attention to stimuli in the left visual field, regardless of the valence of these stimuli. In particular, the effects of anxiety on attention are tied to typical right hemisphere function in both men and women, and the effects of anxiety on attention are not observed in individuals with reduced laterality (i.e., left-handers). The effects of anxiety on attention are strongly correlated with individual differences in attentional impulsivity, supporting theories of hypervigilance for environmental threat (Eysenck, 1996, chapter 3). However, we found that anxiety is also associated with decreased visual sensitivity to peripheral stimuli. Thus, the effect of attentional impulsivity may reflect increased scanning of the environment to compensate for decreased peripheral awareness at each fixation. Alternately, anxiety may show increased scanning until initial fixation and attentional engagement with a stimulus, which is followed by slower disengagement from that stimulus.

Behavioral vs. ERP Measures

As seen in Table 6.1, the behavioral and ERP measures for the attention paradigms showed some complementary and some divergent results. Both Experiment 1 and Experiment 6 showed separate effects of anxiety and valence, but Experiment 6 showed an additional effect of emotionally neutral stimuli for high anxiety that was not observed in the behavioral results. Similarly both Experiments 3 and 4 and Experiment 7 showed shifts in laterality of early compared to late effects of orienting (facilitation = right hemisphere; IOR = left hemisphere), but Experiment 7 also showed the time course of emotional processing of emotional cues. This included an effect of angry face cues that was not observed in the behavior.

The primary divergence between the behavioral paradigms and the ERP paradigms occurred for covert orienting of spatial attention. In Experiment 3, behavioral performance was reduced following positive face cues in individuals with high anxiety when the cue-to-target interval was relatively *short* (320ms after the onset of the cue). In Experiment 7, ERP amplitudes were reduced following positive face cues in individuals with high anxiety when the cue-to-target interval was *long* (650ms after the onset of the cue), and did not show an effect of positive face cues when the cue-to-target interval was short. However, there is a slight difference in the timing of Experiment 3 (320ms) compared to the timing of the short SOA trials in Experiment 7 (250ms). Because the results of Experiment 3 are collected at a later time period, it is possible that they reflect the decreased processing of positive faces (but see previous discussion of differences in positive vs. neutral stimulus processing, p 156).

It is important to note that while behavioral data were collected during the ERP experiments, the data did not show significant results. We believe that this is likely due to the added fatigue and stress of the EEG apparatus during the ERP paradigms, which had a normalizing effect on behavior. Despite this, the ERP data largely supported and extended the findings from the behavioral data gathered in the separate behavioral paradigms. Thus, we believe that these results reflect "true" performance on the task, although this performance is captured by different measures depending on the environment of the task.

Future Directions

These results must be confirmed in clinical populations of individuals with Generalized Anxiety Disorder and mixed anxiety-depressive disorders. Since STAI-TA scores are positively correlated with measures of clinical anxiety, it is reasonable to assume that the pattern observed here will extend to clinical populations. This is important to establish because it provides a model of the clinical condition in the normal population. The existence of such a model makes it easier to study the presentation, diagnosis, and treatment of the disorder.

It is important to consider the independent contributions of depressive symptoms to the effects observed in these studies. Because the STAI-TA measures depression as well as anxiety, it is possible that "pure anxiety" would elicit different effects, including the more specific effect of biased attention to threat stimuli. Depression is often related to decreased processing of positive stimuli (Dalgleish & Watts, 1990; Gotlib, *et al*, 1998). Thus, our results may reflect independent contributions of depression and other more general negative affective states. However, when we analyzed the data from Experiments 2 and 4 using specific measures of anxiety (the anxiety subscale of the STAI-TA; Bieling, *et al*, 1998) and results were consistent with those considering the entire STAI-TA.

These studies will also be strengthened by replications using alternate measures of anxiety. For example, Gray's tridimensional model (1991) provides an alternate account of anxiety measured by the motivational states underlying behavior. The three components in this model are the Behavioral Activation System, the Behavioral Inhibition System, and the Fight-or-Flight System. The Behavioral Activation System, or BAS, measures sensitivity to reward and activates behavior that will lead to goals or reward. The Behavioral Inhibition System, or BIS, measures sensitivity to punishment and novelty, and inhibits behavior that will not lead to reward. The Fight-or-Flight System, or FFS, measures subjective arousal. The BIS system is thought to be overactive in anxiety, the FFS system is thought to be overactive in fear, and the BAS is thought to be underactive in depression. These systems are measured by the BIS/BAS scales developed by Carver and White (1994). Although the BIS/BAS does not explicitly measure anxiety, researchers have begun to use the BIS portion instead of the trait version of the STAI as a measure of anxiety in the general population because it better differentiates between anxiety and depression.

The results found in these experiments inform the Attention Bias Modification Training utilized as a treatment for individuals with clinical anxiety. Specifically, these results suggest that attention in anxiety should not be trained toward positive stimuli. Instead, individuals with high anxiety should be trained to shift attention more flexibly and avoid prolonged engagement with focal stimuli. These shifts in attention should be trained primarily in the left visual field, at least for individuals who are right-handed.

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