ABSTRACT

Title of Dissertation: NEURAL CHRONOMETRY OF VISUAL ATTENTION & THREAT PROCESSING

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Most anxiety disorders in adults emerge during adolescence, and if left untreated, pediatric anxiety disorders predict adverse mental and physical health outcomes in adolescents and adults. While genetic heritability is a contributing risk factor, a heightened tendency to direct attention preferentially to threat represents one of the strongest information-processing correlates of anxiety; such an attention bias may shape both the development and maintenance of anxiety symptoms. Attentional performance differences have been observed on emotion cueing visual attention tasks as a function of both clinical and sub-clinical anxiety levels. Previous work in adults observed that for adults with higher anxiety symptoms, efficiency of visual search was degraded by threat-cueing faces. However, further work is required to clarify the emergence attentional biases in adolescents, to inform methods for early identification, intervention and treatment of individuals at risk for anxiety.

The present study examined the impact of emotional priming on attention as a function of anxiety using a task in which emotional faces were used as primes for a visual search task. Event Related Potentials (ERP) (P1, N170 and N2pc) were recorded in concert with behavioral responses to address the chronometry and quality of attentional processing as a function of anxiety symptoms in adolescents, 12-17 years of age.

Early P1 and N170 processing in the first few hundred milliseconds of viewing face primes, differed as a function of both anxiety and prime emotion. Moreover, these anxiety-related early processing differences related to subsequent behavior. Variability in the N2pc attention-related processing during visual search also varied as a function of anxiety and prime type, as well as affected subsequent behavior. This dissertation found both early and later occurring attentional processes have significant ramifications for individuals with higher anxiety scores, such that in addition to neural differences, high anxious individuals also display significant differences in behavior. While early and late neural processes varied in lower anxious individuals as a function of face prime type, relations with behavior were minimal in comparison. These findings are discussed as they relate to emotion processing, threat responsivity to facial stimuli, and applicability to pediatric and adult clinical anxiety.

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by

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# Chapter 1: Introduction

Anxiety is one of the most prevalent disorders affecting the lives of millions of individuals around the world. Clinicians and researchers have been challenged with designing reliable paradigms to clarify the etiology of anxiety-related disorders (Baxter, Scott, Vos, & Whiteford, 2013; Kessler, Petukhova, Sampson, Zaslavsky, & Wittchen, 2012; Pine, 2007; Pine & Fox, 2015). Most anxiety disorders in adults begin in childhood, and if left untreated, pediatric anxiety disorders predict adverse mental and physical health outcomes in adolescents and adults (Kessler et al., 2012). It is estimated that pediatric anxiety affects 10% of children throughout the world (Strawn et al., 2014).

While there appears to be genetic heritability of risk for anxiety disorders (Fox, Hane, & Pine, 2007; Pine & Fox, 2015), the etiology of anxiety symptoms may also be the result of perturbations in the ability to interpret and regulate responses to ambiguous and potentially threatening situations (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van, 2007; Pine, 2007; Pine & Fox, 2015). A heightened tendency to direct attention preferentially to threat represents one of the strongest information-processing correlates of anxiety; such an attention bias may shape both the development and maintenance of anxiety symptoms (Bar-Haim et al., 2007; Fox, Henderson, Marshall, Nichols, & Ghera, 2005; Pine & Fox, 2015). These patterns of hyper-vigilance have been observed in clinically anxious adults, adolescents and children, as well as at-risk children (Bar-Haim et al., 2007; Fox et al., 2005). In particular, the development of the skills necessary to regulate and inhibit attention to threats may differentiate trajectories, indicating those at higher risk for developing a clinical diagnosis of anxiety (Lau, Molyneaux, Telman, & Belli, 2011; Perez-Edgar & Fox, 2007; Pine & Fox, 2015). For example, in children identified with the temperament of Behavioral Inhibition (BI), early observed hyper-vigilance significantly increases the likelihood of a clinical anxiety disorder later on (Fox et al., 2005) .

A variety of data from several different sources highlights the role of attention in anxiety. For example, compared to healthy and low anxious peers, high and clinically anxious individuals have a significant tendency to look and respond to negative facial expressions, such as angry faces, faster than a concurrently presented positive or neutral face (Bar-Haim et al., 2007). A closely related line of work has examined attentional orienting in individuals with extreme phobias, such as spider and snake phobics when presented with images depicting relevant phobias alongside a competing neutral image (Leutgeb, Sarlo, Schongassner, & Schienle, 2015; LoBue & Perez-Edgar, 2014; Weymar, Gerdes, Low, Alpers, & Hamm, 2013). This line of work has consistently demonstrated significantly biased orienting to images depicting the individuals' phobia. These findings in individuals with specific phobias, as well as increased vigilance to negative facial expressions across anxious individuals more broadly, have led researchers to posit that broadly, anxious individuals process 'threatening' stimuli differently.

LeDoux has (1996) proposed that our brain has a coarse but rapid "gist" processing pathway optimized for threat identification, and a complimentary slower but more detailed processing pathway to facilitate appropriate response and action. In line with this model, individuals display rapid increases in cortisol levels, heart rate, and skin conductance when exposed to threat. And they also exhibit rapid fear–responses after repeated exposure or conditioning to a stimulus paired with an unpleasant or threatening experience. In anxious populations, and in individuals who develop post-traumatic stress disorder, this threat responsivity persists long after extinction is observed in healthy individuals (Cohen Kadosh et al., 2015; Fox, Yates, & Ashwin, 2012). LeDoux's model has provided a strong theoretical framework to examine the development and maintenance of unconscious rapid behavioral and neural "knee-jerk" reflexes to threat.

More recent work argues that the division of visual processing postulated by LeDoux may be misleading. Within the first few hundred milliseconds of viewing a stimulus, there is remarkable communication between areas typically thought of as more "primitive", and areas associated with higher order cognition (Pessoa & Adolphs, 2010). Partitioning the human threat response into an (1) initial rapid "primitive" automatic response, followed by (2) later processing and engagement of association areas of the human brain, such as the prefrontal cortex, may ignore the importance of widespread functionally connected neural circuits, responsible for rapid processing and integration of information (Pessoa & Adolphs, 2010).

While findings support that perturbed threat-related information processing may play critical role in the etiology and maintenance of anxiety disorders, developmental changes and the time-course of threat-related attention processing remains poorly defined. Interpretability of these paradigms is also limited as the visual stimuli do not mimic visual clutter in an individual's day to day environment (Pine, 2007; Pine, Helfinstein, Bar-Haim, Nelson, & Fox, 2009). An individuals' everyday environment is full of social stimuli, and various extraneous visual and auditory stimuli. From a developmental perspective, it is critical to examine attentional processing streams in experimental contexts that attempt replicate attentional demands that individuals face in their typical environment. Moreover, because emotion processing skills and attentional biases develop at a young age, and as a function of experience, an understanding of early attentional biases existing in children and adolescents with pediatric anxiety can provide methods of earlier identification of those at risk for pediatric anxiety, as well as the development of early intervention programs (Pine, 2007).

It is important to clarify differences in how affective stimuli modulate goal-oriented attention in both healthy and anxious pediatric populations. When affective stimuli are relevant, modulation of attentional resources should vary as a function of stimulus relevance or "meaning". However, when affective stimuli are irrelevant to the task at hand, it is ideal to inhibit further processing of the irrelevant affective stimuli, while maximizing resources for task completion. A variety of research findings support the hypothesis that anxious adults do not appropriately inhibit the attentional processing of task-irrelevant affective stimuli. The objective of the current study will be to test this hypothesis in adolescents using Event Related Potentials (ERPs). Employing ERP methods, supports the examination of underlying neural processing related to: (1) sensory and affective characteristics of a stimulus (e.g. P1, N170) and (2) goal-directed attentional orienting (e.g. N2, N2pc).

By examining these ERPs, it is possible to assess (1) how stimulus valence affects sensory processes in the first few hundred milliseconds of viewing, (2) how variability in attention-related processing necessary influences behavioral performance, and (3), how (1) and (2) may independently or additively predict behavioral performance on a visual search task. In addition to assessing the magnitude and type of activity (using amplitude of ERP components), the temporal order of these components may aid in identifying and understanding how underlying circuitry is affected by irrelevant emotion primes.

To achieve this, the current study administered the Emotion Priming Influences on Visual Search (EPIVS) paradigm (Haas, Amso, & Fox, 2016) to adolescents between the ages of 12 and 17. While anxiety-related disorders such as social phobia and generalized anxiety disorder often emerge in adolescence (13-to-17 years of age), anxiety disorders and symptoms may emerge as early as childhood (12 years and younger). The transition from childhood to adolescence is also marked by pubertal changes, cortical maturation of regions supporting executive functions, and increased capacity and need for self-regulation. Thus, to understand the neural processes related to the emergence of anxiety disorders during this period, relations between anxiety symptoms and performance on the visual search task was assessed in a sample of 74 12- to17-year olds.

Event Related Potentials (ERP) were recorded in concert with behavioral responses to address the chronometry and quality of attentional processing during the EPIVS task. To examine anxiety-related perturbations in threat-responsivity, we assessed the relations between self- and parental-report of anxiety symptoms, performance on the EPIVS task, as well as Event-Related sensory and attentional ERP components: P1, N170, N2pc. Variability in these neural proxies of attention were examined as a function of:  prime emotion type, visual search difficulty, as well as anxiety symptomology, age and sex.

This study addressed the links with aberrant visual attention/responsivity to threatening stimuli and anxious symptoms in a pediatric population, and aims to explicate mechanisms relevant to attentional processing.  There were three specific aims. First, investigate the variability in early and late occurring sensory processing of face stimuli, as measured by the P1, & N170, components, and how these relate to emotion prime type, age, sex, adolescent's behavioral visual search performance, and anxiety symptoms (Blau, Maurer, Tottenham, & McCandliss, 2007; Jetha, Zheng, Schmidt, & Segalowitz, 2012; Kolassa & Miltner, 2006; O'Toole, DeCicco, Berthod, & Dennis, 2013). Second, examine the impact of prime type on later occurring attentional processing during visual search (N2 and N2pc), and relations with an adolescent's visual search performance, age, sex, and anxiety symptoms (Bacigalupo & Luck, 2015; Grimshaw, Foster, & Corballis, 2014; Kappenman, MacNamara, & Proudfit, 2015; Kashiwase, Matsumiya, Kuriki, & Shioiri, 2013; Luck & Hillyard, 1994; Weymar et al., 2013). Finally, the third aim examined how early occurring sensory processes and later goal orient attentional processing interact and relate to prime type, age, visual search performance, and anxiety symptoms.

# Chapter 2: Background

## *2.1 Emotion and Attention*

The aim of the current chapter is to review the empirical research on the impact of emotional stimuli on attentional processing. The first part of the chapter briefly summarizes the ability of 'privileged' salient categories of stimuli to rapidly alter attentional processing. Second, studies in adults as well as, cross-sectional and longitudinal developmental studies with focuses on links between anxiety and attentional processing, will be discussed. As well, the extent literature on threat responsivity to faces, anxious traits/temperament, and risk for clinical anxiety will be detailed. Finally, the chapter will discuss the benefits of employing electroencephalography methods to examine attentional processing, particularly to examine aberrant threat responsivity in anxious populations.

Beginning early in the first postnatal year, infants rapidly develop the ability to orient, encode, and respond to visual stimuli. Visual processing and subsequent attentional orienting are driven by visually 'salient' stimuli, while inhibitory mechanisms ensure interfering stimuli are suppressed (Desimone & Duncan, 1995; Itti & Koch, 2001; Koch & Ullman, 1987; Treisman & Gelade, 1980; Wolfe, 1994). Visual attention serves as an information filter, determining input to be further processed for perception and memory (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Markant & Amso, 2013). Within this framework, perceptual information is processed with filters ranging from subconscious saliency driven attention, to conscious allocation of attention to stimuli or people for further encoding.

The typical human attention system comes to selectively privilege classes of stimuli outside conscious awareness, particularly, social stimuli and stimuli that signal threat. Consistent with the rapid improvement in visual acuity over the first year of life, work using ecologically valid indoor and outdoor scenery with people, has demonstrated that initial attentional orienting biases in 4-month infants may follow a more salience dependent model (Itti & Koch, 2001) and by 12-month, this saliency-driven attentional bias changes to a pro-social attentional bias (Amso, Haas, & Markant, 2014).

The literature typically discusses these types of attentional processing in terms of stimulus/saliency-driven, or 'bottom-up', and goal-oriented or 'top-down'. Specific areas of the brain appear to differentially support both types of processes. For example, primary visual cortex (V1) second in line after the lateral geniculate (LGN) in receiving retinal projections, appears to demonstrate regional specificity for 'bottom-up' attention, while the pre-striate region (V2), appears to demonstrate regional specificity 'top-down' attention processes. Moreover, activity in extra-striate cortex (V4) reflects the integration of both types of attention to support task goals (Melloni, van Leeuwen, Alink, & Muller, 2012). The interconnectedness and strong feedback loops across V1-V4 are consistent with theories suggesting that even when attention is directed to the most salient of targets, attending to an area in visual space requires the integration of 'bottom-up' and 'top-down' processes.

Studies examining the effects of emotion-laden stimuli on processing in primary visual cortex, and later processes have found that early sensory processing of emotional stimuli affects subsequent cognitive resources. Single cell recordings in primates, as well as fMRI and EEG/ERP in humans, have also demonstrated that images implying threat, such as negative faces, result in modulations in attention, sometimes referred to as 'weapon focus' (Christianson, 1992; Katsuki & Constantinidis, 2012; Kensinger, Garoff-Eaton, & Schacter, 2007; Schmitz, De Rosa, & Anderson, 2009). While there are benefits to this mode of attention, the costs can prove significant. 'Weapon focus' is often discussed in eyewitness testimony research, as a vigilant attentional mode optimized to detect threat. However, other less critical aspects of the experience, such as colors in the surrounding environment, are not attended to as carefully, thus resulting in limited encoding.

Under conditions which elicit this type of attention, increased engagement of prefrontal cortex (PFC) and parietal regions is observed, believed to play an active role in the observed suppression of areas related to salience driven attention, such as V1 (Zhang, Japee, Safiullah, Mlynaryk, & Ungerleider, 2016). For example, negative and positively valenced faces differentially modulate activity in V1, and result in different patterns of functional connectivity between the dorsolateral prefrontal cortex (dlPFC; typically engaged in 'top-down' processing) and V1. Negative faces narrow attention, increase dlPFC activity, resulting in greater inhibitory control and suppression of V1. The result is a narrower, but more focused field of view. While this facilitates identification of threat, there is limited visual encoding and perception of stimuli in the periphery due to suppression.

These perceptual modulations have been found even when attending to emotional stimuli is unnecessary for task completion. Evidence from steady state visual evoked potentials (ssVEP), thought to originate in the mentioned early visual cortical regions (V1-V4), has demonstrated that a fearful cue facilitates identification of threat (Wieser & Keil, 2014). When a scene containing threat is preceded by a fearful face expression, ssVEP's to the threat scene increase, compared to other scenes (Wieser & Keil, 2014). Phelps, Ling and Carrasco (2006) also demonstrated that fearful expressions have the capability of altering early vision, specifically, contrast sensitivity. Compared to trials preceded by neutral faces, trials preceded by fearful faces lowered the contrast sensitivity threshold necessary to detect the orientation of the subsequent target (Phelps, Ling, & Carrasco, 2006). The observed advantage for trials preceded by a fearful face in early visual processing, was particularly pronounced for the condition in which the emotion cues appeared in a single peripheral location, as opposed to distributed in each of the four possible target locations (Phelps et al., 2006).

Studies using variations of visual search paradigms have also found that emotional stimuli affect deployment of attention. Specifically, emotion priming facilitates visual search for targets embedded in an array of distractors. These types of paradigms are ideal for examining how emotional salient stimuli affect subsequent goal-oriented attention when demands are varied; as the number or difficulty of competing stimuli increases, more attentional resources are required. In the classic visual search literature, task demands are varied by adding distractors to search arrays, resulting in increases in neural indices of attention, reaction times or search slopes (Weierich, Treat, & Hollingworth, 2008).

For example, Becker (2009) found that when individuals are primed with fearful expressions prior to completing a non-valenced visual search task (e.g. looking for a picture of a house amid other common stimuli such as planes and cars), search performance improved. The improvement relative to neutral face-primed performance becomes more pronounced as the number of distracting stimuli increases in search arrays (see also Olatunji, Ciesielski, Armstrong, & Zald, 2011 with consistent findings). Seeing a fearful face results in a flattening of search slopes, or faster target detection than would be expected in the absence of the fearful face prime. In an oddball visual detection task utilizing the same variations in number of distractor stimuli as (Becker, 2009), (Quinlan & Johnson, 2011) found that participants are fastest to detect threatening stimuli compared to non-threatening stimuli when trials are repeatedly preceded by a fearful cue compared to being repeatedly preceded by a neutral cue.

These results suggest that affective stimuli may enhance attention under particular conditions, however, additional research suggests that affective stimuli may interfere with or compete for attentional resources in anxious individuals. For example, in a follow-up study to Phelps et al., (Phelps et al., 2006), (Ferneyhough, Kim, Phelps, & Carrasco, 2013) again observed improved task performance in low trait anxious subjects, however, high trait anxious individuals displayed compromised contrast sensitivity on trials where a peripheral fearful face was followed by a display in which the target was in a different location from the original prime. The attentional cost of diverting attention away from the fearful cue in order detect the orientation of the target, proved costly for the visual perception of individuals who scored highest on trait anxiety (Ferneyhough et al., 2013). Similar findings have been observed on a variety of related attention tasks, using both behavioral and neural proxies of attention. These related findings in anxious/at-risk children, adolescents, and adults will be further discussed in the next section.

## *2.2 Anxiety-related effects of emotion-laden stimuli on attention*

Differences in vigilance have been suggested as contributing to patterns of anxiety. While negative face primes typically facilitate attentional orientating in healthy individuals, a number of studies have reported the opposite effects for high anxious children and adults (Bar-Haim et al., 2007; Becker, 2009; Ferneyhough et al., 2013; Olatunji, Ciesielski, Armstrong, & Zald, 2011a; Olatunji, Ciesielski, Armstrong, Zhao, & Zald, 2011b). Findings suggest that in at risk and anxious individuals, negative emotion primes affect attention resource allocation (Bar-Haim et al., 2007; Helfinstein, White, Bar-Haim, & Fox, 2008b), utilizing finite resources and thus degrading the subject's ability for subsequent attentional orienting. While it is possible that priming with negative emotion stimuli may create more general processing interference in anxious individuals, numerous findings highlight the particularly profound impact of emotion-laden stimuli on attention. This section will review several significant studies examining the effects of emotional stimuli on behavioral and neural processes in populations of at-risk and anxious children, adolescents, and adults.

Early in development, attentional biases may differentiate psychopathology outcomes for individuals with high-risk temperamental traits, such as behavioral inhibition (Fox et al., 2007; Rothbart & Posner, 2015). Behavioral inhibition is a particularly well-established risk factor for anxiety in adolescence as well as early adulthood (Fox et al., 2007; Fox, Henderson, Pérez-Edgar, & White, 2008b; Pérez-Edgar & Fox, 2005; Perez-Edgar et al., 2010; White et al., 2016). Early attention orienting biases and control in behaviorally inhibited individuals relate maladaptive early social interactions, emotion discrimination, and interactions with other aspects of the environment (Fox et al., 2007; Perez-Edgar et al., 2010; Perez-Edgar et al., 2011; White, McDermott, Degnan, Henderson, & Fox, 2011). Longitudinal studies examining behaviorally inhibited individuals have also found that those with these persistent attentional biases towards threat are at greatest risk for future anxiety disorders (Bar-Haim et al., 2007; Fox et al., 2007; Fox et al., 2005; Kagan, Reznick, & Snidman, 1987; McDermott et al., 2009; Pérez-Edgar & Fox, 2005; Perez-Edgar et al., 2010; Schwartz, Wright, Shin, Kagan, & Rauch, 2003; White et al., 2016).

Because these early appearing attentional biases represent a significant risk for the development of anxiety disorders, these biases have also been extensively examined in populations of adults with anxious symptoms and traits, as well as clinically anxious children, adolescents, and adults. To date, the standard "dot-probe task" has been widely used in both adults and children, to examine attention orienting after presentation of threatening stimuli, to inform risk, diagnosis, and treatment of anxiety disorders (Bar-Haim et al., 2007; MacLeod, Mathews, & Tata, 1986). In addition to simple behavioral assays, researchers have extensively examined performance on this task using electroencephalography, magnetoencephalography, functional magnetic resonance imaging, and eye tracking techniques. In the dot-probe task, participants are instructed to press a button indicating the location of a target, which appears in a location previously occupied by one of two faces (MacLeod et al., 1986; Mathews, Mackintosh, & Fulcher, 1997; Mathews & MacLeod, 1985; Mogg, Mathews, & Eysenck, 1992). One of these faces typically expresses a neutral emotion and the other, a negative emotion, such as anger. Studies using the dot-probe paradigm have noted the presence of an attention bias to threat in individuals with both clinical and high levels of anxiety (Bar-Haim et al., 2007). Specifically, increased anxiety is associated with an enhanced bias or vigilance to detect targets that appear in the same location as threatening faces (angry faces) or words compared to non-threatening faces (happy or neutral) compared to non-anxious participants (Bar-Haim et al., 2007; Pine, 2007; Shechner et al., 2012).

These emotion priming effects appear to differentially impact subsequent attention processes as a function of anxiety symptoms in sub-clinical samples, in addition to clinically anxious individuals. Using the dot-probe task, (Helfinstein et al., 2008b) studied adults selected for high and low self-reported social anxiety symptoms, priming them with symptom-relevant (e.g. shy, embarrassed) or neutral words, before each trial on the dot probe task. They found that when socially anxious subjects were primed with symptom-relevant words, they did not display a bias toward threat; however, they displayed a threat bias after being priming with neutral words. Conversely, when subjects with low reported social anxiety symptoms were primed with affective words, they showed an attention bias to threat that was not present when primed with neutral words. Emotional context and high anxiety symptoms, thus, appear to influence the way threat is detected and responded to, even in sub-clinical populations.

There is also evidence to suggest that stressful circumstances alter anxious individuals' pattern of attention to threat. (Bar-Haim et al., 2010 Frenkel, Muller, and colleagues) for example, found that anxious individuals under acute threat displayed attentional avoidance as measured with the dot-probe task, rather than a bias towards threat. In addition, (Shechner et al., 2012) reported plasticity of attentional bias as a function of context. Individuals who previously received shock in one context displayed avoidance using the dot probe compared to others who had not previously received the shock. When children exposed to maltreatment were administered the dot-probe task, emotional stimuli relevant to the experience abuse (e.g. mothers face) negatively impacted attentional orienting (Shackman, Shackman, & Pollak, 2007). Moreover, in a study examining performance on an emotion priming visual search paradigm in veterans high in PTSD symptoms, Olatunji, et al. (Olatunji, Armstrong, Bilsky, & Zhao, 2015) found the high PTSD group was significantly slower to detect the target during moderately difficult visual search, when primed with an angry prime, as compared to the control group. Thus, threat-related cues appear to affect experience-related anxiety symptoms, with the capability to have costly effects on allocating attention.

Behavioral paradigms have demonstrated that attentional biases to negative task-irrelevant stimuli hinder performance when individuals are required to shift attention away from the threatening stimuli (Bar-Haim et al., 2007). Within the context of responsivity to threat, it is likely that anxious individuals require more 'top-down' attentional resources to orient in a task appropriate manner. Indeed neuroimaging dot-probe studies indicate greater neural recruitment of attentional resources when required to orient away from threatening stimuli (Hardee et al., 2013; Roy et al., 2008; Shechner et al., 2012; Telzer et al., 2008).

Evidence from neuroimaging studies compliments the behavioral findings of the dot-probe (Heeren, Maurage, & Philippot, 2015; Telzer et al., 2008; White et al., 2011). These studies among others have demonstrated that anxiety and age-related emotion processing differences may stem from the quality of connectivity between rapid 'bottom-up' processing, and later maturing 'top-down' executive attentional control regions (Pine & Fox, 2015). The recruitment of the late developing prefrontal cortex makes significant contributions to threat appraisal, and subsequent behavioral and attentional orienting responses (Pessoa & Adolphs, 2010; Shechner et al., 2012).

The amygdala has additionally been widely studied in anxiety and fear research, as it appears to be rapidly engaged in with other regions implicated in valence/threat detection, and fear learning. Moreover, amygdala activity and connectivity with regions such as the dlPFC, on tasks like the dot-probe, appears to vary as a function of anxiety (Shackman & Fox, 2016). The amygdala has connections with emotion processing regions, 'top-down' areas such as the prefrontal cortex, as well as to visual and attentional processing streams— due to its' extensive cortical connections, it is thought that the amygdala plays a critical role in relaying and modulating emotion-related attention processing (Hamm, Richter, & Pane-Farre, 2014; Pessoa & Adolphs, 2010).

It is important to consider the functional connectivity of regions implicated in aberrant attention biases. Functional connectivity reflects the degree to which regions in the brain have synchronous activities. Functional connectivity of regions varies as a function of age, and as a function of psychopathology. Specifically, the ventrolateral prefrontal cortex (vlPFC) appears to regulate commonly observed amygdala reactivity to threatening, ambiguous, and uncertain stimuli and events (Ferri, Bress, Eaton, & Proudfit, 2014; Forbes, Phillips, Silk, Ryan, & Dahl, 2011; Hare et al., 2008; Monk et al., 2003; Whalen, 1998; Wieser & Keil, 2014). In contrast to vlPFC regulation of amygdala reactivity in adults, vlPFC activity in children during threat appraisal is concordant with amygdala reactivity. In other words, while the PFC appears to suppress and regulate amygdala responses to emotional stimuli in adults, PFC activity simply mirrors amygdala activity in pre-adolescent children (Ferri et al., 2014; Forbes et al., 2011; Monk et al., 2003; Wieser & Keil, 2014). The mirrored coupling of vlPFC-amygdala activity in children matures most notably throughout adolescence, becoming increasingly inversely coupled into young adulthood (Ferri et al., 2014; Forbes et al., 2011; Monk et al., 2003; Wieser & Keil, 2014).

This critical transition in PFC-amygdala functional connectivity appears to be strongly linked to a shift from a caregiver-buffered emotion regulation sensitive period during childhood, to the adolescent period, requiring autonomous emotion regulation skills (Gee et al., 2014; Gee et al., 2013). Consistent with this developmental change in functional connectivity, behavioral studies examining facial expression assessment display related trajectories (Tottenham, Phuong, Flannery, Gabard-Durnam, & Goff, 2013). Specifically, reactivity to fearful and neutral faces does not differ significantly in young children (Pagliaccio et al., 2013), however in adolescents, reactivity to ambiguous stimuli (neutral faces) is lower and significantly different than to unambiguous threat stimuli (e.g. fearful faces) (Forbes et al., 2011). Moreover, researchers have found that variability in PFC-amygdala circuitry across development and as a function of anxiety symptoms, relates to variability in attention orienting responses (Bar-Haim et al., 2007; Hardee et al., 2013; Pine, 2007; Shechner et al., 2012; Telzer et al., 2008).

As highlighted in this section, attentional biases to negative task-irrelevant stimuli hinders performance when individuals are required to shift attention away from the threatening stimuli (Bar-Haim et al., 2007). Notably, the neural change in PFC-amygdala coupling occurs within a developmental period with marked onset of clinical anxiety symptoms (Spence & Rapee, 2016). Thus, the neural underpinnings of attention biases across development have important implications for furthering our understanding of aberrant automatic threat appraisal of stimuli in at-risk and clinical pediatric populations. However, while neuroimaging dot-probe studies indicate greater neural recruitment of attentional resources when required to orient away from threatening stimuli, it is difficult to determine when the information processing stream may be modulated/affected by the presented affective stimuli (Hardee et al., 2013; Roy et al., 2008; Shechner et al., 2012; Telzer et al., 2008). An alternative to neuroimaging, Event Related Potentials (ERPs) lend themselves well to attention paradigms to examine precisely timed neural processes (Kappenman et al., 2015; Luck, 2014). In the next section, the benefits of the ERP methodology in the study of attention will be highlighted, as well as anxiety- and attention-related findings from paradigms such as the ‘dot-probe’ task.

### *2.3 Event-Related Potentials in the study of emotion, attention & anxiety*

Several studies have found anxiety- and age-related differences in both early sensory processing ERPs and later attention processing ERPs. ERPs record electrical scalp activity, and reflect synchronized postsynaptic action potentials of large bodies of cortical neurons, after a precisely timed event or stimulus with millisecond precision (Kappenman et al., 2015 2015; Luck, Woodman, & Vogel, 2000). Thus, widely studied and defined ERPs differentiate between timing of neural activity (latency) and intensity (amplitude) of early pre-attentive sensory processing phases, and later attentional processes recruiting more extensive resources. As such, ERPs lend themselves well to emotion processing and attention paradigms (e.g. visual search paradigms) to examine precisely timed attentional processes (Kappenman et al., 2015).

### 2.3a P1 Component

Emotion and anxiety related differences have been observed for the P1 ERP component, occurring ~100ms after stimulus onset (Blau et al., 2007; Mühlberger et al., 2009; Turetsky et al., 2007). The P1 appears to reflect automatic saliency driven attention, with larger amplitudes potentially suggesting the recruitment of more cortical resources (Luck et al., 2000; Wauthia & Rossignol, 2016). Studies utilizing dot-probe, Stroop, and emotional oddball tasks are mixed in terms of P1 findings related to anxiety and emotion processing; some studies such as Santesso et al. (2008) have found no P1 related differences, while many others have found a variety of differences as a function of emotional faces and anxiety symptoms (Harrewijn, Schmidt, Westenberg, Tang, & van der Molen, 2017).

In an unselected sample, (Luo, Feng, He, Wang, & Luo, 2010) found larger P1 amplitudes to fearful faces compared to happy and neutral faces during a Rapid Serial Visual Presentation (RSVP) task. Similarly, a study by Holmes, Nielsen, and Green (2008) found enhanced P1 related effects to fearful faces compared to neutral faces in low anxious individuals, and additionally found that the magnitude of this difference was even larger in the high trait anxious individuals. In another study using affective priming to examine P1 in high and low trait anxious participants, the fearful primes also resulted in the strongest priming and P1 effects in the high trait anxious group, and also related to behavioral results (Li, Zinbarg, Boehm, & Paller, 2008). Fajkowska, Eysenck, Zagórska, and Jaśkowski (2011) further separated out participants by anxiety and defensiveness levels, and found that on an Emotional Go/No-go task, high defensive high anxious individuals had greater P1 amplitudes to threatening faces, while low defensive high anxious individuals had greater P1 amplitudes to happy faces. In contrast, several other studies utilizing Stroop, and emotional oddball tasks have only found that high socially anxious individuals have elevated P1 (e.g. heightened vigilance) to all emotions compared to neutral, whereas non socially anxious individuals only demonstrate heighted P1 to angry faces (Peschard, Philippot, Joassin, & Rossignol, 2013; Rossignol et al., 2012).

A recent review of ERP findings on the dot-probe task highlighted several additional mixed P1 related findings (Torrence & Troup, 2017). For target/probe related P1 activity, several studies found fear specific modulation of the P1; P1 amplitude was heightened for trials for which the preceding fearful face had appeared in the congruent location to the probe, compared to trials when the fearful face and subsequent probe appeared in incongruent locations (Brosch, Pourtois, Sander, & Vuilleumier, 2011; Pourtois, Grandjean, Sander, & Vuilleumier, 2004). In another dot-probe task by Fox, Derakshan, and Shoker (2008a), there was similar enhancement of the P1 to the probes for angry trials congruent trials compared the angry incongruent trials, however, this was only for short delay trials when the probe appeared 150ms after the face (in long delay trials, there was a 600ms lag). While Fox et al. (2008a), found anxiety related differences in later occurring components, there were no reported anxiety related group differences the P1 amplitude. Similarly, Thai, Taber-Thomas, and Perez-Edgar (2016) found no relations with P1 amplitude, attention bias, and society anxiety measures in children. Another dot-probe task differed in anxiety related findings: in a dot-probe variant utilizing affective word primes prior to face presentation, Helfinstein, White, Bar-Haim, and Fox (2008a) found that high socially anxious individuals had higher P1 amplitudes to faces, indiscriminate of emotion.

In sample of 8-12 year old children tested on an emotional Go/No Go task, Hum, Manassis, and Lewis (2013a) found that high anxious children had elevated P1 amplitudes across all conditions compared to low anxious children. In a separate Cognitive Behavioral Therapy (CBT) intervention study again with anxious children, Hum, Manassis, and Lewis (2013b), found that pre-/post-treatment P1 levels on the emotional Go/No-Go task were related to which of the anxious children showed anxiety symptom improvement after the 8-week CBT intervention. Specifically, children that did not demonstrate improved anxiety symptoms had elevated P1 amplitudes to the presented facial stimuli, both at pre-and post- treatment compared to the children who improved, as well as a group of comparison children (Hum et al., 2013b). The authors suggested elevated P1 levels found in the high anxious children (Hum et al., 2013a), and non-improvers (Hum et al., 2013b) may reflect heightened arousal and utilization of finite resources that may be necessary for a child to benefit from treatments such as CBT.

Similar to the conclusions drawn by (Hum et al., 2013b), other researchers have interpreted elevated P1 amplitude findings to emotional faces in terms of heightened arousal, attention or a general vigilance to these types of stimuli (Harrewijn et al., 2017; Vuilleumier & Pourtois, 2007). As discussed in the previous section, amygdala activity similarly seems to increase both as a function of anxiety and viewing of threatening facial expressions (Jetha, Zheng, Schmidt, & Segalowitz, 2012; Harrewijn et al., 2017). As reviewed and discussed by Harrewijn et al. (2017), Rotshtein et al. (2010) indeed found that P1 amplitudes were significantly diminished in patients with amygdalar damage. Thus, researchers have suggested that the P1 ERP component may be an electro-cortical analogue of this type of amygdala activity (Jetha, Zheng, Schmidt, & Segalowitz, 2012; Harrewijn et al., 2017; Rotshtein et al., 2010). Another interesting parallel with the discussed fMRI literature is the possibility that P1 activity during face viewing may additionally reflect recruitment of higher order cortical regions (Mattavelli, Rosanova, Casali, Papagno, & Lauro, 2016; Harrewijn et al., 2017). Thus, interpreting amygdalar and P1-related findings as only reflecting arousal, or "bottom-up" processing may undermine key contributions of cortical regions such as the PFC, during face processing (Mattavelli, Rosanova, Casali, Papagno, & Lauro, 2016; Miskovic & Schmidt, 2012; Schulz, Mothes-Lasch, & Straube, 2013; Harrewijn et al., 2017).

Although there are variable anxiety and emotion related P1 findings thus far in the literature, there are several notable commanalities and implications. First, threat-related emotions across a number of studies elicited larger P1 amplitudes in both anxious and non anxious individuals, with several studies demonstrating the largest effects in anxious individuals. Second, P1 related elevations appear to be present in children as young as 8 years of age, and these elevations have signiciant implications for treatment success, as evidenced by Hum et al. (2013b). Thus, it will be critical to further detail the relations between P1 activity to emotional stimuli as well as understand how this commonly observed increased P1 or “vigilance” in anxious children and adults may affect other crucial processes and functioning (e.g. attention, cognitive control).

**2.3b N170 Component**

While the P1 is associated with emotion and arousal related processing, the N170 is more commonly associated with quick expertise processing of salient features, including facial structure and facial emotions (Blau et al., 2007; Luck, 2005). Like the P1 component, the N170 is recorded from temporal occipital sites, and has a latency of ~ 170ms. While the N170 is consistently found to reflect differences in “face vs. non-face”, relations with specific emotions as well as anxiety related findings are less concrete (Harrewijn et al., 2017; Hinojosa, Mercado, & Carretie, 2015). Several studies have specifically noted increased N170 sensitivity for each fear, angry, and happy compared to neutral (Batty & Taylor, 2003; Carlson & Reinke; Denefrio, Simmons, Jha, & Dennis-Tiwary, 2017 & Dennis-Tiwary, 2017; Hinojosa, Mercado, & Carretie, 2015 2015; Itier & Neath-Tavares, 2017; Leppänen, Kauppinen, Peltola, & Hietanen, 2007; Pourtois, Thut, de Peralta, Michel, & Vuilleumier, 2005; Stekelenburg & de Gelder, 2004; Sun, Ren, & He, 2017 2017).

In addition to the P1 findings in the study by Fajkowska et al. (2011), a larger N170 amplitude to threatening faces (collapsed across angry and fearful faces) was observed in the high anxious group, as well as hypervigilance as measured by behavioral reaction time. Similarly, O'Toole et al. (2013) noted that the N170 amplitude to a neutral face versus a angry face varies, with greater amplitude for a angry expression than for a neutral expression (O'Toole et al., 2013). O'Toole et al. (2013) also, documented that children exhibiting higher anxiety as well as larger N170 amplitudes to threatening faces had a greater risk for future anxiety. These findings suggest the N170 component is sensitive to individual differences in processing of threatening facial expressions, specifically due to varying levels of anxiety, and may differentiate those at risk for anxiety.

In comparison to the P1 component, there have been few studies that have found both anxiety and emotion related differences in the N170 component. Given the mixed findings in the literature, significant clarification is needed to understand the function of the N170—whether this component is purely categorical in nature, or whether like the P1 is related to arousal and vigilance in emotion discrimination processes.

**2.3c N2 and related subcomponents**

The “N2” component includes several distinct components that index various aspects of cognitive control and attention (Folstein & Van Petten, 2008). The N2pc component, with a ~200-300ms latency changes in both amplitude and latency as a function of visual search difficulty (Folstein & Van Petten, 2008; Luck & Hillyard, 1994). While the N2pc is generated in extra-striate visual cortex, its’ modulation to task difficulty is believed to reflect the recruitment of, and communication with, top-down posterior parietal attentional control centers.

Studies in adults have found that trait anxiety is related to both behavioral slowing and an enhanced N2pc (Fox et al., 2008a; Luck & Hillyard, 1994). During a valence neutral visual search task, Moran and Moser (2015) found that high anxious individuals showed increased N2pc amplitudes to more difficult trials, however this increase was related to slowed reaction time. Moran and Moser (2015) interpreted these findings as indicating that anxious individuals were using inefficient attentional filters—they had increased attention when there was irrelevant information, but this increased attention did not improve accuracy or reaction time—rather it resulted in behavioral slowing. Similarly, on a non valenced color visual search task, Tsai et al. (2017) found greater N2pc amplitudes as a function of difficulty in high anxious individuals, while low anxious individuals did not display the same differences in N2pc amplitudes. Similar to the conclusions of Moran and Moser (2015), Tsai et al. (2017) attributed these results to high anxious individuals adopting less advantageous attentional mechanisms to inhibit irrelevant items to detect the target, thus using more attentional resources.

The N2pc as well as the N2 has been additional observed during dot-probe tasks (Torrence & Troup, 2017). Several studies have found increased N2pc to the angry faces preceding the probes (Holmes, Bradley, Kragh Nielsen, & Mogg, 2009; Holmes, Mogg, de Fockert, Nielsen, & Bradley, 2014). Moreover, high trait anxious individuals elicit an enhanced N2pc component when viewing an angry face, but not to the subsequent probe. Fox et al. (2008a), found that anxious individuals had a significant enhancement of the N2pc time-locked to face onset toward angry faces, whereas the nonanxious group was not significant. Neither group had differences in N2pc for happy faces. Similar results were also found by Reutter, Hewig, Wieser, and Osinsky (2017). Higher anxiety scores were related to larger attention biases towards threat as measured by the N2pc (e.g. larger N2pc to threat) and the magnitude of the N2pc was larger for more severe anxiety symptoms.

In children, Thai et al. (2016) found that the N2 component related to social anxiety and attention bias. Unlike the N2pc findings from the adult-dot probe literature, here the N2 was associated with a smaller N2 relating to a larger attention bias towards threat, while larger N2 related to threat avoidance. Hum et al. (2013b)'s treatment study also found significant modulations in the N2 as a function of anxiety; anxious children who improved with the CBT intervention demonstrated significantly greater N2 activity on the post treatment Go/No-Go task. The findings from of Hum et al. (2013b) are in line with findings that cognitive treatments such as CBT require the utilization and recruitment of more cognitive regions, and thus changes in related ERP components would correspondingly change as a function of treatment (Maslowsky et al., 2010).

In sum, the N2pc and related N2 subcomponents during visual search have been well studied in adults, however, a very limited number of studies have examined this selective attention component in children and adolescents. In one of the few peer-reviewed studies examining the N2pc component during visual search in children, researchers found that both adults and children showed a significant and reliable N2pc as young as 9 years old (Couperus & Quirk, 2015). However, a gap remains in the understanding of how attention related N2 and N2pc components vary during attention processing after viewing affective stimuli.

The highlighted, ERP anxiety- and attention-related findings coincide with the hypothesis that emotion-laden stimuli interfere with attentional processing in high anxious adults, as well as at-risk children (Kappenman et al., 2015; Luck, 2014).

However, there remain significant gaps in assessing developmental changes and the time-course of threat-related attention processing.

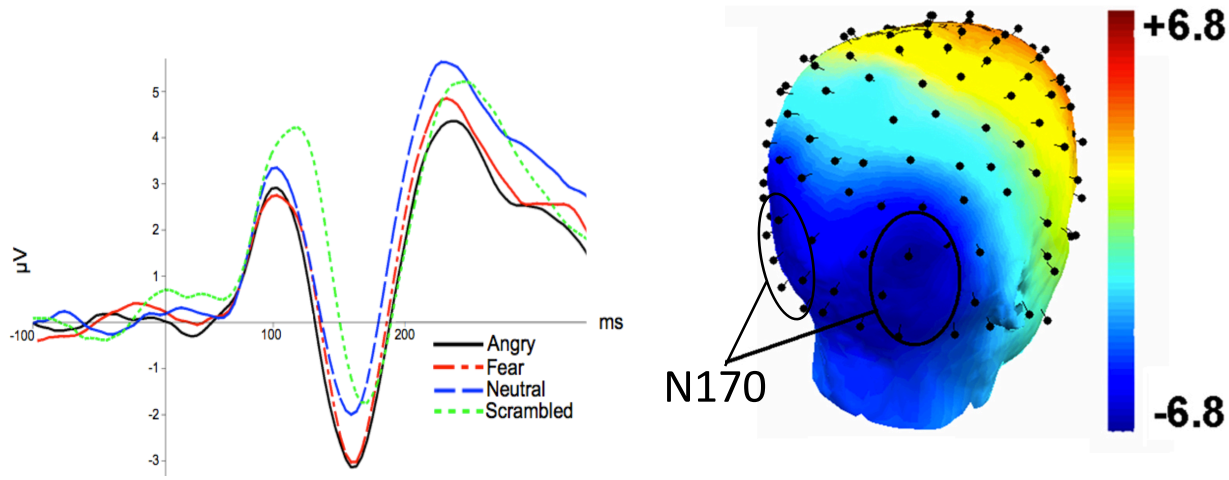



**Figure 1.** (a) Pilot visual search data showing the N170 in the right hemisphere electrodes 90 and 96 to face primes on (b) Scalp Topography of N170

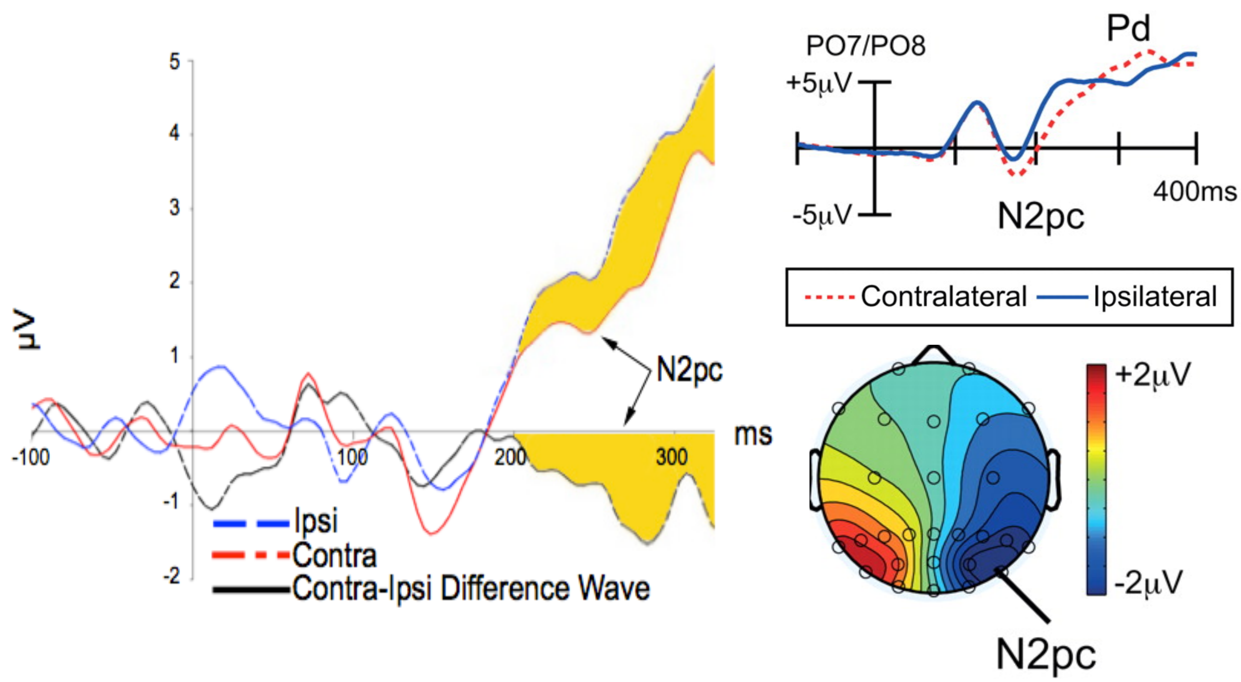



**Figure 2.** (a) Pilot data from visual search: N2pc Ipsi-, contralateral, and difference waves computed using right hemisphere electrodes 90 and 96, and left hemisphere electrodes 65 and 58. (b) N2pc from Luck et al., 2014 (c) Scalp topography of N2pc from Luck et al., 2014.

# Chapter 3: The present study

## *3.1 Overview*

A large number of studies have demonstrated reaction time and attentional performance differences on emotion cueing visual attention tasks as a function of sub-clinical levels of anxiety (Cisler & Koster, 2010; Ferneyhough et al., 2013; Fox, Russo, Bowles, & Dutton, 2001; Helfinstein et al., 2008b; MacLeod et al., 1986; Mogg, Bradley, Miles, & Dixon, 2004a; Olatunji et al., 2011a; Olatunji et al., 2011b). While the dot-probe task has captured patterns of attention bias in anxiety, further work is required to probe the interactions of sensory processing and subsequent effects on attentional processes (Weierich et al., 2008). Research assessing performance on dot-probe tasks does not assess whether threatening stimuli affect visual attention differently as a function of visual attention demands (e.g. complexity of visual stimuli). Thus, there remains a gap in the child and adolescent literature in addressing whether there are anxiety-related differences in the efficiency of attention as a function of the complexity of the visual environment (Pine et al., 2009). This chapter will first detail two recent studies using the proposed Emotion Priming Visual Search Task addressing these concerns, and the results in the context of the discussed extent literature. Next, critical remaining research gaps and proposed directions will be summarized. The remainder of the chapter will be devoted to an overview of the completed study, as well as the specific aims and hypotheses.

## *3.2 Findings from EPIVS Task in Adults (Haas et al., 2016)*

### 3.2a Overview

To add to the current literature examining priming effects on attention across the anxiety continuum, we examined the impact of priming on attention as a function of anxiety by designing a task in which emotional faces were used as primes for a visual search task. Of specific interest was examining how performance on this new task might vary as a function of social anxiety characteristics, thus expanding our understanding of attention in the context of threat. Several studies have demonstrated reaction time and attentional performance differences on emotion cueing visual attention tasks as a function of sub-clinical levels of anxiety (Cisler & Koster, 2010; Ferneyhough et al., 2013; Fox et al., 2001; Helfinstein et al., 2008b; MacLeod et al., 1986; Mogg et al., 2004a; Olatunji et al., 2011a; Olatunji et al., 2011b). In the initial examination of the paradigm used for the current study, we chose to examine social anxiety characteristics within a subclinical population, as this type of anxiety may be the most sensitive to priming effects of facial expressions. Our novel search task may allow greater insight into the specific attention components that influence emotional processing in anxious individuals. That is, while the dot-probe task has captured patterns of attention bias in anxiety, it is not clear how attention biases affect visual attention in the presence of distracting stimuli (Weierich et al., 2008).

### 3.2b Hypotheses

We predicted that similar to the findings reported in work by Olatunji et al. (Olatunji et al., 2011a), Olatunji et al. (Olatunji et al., 2015), Quinlan & Johnson

(Quinlan & Johnson, 2011), Phelps et al., (Phelps et al., 2006), Ferneyhough et al. (Ferneyhough et al., 2013) and Becker (Becker, 2009), that for participants in the normal or low range of reported in social anxiety symptoms, being primed with threat-relevant cues would facilitate visual search performance, (e.g. smaller slope, indicating reduced reaction time costs when more distractors are added). Based on the literature demonstrating deterioration in visual attention across a variety of attentional tasks and anxiety dimensions (Amir, Bower, Briks, & Freshman, 2003; Amir, Elias, Klumpp, & Przeworski, 2003; Ferneyhough et al., 2013; Gilboa-Schechtman, Foa, & Amir, 1999; Gilboa-Schechtman, Presburger, Marom, & Hermesh, 2005; Helfinstein et al., 2008b; Mogg et al., 2004a; Mogg, Philippot, & Bradley, 2004b; Ohman, Flykt, & Esteves, 2001; Olatunji et al., 2011a), we predicted that for participants scoring higher on social anxiety measures, threatening faces would degrade visual search performance (e.g. larger slope, indicating increased reaction time costs when more distractors are added). The major aim of this study was to further clarify whether previous findings of costly visual attentional control when primed with threatening images is due to initial alerting or attention capture, examine which emotional contexts affect attention similarly to reported threatening emotional contexts, as well as, whether these emotional contexts additionally affect later visual attentional processes, specifically attentional orienting during a visual search.

**3.2c Experimental Design**

We used the EPIVS task (See Methods for more detailed information) to examine the effects of emotion priming on visual search in participants characterized for different levels of social anxiety. We primed participants with five facial emotions (angry, fear, happy, neutral, and surprised) and one scrambled face immediately prior to visual search trials involving finding a slanted colored line amongst distractors, as reaction times and accuracy to target detection were recorded. Our two baseline comparison conditions were: neutral faces and scrambled faces. The sample tested consisted of healthy University of Maryland Undergraduates ($n$ = 70) who completed the EPIVS task, as well as completed questionnaires examining social anxiety symptomology (LSAS) generalized state and trait anxiety (STAI).

We confirmed that our 4 set size conditions (no distractors, 4 distractors, 14 distractors, 29 distractors) were sufficient to detect the effects of increasing demands selective measures of attention, as measured by reaction time (Treisman & Gelade, 1980). We also confirmed our 600 ms inter-trial interval (ITI) between the face prime and the visual search was enough time to extinguish any residual effects of disengagement (Becker, 2009), we examined whether there were reaction time during the no distractor condition, as a function of the emotion prime condition, social anxiety, state anxiety, or sex. The lack of reaction time differences confirmed that baseline reaction time did not differ as a function of emotion prime condition, Social or State Anxiety. Thus, to optimize power in our analyses, final analyses were conducted using a single slope value calculated per participant and per emotion priming condition (Weierich et al., 2008). Slopes were calculated as change in reaction time for target detection as a function of change in number of items in each of the set sizes. Each participant's reaction time data for each emotion priming condition expression was fitted to linear slopes, using reaction time to detect the target during Set Size 1 as the intercept.

### 3.2d Results

To test whether emotions differentially affected visual search efficiency (slope) as a function of social anxiety, we examined whether there were differences in visual search slope as a function of, emotion (surprised, angry, fear, happy, neutral, scrambled), Social Anxiety, State Anxiety and Sex. We examined emotion differences using each participants Scrambled Slope as the reference or "baseline" condition. As previously mentioned, we chose to use a scrambled face was used as our reference condition/ baseline comparison because a scrambled face stimuli contains all the components of a face, however they do not allow the participant to perceive an actual face or any type of emotion, making it a potentially better comparison condition or baseline than the commonly used neutral face. While there were no main effects for social anxiety score, or State Anxiety, there were trend main effects for sex, and emotion, as well as two significant interactions: Emotion by Social Anxiety and Emotion by State Anxiety. Follow-up analyses indicated that as State Anxiety increased, all emotion primes, facilitated more efficient visual search compared to being primed with a scrambled face. Relevant to our specific aims and hypothesis our analyses indicated that Social Anxiety, as measured by LSAS score, moderated the impact of fear, angry, and surprised, primes on visual search (see Figure 5). Moreover, visual search performance did not significantly differ after happy, or neutral primes, as a function of social anxiety score.

To examine the generalizability of whether the facial expressions functioned as threatening or non-threatening, we additionally examined grouping threatening emotions together, and non-threatening emotions together. Fearful, and Angry emotions functioned similarly in our analyses, and have been commonly used in emotion priming tasks; thus, we grouped those together to create an average "threat" prime condition. Because Happy and Neutral functioned similarly, we grouped those together to create an average "no threat" prime condition. As in our original analyses, the scrambled condition was the reference or "baseline" condition in the model. There was no main effect of LSAS score or State Anxiety, but a main effect of Emotion type. We again found two significant two-way interactions: Emotion by Social Anxiety, and Emotion by State Anxiety.

Like our initial analyses, as State Anxiety increased, all prime types facilitated more efficient visual search compared to being primed with a scrambled face. Conversely, as Social Anxiety increased, only threatening degraded visual search

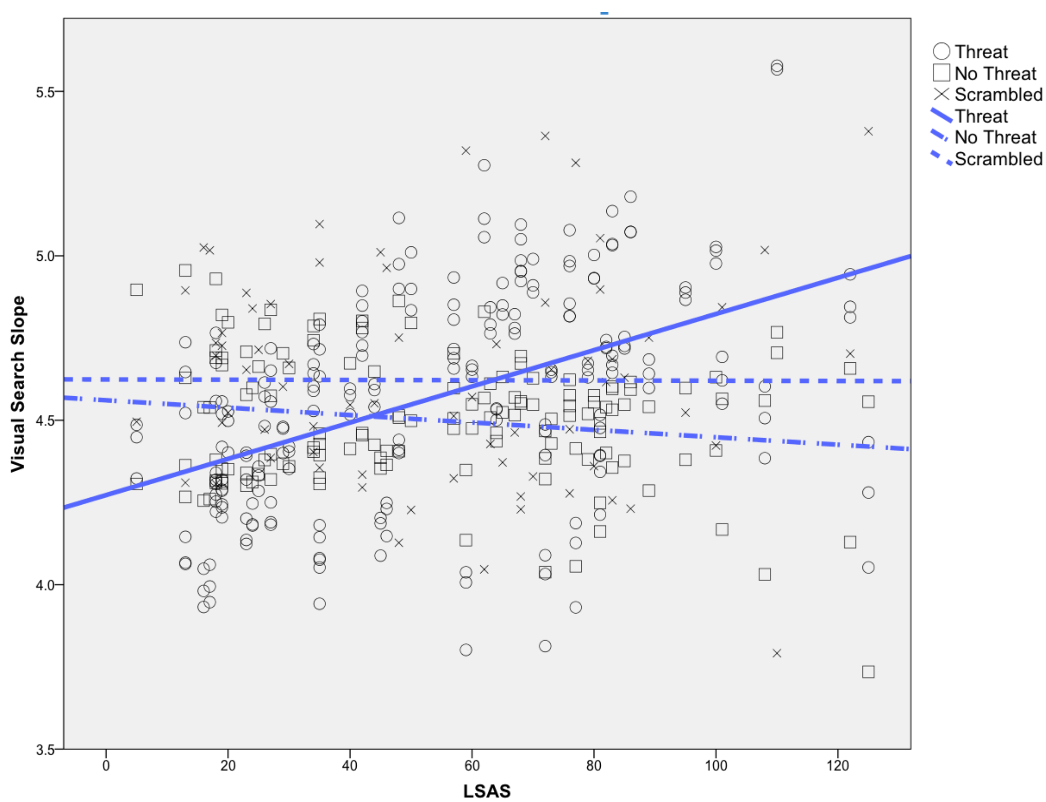



**Figure 3.** Study 1 interaction between LSAS score and face prime type (threat, no threat, or scrambled), predicting visual search slope.

efficiency compared to being primed with a scrambled face. Visual search efficiency did not differ as a function of LSAS score when primed with non-threatening primes as compared to being primed with a scrambled face.

### 3.2e Conclusions

This study builds upon previous literature examining attention in socially anxious individuals. Using a newly modified visual search task, results from this study indicated that for individuals who reported higher levels of social anxiety symptomology displayed visual search efficiency was *degraded* (e.g. as the number of distractors in the visual search increased, the cost to detect the target also increased) when primed with surprised, angry, or fearful faces, as compared to when primed with neutral or scrambled primes. The opposite was true for individuals who reported the lowest levels of social anxiety symptomology; visual search efficiency *improved* when primed with surprised, angry or fearful faces as compared to when primed with neutral or scrambled primes (e.g. there was an attenuation in the cost to detect the target as a function of increasing number of distractors in the visual search for these prime conditions) **(Fig. 3)**.

The effect of task irrelevant emotion primes extended to the processing of non-affective perceptual stimuli, indicating that emotion faces impacted broad, context-independent processing mechanisms. The current findings suggest that the effortful allocation of attention is affected by social anxiety symptom severity: individuals who report higher social anxiety severity are differentially impacted by exposure to threat and/or ambiguity, such that their ability to subsequently search their environment in the presence of distracting information is degraded. This significant deterioration in visual search performance did not occur when primed with Happy or Neutral emotions, and was independent of the individuals' state anxiety or arousal at the time of test. This difficulty in "recovering" from threat exposure may diminish anxious individuals' ability to flexibly respond to environmental demands. This may be evident even in affect-neutral tasks. Over time, the negative consequences that accompany inflexibility may further reinforce their initial response to threat/ambiguity, contributing to the broad behavior patterns typically observed in social anxiety: behavioral freezing, rigidity, and withdrawal.

## *3.3 Findings from EPIVS Task in Children (Haas et al., In prep)*

### 3.3a Overview

The Haas et al. (Haas et al., 2016) study in adults prompted further examination of developmental trajectories of threat-vigilance from middle childhood through late adolescence and consideration of how variations in sub clinical anxiety symptoms affects how these children perform on the present visual search. This cross-sectional study examined the effects of emotion priming on a visual search task in a group of children (6-8 years) and adolescents (13-15). We collected participant level of sub-clinical anxiety and examined whether level of anxiety affected visual search task performance.

### 3.3b Hypotheses

Consistent with Haas et al. (Haas et al., 2016) as well as the extent behavioral and neuroscience literature reports of enhanced negativity-biases and reactivity in high anxious children to ambiguous stimuli, we predicted that for children with higher social anxiety symptoms, priming with threatening (fearful and angry) or ambiguous faces (surprised and neutral), would degrade their ability to effectively search their environment in the presence of distracting information, independent of the effects of initial attention capture or disengagement. In adolescents, we predicted similar patterns to those found in adults; fearful, angry and surprised primes would degrade visual search in those with high social anxiety symptoms, and would have the opposite effect in those with low social anxiety symptoms.

It was predicted that effects of the neutral and/or surprised primes might impact visual search differently as a function of both age and anxiety levels. Specifically, for high socially anxious children with higher negative ratings of ambiguous emotions, the ambiguous face primes would function as a threat prime, degrading visual search. Because the literature suggests that high anxious adolescents recruit more top down attentional control resources during orientating tasks in the presence of threat (Britton et al., 2013; Hardee et al., 2013; Monk et al., 2003; Monk et al., 2006), we predicted that ambiguous face primes would also function as a threat primes, degrading visual search in high socially anxious adolescents who rated ambiguous emotions as 'more ambiguous'.

**3.3c Experimental Design**

As in Haas et al. (Haas et al., 2016), participants were primed with the same five facial emotions (angry, fear, happy, neutral, and surprised) and one scrambled face immediately prior to visual search trials. The participants in this study were also instructed to indicate when they had identified the target location, and reaction times and accuracy of target detection were recorded. The final sample in this study included

41 participants; twenty-two 6-8 year, and nineteen 13-15 year olds, from the D.C. metropolitan. In addition to completing the EPIVS task, parents and children completed the Screening for Child Anxiety Related Disorders (SCARED) (Muris, Dreessen, Bogels, Weckx, & van Melick, 2004) that assess symptoms related to Panic, General Anxiety, Separation Anxiety, Social Phobia, School Phobia, and Total Anxiety.

### 3.3d Results

To test whether emotions differentially affected visual search efficiency (slope) as a function of social anxiety, we examined whether there were differences in visual search slope as a function of, emotion (surprised, angry, fear, happy, neutral, scrambled), Social Anxiety, and Age Group (children and adolescents). As in Haas et al. (Haas et al., 2016), the Scrambled Slope was used as the reference or “baseline” condition. Results indicated a main effect of age group, emotion, as well as interactions with Emotion by Age, and Emotion by Social Anxiety. These interactions were superseded by an Age by Social Anxiety by Emotion interaction. Specifically, when compared to the scrambled prime condition, both neutral and fear primes degraded visual search efficiency for 6 to 8 year olds with higher social anxiety scores, whereas adolescents showed no differences as a function of social anxiety or emotion. No other emotions compared to scrambled were significantly different.

### 3.3e Conclusions

The results of this study found that for children low in social anxiety, fearful and neutral face primes facilitated visual search. For children, high in social anxiety the opposite pattern emerged: priming with fear and neutral faces degraded visual search.

Other facial expressions of emotion, particularly neutral faces, functioned in a similar manner as the fearful prime.

### *3.4 Research Questions and Hypotheses*

*Examine chronometry of attention related to individual differences in anxiety symptomology and of threat-vigilance in middle childhood.* To gain a deeper understanding of the neural signatures of visual attention and emotion processing during the task, electrophysiology measures including Event Related Potentials (ERPs) and electroencephalography (EEG), were examined.

Specifically, we used ERPs to examine the underlying neural processing related to: (1) sensory and affective processing of the face prime (e.g. P1, N170) and (2) executing goals of a task (e.g. N2, N2pc). By examining these ERPs, it is possible to assess (1) how stimulus valence affects sensory processes in the first few hundred milliseconds of viewing, (2) how attention-related processing are affected and relate to task performance, and (3), how (1) and (2) may independently or additively predict behavioral performance on the visual search task. In addition to assessing the magnitude and type of activity (using amplitude of ERP components), the temporal order of these components may aid in identifying and understanding how underlying circuitry is affected by these irrelevant emotion primes.

The goal is to clarify the emergence attentional biases in adolescents, which will inform methods for early identification, intervention and treatment of individuals at risk for anxiety. This project aimed to address both behavioral differences, and the neural chronometry of attentional orienting, as a function of normal variation in social anxiety symptomology in adolescents, 12-17 years of age. Results from this work will address critical gaps in the extent scientific literature on the neural correlates of attentional biases, threat appraisal, and anxiety symptomology, thereby making critical contributions to the understanding of the etiology, and treatment of anxiety disorders in children, adolescents and adults.

### 3.4a Aim 1

*The purpose of the first aim is to examine whether (1) neural responses to face primes differ as a function of emotion prime condition, task difficulty, age and anxiety and (2) whether these neural responses influence subsequent behavioral performance (reaction time) on the visual search task.*

We examined several sensory ERPs responses to the face-primes. These include: the P1 and N170. A well-established neural signature of rapid face detection, the N170, is characterized by a marked deflection in the ERP waveform, recorded from occipital temporal sites, and is associated with quick expertise processing of salient features, including facial structure and facial emotions (Blau et al., 2007). Still unanswered is how the N170 amplitude may influence attention, as defined in the two-step threat detection model, in anxious versus non-anxious children. N170 sensitivity to emotion is typically elicited when subjects view faces in passing or unconsciously thus avoiding habituation to the stimulus (Blau et al., 2007).

**Hypotheses:** We expect that anxiety symptoms will mediate the relations between emotion prime, sensory ERPs to the face prime, and reaction time slope. In addition, consistent with an extensive literature on the developmental changes in ERP waveforms, we expect to find differences in amplitude as a function of age in sensory ERPs, the P1 and N170.

**3.4b Aim 2**

*The purpose of the second aim is to examine whether (1) neural correlates of attention processing during visual search differ as a function of emotion prime condition, task difficulty, age and anxiety and (2) whether these neural responses influence subsequent behavioral performance (reaction time) on the visual search task.*

***Hypotheses***: Given prior research, we expect to replicate our previous findings in children, that and fear primes degrade visual search for females with high anxiety. We also expect that anxiety symptoms will mediate the relations between emotion prime, N2pc or N2 during harder visual search trials, and reaction time slope. In addition, consistent with an extensive literature on the developmental changes in ERP waveforms, greater variation in amplitude as a function of age.

**3.4c Aim 3**

*Examine the interaction of significant sensory (Aim 1), and significant attention processing during visual search (Aim 2), and relations with behavioral performance, prime condition, task difficulty, age and anxiety.*

***Hypotheses*:** We anticipate that greater sensory activity, as measured by the P1 and/or N170, to the emotional stimuli will result in greater N2pc or N2 amplitude overall. For the larger set sizes, this should result in increasingly larger N2pc or N2 amplitudes. In the threat prime conditions, we expect that high anxious adolescents will exhibit the greatest sensory activity, greater N2pc during visual search, and subsequent behavioral reaction time slowing. Due to the protracted development of the prefrontal cortex, we expect the largest interference in the youngest high anxious adolescents.

# Chapter 4: Methods

## *4.1 Participants*

Families in the UMD Infant and Child Database (from the DC, Maryland, and Virginia metro area), were invited to participate based on the following criteria: children were between 12 years 0 days, and 17 years old and 350 days, no history of any neurological, psychiatric, or learning disorders and child were full term or born 36 weeks or later. The recruited sample included 74 participants, 32 males and 42 females. Of these 74 participants, 1 participant did not finish the entire session, and 2 participants did not meet criteria for inclusion based on parental report of ADHD on the CBCL. Of the remaining 71 participants, 5 participants completed the behavioral only portion of the task; at the start of each of these study sessions it was determined that these participants had hairstyles (such as thick curly hair or braids) that would be incompatible with the application of the EEG net. For these 5 individuals, the researcher did not attempt to apply the EEG cap. Of the 66 participants who completed the EEG recording, data from 9 participants was unusable (Netstation crash $N = 5$, EEG data saved without event markers $N = 4$, power outage $N = 1$). Thus, 71 participants contributed behavioral data only and 57 participants contributed both EEG and behavioral data (See **Table 1**).

**Table 1** *Demographic characteristics of participants.*

| | Behavioral Data | Behavioral & EEG Data |
|---|---|---|
| *N* | 71 | 57 |
| No. of males (*%*) | 30 (42%) | 25 (44%) |
| Race/ethnicity (*%*) | 34 (48%) White | 30 (53%) White |
| | 13 (18%) Hispanic | 12 (21%) Hispanic |
| | 1 (1%) Hispanic/Black | 1 (2%) Hispanic/Black |
| | 11 (16%) Black/African American | 4 (7%) Black/African American |
| | 2 (3%) Black/ White | 2 (4%) Black/ White |
| | 4 (6%) Asian | 3 (5%) Asian |
| | 6 (8%) Asian/White | 5 (9%) Asian/White |
| Females: age in years (*SD*) | 14.34 (1.52) | 14.05 (1.36) |
| Males: age in years (*SD*) | 13.91 (1.68) | 13.89 (2.60) |
| Entire sample: age in years (*SD*) | 14.10 (1.59) | 13.97 (1.46) |

The range of 12-to 17-year testing ages was chosen to closely adhere to the ages of children previously tested to examine the N2pc (Couperus & Quirk, 2015) optimizing our ability to detect task related differences in the N170 and N2pc, related to reported social anxiety symptoms in children. Moreover, the 12-to17 year testing range includes the typical onset and diagnosis age, 13 years of age, of clinical social anxiety disorder (SAD) (Kessler et al., 2012).

## *4.2 Questionnaires*

Parents completed a form asking about family demographics (e.g., child date of birth, race/ethnicity, family income, parental education) and child health information. Child health information questionnaires included:

Child Behavior Checklist (Achenbach, 1991): Parents completed the CBCL, a parent-report measure of behavioral problems in childhood and adolescence. Using a three-point scale ranging from 0 (not true) to 7 (very true), parents rate statements about how often their child displays a series of externalizing and internalizing problem behaviors. Of relevance to the present study, parents were asked (in part VII), "Does your child have any illness or disability (either physical or mental)? If so, please describe". This portion of the CBCL was used as an additional confirmation of whether participants met eligibility criteria. Two participants were excluded from final analyses based on parental report of ADHD on this section. For the purposes of this study, other measures of the CBCL were not examined. However, a DSM-oriented T-score can be computed for the following domains: affective problems, anxiety problems, somatic problems, attention deficit/ hyperactivity problems, oppositional defiant problems, conduct problems. For each domain, T-scores are based on the raw scores and child's age.

Screen for Child Anxiety Disorders (Muris et al., 2004): This 41-item questionnaire assesses symptoms that parallel the DSM-IV classification of anxiety disorders: Panic, General Anxiety, Separation Anxiety, Social Phobia, School Phobia, and Total Anxiety. Adolescents completed a self-report version, and Parents completed a parent-report version of the SCARED. The SCARED has robust psychometric properties to assesses symptoms that parallel the DSM-IV classification of anxiety disorders children and adolescents (Muris et al., 2004). Items on this questionnaire included evaluating the frequency of scenarios such as "When I feel frightened, it is hard to breath", "I get scared if I sleep away from home", and "I worry about other people liking me". For each item, individuals select one of the three options for frequency: 0—not true or hardly ever true, 1—somewhat true or sometimes true, or 2—very true or often true. Self-report and Parent-report scores can each range from 0 to 84. For the present study, for each participant, the total self-report SCARED score was averaged with the total parent-report score. Average SCARED scores ranged from .5 to 59, and across the entire sample, the average score was 20.41 (*SD* = 11.89). For Females, average SCARED scores ranged from .5 to 59, and the average score was 23.18 (*SD* = 14.42). For males, average SCARED scores ranged from .4 to 35.5, and the average score was 17.04 (*SD* = 7.88). For the purposes of interpretability, the average of Parent & Child SCARED scores was z-scored in our sample such that the sample had a mean score of 0, with a standard deviation of 1.

Physical Development Scale (Petersen, Crockett, Richards, & Boxer, 1988): Pubertal Development Scale (Petersen et al.): Male and Females completed the PDS, a 6-item, standardized, validated measure of puberty. Parents also completed the parent-report version of the PDS. Questions reflect the main axes of puberty for females' and males', growth (item 1), adrenal (items 2, 3), and gonadal (item 5), are measured in this questionnaire (Dorn, Dahl, Woodward, & Biro, 2006; Quevedo, Benning, Gunnar, & Dahl, 2009). The PDS is a robust index of pubertal development; The PDS parallels clinical exams and relates to sex hormone concentrations (Brooks-Gunn, Warren, Rosso, & Gargiulo, 1987; Shirtcliff, Dahl, & Pollak, 2009 2009). Parent and child PDS reports were averaged together to create a composite score. In our sample, age and average puberty score are highly correlated, $r(70) = .743$, $p < .0001$, thus, only age was used in our analyses as a proxy variable for 'development' (See **Table 2** for correlations of questionnaires).

**Table 2** *Correlations Among Variables.*

| | Puberty: Child | Puberty: Parent | SCARED: Parent | SCARED: Child | Age | Puberty: Average |
|---|---|---|---|---|---|---|
| Puberty: Parent | .521** | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| SCARED: Parent | -0.129 | -0.117 | | | | |
| SCARED: Child | 0.122 | .252* | .419** | | | |
| Age | .694** | .611** | -0.076 | .203* | | |
| Puberty: Average | .885** | .858** | -0.113 | .227* | .743** | |
| SCARED: Average | 0.001 | 0.086 | .832** | .852** | 0.08 | 0.076 |

* $p < 0.05$; ** $p < 0.01$

### *4.3 Experimental Design*

Participants were fitted with an EEG cap (see below for EEG recording and processing), and completed the *Emotion Priming Visual Search Task* (*EPIVS-ERP*) (Haas et al., 2016). Participants were seated in front of a 22-inch computer monitor (1920x1080, 16:9 aspect ratio), and shown a fixation cross for 500 ms-1050ms (jittered), followed by a face from the NimStim Inventory for 300ms. The face was either depicting an angry, fearful, or happy, happy expression, or was a scrambled face (non-face comparison condition). The face was followed by a blank screen for 600 ms, followed by the visual search for 1500ms, or until the subject responded. Both the series of faces and the visual search tasks presented in a pseudo-randomized order by E-prime software, creating different combinations for each participant tested. Participants first completed a practice block to ensure they understood the instructions and became familiar with the presentation of the stimuli. While the search array was on the screen, participants responded by pressing the “1” button if the bar is slanted to the left, and the “4” button if the bar is slanted to the right.

The instructions for the 22 practice trials (practice trials did not include face primes) were described in the following manner, “For the next 15-20 minutes, you are going to be looking for a black slanted line in every visual search image. You are going to see several types of other bars in the pictures as well: black upright bars, white upright bars, and white slanted bars. Your job is to look for the black slanted bar, and using the button box, press “1” if it is slanted to the left like this (researcher demonstrated), and press the “4” button if it is slanted to the right, like this (researcher demonstrated). Some pictures have just the black slanted bar, some have the black slanted bar and a few other bars, and some pictures have the black slanted bar and many other bars. We want you to answer as quickly, but as accurately as possible when you find the black slanted bar in every image. There will be a plus sign in the middle of the screen to get you ready for each trial—we want you to look at that plus sign when there is no search on the screen, but as soon as the search comes up, feel free to move your eyes to find the black slanted bar—do what feels natural.” The researcher stayed in the room with the participant during the practice trials and monitored the subjects’ performance during the practice trials. After the practice trials, the researcher repeated the same instructions as the practice trials, and additional added, “In the actual task, you may notice some faces flashing—don’t worry about these. We want you to remember to keep your gaze centered until each visual search is on the screen, and focus on finding the black slanted line and responding as quickly as you can. Are you ready to begin?” Upon confirmation from the participant, the researcher exited the testing room to start the task, and participants’ task progress as well as EEG quality was monitored from an adjoining control room.

Face Stimuli. 80 pictures of facial expressions were selected from the NimStim Inventory (Tottenham et al., 2009). The selection of NimStim faces used for this paradigm was based on the following criterion: NimStim faces that had comparable luminance, no visible jewelry, comparable face size, comparable head tilt angle, minimal hair on face/facial hair, and included a variety of races. The pictures depicting the emotional faces were all presented at a size of 2.9 by 4.2 inches and centered on the computer screen so that the nose of the stimulus replaced the previously presented crosshair. All faces were grey scaled, and cropped to fit within a 2.9 by 4.2 inches oval, thus controlling for variations in color (Blau et al., 2007) (See Figure 4). The racial breakdown of the faces for males included: 2 black, 1 Hispanic, and 5 white faces. For female faces: 2 black, 1 Hispanic, 1 Asian and 4 white faces. The selected NimStim actor numbers were as follows: f03, f05, f06, f07, f09, f11, f13, f18, m23, m24, m26, m27, m34, m37, m41, m42. These included 3 pictures of each of the 8 female actors with angry, fearful, and happy expressions and 3 pictures of each of the 8 male actors expressing the same emotions. The scrambled face used, designed by Katoni (2012) was a picture of a female actor presenting a neutral face, divided into various small squares and changing the position of each square so that the face appeared scrambled. Moreover, these faces never overlapped with the locations of any of the visual search targets (targets are on average approximately 1.65 inches from the nearest edge of the face oval)—this was to ensure that no target location was inhibited or primed by prior visual stimuli.

Search Stimuli. In the conjunction visual search stimuli, participants were asked to locate a black slanted bar amongst a set of distractors. The distractors included white vertical bars, white slanted bars, and black vertical bars. Set size varied from 1 (the target black diagonal bar), 5, or 30 items. The position of the black diagonal bar varied between 6 different positions of a radius of 3.1 inches from the center of the screen during the visual search paradigm. The black diagonal bar could appear at 45°, 90°, 135°, 225°, 270°, and 315° along this radius. A total of 3 trials were in each the left and right visual fields. Two versions of each target location type visual search array were displayed for each of the 3 set sizes, for each of the 4 emotion conditions. One version had the black slanted bar slanted to the left, and the other version had the black slanted bar slanted to the right. Pictures of 12 female actors, and 12 male actors, randomly primed the visual search versions for each set size and emotion (4 of the 8 female actors and 4 of the 8 male actors randomly repeated to achieve priming of all 12 target trials. These repeating primes were randomized across participants). Thus, each emotion condition had 24 trials of each set size type, with a total of 72 trials per emotion. Collapsed across all emotions, there were 96 trials per set size, and a grand total of 288 trials. X, Y coordinates of every distractor item in each visual search were randomly assigned using a random number generator program (randomizer.org).

Participants completed a total of 288 visual search trials. E-prime software created a random order of trials per each participant so that no two participants saw the same presentation of trials. To prevent habituation to any face prime, the task cycled through each of the 4 priming conditions in a random order, before repeating any of the 4 priming conditions. Within each priming condition, and within each of the 3 set sizes, the 24 faces were randomly presented before each visual search to ensure the same face did not show up more than once per set size. Order of presentation of the visual search arrays was completely randomized within each priming condition. The length of the EPIVS-ERP task was approximately 25 minutes.

Reaction time data were recorded by E-prime software and measured the length of time from the beginning of the visual search presentation until the participant detected the target and responded. Reaction time data were summarized as mean RT data per emotion and set size for each participant. For each participant's trial data, trails with reaction times +/- two standard deviations from the participants' mean reaction time were not included in the calculation of each participant's mean RT. After removing missed trials and outliers, the percentage of usable trials was calculated for each participant. The average accuracy across the entire sample was 89.87%, $Stdev_{\text{Acc}}$ = 9%. Participants whose accuracy levels were below 71.71% (two standard deviations below the mean) were excluded from further analyses ($N$ = 4).

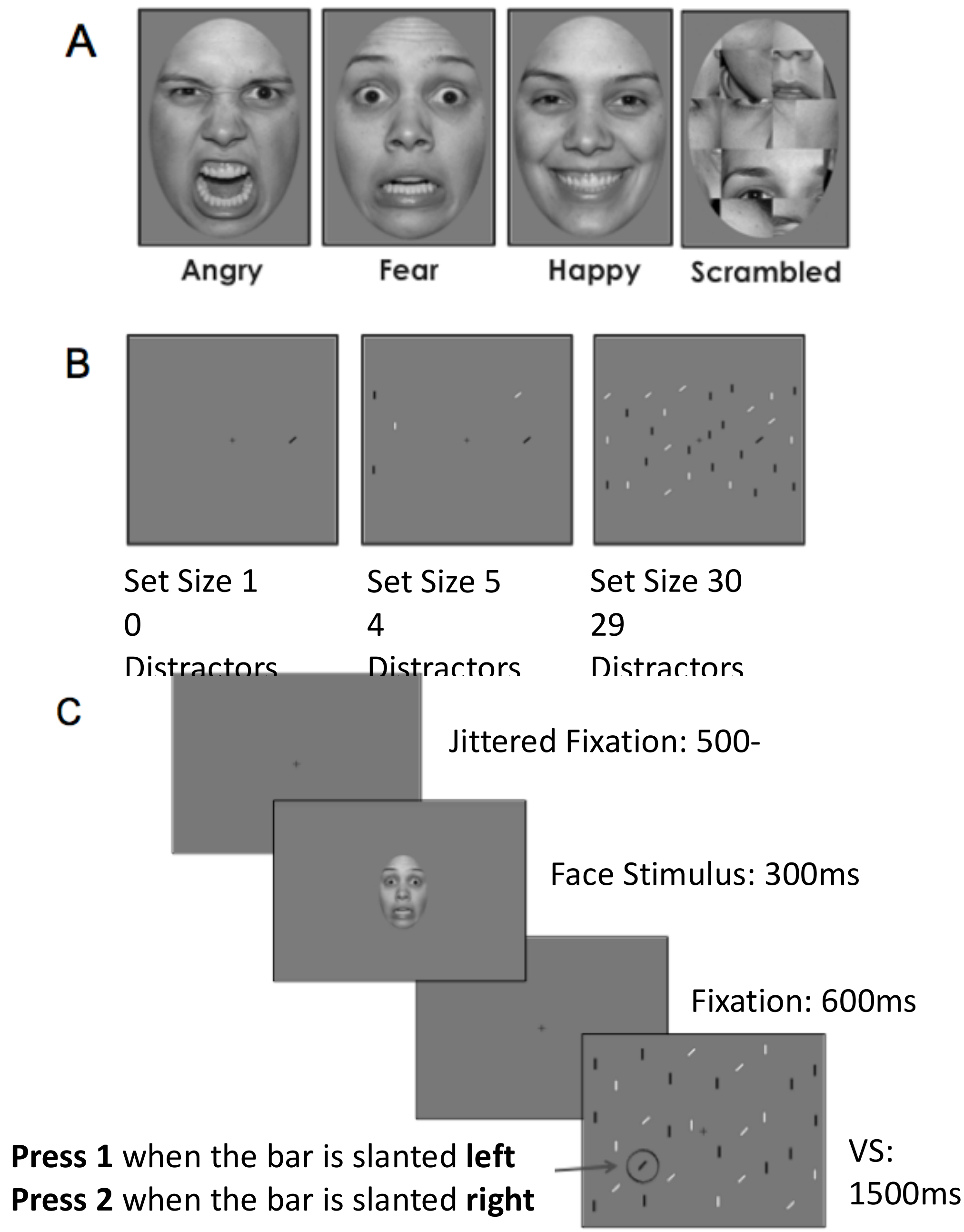



**Figure 4.** Visual search task design.

### 4.4 EEG Recording and Data Reduction

EEG was acquired using a 128-channel HydroCel Geodesic Sensor Net and EGI software (Tucker, 1993 OR); EEG analyses were performed using EEGLab (Delorme & Makeig, 2004), the ERPLab (Luck, 2014) plug-in for EEGLab (Delorme & Makeig, 2004), and custom MATLAB scripts (MathWorks, 2012) (Buzzell et al., 2017a Barker, Pine, & Fox, 2017; Buzzell et al., 2017b Bowman, Chronis-Tuscano, et al., 2017). Given that EEG data were acquired using a high input-impedance system, electrode impedances were maintained below 50 kΩ; data were sampled at 500 Hz, and referenced online to the vertex. Following acquisition, systematic marker offsets were measured and corrected for the EGI system (constant 16 ms offset) and E-Prime computer (constant 16 ms offset). Data were then high-pass filtered at .1 Hz using a Hamming windowed sinc FIR filter (16501 point high pass, .1-Hz transition bandwidth, -6dB/octave: .05-hz cut-off frequency). Data were also low-pass filtered at 49 Hz using a Hamming windowed sinc FIR filter (166 point low pass, 10-Hz transition bandwidth, -6dB/octave: 54-Hz cut-off frequency). FAST tools (Nolan, Whelan, & Reilly, 2010 2010) were used to identify and remove bad channels. No participants met the rejection criteria of less than 90% usable channels ($M_{\text{rejected}}$ = 3.4%, $StDev_{\text{rejected}}$ = 1.7%, $Max_{\text{rejected}}$ = 8.5%).

To identify and remove artifactual activity from the data, ICA decomposition was run on an identical data set with the addition of a 1-Hz high-pass filter. This 1-Hz filtered data set was first epoched into arbitrary 1000 ms epochs; prior to running ICA, noisy epochs were detected and removed if amplitude was +/- 1000 uV or if power within the 20-40 Hz band (after Fourier analysis) was greater than 30 dB If a channel led to more than 20% of the data being rejected, this channel was instead rejected. ICA was then run on the 1-Hz high-pass filtered dataset and the ICA weights were then copied back to the original (continuous) .1-Hz high-pass filtered dataset; all subsequent processing was performed on the .1-Hz high-pass filtered dataset. Artifactual ICA components were first detected in an automated procedure using the ADJUST toolbox (Mognon, Jovicich, Bruzzone, & Buiatti, 2011 & Buiatti, 2011) followed by manual inspection of the ICA components. While trials with ocular artifacts have typically been rejected for the examination of the N2pc component, recent work supports the use of ICA to instead correct these artifacts, finding that the underlying neural activity is left intact (Drisdelle, Aubin, & Jolicoeur, 2017 2017). Thus, all ICA components identified as reflecting artifacts (e.g. blinks, heart rate, saccades, bad electrodes) were subtracted from the data.

For ERP analyses, data were epoched to the stimulus markers of each of the emotion face primes and visual searches from -400 pre-stimuli to 1000 ms post stimulus. All stimulus-locked epochs were baseline corrected using the 100 ms period preceding stimulus onset. A final rejection of voltage differences of +/- 150 μV as well as voltage steps exceeding +/- 50μV between contiguous sampling points within the analysis time window (-100 to 350ms) were used to identify epochs containing channels with artifacts that might have been missed by preceding methods. Rejected channels within epochs were interpolated, using a spherical spline interpolation. Epochs were subsequently rejected if more than 10% of channels within the epoch were interpolated. Finally, channels originally rejected prior to ICA were interpolated using a spherical spline interpolation. Across the sample, participants had an average of

264.27 usable trials out of 288 ($StDev_{\text{trials}}$= 17.21, $Min_{\text{trials}}$ = 202). The minimum number of usable trials (out of 24 trials for each emotion/set size) was 12 trials. See **Table 3** for average usable trials across the across conditions condition. Data were referenced to the average of all electrodes for P1 and N170 analyses, and referenced to the mastoid electrodes (average of electrodes: 56, 57, 107, and 100) for N2 and N2pc analyses.

**Table 3** *Usable EEG trials across conditions*

| | Set Size 1 | Set Size 5 | Set Size 15 |
|---|---|---|---|
| Angry trials (*SD*) | 21.78 (2.42) | 22.06 (2.39) | 21.81, (2.42) |
| Fear trials (*SD*) | 21.81 (2.15) | 22.43 (1.94) | 21.67 (2.50) |
| Happy trials (*SD*) | 22.13 (2.55) | 22.19 (2.39) | 21.48 (2.49) |
| Scrambled trials (*SD*) | 22.06 (2.19) | 22.00 (2.21) | 21.56 (2.65) |

<u>P1 & N170 Processing.</u> To evaluate the P1 & N170 amplitudes at occipital-temporal sites, left hemisphere (average of electrodes 64, 58, 51, 59, & 65) and right hemisphere clusters (90, 95, 91, 97 & 96) were created (Blau et al., 2007) (**see Figure 5a)**. Mean amplitude of the P1 was calculated from individualized 20ms windows between 70-150ms during which the P1 was maximal for each participant. Mean amplitude of the N170 was calculated from individualized 20ms windows between 120-230ms during which the N170 negativity was maximal for each participant. The final computed N170 value for analysis controlled for the previous P1 peak by using a mean to mean calculation: the difference between the maximal P1 20ms-window mean amplitude and maximal (negative) N170 20ms-window mean amplitude.

N2[1] & N2pc Processing. To extract the N2 & N2pc components, continuous, filtered, ICA corrected data (see preprocessing steps above) were re-referenced to the mean of the mastoid electrodes 57, 56, 100, and 107 (Luck & Hillyard, 1994). Consistent with previous studies of the N2pc in children and adults, parietal occipital sites were analyzed: left hemisphere electrodes 58, 59, 60, 65, 66, 67, 69, 70 & 71 and right hemisphere electrodes 96, 91, 85, 90, 84, 77, 89, 83, & 76 (Luck & Hillyard 1994) (Couperus & Quirk, 2015) (**see Figure 5b)**. The N2pc was defined based on the mean amplitude of the contralateral-ipsilateral difference waveforms during the window 230-330 ms for each condition (Luck & Hillyard, 1994) (Couperus & Quirk, 2015).

Consistent with previous studies of the central N2 in children and adults, a cluster of

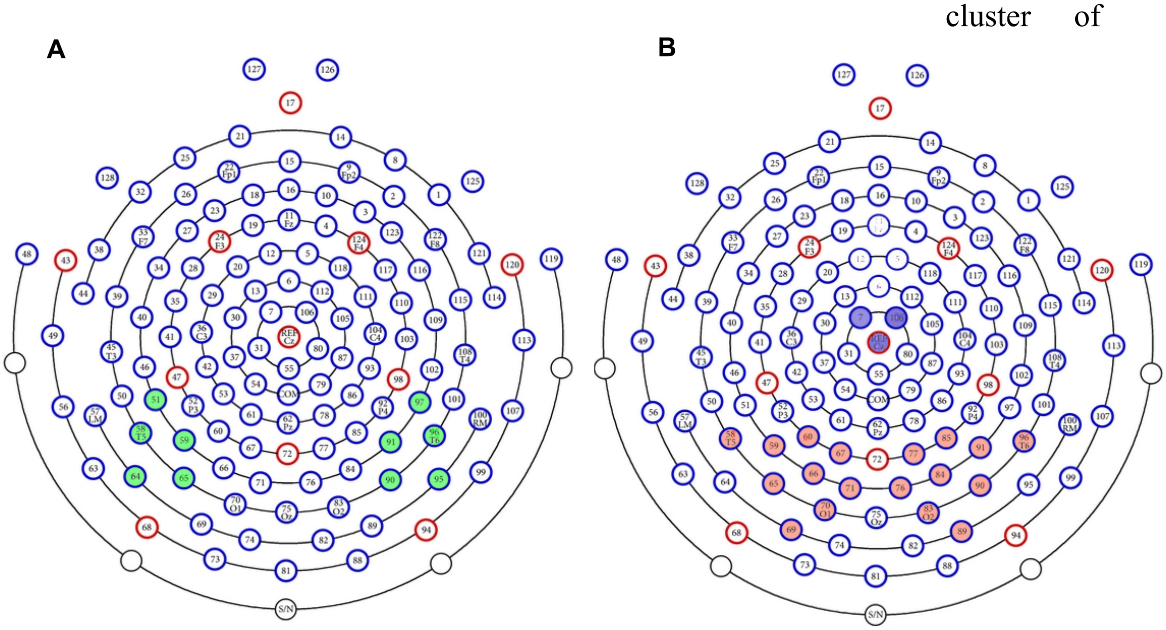



**Figure 5.** EGI 128-channel net electrode clusters. (a) P1 & N170 left hemisphere (average of electrodes 64, 58, 51, 59, & 65) and right hemisphere clusters (90, 95, 91, 97 & 96) (b) N2pc left hemisphere electrodes 58, 59, 60, 65, 66, 67, 69, 70 & 71 and right hemisphere electrodes 96, 91, 85, 90, 84, 77, 89, 83, & 76, N2 electrodes: Cz, 7, & 106.

[1] The results section and discussion focus on the N2pc only. The N2 was initially examined as the N2pc is commonly prone to artifactual data loss. In the present study, this was not the case, and thus analyzing both components was superfluous. In Appendix A, the N2 analyses are discussed.

central sites was analyzed: electrodes Cz, 7, & 106 (Ladouceur, Dahl, & Carter, 2007) (**see Figure 5b)**. When calculating the mean N2 amplitude, to reduce the possibility of including temporally close components such as the P3, the time window of 240-300ms was determined based on previous literature and inspection of the grand-average ERP waveforms, collapsed across conditions (Ladouceur et al., 2007).

### *4.5 Data Analysis Plan*

<u>Linear Mixed Effects Modeling.</u> Aims 1 and 2 utilized LMM as opposed to repeated measures analysis of variance (RM-ANOVA), one of the most commonly used statistical procedures to examine study designs with repeated measures (McCulloch, 2013). While there are numerous benefits to utilizing RM-ANOVA, many researchers and statisticians caution against the use of RM-ANOVA, and encourage the use of more flexible, sophisticated method, including Linear Mixed-Effects Models (LMM), utilizing Maximum Likelihood Estimation (MLE) (McCulloch, 2013).

In the context of longitudinal studies or repeated measures such as in the current study, attrition and missed data points are common, and require models that can flexibly estimate the data for both Missing at Random (MAR) and Not Missing at Random (NMAR) scenarios. Importantly, LMM are exceptional to characterize longitudinal or characterize both *rate* (parameter estimates), and *function* (e.g. linear, log, quadratic) of change. In the FLM framework, model specifications can be adjusted outside the linear framework, and be applied to datasets that fit for example, a quadratic trend.

Thus, data analysis took advantage of Linear Mixed Effects Model (LMM) (also referred to hierarchical linear modeling) to model each of the hypotheses, as described below. LMM is well suited to examine covariates (such as age and puberty), as well as examine individual differences, as it estimates inter-individual and intra-individual patterns for repeated measures (e.g. emotion primes). Power estimates for LMM are strong, as individuals with missing data are not removed as with traditional analyses of variance, rather, contribute to the model estimates with a reduced covariance matrix. This was particularly useful in the present study as it is common to have EEG/ERP data loss, particularly in younger ages. Even if a subject does not have usable data for a condition (e.g. due to artifact rejection), data from the other conditions can contribute to the final model. Moreover, modeling data from the present study was useful as this modeling framework is appropriate testing fixed & random effects and covariates in a LMM for sample sizes greater than 30 (Kliegl, Wei, Dambacher, Yan, & Zhou, 2010). When considering variability in attrition rates across age groups, the LMM was an ideal model choice as it is robust for handling unbalanced designs, as well as non-normal distributions. Each model was examined using both Maximum Likelihood and Restricted Estimation Maximum Likelihood. Only in instances where the REML model was nearly significant, and the same trend level terms were significant for the ML model was the ML model interpreted.

*Aim 1: The purpose of the first aim is to examine whether (1) neural responses to face primes differ as a function of emotion prime condition, task difficulty, age and anxiety and (2) whether these neural responses influence subsequent behavioral performance (reaction time) on the visual search task.*

<u>Examining variability in P1 Amplitude.</u> To test whether emotions differentially affected P1 amplitude as a function of anxiety, a LMM was computed using average

P1 Amplitude as the dependent measure, with the predictors: average of parent and child report of SCARED, and Emotion (angry, fear, happy, scrambled) and covariates: Age and sex, all as fixed effects. The Scrambled condition was the reference or "comparison" condition in the model (as well as all proceeding models). In the LMM, a reference for each categorical variable is utilized to examine differences between the reference (one level of the categorical variable) and other levels of the categorical variable. In this model, the selected reference condition was the scrambled condition, so that our estimated fixed-effects were comparing each emotion condition to the scrambled condition. As mentioned, a scrambled face was used as our reference condition/ baseline comparison because a scrambled face stimuli contains all the components of a face, however they do not allow the participant to however they do not allow the participant to perceive an actual face or any type of emotion, making it a potentially better comparison condition or baseline than the commonly used neutral face. Thus, our model tested specifically tested whether any of the other 3 emotions differed from the scrambled condition.

Examining the relations of P1 Amplitude variability and behavioral performance. To test whether emotions differentially affected visual search efficiency (slope) as a function of anxiety and sensory processing components, a LMM was be computed using visual search slope as the dependent measure, with the predictors: average of parent and child report of SCARED, P1 amplitude, and emotion (angry, fear, happy, scrambled) and covariates: Age and sex, all as fixed effects. Again here, of the four emotions repeated in our Emotions factor, we designated the scrambled condition as the reference or comparison condition in the model. Thus, our model tested specifically tested whether any of the other 3 emotions differed from the scrambled condition.

<u>Examining variability in N170 Amplitude.</u> To test whether emotions differentially affected N170 amplitude as a function of anxiety, a LMM was computed using N170 amplitude (right hemisphere) as the dependent measure, with the predictors: average of parent and child report of SCARED, and Emotion (angry, fear, happy, scrambled) and covariates: Age and sex, all as fixed effects. Again here, of the four emotions repeated in our Emotions factor, we designated the scrambled condition as the reference or comparison condition in the model. Thus, our model tested specifically tested whether any of the other 3 emotions differed from the scrambled condition.

<u>Examining the relations of N170 Amplitude variability and behavioral performance</u>. To test whether emotions differentially affected visual search efficiency (slope) as a function of anxiety and sensory processing components, a LMM was computed using visual search slope as the dependent measure, with the predictors: average of parent and child report of SCARED, N170 amplitude (right hemisphere), and Emotion (angry, fear, happy, scrambled) and covariates: Age and sex, all as fixed effects. Again here, of the four emotions repeated in our Emotions factor, we designated the scrambled condition as the reference or comparison condition in the model. Thus, our model tested specifically tested whether any of the other 3 emotions differed from the scrambled condition.

*Aim 2: The purpose of the second aim is to examine whether (1) neural correlates of attention processing during visual search differ as a function of emotion*

*prime condition, task difficulty, age and anxiety and (2) whether these neural responses influence subsequent behavioral performance (reaction time) on the visual search task.*

Examining variability in N2 Amplitude as a function of set size (slope). To test whether emotions differentially affected N2 slope as a function of anxiety, a LMM was computed using N2 slope as the dependent measure, with the predictors: average of parent and child report of SCARED, and Emotion (angry, fear, happy, scrambled) and covariates: Age and sex, all as fixed effects. Again here, of the four emotions repeated in our Emotions factor, we designated the scrambled condition as the reference or comparison condition in the model. Thus, our model tested specifically tested whether any of the other 3 emotions differed from the scrambled condition.

Examining the relations of N2 Slope variability and behavioral performance. To test whether emotions differentially affected visual search efficiency (slope) as a function of anxiety and attention processing components, a LMM was computed using visual search slope as the dependent measure, with the predictors: average of parent and child report of SCARED, N2 slope, and Emotion (angry, fear, happy, scrambled) and covariates: Age and sex, all as fixed effects. Again here, of the four emotions repeated in our Emotions factor, we designated the scrambled condition as the reference or comparison condition in the model. Thus, our model tested specifically tested whether any of the other 3 emotions differed from the scrambled condition.

Examining variability in N2pc Amplitude as a function of set size (slope). To test whether emotions differentially affected N2pc Slope as a function of anxiety, a LMM was computed using N2pc slope as the dependent measure, with the predictors: average of parent and child report of SCARED, and Emotion (angry, fear, happy, scrambled) and covariates: Age and sex, all as fixed effects. Again here, of the four emotions repeated in our Emotions factor, we designated the scrambled condition as the reference or comparison condition in the model. Thus, our model tested specifically tested whether any of the other 3 emotions differed from the scrambled condition.

Examining the relations of N2pc Slope variability and behavioral performance. To test whether emotions differentially affected visual search efficiency (slope) as a function of anxiety and attention processing components, a LMM was be computed using visual search slope as the dependent measure, with the predictors: average of parent and child report of SCARED, N2pc Slope, and Emotion (angry, fear, happy, scrambled) and covariates: Age and sex, all as fixed effects. Again here, of the four emotions repeated in our Emotions factor, we designated the scrambled condition as the reference or comparison condition in the model. Thus, our model tested specifically tested whether any of the other 3 emotions differed from the scrambled condition.

*Aim 3. Examine the interaction of significant sensory (Aim 1), and significant attention processing during visual search (Aim 2), and relations with behavioral performance, prime condition, task difficulty, age and anxiety.*

To examine interactions of Aims 1 & 2, Mplus (Muthén & Muthén, 2010) was used to create several path models. The overarching goal was to inform a comprehensive theoretical model of the findings from Aims 1 & 2. To examine how age, sex, and anxiety relate to the effects of the fear, angry, and happy primes on the P1, N170, N2 and N2pc ERPs, as well as predict reaction time, several additional data processing steps were applied. First, given the limited applications of path SEM models to repeated categorical predictors, differences scores (e.g. Scrambled – Angry) were calculated for each of the dependent variables: P1 amplitude, N170 amplitude, N2 Slope, N2pc Slope, and Reaction Time slope. Given the findings from Aims 1 & 2, the final discussed path models only include the P1 and N2pc variables, however a full model can be found in the appendix (See Appendix B). We added an anxiety group variable to more easily examine anxiety related effects; a median split was used to create two groups such that one group represented half of the participants with the highest anxiety scores, while the second represented the half of the participants with the lowest anxiety scores. These anxiety-specific groupings were used to aid in interpretation of resulting pathways using Mplus (Muthén & Muthén, 2010) by directly testing whether path estimates for each group significantly differed. Thus, each of the models included data from all 54 participants with usable EEG and RT data, compared model findings from each anxiety half of the sample ($n$ = 27 per group), and included the independent variables age (centered) and sex (coded as 0 or 1), and the following predictors in the specified order (all difference scores for each condition in relation to scrambled): P1, N2pc, with a final dependent variable of reaction time slope. For each model, insignificant terms and paths above $p$ = .2 were removed, and all indirect effects were examined.

# Chapter 5: Results

## *5.1 Aim 1*

*Aim 1: The purpose of the first aim is to examine whether (1) neural responses to face primes differ as a function of emotion prime condition, task difficulty, age and anxiety and (2) whether these neural responses influence subsequent behavioral performance (reaction time) on the visual search task.*

### 5.1a Examining variability in P1 Amplitude

The final model, with a AIC fit-value of 727.561, was fitted using the Factor Analytic: First Order covariance structure and Restricted Maximum Likelihood Estimation (REML), with both fixed effects and subject level random effects intercepts. This final model included all interaction possibilities of the fixed-effects variables: Age, Emotion, and Sex, with insignificant higher level interactions removed from the final model. Average SCARED score was removed from the final model as it did not produce any significant main effects or interaction effects, nor did it improve the model fit. The following the following fixed effects terms were significant (See Tables 4-5 for statistical results): Intercept, main effect of Emotion, main effect of Sex, and main effect of Age. These were superseded by two significant two-way interactions: Emotion x Sex, and Emotion X Age.

Estimates of fixed effects indicated that for the main effect of Emotion, P1 amplitudes to the angry, fear, and happy, primes were significantly smaller than to the scrambled prime. For the main effect of Sex, males had significantly larger P1 amplitudes across all conditions than females (See Figure 6 and Tables 4-5). The main effect of Age was driven by decreasing average P1 Amplitude differences between scrambled and all three emotions; while the younger children in the sample had larger P1 amplitudes to the Scrambled prime compared to the other primes, the reverse was true for the oldest children in the sample: P1 amplitudes to all other emotions were larger than P1 amplitude to the Scrambled prime (**See Figures 6a-e; Tables 4-5**).

The Emotion X Sex interaction, was driven by males having smaller P1 Amplitudes the angry, fear, and happy, primes compared to Scrambled prime, while females only had significantly smaller P1 Amplitudes the and happy primes compared to Scrambled prime. Moreover, for males only, P1 Amplitudes to the angry and fear primes were significantly larger than to the happy.

**Table 4** Type III Tests of Fixed Effects: P1 Amplitude

| Source | Num. df | Den. df | F | Sig. |
|---|---|---|---|---|
| Intercept | 1.000 | 51.000 | 107.643 | 0.000 |
| Emotion | 3.000 | 71.072 | 16.991 | 0.000 |
| Age | 1.000 | 51.000 | 6.184 | 0.016 |
| Sex | 1.000 | 51.000 | 16.409 | 0.000 |
| Emotion x Age | 3.000 | 71.072 | 3.630 | 0.017 |
| Emotion x Sex | 3.000 | 71.072 | 4.684 | 0.005 |

**Table 5** Estimates of Fixed Effects: P1 Amplitude

| Parameter | Est. | SE | df | t | *Sig.* | -95% CI | + 95% CI |
|---|---|---|---|---|---|---|---|
| Int./Contrast: Scrambled (Male) | 10.720 | 0.882 | 51.468 | 12.156 | 0.000 | 8.950 | 12.489 |
| Angry (Male) | -1.877 | 0.432 | 50.344 | -4.345 | 0.000 | -2.745 | -1.010 |
| Fear (Male) | -2.168 | 0.480 | 51.389 | -4.512 | 0.000 | -3.132 | -1.204 |
| Happy (Male) | -2.760 | 0.387 | 57.959 | -7.129 | 0.000 | -3.535 | -1.985 |
| Contrast: Scrambled (Female) | -3.483 | 0.708 | 51.468 | -4.921 | 0.000 | -4.903 | -2.062 |
| Angry (Female) | 0.556 | 0.347 | 50.344 | 1.603 | 0.115 | -0.140 | 1.252 |
| Fear (Female) | 0.972 | 0.386 | 51.389 | 2.522 | 0.015 | 0.198 | 1.746 |
| Happy (Female) | 1.099 | 0.311 | 57.959 | 3.536 | 0.001 | 0.477 | 1.721 |
| Contrast: Scrambled x Age | -0.820 | 0.242 | 51.468 | -3.392 | 0.001 | -1.306 | -0.335 |
| Angry x Age | 0.276 | 0.118 | 50.344 | 2.332 | 0.024 | 0.038 | 0.514 |
| Fear x Age | 0.285 | 0.132 | 51.389 | 2.160 | 0.035 | 0.020 | 0.549 |
| Happy x Age | 0.349 | 0.106 | 57.959 | 3.286 | 0.002 | 0.136 | 0.561 |

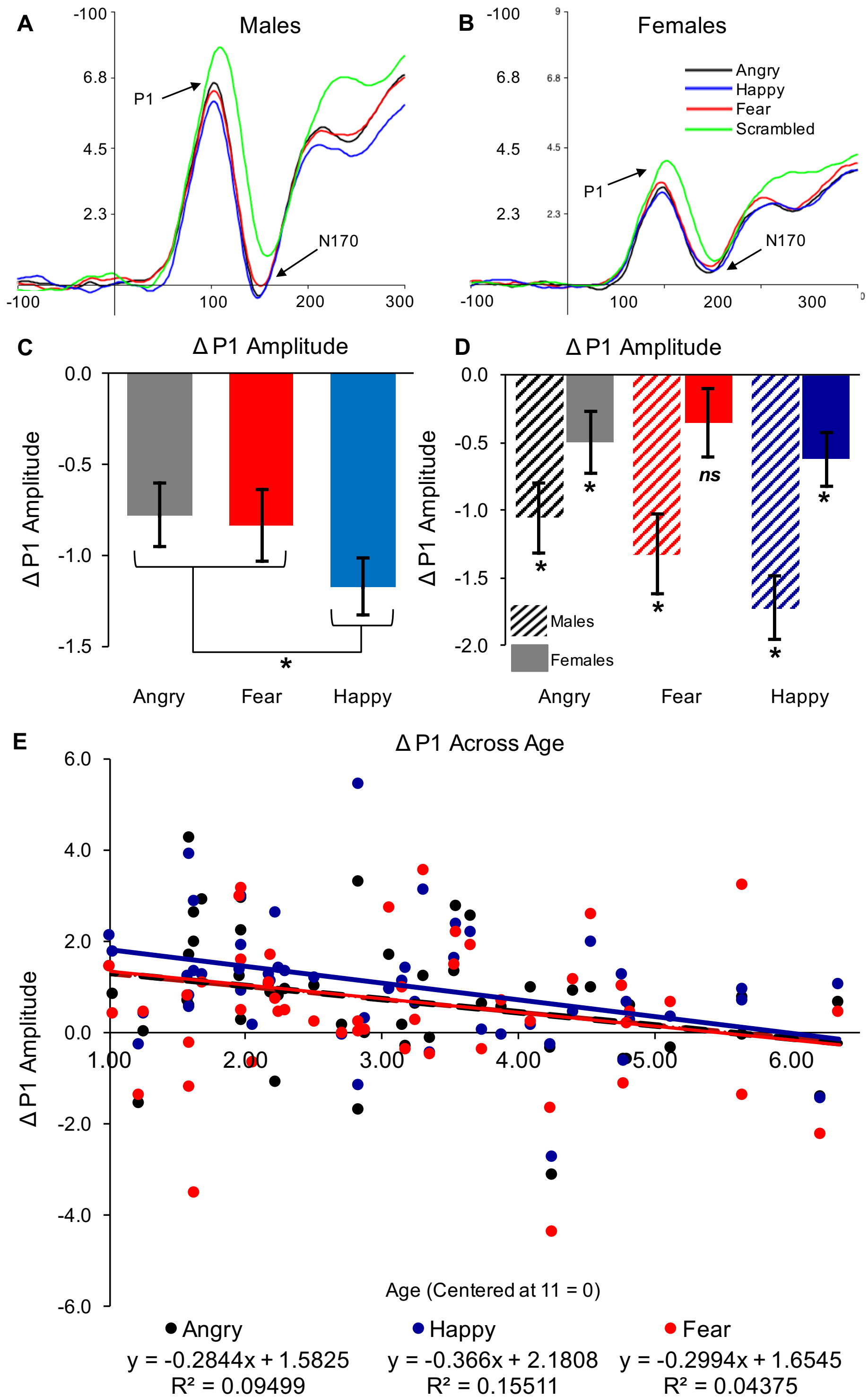



**Figure 6.** Relations between Average P1 Amplitude, Emotion, Sex & Age. (a) Mean P1 & N170 amplitudes: Males (*N* = 22) (b) Mean P1 & N170 amplitudes: Females (*N* = 32) (c) ΔP1 amplitude by Emotion (d) ΔP1 amplitude by Sex & Emotion (e) ΔP1 amplitude by Age & Emotion.

**5.1b Examining the relations of P1 Amplitude variability and behavior**

The final model, with a AIC fit-value of 2040.89, was fitted using the Factor Analytic: First Order covariance structure, and Restricted Maximum Likelihood Estimation (REML), with both fixed effects and subject level random effects intercepts. Insignificant terms were removed to reduce the model parameters. The following the following fixed effects terms were significant: Intercept, main effect of Emotion, Sex. The two-way interaction Emotion X Average P1 Amplitude as well as the three-way interaction Emotion X Average P1 Amplitude X Average SCARED Score were nearly significant ($p = .059$ and $p = .065$ respectively). Note: these terms were significant using Maximum Likelihood Estimate, therefor interpretations of these findings are discussed.

Estimates of fixed effects indicated that compared to the scrambled prime condition fear and significantly vary as a function of both average P1 Amplitude and Average SCARED score. To further probe this interaction, the sample was divided by a median split of Average SCARED Scores, and the relations of ΔP1 Amplitude (Scrambled-Fear) and ΔVisual Search Slope (Scrambled-Fear) were examined for halves of the sample (**See Figure 7**). Larger P1 to the scrambled compared to the fear primes led to costlier visual search slope following fear compared to the scrambled primes. While both halves of the sample displayed the same pattern, anxiety mediated the relation between ΔP1 Amplitude and ΔVisual Search Slope such that the magnitude of visual search slope change (e.g. costlier) increased as a function of higher anxiety scores.

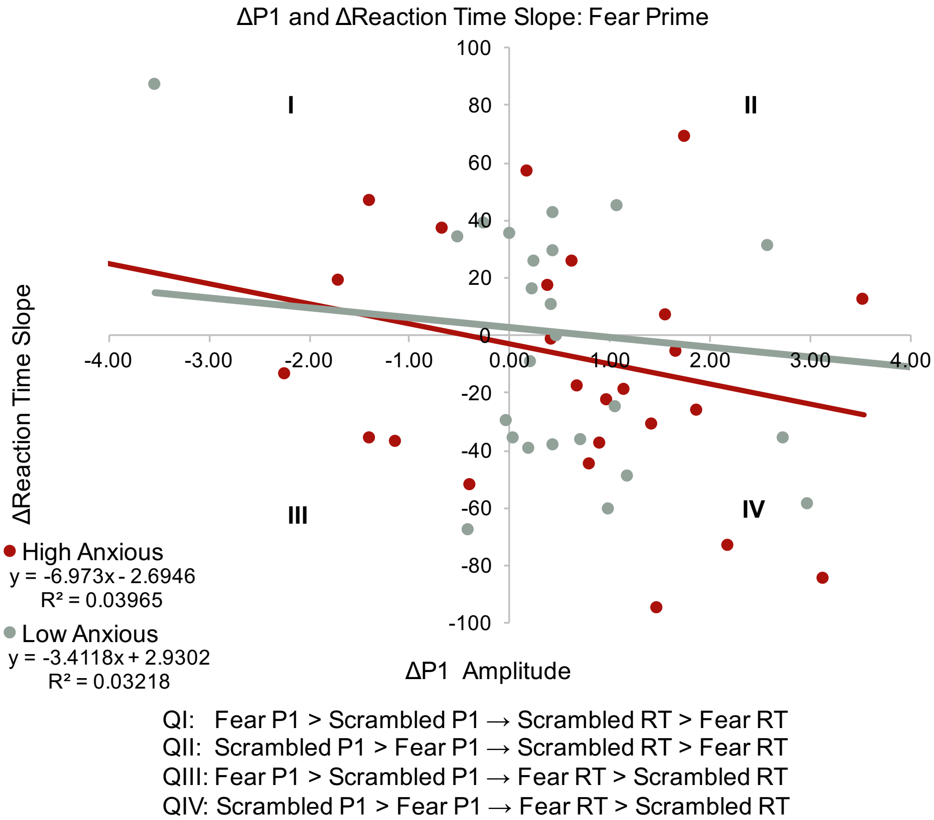



**Figure 7.** Relations between Average ΔP1 Amplitude and ΔVisual Search Slope for the fear condition between Low Anxious Subjects (*N* = 27) and High Anxious Subjects (*N* = 27)

**Table 6** Type III Tests of Fixed Effects: Visual Search Slope (P1)

| Source | Num. df | Den. df | F | Sig. |
|---|---|---|---|---|
| Intercept | 1 | 67.706 | 15.099 | 0.000 |
| Emotion | 3 | 61.860 | 3.698 | 0.016 |
| Average SCARED | 1 | 66.448 | 3.645 | 0.061 |
| P1 Amplitude | 1 | 91.513 | 2.211 | 0.140 |
| Sex | 1 | 48.324 | 5.925 | 0.019 |
| Average SCARED x Sex | 1 | 102.038 | 1.312 | 0.255 |
| Age x Sex | 1 | 46.022 | 5.063 | 0.029 |
| Age x P1 Amplitude | 1 | 95.692 | 2.659 | 0.106 |
| Average SCARED x Age | 1 | 67.123 | 3.962 | 0.051 |
| Average SCARED x P1 Amplitude | 1 | 72.457 | 3.510 | 0.065 |
| Emotion x Average SCARED | 3 | 62.463 | 1.942 | 0.132 |
| Emotion x Age | 4 | 68.478 | 1.778 | 0.143 |
| Emotion x P1 Amplitude | 3 | 64.514 | 2.610 | 0.059 |
| P1 Amplitude X Averaged SCARED x Sex | 1 | 106.210 | 1.410 | 0.238 |
| Averaged SCARED x Age x P1 Amplitude | 1 | 79.319 | 2.909 | 0.092 |
| Emotion x Averaged SCARED x Sex | 3 | 65.935 | 0.845 | 0.474 |
| Emotion x Averaged SCARED x Age | 3 | 62.802 | 1.780 | 0.160 |
| Emotion x Age x P1 Amplitude | 3 | 65.178 | 1.516 | 0.219 |
| Emotion x Averaged SCARED x P1 Amplitude | 3 | 64.704 | 2.522 | 0.065 |
| Emotion x Averaged SCARED x Age x P1 Amplitude | 3 | 64.984 | 2.109 | 0.108 |

**Table 7** Estimates of Fixed Effects: Visual Search Slope (P1)

| Parameter | Est. | Std. E | df | t | Sig. | - 95% CI | + 95% CI |
|---|---|---|---|---|---|---|---|
| Sex | -80.02 | 32.87 | 48.32 | -2.43 | 0.019 | -146.11 | -13.93 |
| Age (Males) | 23.07 | 10.25 | 46.02 | 2.25 | 0.029 | 2.43 | 43.70 |
| Average SCARED x P1 (Males) | -7.03 | 5.92 | 106.21 | -1.19 | 0.238 | -18.77 | 4.71 |
| | | | | | | | |
| Contrast: Scrambled (All) | 115.21 | 42.38 | 76.87 | 2.72 | 0.008 | 30.81 | 199.60 |
| Angry (All) | -55.81 | 44.08 | 52.16 | -1.27 | 0.211 | -144.25 | 32.64 |
| Fear (All) | 63.91 | 36.04 | 89.57 | 1.77 | 0.080 | -7.68 | 135.51 |
| Happy (All) | 60.91 | 36.63 | 76.20 | 1.66 | 0.100 | -12.04 | 133.85 |
| | | | | | | | |
| Contrast: Scrambled x Averaged SCARED (Female) | -129.62 | 52.55 | 76.64 | -2.47 | 0.016 | -234.26 | -24.97 |
| Angry x Averaged SCARED (Female) | 79.39 | 53.20 | 51.52 | 1.49 | 0.142 | -27.39 | 186.17 |
| Fear x Averaged SCARED (Female) | 92.05 | 40.76 | 93.46 | 2.26 | 0.026 | 11.12 | 172.98 |
| Happy x Averaged SCARED (Female) | 41.23 | 41.69 | 72.44 | 0.99 | 0.326 | -41.87 | 124.34 |
| | | | | | | | |
| Contrast: Scrambled x Averaged SCARED (Male) | 32.03 | 48.85 | 105.67 | 0.66 | 0.513 | -64.81 | 128.88 |
| Angry x Averaged SCARED (Male) | 23.43 | 24.26 | 57.61 | 0.97 | 0.338 | -25.13 | 72.00 |
| Fear x Averaged SCARED (Male) | 29.15 | 19.60 | 104.86 | 1.49 | 0.140 | -9.72 | 68.01 |
| Happy x Averaged SCARED (Male) | 12.46 | 19.92 | 86.88 | 0.63 | 0.533 | -27.13 | 52.06 |
| | | | | | | | |
| Contrast: Scrambled x Age (All) | -1.90 | 12.44 | 79.67 | -0.15 | 0.879 | -26.65 | 22.85 |
| Angry x Age (All) | 13.30 | 12.28 | 53.26 | 1.08 | 0.284 | -11.34 | 37.93 |
| Fear x Age (All) | -15.33 | 12.94 | 80.69 | -1.19 | 0.240 | -41.08 | 10.42 |
| Happy x Age (All) | -15.18 | 12.44 | 96.22 | -1.22 | 0.225 | -39.87 | 9.51 |
| | | | | | | | |
| Contrast: Scrambled x P1 (All) | 10.32 | 5.69 | 91.56 | 1.81 | 0.073 | -0.98 | 21.63 |
| Angry x P1 (All) | 6.82 | 6.27 | 53.01 | 1.09 | 0.282 | -5.75 | 19.39 |
| Fear x P1 (All) | -9.41 | 5.29 | 88.83 | -1.78 | 0.079 | -19.92 | 1.11 |
| Happy x P1 (All) | -7.52 | 5.61 | 91.39 | -1.34 | 0.183 | -18.66 | 3.62 |
| | | | | | | | |
| Contrast: Scrambled x Age x P1(All) | -3.51 | 1.87 | 94.35 | -1.88 | 0.063 | -7.22 | 0.19 |
| Angry x Age x P1 (All) | -1.47 | 2.10 | 53.76 | -0.70 | 0.487 | -5.67 | 2.74 |
| Fear x Age x P1 (All) | 2.53 | 1.79 | 90.04 | 1.41 | 0.162 | -1.03 | 6.08 |
| Happy x Age x P1 (All) | 2.04 | 1.86 | 89.18 | 1.10 | 0.276 | -1.66 | 5.75 |
| | | | | | | | |
| Contrast: Scrambled x Averaged SCARED x Age (All) | 33.61 | 12.67 | 76.89 | 2.65 | 0.010 | 8.37 | 58.85 |
| Angry x Averaged SCARED x Age (All) | -22.75 | 13.29 | 51.30 | -1.71 | 0.093 | -49.43 | 3.92 |
| Fear x Averaged SCARED x Age (All) | -21.33 | 10.48 | 91.80 | -2.03 | 0.045 | -42.15 | -0.50 |
| Happy x Averaged SCARED x Age (All) | -11.18 | 10.53 | 74.43 | -1.06 | 0.292 | -32.17 | 9.81 |
| | | | | | | | |
| Contrast: Scrambled x Averaged SCARED x P1(All) | 22.65 | 7.84 | 80.45 | 2.89 | 0.005 | 7.05 | 38.25 |
| Angry x Averaged SCARED x P1 (All) | -12.28 | 8.84 | 51.51 | -1.39 | 0.171 | -30.03 | 5.47 |
| Fear x Averaged SCARED x P1 (All) | -17.85 | 6.65 | 88.54 | -2.68 | 0.009 | -31.07 | -4.63 |
| Happy x Averaged SCARED x P1 (All) | -9.46 | 6.66 | 78.74 | -1.42 | 0.159 | -22.71 | 3.79 |
| | | | | | | | |
| Contrast: Scrambled x Averaged SCARED x Age x P1 (All) | -5.83 | 2.13 | 84.15 | -2.73 | 0.008 | -10.08 | -1.59 |
| Angry x Averaged SCARED x Age x P1(All) | 3.40 | 2.46 | 52.81 | 1.38 | 0.173 | -1.54 | 8.34 |
| Fear x Averaged SCARED x Age x P1(All) | 4.77 | 1.96 | 90.76 | 2.43 | 0.017 | 0.88 | 8.67 |
| Happy x Averaged SCARED x Age x P1(All) | 2.65 | 1.96 | 82.03 | 1.35 | 0.180 | -1.25 | 6.54 |

### *5.1c Examining variability of N170 Amplitude*

The final model, with a AIC fit-value of 898.485, was fitted using the Auto-Regressive First Order covariance structure (Factor Analytic did not converge), and Restricted Maximum Likelihood Estimation (REML) with both fixed effects and subject level random effects intercepts. This final model included all interaction possibilities of the 4 fixed-effects variables, with no interactions removed; the highest order interaction was close to significant. The Intercept, main effect of Sex, three-way interaction of Emotion X Sex X Average SCARED, as well as a trend level four-way interaction of Emotion X Sex X Average SCARED X Age.

Estimates of fixed effects indicated that for the main effect of Sex, N170 amplitudes were significantly larger (greater negative deflection) for males than for females. For the three-way interaction of Emotion X Sex X Average SCARED, estimates of fixed effects indicated that compared to the scrambled prime condition, angry, fear, and happy significantly differ by Sex, as well as varied as a function of anxiety. Estimates of fixed effects indicated that for Females only, N170 Amplitude to Angry and Happy Primes significantly varied as a function of SCARED score compared to N170 Amplitude to Scrambled Primes. For both males and females, there was a positive correlation between anxiety and ΔN170 for fear (Scrambled N170-Fear N170). For males, lower anxiety scores were associated with larger N170 amplitudes to scrambled primes compared to fear primes, while higher anxiety scores were associated with larger N170 amplitudes to fear compared to scrambled primes. While the correlation was in the same direction for females, low anxious females started with ΔN170 for fear close to zero, and higher anxiety scores were related to increasing N170 amplitudes to fear relative to scrambled primes. Moreover, while in males there was no significant relation for ΔN170 and anxiety for angry and happy emotions, for females there was. For both emotions, the relation was the opposite of ΔN170 for fear; lower anxiety scores related to larger N170 amplitudes to angry or happy compared to scrambled primes, while higher anxiety scores were associated with larger N170 amplitudes to scrambled compared to angry and happy primes. (**See Figures 6a &b, 8 and Tables 8 & 9**).

**Table 8** Type III Tests of Fixed Effects: N170 Amplitude

| Source | Num. df | Den. df | F | Sig. |
|---|---|---|---|---|
| Intercept | 1 | 46.03 | 65.31 | 0.00 |
| Emotion | 3 | 77.27 | 0.80 | 0.50 |
| Sex | 1 | 46.03 | 4.07 | 0.05 |
| Average SCARED | 1 | 46.03 | 0.01 | 0.95 |
| Age | 1 | 46.03 | 3.25 | 0.08 |
| Emotion x Sex | 3 | 77.27 | 0.23 | 0.87 |
| Emotion x Average SCARED | 3 | 77.27 | 0.62 | 0.61 |
| Emotion x Age | 3 | 77.27 | 1.34 | 0.27 |
| Sex x Average SCARED | 1 | 46.03 | 0.09 | 0.76 |
| Sex x AGE | 1 | 46.03 | 0.21 | 0.65 |
| Average SCARED x Age | 1 | 46.03 | 0.08 | 0.78 |
| Emotion x Sex x Average SCARED | 3 | 77.27 | 2.85 | 0.04 |
| Emotion x Sex x Age | 3 | 77.27 | 0.50 | 0.68 |
| Emotion x Average SCARED x Age | 3 | 77.27 | 0.89 | 0.45 |
| Sex x Average SCARED x Age | 1 | 46.03 | 0.00 | 0.95 |
| Emotion x Sex x Average SCARED x Age | 3 | 77.27 | 2.64 | 0.06 |

**Table 9** Estimates of Fixed Effects: N170 Amplitude

| Parameter | Est. | Std. E. | df | t | Sig. | -95% CI | +95% CI |
|---|---|---|---|---|---|---|---|
| Int./Contrast: Scrambled (Male) | -11.12 | 1.66 | 57.98 | -6.69 | 0.00 | -14.45 | -7.79 |
| Angry (Male) | -0.90 | 0.99 | 53.86 | -0.91 | 0.37 | -2.88 | 1.08 |
| Fear (Male) | 0.44 | 0.95 | 93.46 | 0.46 | 0.65 | -1.45 | 2.34 |
| Happy (Male) | -0.13 | 0.84 | 116.40 | -0.16 | 0.87 | -1.79 | 1.52 |
| | | | | | | | |
| Contrast: Scrambled (Female) | 4.57 | 2.37 | 57.98 | 1.93 | 0.06 | -0.17 | 9.31 |
| Angry (Female) | 0.49 | 1.41 | 53.86 | 0.35 | 0.73 | -2.33 | 3.30 |
| Fear (Female) | -0.50 | 1.36 | 93.46 | -0.37 | 0.72 | -3.20 | 2.20 |
| Happy (Female) | -0.26 | 1.19 | 116.40 | -0.22 | 0.83 | -2.62 | 2.10 |
| | | | | | | | |
| Contrast: Scrambled x Average SCARED (Male) | 2.49 | 2.94 | 57.98 | 0.85 | 0.40 | -3.41 | 8.38 |
| Angry x Average SCARED (Male) | -2.64 | 1.75 | 53.86 | -1.51 | 0.14 | -6.15 | 0.86 |
| Fear x Average SCARED (Male) | -2.56 | 1.69 | 93.46 | -1.51 | 0.13 | -5.91 | 0.80 |
| Happy x Average SCARED (Male) | -3.29 | 1.48 | 116.40 | -2.22 | 0.03 | -6.23 | -0.36 |
| | | | | | | | |
| Contrast: Scrambled x Average SCARED (Female) | -3.84 | 3.21 | 57.98 | -1.20 | 0.24 | -10.26 | 2.58 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Angry x Average SCARED (Female) | 3.96 | 1.90 | 53.86 | 2.08 | 0.04 | 0.14 | 7.78 |
| Fear x Average SCARED (Female) | 3.21 | 1.84 | 93.46 | 1.75 | 0.08 | -0.44 | 6.87 |
| Happy x Average SCARED (Female) | 4.47 | 1.61 | 116.40 | 2.77 | 0.01 | 1.27 | 7.66 |
| | | | | | | | |
| Contrast: Scrambled x Age (Male) | 0.63 | 0.58 | 57.98 | 1.08 | 0.29 | -0.54 | 1.80 |
| Angry x Age (Male) | 0.42 | 0.35 | 53.86 | 1.20 | 0.24 | -0.28 | 1.11 |
| Fear x Age (Male) | 0.01 | 0.34 | 93.46 | 0.02 | 0.99 | -0.66 | 0.67 |
| Happy x Age (Male) | 0.43 | 0.29 | 116.40 | 1.45 | 0.15 | -0.16 | 1.01 |
| | | | | | | | |
| Contrast: Scrambled x Age (Female) | -0.14 | 0.79 | 57.98 | -0.18 | 0.86 | -1.73 | 1.44 |
| Angry x Age (Female) | -0.32 | 0.47 | 53.86 | -0.68 | 0.50 | -1.26 | 0.63 |
| Fear x Age (Female) | -0.08 | 0.46 | 93.46 | -0.17 | 0.87 | -0.98 | 0.83 |
| Happy x Age (Female) | -0.39 | 0.40 | 116.40 | -0.97 | 0.33 | -1.18 | 0.40 |
| | | | | | | | |
| Contrast: Scrambled x Average SCARED x Age (Male) | -0.47 | 1.05 | 57.98 | -0.45 | 0.66 | -2.58 | 1.63 |
| Angry x Average SCARED x Age (Male) | 0.93 | 0.63 | 53.86 | 1.49 | 0.14 | -0.32 | 2.18 |
| Fear x Average SCARED x Age (Male) | 0.54 | 0.60 | 93.46 | 0.89 | 0.38 | -0.66 | 1.74 |
| Happy x Average SCARED x Age (Male) | 1.14 | 0.53 | 116.40 | 2.14 | 0.03 | 0.09 | 2.18 |
| | | | | | | | |
| Contrast: Scrambled x Average SCARED x Age (Female) | 0.77 | 1.12 | 57.98 | 0.69 | 0.49 | -1.46 | 3.01 |
| Angry x Average SCARED x Age (Female) | -1.27 | 0.66 | 53.86 | -1.91 | 0.06 | -2.60 | 0.06 |
| Fear x Average SCARED x Age (Female) | -0.68 | 0.64 | 93.46 | -1.06 | 0.29 | -1.96 | 0.59 |
| Happy x Average SCARED x Age (Female) | -1.40 | 0.56 | 116.40 | -2.49 | 0.01 | -2.51 | -0.28 |

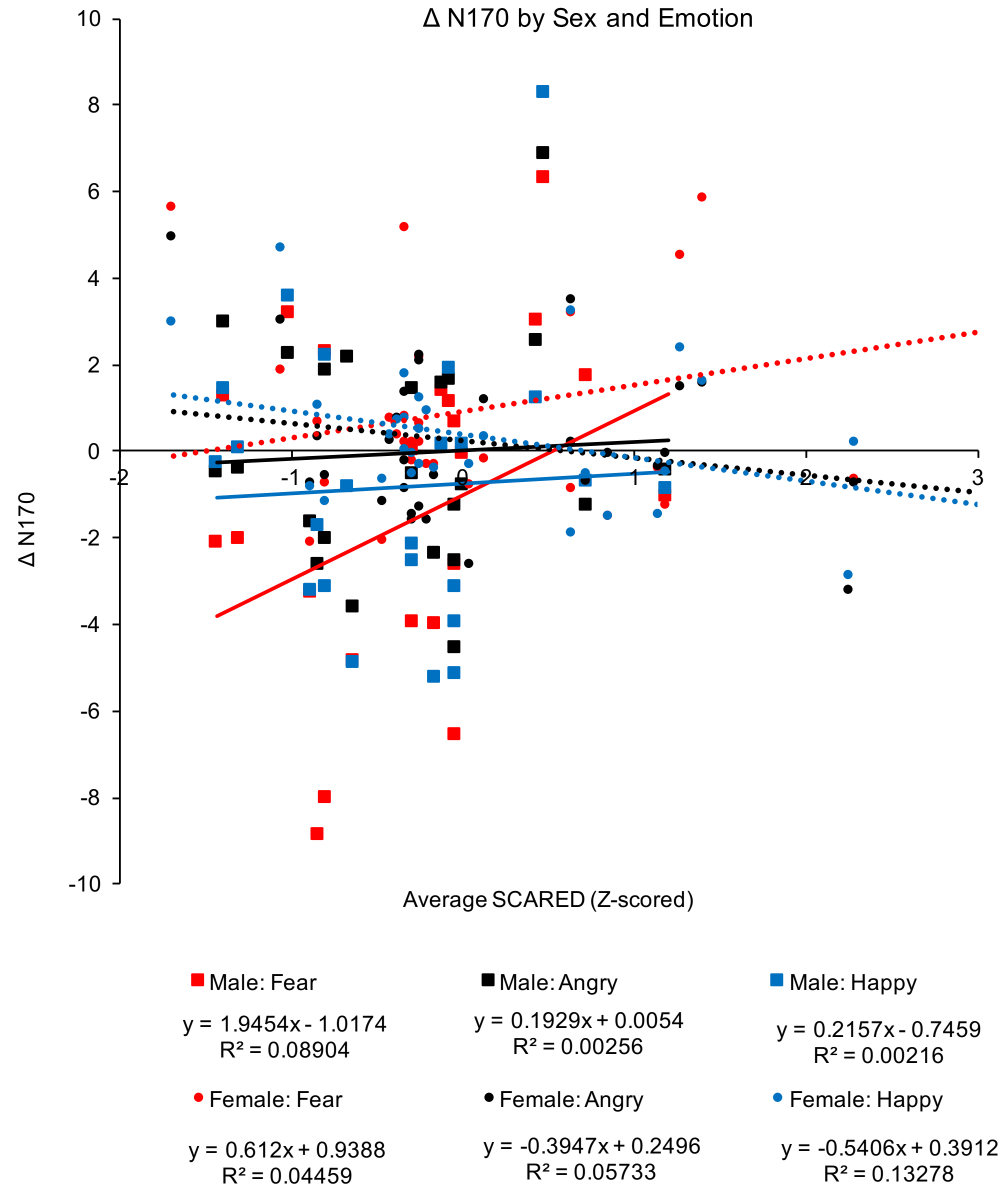



**Figure 8.** Relations between Average ΔN170 Amplitude, Sex, and Anxiety

### *5.1d Examining the relations of N170 Amplitude variability and behavior*

The final model, with a AIC fit-value of 1972.227, was fitted using the Factor Analytic: First Order covariance structure, Restricted Maximum Likelihood Estimation

(REML), with both fixed effects and subject level random effects intercepts. This final model included all interaction possibilities of the 5 fixed-effects variables, with insignificant higher level interactions removed from the final model. The following the following fixed effects terms were significant: Intercept, main effect of as well as several significant and trend-level two-way interactions; Emotion x Sex, Emotion x Age, Emotion x Average N170 Amplitude. These were superseded by two three-way interactions:  Emotion x Average N170 Amplitude X Sex and Emotion X Age X Average N170 Amplitude.

Estimates of fixed effect indicated that Emotion X Average N170 Amplitude X Age was driven by age-related changes in the ΔN170 for fear (Scrambled N170-Fear N170) predicted ΔVisual Search Slope for fear (Scrambled RT-Fear RT). In the younger half of the participants, there was a positive relation for the fear prime between ΔN170 and ΔVisual Search Slope: greater N170 amplitudes to fear primes compared to scrambled primes related to facilitation of visual search slopes for fear compared to scrambled. In the older half of the participants, there was a negative relation for the fear prime ΔN170 and ΔVisual Search Slope: greater N170 amplitudes to fear primes compared to scrambled primes related to degradation of visual search slopes for fear compared to scrambled.

Estimates of fixed effect indicated that Emotion X Average N170 Amplitude X Sex was driven by sex-related difference in the ΔN170 for fear and angry predicting ΔVisual Search Slope for these emotions. For the fear condition, males did not show a significant relation between ΔN170 and ΔVisual Search Slope, however for females, greater N170 amplitudes to fear primes compared to scrambled primes related to facilitation of visual search slopes for fear compared to scrambled. For the angry condition, females did not show a significant relation between ΔN170 and ΔVisual Search Slope however for males, there was a negative relation for the angry prime ΔN170 and ΔVisual Search Slope: greater N170 amplitudes to angry compared to scrambled primes related to degradation of visual search slopes for angry compared to scrambled.

**Table 10** Type III Tests of Fixed Effects: Visual Search

| Source | Num. df | Den. df | F | Sig. |
|---|---|---|---|---|
| Intercept | 1 | 82.61 | 16.50 | 0.00 |
| Emotion | 3 | 56.64 | 4.19 | 0.01 |
| Average SCARED | 1 | 84.88 | 2.18 | 0.14 |
| N170 | 1 | 106.98 | 0.00 | 0.95 |
| Age | 1 | 73.93 | 2.10 | 0.15 |
| Sex | 1 | 82.28 | 1.53 | 0.22 |
| Emotion x Average SCARED | 3 | 57.79 | 1.56 | 0.21 |
| Emotion x N170 | 3 | 57.85 | 3.47 | 0.02 |
| Emotion x Age | 3 | 55.88 | 3.81 | 0.02 |
| Emotion x Sex | 3 | 55.67 | 2.41 | 0.08 |
| Average SCARED x N170 | 1 | 114.69 | 2.75 | 0.10 |
| Average SCARED x Age | 1 | 77.14 | 3.07 | 0.08 |
| Average SCARED x Sex | 1 | 51.89 | 0.04 | 0.84 |
| N170 x Age | 1 | 91.16 | 0.03 | 0.86 |
| N170 x Sex | 1 | 101.83 | 0.07 | 0.79 |
| Age x Sex | 1 | 83.76 | 1.60 | 0.21 |
| Emotion x Average SCARED x N170 | 3 | 59.21 | 1.84 | 0.15 |
| Emotion x Average SCARED x Age | 3 | 59.10 | 1.47 | 0.23 |
| Emotion x Average SCARED x Sex | 3 | 54.28 | 1.14 | 0.34 |
| Emotion x N170 x Age | 3 | 56.89 | 3.17 | 0.03 |
| Emotion x N170 x Sex | 3 | 56.65 | 3.56 | 0.02 |
| Emotion x Sex x Age | 3 | 56.17 | 1.41 | 0.25 |
| Average SCARED x N170 x Sex | 1 | 100.29 | 2.44 | 0.12 |
| N170 x Age x Sex | 1 | 95.71 | 0.29 | 0.59 |
| Emotion x Average SCARED x N170 x Age | 3 | 59.74 | 2.03 | 0.12 |
| Emotion x N170 x Age x Sex | 3 | 56.49 | 2.56 | 0.06 |

**Table 11** Estimates of Fixed Effects: Visual Search Slope (N170)

| Parameter | Est. | Std. E | df | t | Sig. | -95% CI | +95% |
|---|---|---|---|---|---|---|---|
| Int./Contrast: Scrambled (Female) | 218.19 | 48.52 | 77.20 | 4.50 | 0.00 | 121.58 | 314.80 |
| Angry (Female) | -150.28 | 56.71 | 49.25 | -2.65 | 0.01 | -264.24 | -36.33 |
| Fear (Female) | -74.79 | 45.75 | 82.71 | -1.64 | 0.11 | -165.79 | 16.22 |
| Happy (Female) | 21.89 | 49.51 | 75.31 | 0.44 | 0.66 | -76.73 | 120.51 |
| Contrast: Scrambled (Male) | -147.53 | 73.09 | 78.62 | -2.02 | 0.05 | -293.02 | -2.03 |
| Angry (Male) | 144.65 | 84.65 | 48.80 | 1.71 | 0.09 | -25.48 | 314.77 |
| Fear (Male) | 136.52 | 68.05 | 83.43 | 2.01 | 0.05 | 1.19 | 271.85 |
| Happy (Male) | 6.36 | 72.13 | 73.55 | 0.09 | 0.93 | -137.37 | 150.10 |
| Contrast: Scrambled x Average SCARED (Female) | -68.40 | 37.65 | 78.79 | -1.82 | 0.07 | -143.34 | 6.54 |
| Angry x Average SCARED (Female) | 80.01 | 42.11 | 61.73 | 1.90 | 0.06 | -4.18 | 164.20 |
| Fear x Average SCARED (Female) | 23.11 | 35.46 | 87.73 | 0.65 | 0.52 | -47.36 | 93.58 |
| Happy x Average SCARED (Female) | 11.32 | 36.76 | 73.57 | 0.31 | 0.76 | -61.92 | 84.57 |
| Contrast: Scrambled x Average SCARED (Male) | -17.98 | 24.15 | 64.76 | -0.74 | 0.46 | -66.22 | 30.26 |
| Angry x Average SCARED (Male) | 38.54 | 25.01 | 46.24 | 1.54 | 0.13 | -11.80 | 88.88 |
| Fear x Average SCARED (Male) | 30.49 | 19.79 | 84.12 | 1.54 | 0.13 | -8.88 | 69.85 |
| Happy x Average SCARED (Male) | 18.61 | 20.33 | 66.74 | 0.92 | 0.36 | -21.97 | 59.20 |
| Contrast: Scrambled x N170 (Female) | 10.16 | 7.12 | 83.61 | 1.43 | 0.16 | -4.01 | 24.33 |
| Angry x N170 (Female) | -21.67 | 8.48 | 51.87 | -2.56 | 0.01 | -38.70 | -4.65 |
| Fear x N170 (Female) | -16.80 | 7.32 | 85.32 | -2.30 | 0.02 | -31.34 | -2.25 |
| Happy x N170 (Female) | -3.66 | 7.78 | 76.44 | -0.47 | 0.64 | -19.15 | 11.83 |
| Contrast: Scrambled x N170 (Male) | -16.04 | 8.95 | 83.19 | -1.79 | 0.08 | -33.85 | 1.77 |
| Angry x N170 (Male) | 22.41 | 10.29 | 51.06 | 2.18 | 0.03 | 1.75 | 43.06 |
| Fear x N170 (Male) | 25.40 | 8.70 | 83.92 | 2.92 | 0.01 | 8.10 | 42.70 |
| Happy x N170 (Male) | 8.63 | 9.29 | 74.43 | 0.93 | 0.36 | -9.88 | 27.13 |
| Contrast: Scrambled x Age (Female) | -37.92 | 14.89 | 72.76 | -2.55 | 0.01 | -67.59 | -8.24 |
| Angry x Age (Female) | 47.13 | 16.76 | 47.96 | 2.81 | 0.01 | 13.44 | 80.82 |
| Fear x Age (Female) | 26.77 | 13.53 | 82.21 | 1.98 | 0.05 | -0.14 | 53.68 |
| Happy x Age (Female) | 4.42 | 14.40 | 73.85 | 0.31 | 0.76 | -24.27 | 33.12 |
| Contrast: Scrambled x Age (Male) | 49.97 | 23.98 | 77.81 | 2.08 | 0.04 | 2.24 | 97.71 |
| Angry x Age (Male) | -40.01 | 27.88 | 47.55 | -1.44 | 0.16 | -96.08 | 16.06 |
| Fear x Age (Male) | -40.61 | 23.10 | 82.46 | -1.76 | 0.08 | -86.57 | 5.35 |
| Happy x Age (Male) | -13.48 | 24.58 | 76.27 | -0.55 | 0.59 | -62.44 | 35.47 |
| Contrast: Scrambled x Age x N170 (Female) | -4.05 | 2.41 | 78.68 | -1.68 | 0.10 | -8.86 | 0.75 |
| Angry x Age x N170 (Female) | 6.85 | 2.68 | 49.84 | 2.56 | 0.01 | 1.48 | 12.23 |
| Fear x Age x N170 (Female) | 5.50 | 2.28 | 84.72 | 2.41 | 0.02 | 0.96 | 10.03 |
| Happy x Age x N170 (Female) | 2.43 | 2.41 | 74.25 | 1.01 | 0.32 | -2.37 | 7.23 |
| Contrast: Scrambled x Age x N170 (Male) | 6.20 | 3.30 | 80.47 | 1.88 | 0.06 | -0.38 | 12.77 |
| Angry x Age x N170 (Male) | -6.78 | 3.67 | 48.62 | -1.85 | 0.07 | -14.15 | 0.58 |
| Fear x Age x N170 (Male) | -8.00 | 3.06 | 82.37 | -2.61 | 0.01 | -14.09 | -1.91 |
| Happy x Age x N170 (Male) | -4.20 | 3.37 | 74.86 | -1.25 | 0.22 | -10.92 | 2.51 |
| Contrast: Scrambled x Average SCARED x N170 (All) | -14.92 | 5.68 | 78.52 | -2.63 | 0.01 | -26.23 | -3.62 |
| Angry x Average SCARED x Average SCARED x N170 (All) | 15.07 | 6.73 | 64.52 | 2.24 | 0.03 | 1.62 | 28.51 |
| Fear x Average SCARED x Average SCARED x N170 (All) | 10.20 | 5.86 | 89.66 | 1.74 | 0.09 | -1.43 | 21.84 |
| Happy x Average SCARED x Average SCARED x N170 (All) | 8.16 | 6.13 | 77.92 | 1.33 | 0.19 | -4.04 | 20.36 |
| Contrast: Scrambled x Average SCARED x Age (All) | 24.33 | 9.93 | 75.85 | 2.45 | 0.02 | 4.55 | 44.11 |
| Angry x Average SCARED x Average SCARED x Age (All) | -23.13 | 11.90 | 54.83 | -1.94 | 0.06 | -46.97 | 0.71 |
| Fear x Average SCARED x Average SCARED x Age (All) | -11.09 | 9.20 | 87.03 | -1.21 | 0.23 | -29.38 | 7.20 |
| Happy x Average SCARED x Average SCARED x Age (All) | -6.09 | 9.80 | 76.55 | -0.62 | 0.54 | -25.61 | 13.43 |
| Contrast: Scrambled x Average SCARED x N170 x Age (All) | 4.82 | 1.76 | 81.81 | 2.73 | 0.01 | 1.31 | 8.33 |
| Angry x Average SCARED x Average SCARED x N170 x Age (All) | -3.83 | 2.17 | 53.60 | -1.77 | 0.08 | -8.17 | 0.52 |
| Fear x Average SCARED x Average SCARED x N170 x Age (All) | -3.96 | 1.72 | 89.74 | -2.30 | 0.02 | -7.37 | -0.54 |
| Happy x Average SCARED x Average SCARED x N170 x Age (All) | -2.54 | 1.89 | 80.56 | -1.34 | 0.18 | -6.31 | 1.22 |

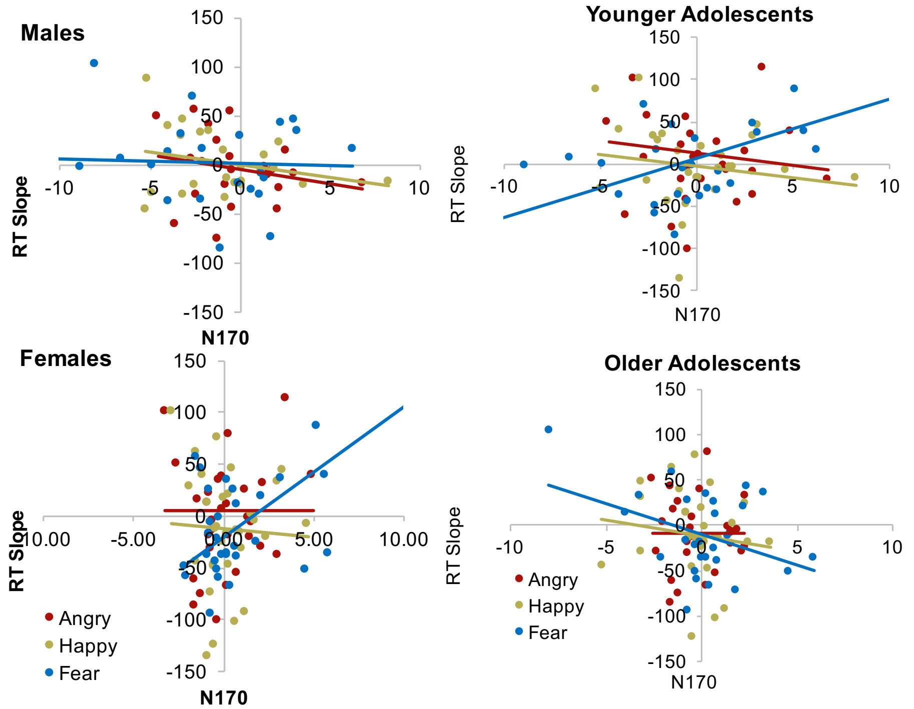



**Figure 9.** Relations between Average ΔN170 Amplitude, Age Sex, Anxiety, and Behavior.

## *5.2 Aim 2*

*Aim 2: The purpose of the second aim is to examine whether (1) neural correlates of attention processing during visual search differ as a function of emotion prime condition, task difficulty, age and anxiety and (2) whether these neural responses influence subsequent behavioral performance (reaction time) on the visual search task.*

### 5.2a Examining variability in N2pc Amplitude/Slope

The final model, with a AIC fit-value of 1011.65, was fitted using the Factor Analytic: First Order covariance structure, using Maximum Likelihood Estimation[2],

[2] The same model was run using REML, however, each of the significant terms from the ML model were trend level ~.7. Given the small sample size, and that REML is a more conservative measurement, results here are interpreted from the ML model.

with both fixed effects and subject level random effects intercepts. This final model included all interaction possibilities of the 4 fixed-effects variables. The following the following terms were significant: Intercept, Emotion X Average SCARED; these were superseded by two three-way interactions: Emotion X Average SCARED Score X Sex, and Emotion X Average SCARED X Age.

Estimates of fixed effects indicated that compared to the scrambled prime condition, angry significantly differed by Sex and Anxiety. This was driven by the females: for females only, the N2pc slope for the Angry prime became more negative as anxiety scores increased. In other words, set size related modulations of the N2pc after Angry primes were the smallest for the low anxious females, and became increasingly larger as anxiety scores increased (**Figure 10**).

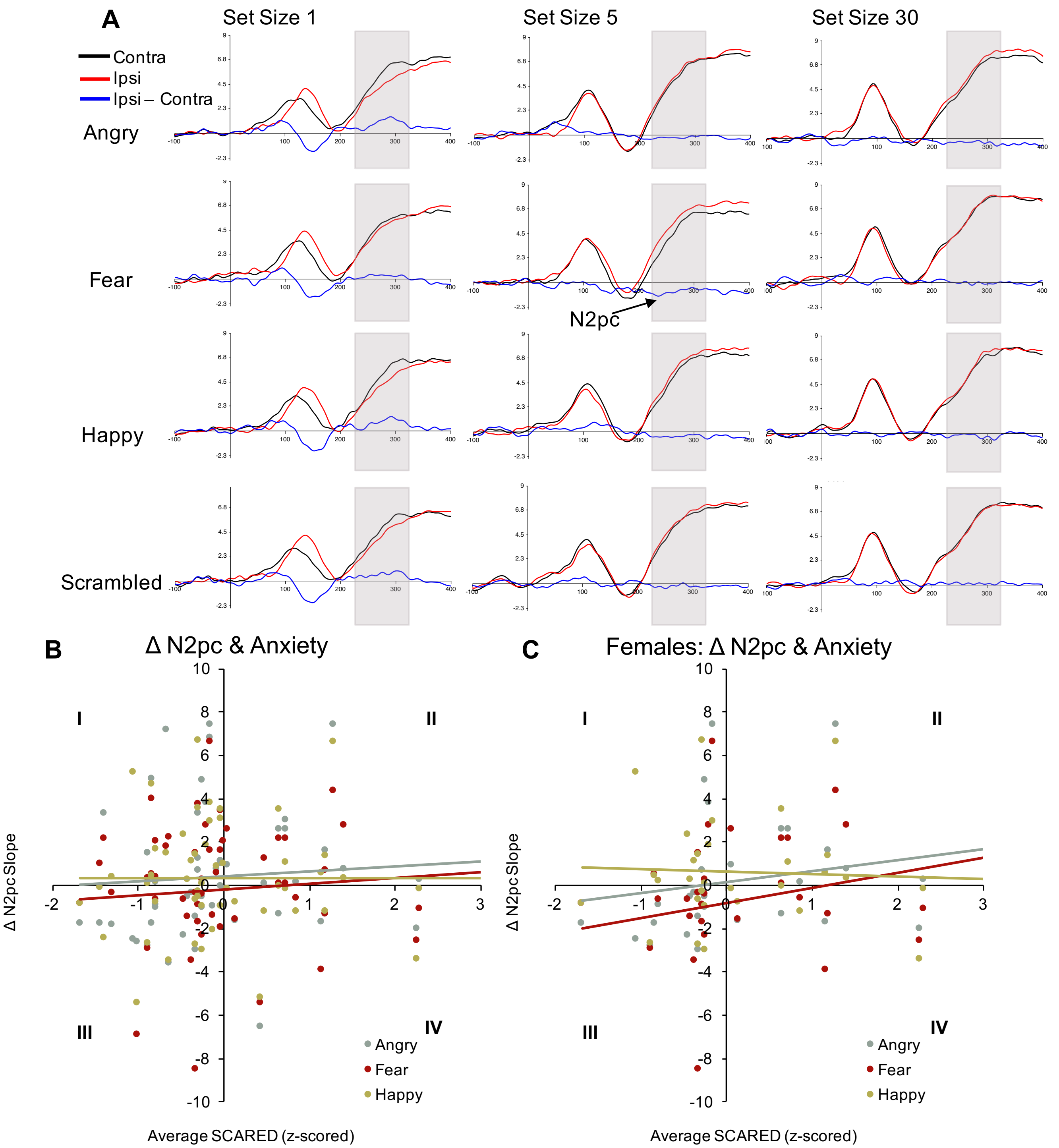
**Table 12** Type III Tests of Fixed Effects (N2pc)

| Source | Num. df | Den. df | F | Sig. |
|---|---|---|---|---|
| Intercept | 1 | 54.00 | 4.48 | 0.04 |
| Emotion | 3 | 69.00 | 0.82 | 0.49 |
| Sex | 1 | 54.00 | 0.22 | 0.64 |
| Average SCARED | 1 | 54.00 | 0.01 | 0.94 |
| Age | 1 | 54.00 | 1.34 | 0.25 |
| Emotion x Sex | 3 | 69.00 | 1.26 | 0.30 |
| Emotion x Average SCARED | 3 | 69.00 | 2.84 | 0.04 |
| Emotion x Age | 3 | 69.00 | 1.01 | 0.39 |
| Sex x Average SCARED | 1 | 54.00 | 0.14 | 0.71 |
| Sex x Age | 1 | 54.00 | 0.01 | 0.94 |
| Average SCARED x Age | 1 | 54.00 | 0.01 | 0.93 |
| Emotion x Sex x Average SCARED | 3 | 69.00 | 2.87 | 0.04 |
| Emotion x Sex x Age | 3 | 69.00 | 0.71 | 0.55 |
| Emotion x Average SCARED x Age | 3 | 69.00 | 2.84 | 0.04 |
| Sex x Average SCARED x Age | 1 | 54.00 | 0.01 | 0.92 |
| Emotion Sex x Average SCARED x Age | 3 | 69.00 | 2.68 | 0.05 |

**Table 13** Estimates of Fixed Effects: N2pc Slope

| Parameter | Est. | Std. E | df | t | Sig. | -95% | + 95% |
|---|---|---|---|---|---|---|---|
| Int./Contrast: Scrambled (Male) | -1.36 | 0.95 | 138.88 | -1.43 | 0.16 | -3.24 | 0.52 |
| Angry (Male) | -0.15 | 1.11 | 84.95 | -0.13 | 0.89 | -2.35 | 2.05 |
| Fear (Male) | -0.24 | 1.33 | 59.32 | -0.18 | 0.86 | -2.89 | 2.42 |
| Happy (Male) | 0.77 | 1.16 | 79.84 | 0.66 | 0.51 | -1.54 | 3.07 |
| Contrast: Scrambled (Female) | -0.63 | 1.35 | 138.88 | -0.46 | 0.64 | -3.31 | 2.05 |
| Angry (Female) | 1.48 | 1.58 | 84.95 | 0.94 | 0.35 | -1.65 | 4.62 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fear (Female) | 3.36 | 1.89 | 59.32 | 1.78 | 0.08 | -0.41 | 7.13 |
| Happy (Female) | -0.52 | 1.65 | 79.84 | -0.31 | 0.75 | -3.80 | 2.76 |
| Contrast: Scrambled x Average SCARED (Male) | -1.42 | 1.68 | 138.88 | -0.84 | 0.40 | -4.75 | 1.91 |
| Angry x Average SCARED (Male) | 4.97 | 1.96 | 84.95 | 2.54 | 0.01 | 1.07 | 8.86 |
| Fear x Average SCARED (Male) | -0.90 | 2.35 | 59.32 | -0.38 | 0.70 | -5.59 | 3.79 |
| Happy x Average SCARED (Male) | 2.40 | 2.05 | 79.84 | 1.17 | 0.25 | -1.68 | 6.48 |
| Contrast: Scrambled x Average SCARED (Female) | 1.25 | 1.84 | 138.88 | 0.68 | 0.50 | -2.38 | 4.88 |
| Angry x Average SCARED (Female) | -5.28 | 2.13 | 84.95 | -2.47 | 0.02 | -9.52 | -1.04 |
| Fear x Average SCARED (Female) | 0.34 | 2.56 | 59.32 | 0.14 | 0.89 | -4.77 | 5.46 |
| Happy x Average SCARED (Female) | -2.05 | 2.23 | 79.84 | -0.92 | 0.36 | -6.50 | 2.39 |
| Contrast: Scrambled x Age (Male) | 0.33 | 0.33 | 138.88 | 0.98 | 0.33 | -0.33 | 0.99 |
| Angry x Age (Male) | -0.29 | 0.39 | 84.95 | -0.74 | 0.46 | -1.06 | 0.49 |
| Fear x Age (Male) | 0.04 | 0.47 | 59.32 | 0.08 | 0.94 | -0.90 | 0.97 |
| Happy x Age (Male) | -0.35 | 0.41 | 79.84 | -0.86 | 0.39 | -1.16 | 0.46 |
| Contrast: Scrambled x Age (Female) | 0.29 | 0.45 | 138.88 | 0.64 | 0.52 | -0.61 | 1.19 |
| Angry x Age (Female) | -0.23 | 0.53 | 84.95 | -0.43 | 0.67 | -1.28 | 0.82 |
| Fear x Age (Female) | -0.88 | 0.63 | 59.32 | -1.40 | 0.17 | -2.15 | 0.38 |
| Happy x Age (Female) | 0.06 | 0.55 | 79.84 | 0.10 | 0.92 | -1.04 | 1.16 |
| Contrast: Scrambled x Average SCARED x Age (Male) | 0.48 | 0.60 | 138.88 | 0.80 | 0.42 | -0.71 | 1.68 |
| Angry x Average SCARED x Age (Male) | -1.66 | 0.70 | 84.95 | -2.37 | 0.02 | -3.05 | -0.26 |
| Fear x Average SCARED x Age (Male) | 0.41 | 0.84 | 59.32 | 0.49 | 0.63 | -1.27 | 2.09 |
| Happy x Average SCARED x Age (Male) | -0.87 | 0.73 | 79.84 | -1.19 | 0.24 | -2.33 | 0.59 |
| Contrast: Scrambled x Average SCARED x Age (Female) | -0.51 | 0.64 | 138.88 | -0.80 | 0.43 | -1.78 | 0.75 |
| Angry x Average SCARED x Age (Female) | 1.70 | 0.74 | 84.95 | 2.28 | 0.03 | 0.22 | 3.18 |
| Fear x Average SCARED x Age (Female) | -0.29 | 0.89 | 59.32 | -0.32 | 0.75 | -2.07 | 1.50 |
| Happy x Average SCARED x Age (Female) | 0.83 | 0.78 | 79.84 | 1.07 | 0.29 | -0.72 | 2.38 |




QI: Low Anxiety → Angry N2pc > Scrambled N2pc
QII: High Anxiety → Scrambled N2pc > Angry N2pc
QIII: Low Anxiety → Angry N2pc > Scrambled N2pc
QIV: High Anxiety → Scrambled N2pc > Angry N2pc

**Figure 10.** Relations between Average N2pc Slope, Emotion, Sex, and Anxiety (a) N2pc contra, ipsi, and difference waveforms by emotion and set size (b) All Participants: change in N2pc Slope as a function of Average SCARED and Emotion condition. (c) Females: change in N2pc Slope as a function of Average SCARED and Emotion conditions

### 5.2b Examining the relations of N2pc Slope variability and behavior

The final model, with a AIC fit-value of 1985.99, was fitted using the Autoregressive covariance structure, using REML, with both fixed effects and subject level random effects intercepts. The Factor Analytic covariance structure was initially used however the model did not converge. This final model included all interaction possibilities of the 5 fixed-effects variables, with insignificant higher level interactions removed from the final model. Numerous main effects and interaction terms were significant in this model (**See Table 5**). The Emotion X Average SCARED X N2pc Slope Interaction was of main interest, and this interaction was driven by anxiety and N2pc slope differences for all emotions compared to scrambled. For lower anxious adolescents, there is no relation between the N2pc slope for the happy condition and subsequent visual search slope. However, in the high anxious group, for the happy condition (as well as angry and fear conditions) the larger the magnitude of set size related modulations of the N2pc (e.g. "larger" more negative slope value), the larger the reaction time visual search slope. Specifically, for high anxious adolescents, more negative N2pc slopes during the all face prime conditions (Angry, Fear & Happy) degraded visual search slope, while smaller / less negative slopes facilitated visual search performance. (**See Figure 11a & b**).

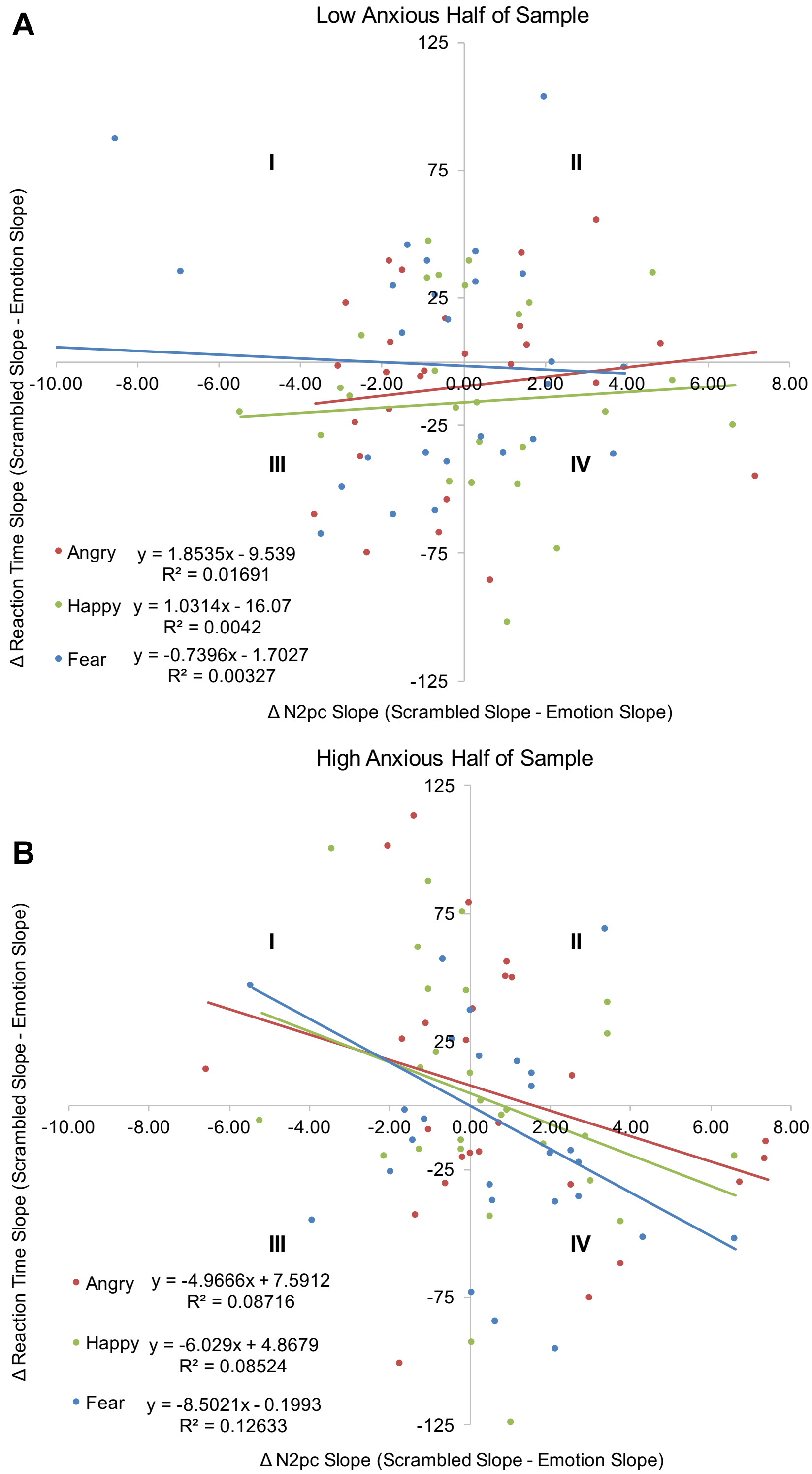
**Table 13** Type III Tests of Fixed Effects: Visual Search

| Source | Num. | Den. df | F | Sig. |
|---|---|---|---|---|
| Intercept | 1 | 47.50 | 88.30 | 0.00 |
| Emotion | 3 | 92.37 | 2.06 | 0.11 |
| Sex | 1 | 47.01 | 6.00 | 0.02 |
| Average SCARED | 1 | 48.18 | 0.39 | 0.54 |
| Age | 1 | 46.57 | 3.61 | 0.06 |
| N2pc | 1 | 116.21 | 0.47 | 0.50 |
| Emotion x Sex | 3 | 92.38 | 3.64 | 0.02 |
| Emotion x Average SCARED | 3 | 93.53 | 3.52 | 0.02 |
| Emotion x Age | 3 | 90.05 | 1.51 | 0.22 |
| Emotion x N2pc | 3 | 116.57 | 3.28 | 0.02 |
| Sex x Average SCARED | 1 | 46.18 | 0.09 | 0.76 |

| | | | | |
|---|---|---|---|---|
| Sex x Age | 1 | 46.24 | 4.20 | 0.05 |
| Sex x N2pc | 1 | 123.42 | 12.71 | 0.00 |
| Average SCARED x Age | 1 | 47.34 | 1.30 | 0.26 |
| Average SCARED x N2pc | 1 | 130.58 | 1.33 | 0.25 |
| Age x N2pc | 1 | 116.26 | 0.61 | 0.44 |
| Emotion x Sex x Average SCARED | 3 | 85.66 | 1.57 | 0.20 |
| Emotion x Sex x Age | 3 | 90.41 | 2.00 | 0.12 |
| Emotion x Sex x N2pc | 3 | 118.35 | 2.50 | 0.06 |
| Emotion x Average SCARED x Age | 3 | 92.70 | 3.13 | 0.03 |
| Emotion x Average SCARED x N2pc | 3 | 119.69 | 3.72 | 0.01 |
| Sex x Age x N2pc | 1 | 124.63 | 6.28 | 0.01 |

**Table 14** Estimates of Fixed Effects: Visual Search Slope (N2pc)

| Parameter | Est. | Std. E | df | t | Sig. | - 95% CI | + 95% CI |
|---|---|---|---|---|---|---|---|
| Int./Contrast: Scrambled (Male) | 97.00 | 25.44 | 91.19 | 3.81 | 0.00 | 46.48 | 147.53 |
| Angry (Male) | 19.06 | 22.00 | 107.12 | 0.87 | 0.39 | -24.55 | 62.67 |
| Fear (Male) | 5.23 | 20.12 | 90.60 | 0.26 | 0.80 | -34.73 | 45.20 |
| Happy (Male) | 5.72 | 24.19 | 76.46 | 0.24 | 0.81 | -42.46 | 53.90 |
| Contrast: Scrambled (Female) | 73.94 | 37.91 | 92.11 | 1.95 | 0.05 | -1.34 | 149.23 |
| Angry (Female) | -44.30 | 32.19 | 105.93 | -1.38 | 0.17 | -108.12 | 19.52 |
| Fear (Female) | 5.47 | 30.14 | 92.05 | 0.18 | 0.86 | -54.39 | 65.34 |
| Happy (Female) | 50.89 | 36.44 | 78.70 | 1.40 | 0.17 | -21.65 | 123.42 |
| Age x N2pc (Female) | -5.66 | 2.26 | 124.63 | -2.51 | 0.01 | -10.14 | -1.19 |
| Age x N2pc (Male) | 1.97 | 1.57 | 111.13 | 1.26 | 0.21 | -1.14 | 5.07 |
| Contrast: Scrambled x Average SCARED (Male) | -36.22 | 25.15 | 103.26 | -1.44 | 0.15 | -86.08 | 13.65 |
| Angry x Average SCARED (Male) | 57.24 | 22.04 | 115.75 | 2.60 | 0.01 | 13.59 | 100.89 |
| Fear x Average SCARED (Male) | 39.46 | 19.83 | 93.48 | 1.99 | 0.05 | 0.09 | 78.82 |
| Happy x Average SCARED (Male) | 18.88 | 23.95 | 86.11 | 0.79 | 0.43 | -28.73 | 66.49 |
| Contrast: Scrambled x Average SCARED (Female) | 11.09 | 20.70 | 84.01 | 0.54 | 0.59 | -30.08 | 52.25 |
| Angry x Average SCARED (Female) | -18.10 | 17.33 | 99.50 | -1.04 | 0.30 | -52.48 | 16.29 |
| Fear x Average SCARED (Female) | -33.04 | 15.99 | 88.37 | -2.07 | 0.04 | -64.82 | -1.26 |
| Happy x Average SCARED (Female) | -14.74 | 19.73 | 72.68 | -0.75 | 0.46 | -54.06 | 24.58 |
| Contrast: Scrambled x Age (Male) | 2.49 | 7.98 | 87.63 | 0.31 | 0.76 | -13.37 | 18.35 |
| Angry x Age (Male) | -3.42 | 6.70 | 101.69 | -0.51 | 0.61 | -16.72 | 9.88 |
| Fear x Age (Male) | 0.70 | 6.13 | 88.44 | 0.11 | 0.91 | -11.49 | 12.88 |
| Happy x Age (Male) | -1.32 | 7.53 | 73.41 | -0.18 | 0.86 | -16.32 | 13.68 |
| Contrast: Scrambled x Age (Female) | -21.16 | 12.19 | 90.12 | -1.74 | 0.09 | -45.38 | 3.05 |
| Angry x Age (Female) | 12.08 | 10.20 | 102.87 | 1.18 | 0.24 | -8.15 | 32.30 |
| Fear x Age (Female) | -0.70 | 9.50 | 90.23 | -0.07 | 0.94 | -19.56 | 18.17 |
| Happy x Age (Female) | -9.80 | 11.64 | 76.74 | -0.84 | 0.40 | -32.98 | 13.37 |
| Contrast: Scrambled x N2pc (Male) | -12.78 | 5.60 | 117.60 | -2.28 | 0.02 | -23.87 | -1.70 |
| Angry x N2pc (Male) | 5.17 | 4.98 | 123.58 | 1.04 | 0.30 | -4.69 | 15.03 |
| Fear x N2pc (Male) | 7.27 | 5.28 | 110.51 | 1.38 | 0.17 | -3.20 | 17.74 |
| Happy x N2pc (Male) | 1.02 | 5.55 | 137.92 | 0.18 | 0.85 | -9.96 | 12.01 |
| Contrast: Scrambled x N2pc (Female) | 17.45 | 8.01 | 121.42 | 2.18 | 0.03 | 1.59 | 33.32 |
| Angry x N2pc (Female) | 11.77 | 6.44 | 113.63 | 1.83 | 0.07 | -0.99 | 24.53 |
| Fear x N2pc (Female) | -1.46 | 6.37 | 97.69 | -0.23 | 0.82 | -14.10 | 11.17 |
| Happy x N2pc (Female) | 13.78 | 7.42 | 134.08 | 1.86 | 0.07 | -0.89 | 28.45 |
| Contrast: Scrambled x Averaged SCARED x Age (All) | 9.51 | 6.01 | 104.33 | 1.58 | 0.12 | -2.41 | 21.42 |
| Angry x Averaged SCARED x Age (All) | -12.66 | 5.20 | 114.51 | -2.44 | 0.02 | -22.96 | -2.37 |
| Fear x Averaged SCARED x Age (All) | -1.51 | 4.86 | 94.95 | -0.31 | 0.76 | -11.15 | 8.13 |
| Happy x Averaged SCARED x Age (All) | -2.08 | 5.79 | 88.77 | -0.36 | 0.72 | -13.59 | 9.43 |
| Contrast: Scrambled x Averaged SCARED x N2pc (All) | -12.23 | 3.79 | 114.29 | -3.23 | 0.00 | -19.74 | -4.72 |
| Angry x Averaged SCARED x N2pc (All) | 8.86 | 4.94 | 121.47 | 1.79 | 0.08 | -0.92 | 18.65 |
| Fear x Averaged SCARED x N2pc (All) | 15.89 | 5.36 | 125.53 | 2.97 | 0.00 | 5.29 | 26.49 |
| Happy x Averaged SCARED x N2pc (All) | 15.11 | 5.38 | 135.68 | 2.81 | 0.01 | 4.47 | 25.75 |




**QI:** Scrambled N2pc > Emotion N2pc → Scrambled RT > Emotion RT
**QII:** Emotion N2pc > Scrambled N2pc → Scrambled RT > Emotion RT
**QIII:** Scrambled N2pc > Emotion N2pc → Emotion RT > Scrambled RT
**QIV:** Emotion N2pc > Scrambled N2pc → Emotion RT > Scrambled RT

**Figure 11.** Relations between Average N2pc Slope, Emotion, Anxiety and Visual Search Reaction Time Slope. (a) Low Anxious Half of Sample. (b) High Anxious Half of Sample

### *5.3 Aim 3*

*Aim 3. Examine the interaction of significant sensory (Aim 1), and significant attention processing during visual search (Aim 2), and relations with behavioral performance, prime condition, task difficulty, age and anxiety.*

Given the numerous interactions across Aims 1 & 2, several path models were constructed, with the overarching goal of informing a comprehensive theoretical model of the present findings. To examine how age, sex, and anxiety relate to the effects of the fear, angry, and happy primes on the P1, N170, N2 and N2pc ERPs, as well as predict reaction time, several additional data processing steps were applied. First, given the limited applications of path SEM models to repeated categorical predictors, differences scores (e.g. Scrambled – Angry) were calculated for each of the dependent variables: P1 amplitude, N170 amplitude, N2 Slope, N2pc Slope, and Reaction Time slope. Given the findings from Aims 1 & 2, this section focuses on models only including P1 and N2pc variables, however a full model can be found in the appendix (See Appendix B). We added an anxiety group variable to more easily examine anxiety related effects; a median split was used to create two groups such that one group represented half of the participants with the highest anxiety scores, while the second represented the half of the participants with the lowest anxiety scores. These anxiety-specific groupings were used to aid in interpretation of resulting pathways using (Muthén & Muthén) by directly testing whether path estimates for each group significantly differed. Thus, each of the models included data from all 54 participants with usable EEG and RT data, compared model findings from each anxiety half of the sample ($n$ = 27 per group), and included the independent variables age (centered) and sex (coded as 0 or 1), and the following predictors in the specified order (all difference scores for each condition in relation to scrambled): P1, N2pc, with a final dependent variable of reaction time slope. For each model, insignificant terms and paths above *p* = .2 were removed, and all indirect effects were examined.

**5.3a Path Model Results**

Across the three emotion comparisons, there were several consistent paths for both the high and low anxious halves of the sample. Sex was a significant predictor of ΔP1 for the fear and happy comparisons; moreover, this path was at trend level for the angry comparison in the high anxious half of the sample. Group comparisons of these paths indicated that the path estimates across each of the three model comparisons did not differ significantly between the high and low anxious halves of the sample. Thus, across the entire sample, males had larger positive differences in P1 amplitudes to scrambled compared to each emotion, angry fear, and happy, while females had differences closer to zero. These results mirror sex-related P1 differences found in *Aim 1* (**See Figure 12**).

While age was not a significant predictor in the fear model, there were consistent findings in the Angry and Happy models for the age to ΔP1. The significant paths from Age to ΔP1 predicted significantly larger ΔP1 in younger participants, specifically with P1 amplitudes to scrambled larger than to angry or happy, and these differences becoming increasingly smaller, and reversed with increasing age. While this path wasn't significant for the high anxious sample for the angry model, or the low anxious for the fear model, tests of the path estimates indicated that the paths did not significantly differ from the low anxious half of the sample, and were still consistent with the above findings (**See Tables 15 & 16**).

The ΔP1 to ΔN2pc slope was only significant for the low anxious half of the sample in the fear model. Specifically, in this case, larger P1 amplitude to a fearful compared to a scrambled face related to attenuation of the N2pc slope to the fearful prime condition compared to the scrambled prime condition *(***See Figure 12d**).

For the low anxious participants, Sex related to ΔReaction Time Slope in the angry and happy models. While males did not display large behavioral differences in angry and happy versus scrambled, females tended to have larger reaction time slopes to angry and happy primes as compared to scrambled. Perhaps most importantly, across each of the three models, for high anxious participants, there were significant pathways neural pathways that predicted changes in behavior: for the high anxious participants only, there were significant negative relations between ΔN2pc and ΔReaction Time Slope. The greater the difference of the N2pc slope (e.g. more negative slope) to the angry, happy or fear conditions compared to scrambled, the larger reaction the reaction time slope cost (e.g. increasingly costly) to these emotions compared to scrambled (**See Figure 12**). These findings were highly consistent with the second set of analyses for *Aim 2*. The trend level effect for the ΔN2pc and ΔReaction Time Slope path in the low anxious participants was exactly the opposite for the angry condition only: the greater the difference of the N2pc slope (e.g. more negative slope) to the angry condition compared to scrambled, the larger facilitation effect of reaction time slope cost (e.g.

less costly) to angry compared to scrambled. Comparisons of path estimates indicated that high and low halves of the sample significantly differed for the Happy and Angry models, however, not for the fear model (**See Tables 15 & 16**).

**Table 15** Path Mediation Models.

| ***Angry Model*** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Low Anxious | | | | High Anxious | | | |
| Path | Estimate | SE | Est./S.E. | P-Value | Estimate | SE | Est./S.E. | P-Value |
| RT on N2pc | 0.347 | 0.219 | 1.585 | 0.113 | -0.295 | 0.135 | -2.178 | 0.029 |
| N2pc on P1 | 0.217 | 0.265 | 0.821 | 0.412 | 0.033 | 0.277 | 0.118 | 0.906 |
| P1 on Sex | -0.100 | 0.211 | -0.471 | 0.638 | -0.335 | 0.196 | -1.711 | 0.087 |
| P1 on Age | -0.357 | 0.146 | -2.444 | 0.015 | -0.210 | 0.170 | -1.237 | 0.216 |
| Intercepts | | | | | | | | |
| P1 | 1.665 | 0.638 | 2.609 | 0.009 | 1.180 | 0.524 | 2.254 | 0.024 |
| N2pc | -0.152 | 0.191 | -0.793 | 0.428 | 0.249 | 0.261 | 0.957 | 0.339 |
| RT | -0.024 | 0.214 | -0.114 | 0.909 | 0.152 | 0.213 | 0.713 | 0.476 |
| Residual Variances | | | | | | | | |
| P1 | 0.872 | 0.117 | 7.453 | 0.000 | 0.816 | 0.139 | 5.863 | 0.000 |
| N2pc | 0.953 | 0.107 | 8.875 | 0.000 | 0.999 | 0.095 | 10.561 | 0.000 |
| RT | 0.879 | 0.132 | 6.672 | 0.000 | 0.913 | 0.082 | 11.148 | 0.000 |

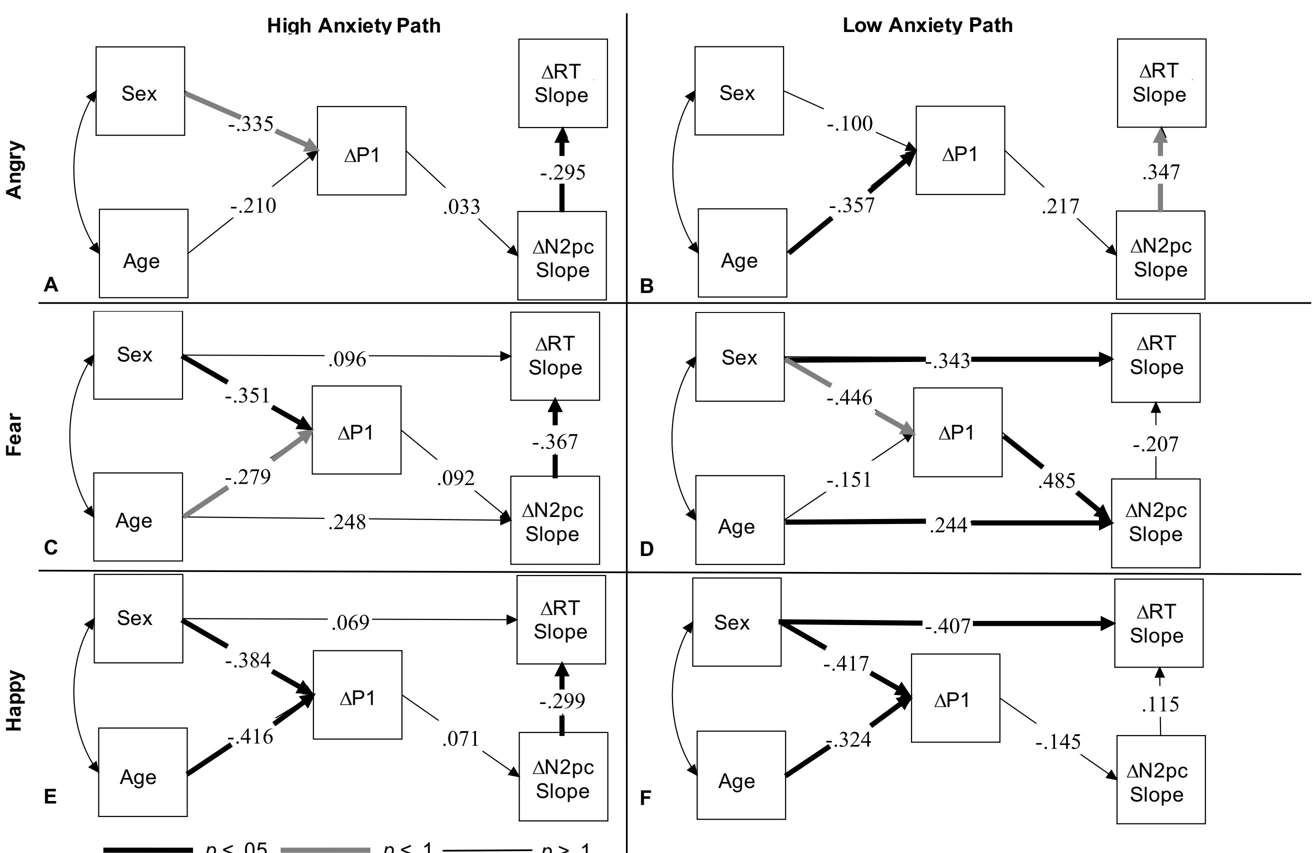



**Figure 15.** Path analyses for comparisons of Angry, Fear, and Happy compared to Scrambled Primes.

| ***Fear Model*** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Low Anxious | | | | High Anxious | | | |
| Path | Estimate | SE | Est./S.E. | P-Value | Estimate | SE | Est./S.E. | P-Value |
| RT on N2pc | -0.207 | 0.221 | -0.937 | 0.349 | -0.367 | 0.170 | -2.159 | 0.031 |
| RT on Sex | -0.343 | 0.165 | -2.081 | 0.037 | 0.096 | 0.196 | 0.492 | 0.623 |
| N2pc on P1 | 0.485 | 0.170 | 2.845 | 0.004 | 0.092 | 0.235 | 0.391 | 0.696 |
| N2pc on Age | 0.244 | 0.124 | 1.965 | 0.049 | 0.248 | 0.180 | 1.378 | 0.168 |
| P1 on Sex | -0.446 | 0.133 | -3.343 | 0.001 | -0.351 | 0.171 | -2.051 | 0.040 |
| P1 on Age | -0.151 | 0.192 | -0.789 | 0.430 | -0.279 | 0.172 | -1.628 | 0.103 |
| Intercepts | | | | | | | | |
| P1 | 1.328 | 0.592 | 2.245 | 0.025 | 1.189 | 0.436 | 2.731 | 0.006 |
| N2pc | -1.065 | 0.396 | -2.690 | 0.007 | -0.259 | 0.571 | -0.454 | 0.650 |
| RT | 0.302 | 0.230 | 1.310 | 0.190 | -0.116 | 0.303 | -0.384 | 0.701 |
| Residual Variances | | | | | | | | |
| P1 | 0.797 | 0.113 | 7.080 | 0.000 | 0.759 | 0.126 | 6.044 | 0.000 |
| N2pc | 0.727 | 0.140 | 5.171 | 0.000 | 0.946 | 0.106 | 8.957 | 0.000 |
| RT | 0.874 | 0.126 | 6.959 | 0.000 | 0.857 | 0.138 | 6.227 | 0.000 |

| ***Happy Model*** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Low Anxious | | | | High Anxious | | | |
| Path | Estimate | SE | Est./S.E. | P-Value | Estimate | SE | Est./S.E. | P-Value |
| RT on N2pc | 0.115 | 0.155 | 0.744 | 0.457 | -0.299 | 0.146 | -2.050 | 0.040 |
| RT on Sex | -0.407 | 0.152 | -2.681 | 0.007 | 0.069 | 0.202 | 0.343 | 0.732 |
| N2pc on P1 | -0.145 | 0.253 | -0.571 | 0.568 | 0.071 | 0.302 | 0.236 | 0.813 |
| P1 on Sex | -0.417 | 0.177 | -2.355 | 0.019 | -0.384 | 0.178 | -2.155 | 0.031 |
| P1 on Age | -0.324 | 0.125 | -2.600 | 0.009 | -0.416 | 0.160 | -2.609 | 0.009 |
| Intercepts | | | | | | | | |
| P1 | 2.186 | 0.535 | 4.086 | 0.000 | 1.922 | 0.441 | 4.360 | 0.000 |
| N2pc | 0.248 | 0.258 | 0.959 | 0.337 | 0.127 | 0.354 | 0.357 | 0.721 |
| RT | 0.073 | 0.211 | 0.348 | 0.728 | 0.016 | 0.256 | 0.064 | 0.949 |
| Residual Variances | | | | | | | | |
| P1 | 0.758 | 0.153 | 4.954 | 0.000 | 0.615 | 0.146 | 4.206 | 0.000 |
| N2pc | 0.979 | 0.082 | 11.926 | 0.000 | 0.995 | 0.126 | 7.894 | 0.000 |
| RT | 0.826 | 0.125 | 6.586 | 0.000 | 0.905 | 0.121 | 7.454 | 0.000 |

**Table 16** Group-level Path Comparisons

| ***Angry Model*** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Path | Low Anxious Est. | High Anxious Est. | Low Anxious SE | High Anxious SE | Contrast Estimate | t-value | P-value |
| RT on N2pc | 0.347 | -0.295 | 0.219 | 0.135 | 0.642 | 2.495 | 0.016 |
| N2pc on P1 | 0.217 | 0.033 | 0.265 | 0.277 | 0.184 | 0.480 | 0.633 |
| P1 on Sex | -0.1 | -0.335 | 0.211 | 0.196 | 0.235 | 0.816 | 0.418 |
| P1 on Age | -0.357 | -0.21 | 0.146 | 0.17 | -0.147 | 0.656 | 0.515 |

| ***Fear Model*** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Path | Low Anxious Est. | High Anxious Est. | Low Anxious SE | High Anxious SE | Contrast Estimate | t-value | P-value |
| RT on N2pc | -0.207 | -0.367 | 0.221 | 0.17 | 0.16 | 0.574 | 0.569 |
| RT on Sex | -0.343 | 0.096 | 0.165 | 0.196 | -0.439 | 1.713 | 0.093 |
| N2pc on P1 | 0.485 | 0.092 | 0.17 | 0.235 | 0.393 | 1.360 | 0.182 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| N2pc on Age | 0.244 | 0.248 | 0.124 | 0.18 | -0.004 | 0.018 | 0.985 |
| P1 on Sex | -0.446 | -0.351 | 0.133 | 0.171 | -0.095 | 0.439 | 0.663 |
| P1 on Age | -0.151 | -0.279 | 0.192 | 0.172 | 0.128 | 0.497 | 0.620 |

***Happy Model***

| Path | Low Anxious Est. | High Anxious Est. | Low Anxious SE | High Anxious SE | Contrast Estimate | t-value | P-value |
|---|---|---|---|---|---|---|---|
| RT on N2pc | 0.115 | -0.299 | 0.155 | 0.146 | 0.414 | 1.944 | 0.058 |
| RT on Sex | -0.407 | 0.069 | 0.152 | 0.202 | -0.476 | 1.883 | 0.066 |
| N2pc on P1 | -0.145 | 0.071 | 0.253 | 0.302 | -0.216 | 0.548 | 0.586 |
| P1 on Sex | -0.417 | -0.384 | 0.177 | 0.178 | -0.033 | 0.131 | 0.896 |
| P1 on Age | -0.324 | -0.416 | 0.125 | 0.16 | 0.092 | 0.453 | 0.652 |

### 5.3b Summary of Model Findings

Sex- and age- related differences across the models appear to function similarly in both low and high anxious halves of our sample. However, significant behavioral paths with the N2pc, only appear to be present in the high anxious portion of our sample. For both low and anxious participants, there were sex differences in the magnitude of the ΔP1, with males having larger P1 amplitudes to scrambled compared to other emotions.

For the high anxious participants across all emotions, the N2pc was the only significant neural predictor of behavior. While there were no significant neural correlates to behavior in the low anxious participants, larger P1 to the scrambled prime compared to the fear primes led to attenuated N2pc slope following an emotion prime compared to the scrambled prime. Finally, across all emotion conditions for the high anxious half of the sample, greater N2pc slopes to the emotion prime compared to scrambled resulted in less efficient reaction time slopes for the emotion compared to scrambled. The trend level effect for the ΔN2pc and ΔReaction Time Slope path in the low anxious participants was exactly the opposite for the angry condition only: the greater the difference of the N2pc slope (e.g. more negative slope) to the angry condition compared to scrambled, the larger facilitation effect of reaction time slope cost (e.g. less costly) to angry compared to scrambled. Comparisons of path estimates indicated that high and low halves of the sample significantly differed for the both the Angry and Happy models.

These findings suggest that in high anxious individuals, both positive and negative emotions have the potential to disrupt attentional neural processes, and affect subsequent behavior, while in low anxious individuals, modulations in related neural processes may be subtler, and differences appear to be emotion specific. Moreover, appropriate initial neural responses during the emotion and face recognition phases may only be relevant to processing of emotions (e.g. fear), and determine the efficiency of subsequent attention related processes, and potentially, behavior. These findings will be further discussed in the context of related literature in the next chapter.

# Chapter 6: Discussion

The objective of the current study was to clarify differences in how various types of irrelevant affective stimuli modulate goal-oriented attention in adolescents, and relate to adolescent anxiety ratings. The first aim of this study was to investigate the variability in early and late occurring sensory processing of face stimuli, as measured by the P1, & N170, components, and how these relate to emotion prime type, age, sex, adolescent's behavioral visual search performance, and anxiety symptoms (Blau et al., 2007; Jetha et al., 2012; Kolassa & Miltner, 2006; O'Toole et al., 2013). In *Aim 1* of this study, early visual processing in the first few hundred milliseconds of viewing the face primes differed as a function of both anxiety and face prime emotion. Moreover, these anxiety-related early processing differences related to subsequent behavior.

The second aim examined the impact of prime type on later occurring attentional processing during visual search, and relations with an adolescent's visual search performance, age, sex, and anxiety symptoms (Bacigalupo & Luck, 2015; Grimshaw et al., 2014; Kappenman et al., 2015; Kashiwase et al., 2013; Luck & Hillyard, 1994; Weymar et al., 2013). In *Aim 2*, variability in attention-related processing during the visual search also varied as a function of anxiety and prime type, as well as affected subsequent behavioral performance.

Finally, the third aim examined how early occurring sensory processes and later goal oriented attentional processing interact and relate to prime type, age, visual search performance, and anxiety symptoms. Results from Aims 1 & 2 supported the theoretical model presented in *Aim 3*: both early and later occurring attentional processes have significant ramifications for individuals with higher anxiety scores, such that in addition to neural differences, high anxious individuals also display significant differences in behavior. While early and late neural processes varied in lower anxious individuals as a function of face prime type, relations with behavior were minimal in comparison.

The present study demonstrates that anxiety related emotion processing differences exist in early and late occurring attentional processes. The observed results support that anxiety symptoms relate to perturbations in the ability to interpret and regulate responses to ambiguous and potentially threatening situations. These neural and behavioral findings are significant—over time, these patterns of biased attention and information processing may shape both the development and maintenance of anxiety symptoms (Bar-Haim et al., 2007; Fox et al., 2005; Pine & Fox, 2015).

The development of the skills necessary to regulate and inhibit attention to threats may differentiate trajectories, indicating those at higher risk for developing a clinical diagnosis of anxiety (Lau et al., 2011; Perez-Edgar & Fox, 2007; Pine & Fox, 2015). The present study adds to prior work, finding modulations in underlying neural processes, particularly the N2pc, that account for anxiety related modulations in behavior in a younger population than originally examined by Haas, et al. (2016).

## *6.1 Aim 1: Emotion, anxiety, P1 and N170 related findings*

The first aim of this study was to investigate the variability in early and late occurring sensory processing of face stimuli, as measured by the P1, & N170, components, and how these relate to emotion prime type, age, sex, adolescent's behavioral visual search performance, and anxiety symptoms (Blau et al., 2007; Jetha et al., 2012; Kolassa & Miltner, 2006; O'Toole et al., 2013). In *Aim 1* of this study, early visual processing in the first few hundred milliseconds of viewing the face primes differed as a function of both anxiety and face prime emotion. Moreover, these anxiety-related early processing differences related to subsequent behavior.

### 6.1a P1 Component

The first aim of this study was to investigate the variability in early and late occurring sensory processing of face stimuli, as measured by the P1, & N170, components, and how these relate to emotion prime type, age, sex, adolescent's behavioral visual search performance, and anxiety symptoms (Blau et al., 2007; Jetha et al., 2012; Kolassa & Miltner, 2006; O'Toole et al., 2013). In *Aim 1* of this study, early visual processing in the first few hundred milliseconds of viewing the face primes differed as a function of both anxiety and face prime emotion. Moreover, these anxiety-related early processing differences related to subsequent behavior.

*P1 Component*

The present study found emotion and anxiety related differences with the P1 ERP component. The most pervasive P1 finding throughout all the analyses was the effect of gender: males had smaller P1 to angry, fear, and happy primes compared to Scrambled prime. Moreover, younger children had larger P1 amplitudes to the Scrambled prime compared to the other primes whereas, for older children, the reverse was true; P1 amplitudes to all other emotions trended towards being larger than the P1 amplitude to the Scrambled prime.

While anxiety did not predict differences in P1 amplitudes, our analyses in *Aim 1* indicated that anxiety interacted with P1 amplitudes and emotion prime condition to predict behavior: when participants were primed with fearful faces, anxiety moderated the relation between early sensory processing (P1 Amplitude) and later performance on the visual search task. Specifically, for participants who elicited a greater initial P1 processing response primed to the scrambled compared to fear prime condition, subsequent visual search performance for fear prime trial types was degraded, compared to scrambled prime trial types. For participants with higher anxiety scores, the same pattern was observed, however, initial P1 processing predicted increasingly larger differences as a function of anxiety between subsequent visual search performance for fear compared to scrambled prime trial types.

Researchers have previously attributed heighted P1 to emotional faces to heightened arousal, attention or a general vigilance to these types of stimuli (Harrewijn et al., 2017; Vuilleumier & Pourtois, 2007). On average across our sample, the scrambled prime elicited the largest P1 response of all 4 conditions. While this did not vary by anxiety, the magnitude of the difference between the P1 response to the fearful versus scrambled prime interacted with anxiety to predict behavioral performance. The smaller the P1 to the fear prime, the more behavioral performance on the task was degraded for the fear compared to the scrambled condition.

It may be that the P1 amplitude to the scrambled face was reflecting an "oddball" detection. From this perspective, greater activity to the oddball condition resulted in better behavioral performance during the oddball condition compared to the fear condition, with anxiety moderating this relation. This interpretation would suggest that stimuli that lead to larger arousal as measured by the P1, facilitates or primes attention for subsequent goal completion. This relation gets stronger with higher anxiety scores. These results are distinct from prior P1-related findings.

Our main effect findings are consistent with number of studies: on average, participants had larger P1 amplitudes to angry and fear faces primes compared to happy face primes. Several studies have found larger P1 amplitudes to negative versus neutral or happy emotions (Luo et al., 2010), and additionally found that the magnitude of this difference was even larger in high anxious individuals (Holmes et al., 2008). As well, one study found that the large priming effect of fearful primes in high trait anxious individuals, also related to behavioral results (Li et al., 2008). While these studies used other emotional stimuli, the present study used a scrambled face as the baseline/comparison condition.

To examine whether there were consistent findings for the fear and angry comparisons as found in prior studies, exploratory analyses were run using the happy prime condition as the baseline. The exploratory analyses did not yield any signficaint anxiety related or behavioral differences. These analyses further support that the comparison of the fear prime to the scrambled was driving the anxiety related interaction.

Perhaps the priming effects of the scrambled condition observed in the present study reflect a combination of an oddball detection, and lack of recruitment of more limbic structures. It is possible that the event related P1 to the scrambled face reflected a visual oddball effect, but because the scrambled stimuli have no emotional content to be interpreted, widespread recruitment of emotion processig circuitry is not engaged, and thus does not deplete resources needed to complete the visual search task. Even though the P1 is not modulated in the fear condition to the extent of the scrambled prime condition, perhaps subsequent engagement of emotion processing circuitry uses up resources that would otherwise be utilized for task completion. Thus the obesreved anxiety related differences may be the result of greater deficits in the fear related performance as opposed to facilitation of performance for the scrambled condition.

Related, while Rotshtein et al. (2010) found that P1 amplitudes were significantly diminished in patients with amygdalar damage, the P1 component was still present. This suggests that while amygdala activity may make significant contributions to the P1 ERP component, activity from other areas also modulate the P1 (Jetha, Zheng, Schmidt, & Segalowitz, 2012; Harrewijn et al., 2017; Rotshtein et al., 2010). Thus, interpreting amygdalar and P1-related findings in terms of vigilance and bottom up processing may not account for key contributions of regions, during stimulus processing (Mattavelli, Rosanova, Casali, Papagno, & Lauro, 2016; Miskovic & Schmidt, 2012; Schulz, Mothes-Lasch, & Straube, 2013; Harrewijn et al., 2017).

The present study had both consistent and inconsistent P1 results with the extant literature. First, consistent with a number of studies, threat-related emotions elicited larger P1 amplitudes across the entire sample. While several studies have demonstrated that the largest effects of threat-related emotions on the P1 are in anxious individuals, the present study did not find anxiety related differences. Lastly, inconsistent with prior studies, anxiety related differences in behavior were driven by the mangintude of the difference of the P1 amplitude for the fear versus the scrambled condition.

### 6.1b N170 Component

While the P1 is associated with emotion and arousal related processing, the N170 is more commonly associated with quick expertise processing of salient features, including facial structure and facial emotions (Blau et al., 2007; Luck, 2005). In the present study, P1 amplitude did not vary as a function of anxiety, however, the N170 did. Lower anxiety scores were associated with larger N170 amplitudes to scrambled primes compared to fear primes, while higher anxiety scores were associated with larger N170 amplitudes to fear compared to scrambled primes. For females, low anxious females had close to equal N170 amplitudes to scrambled and fear primes, and higher anxiety scores were related to increasingly larger N170 amplitudes to fear relative to scrambled primes. Moreover, in females only, lower anxiety scores related to larger N170 amplitudes to angry or happy compared to scrambled primes, while higher anxiety scores were associated with larger N170 amplitudes to scrambled compared to angry and happy primes.

These findings are somewhat consistent with prior findings of increased N170 sensitivity for each fear, angry, and happy compared to neutral faces (Batty & Taylor, 2003; Carlson & Reinke; Denefrio et al., 2017 & Dennis-Tiwary, 2017; Hinojosa et al., 2015 2015; Itier & Neath-Tavares, 2017; Leppänen et al., 2007; Pourtois et al., 2005; Stekelenburg & de Gelder, 2004; Sun et al., 2017 2017). For example, Fajkowska et al. (2011), noted a larger N170 amplitude to threatening faces (collapsed across angry and fearful faces) in the high anxious group, as well as hypervigilance as measured by behavioral reaction time. While the present study found consistent findings with the fear prime, no anxiety related modulations of behavior related to N170 amplitude were observed. Moreover, fearful primes and angry primes each related differently to anxiety.

In contrast to the findings of the present study, several studies have noted larger amplitudes to angry faces as a function of anxiety. O'Toole et al. (2013) noted that the N170 amplitude to an angry face versus neutral face varies, and children exhibiting higher anxiety as well as larger N170 amplitudes to angry faces had a greater risk for future anxiety. These findings have led researchers to suggest that the N170 component is sensitive to individual differences in processing of threatening facial expressions, specifically due to varying levels of anxiety, and may differentiate those at risk for anxiety.

One significant limitation of previous work examining the N170 has been the lack of co-varying the preceding P1 amplitude. While the P1 amplitude is an average of both hemispheres, the P1 in the right hemisphere is typically maximal a mere 70ms prior to the N170. Thus, without controlling for the preceding P1 peak in the right hemisphere, measurements of the N170 are potentially confounded. Given the mixed findings in the literature, as well as observed findings in the present study, further clarification is needed to understand the function of the N170, as well as anxiety related findings (Harrewijn et al., 2017; Hinojosa, Mercado, & Carretie, 2015).

### *6.2 Aim 2: Emotion, anxiety, and N2pc related findings*

The second aim examined the impact of prime type on later occurring attentional processing during visual search, and relations with an adolescent’s visual search performance, age, sex, and anxiety symptoms (Bacigalupo & Luck, 2015; Grimshaw et al., 2014; Kappenman et al., 2015; Kashiwase et al., 2013; Luck &

Hillyard, 1994; Weymar et al., 2013). In *Aim 2*, variability in attention-related processing during the visual search also varied as a function of anxiety and prime type, as well as affected subsequent behavioral performance.

Consistent with Moran & Moser (2017) we found anxiety related N2pc variability and behavior. Across the entire sample, angry and fear conditions led to larger N2pc changes as a function of difficulty compared to the scrambled condition. Particularly in females, this was significant for the angry condition compared to the scrambled condition. that heightened N2pc related to slowed behavioral reaction time for the high anxious half of the sample.  Moran and Moser (2015) had proposed that their findings may have reflected that anxious individuals were using inefficient attentional filters—they had increased attention when there was irrelevant information, but this increased attention did not improve accuracy or reaction time—rather it resulted in behavioral slowing. As well, Tsai et al. (2017) found greater N2pc amplitudes as a function of difficulty in high anxious individuals, while low anxious individuals did not display the same differences in N2pc amplitudes. Similar to the conclusions of Moran and Moser (2015), Tsai et al. (2017) attributed these results to high anxious individuals adopting less advantageous attentional mechanisms to inhibit irrelevant items to detect the target, thus using more attentional resources. While the N2pc is generated in extra-striate visual cortex, its' modulation to task difficulty is believed to reflect the recruitment of, and communication with, top-down posterior parietal attentional control centers (Fox et al., 2008a; Luck & Hillyard, 1994).

The present study added an additional dimension: irrelevant emotional stimuli. The presented results emerged as a function of face versus non-face for the N2pc and behavioral relations with anxiety. While prior work on the same task has found attentional slowing in higher anxious individuals (Haas et al., 2016), this effect was specific to threat-cuing emotions, surprised, fearful and angry emotions. One possibility for this difference could be the sensitivity of the neural measures collected as part of this study. It is quite possible that all valenced facial expressions differentially modulate attention in high anxious individuals, but the behavioral effect is more pronounced and observable for threat cuing conditions.

These findings also have similarities to prior N2pc findings observed during dot-probe tasks (Torrence & Troup, 2017). The N2pc anxiety findings during the angry prime condition is consistent with studies that have found increased N2pc to the angry faces preceding the probes (Holmes et al., 2009; Holmes et al., 2014). Similar results were also found by Reutter et al. (2017). Higher anxiety scores were related to larger attention biases towards threat as measured by the N2pc (e.g. larger N2pc to threat) and the magnitude of the N2pc was larger for more severe anxiety symptoms.

In sum, the N2pc findings are consistent with prior work both on a non valenced visual search and emotion related modulation examined during the dot-probe. These findings add that larger N2pc following all emotions may potentially affect behavioral outcomes as a function of anxiety.

### *6.3 Aim 3: Model of early emotion processing, attention & behavior*

The third aim examined how early occurring sensory processes and later goal oriented attentional processing interact and relate to prime type, age, visual search performance, and anxiety symptoms. Results from Aims 1 & 2 supported the theoretical model presented in *Aim 3*: both early and later occurring attentional processes have significant ramifications for individuals with higher anxiety scores, such that in addition to neural differences, high anxious individuals also display significant differences in behavior. While early and late neural processes varied in lower anxious individuals as a function of face prime type, relations with behavior were minimal in comparison.

Furthermore, when we put P1 and N2pc in the same path model, only N2pc predicted behavior. Given our significant findings in Aim 1, the high correlation between the two measures, it is possible that due to a multicollinearity issue of the two variables, as well as having an underpowered sample, that the N2pc path reflected more variance and the P1 effects on behavior were no longer signficant.

Consistent with the existing literature, our N170 findings were not compelling. N170 did not significantly predict anxiety related differences in behavior as did N2pc and P1. Given the close temporal proximity of the two components, one might expect them to have consistent results. It may be that while the N170 is a "face-processing" index, the P1 process is better sensitive to valence and emotion related processing.

### *6.4 Limitations and Future Directions*

There were several limitations to this study that may have limited detectability for additional findings. First, the study sample size with usable ERP data was rather small for the number of variables included across the various analyses. Moreover, for each analysis, numerous parameters were used to estimate each model. One option to control for false discovery rate (FDR) is the Benjamini-Hochberg procedure (Benjamini and Hochberg, 1995). As noted in the appendix, many of the significant findings across the models did not survive the FDR correction (See Appendix C). Of note, all reported findings examining differences in P1 amplitude survived, as well as N2pc anxiety related findings with behavior, for the fear condition specifically. For all N170 analyses, only the intercept survived as a significant parameter. As well, neither the P1 model predicting behavior nor model examining differences in N2pc amplitude had any parameters which survived the FDR correction. While the surviving results mirrored findings of the path analysis, as well as reflected the most important findings of the study, it is important to consider that the analyses in the present study were underpowered, and many of the reported statistics may have survived the FDR correction if for example, greater power were achieved by a larger number of participants.

As well, the detectability of the effect may have been diminished based on actual measurement of summary scores: reaction time, and ERP components. Each set size and emotion condition only included 24 trials, due to time constraints and likelihood of study fatigue in children. Many studies examining components such as the N2pc include close to 100 trials per condition. Future versions of the study will aim to reduce the number of conditions to increase the number of trials per condition. There were very few related age effects in our study. Given our age range was 12-17, there is a strong possibility that this did not allow for enough developmental variability. Because anxiety disorders begin earlier than adolescents, or children may demonstrate at risk temperaments such as behavioral inhibition, it would be important to run a similar study across a wide age range, including children younger than 12 years of age.

Understanding the typical development of both emotion processing and the effects of emotion context on visual attention is essential to creating effective treatment programs for children and adolescents with pediatric anxiety. Research has suggested that in subclinical levels of anxiety, children who do not develop the ability to appropriately regulate and inhibit automatic fear responses to ambiguous stimuli may be at higher risk for developing a clinical anxiety disorder than others (Lau et al, 2011, Pine & Fox, 2015). Moreover, because emotion processing skills and attentional biases develop at a young age, and as a function of experience, an understanding of early attentional biases existing in children can provide methods of earlier identification of children at risk for disorders such as pediatric anxiety, as well as the development of early intervention programs (Pine, 2007). This is particularly relevant to attention bias modification treatments currently in place, which have shown that changing an individuals' visual attention bias away from threatening faces improves anxiety symptomology (Eldar et al., 2012).

To add to this growing body of literature, future directions will incorporate other means of neural imaging, as well as eye tracking and pupillometry measures to understand the precise timing of neural mechanisms driving the behavioral findings observed in this study, and previous findings in adults (Haas et al., 2016). Moreover, to understand how risk factors, such as infant temperament and behavioral inhibition, for later anxiety disorders in adolescence may also affect visual attention (Perez-Edgar et al., 2011), follow up studies with younger ages are necessary. Understanding how to capitalize on the development and plasticity of emotion processing, a key contributing factor in risk for anxiety, is essential to the improvement of currently existing interventions, as well as the development of new early intervention programs. In addition to a wider age range, future studies should also include clinical populations.

While this study found anxiety related differences, the sample was for the most part below the clinical threshold, and may not reflect aberrant processing that occurs when someone has a diagnosis of an anxiety related disorder.

Importantly, limited developmental work has examined the effects of emotional context on efficiency of attention with various levels of clutter in the visual environment as the present study examined (Pine, 2007; Pine et al., 2009). A child's everyday environment is full of social stimuli, and various extraneous visual and auditory stimuli. Excessive processing of irrelevant affective stimuli may tax and interfere with resources necessary for other important demands. Thus, it is imperative to examine attentional processing streams in experimental contexts that attempt emulate attentional demands that individuals face in their typical environment. As well, given the concerns of reliability with related attention and threat processing tasks such as the dot-probe task, further replications of the present study, as well as test-retest iterations are necessary. This emotion priming visual search task has not be psychometrically validated, and the present results would be more impactful (as with any paradigm) if reliability is established.

While the present study aimed to vary the amount of visual clutter to more accurately examine attention, as with any computer based psychological test, understanding the real-life implications of the observed findings are limited. Additional measures that would bridge this gap would include examining indicators of success and achievement such as standardized school assessments. While the results of the present study do find significant and anxiety related findings, further research and clarification is necessary to understand how these affect day to day attention and information processing.

### 6.5 Conclusions: overarching significance and implications

The present study demonstrates that anxiety related emotion processing differences exist in early and late occurring attentional processes, and adds to prior findings that anxiety symptoms relate to perturbations in the ability to interpret and regulate responses to ambiguous and potentially threatening situations (Bar-Haim et al., 2007; Pine, 2007; Pine & Fox, 2015). It is important to consider that emotion processing may rely on the quality of connectivity between rapid 'bottom-up' processing, and later maturing 'top-down' executive attentional control regions (Pine & Fox, 2015; Heeren, Maurage, & Philippot, 2015; Telzer et al., 2008; White, McDermott, Degnan, Henderson, & Fox, 2011). As well, the recruitment of the late developing prefrontal cortex makes significant contributions to threat appraisal, and subsequent behavioral and attentional orienting responses (Pessoa & Adolphs, 2010; Shechner et al., 2012). Thus, the observed N2pc related results could reflect anxiety related differences in the coordination of emotion processing and attentional networks.

These neural and behavioral findings are significant—over time, these patterns of biased attention and information processing may shape both the development and maintenance of anxiety symptoms (Bar-Haim et al., 2007; Fox et al., 2005; Pine & Fox, 2015). The development of the skills necessary to regulate and inhibit attention to threats may differentiate trajectories, indicating those at higher risk for developing a clinical diagnosis of anxiety (Lau et al., 2011; Perez-Edgar & Fox, 2007; Pine & Fox, 2015). For example, in children identified with the temperament of Behavioral

Inhibition (BI), early observed hyper-vigilance significantly increases the likelihood of a clinical anxiety disorder later (Fox et al., 2005). As with other studies, the present study observed anxiety-related findings in a typical population (Bar-Haim et al., 2007; Fox et al., 2005). The prevalence of anxiety related findings further warrants examining these same relations in clinical populations, as the effect may be stronger and result in significantly more negative trajectories.

Most relevant to the present findings is work in adults (Haas, Amso, & Fox, 2016) which used a variant of the emotion priming visual search. Haas, et al. (2016) demonstrated consistent results as reported by Becker (2009) in healthy adults: individuals with low reported levels of social anxiety exhibited enhanced visual search efficiency when primed with fear, angry, and surprised emotions. When affective stimuli are relevant, modulation of attentional resources should vary as a function of stimulus relevance or "meaning". However, when affective stimuli are irrelevant to the task at hand, it is ideal to inhibit further processing of the irrelevant affective stimuli, while maximizing resources for task completion. A variety of research findings support the hypothesis that anxious adults do not appropriately inhibit the attentional processing of task-irrelevant affective stimuli.

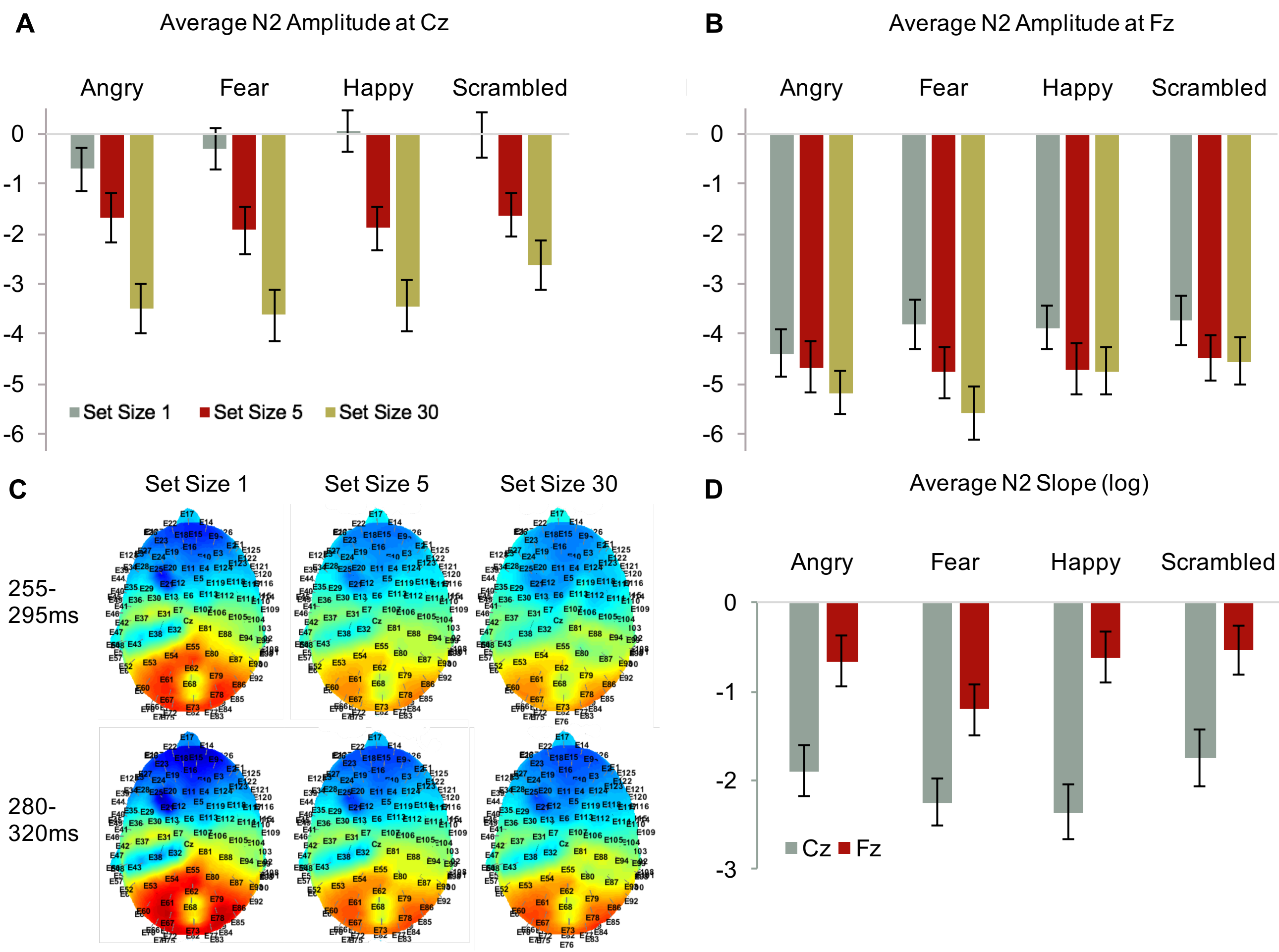
The present study adds to these findings, finding modulations in underlying neural processes, particularly the N2pc, that account for anxiety related modulations in behavior in a younger population than originally examined by Haas, et al. (2016). The strongest N2pc and anxiety related findings were specific to the fear condition—only this emotion effect survived the most stringent criteria for significance in the post-hoc Benjamini-Hochberg correction (Benjamini and Hochberg, 1995). Thus, while positive and negative emotions may have the potential to disrupt attentional neural processes, negative emotions, specifically fear, have the strongest effects on subsequent behavior as a function of higher anxiety symptoms, while in low anxious individuals, modulations in related neural processes may be subtler or could be statistical artifacts. Further research is deserved.

# Appendices

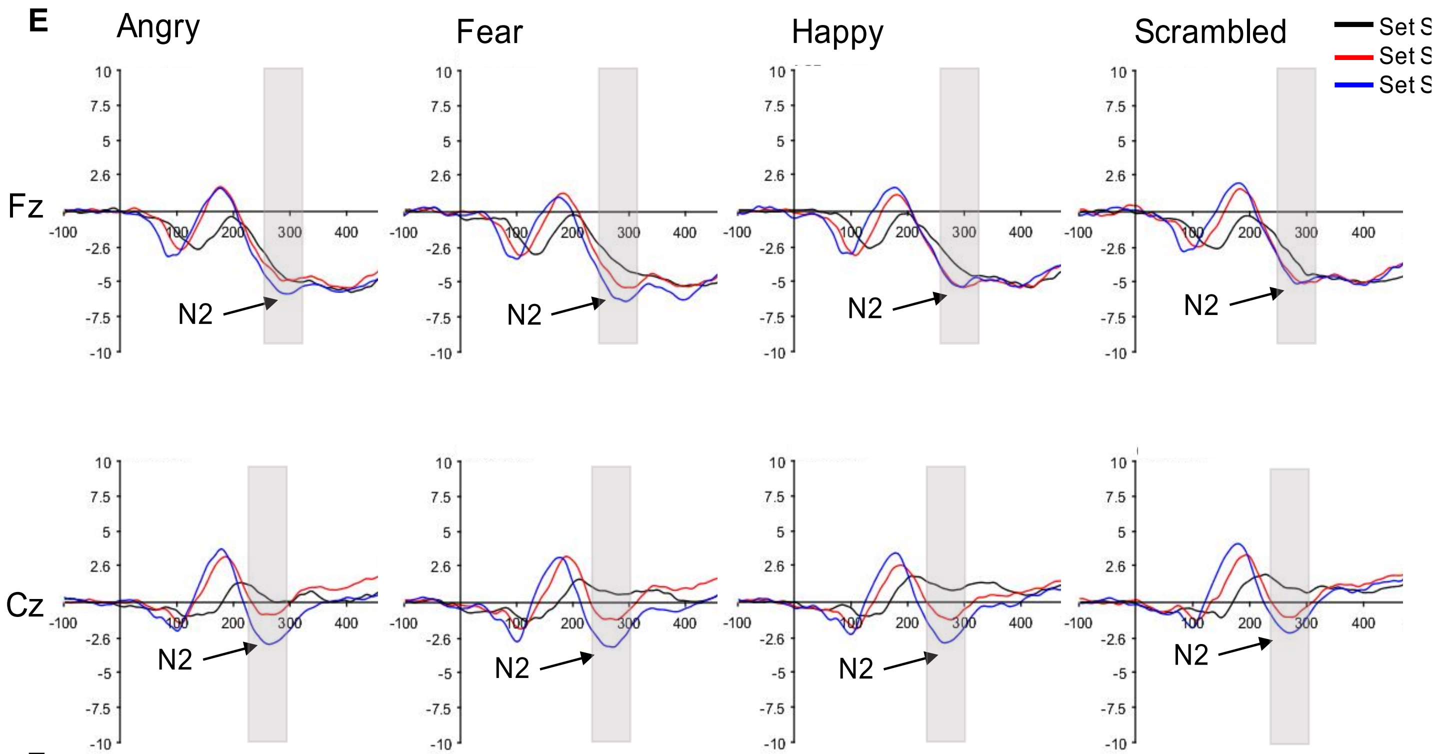
## *Appendix A: Emotion, anxiety, N2 related findings*

### A1. Examining variability in N2 Amplitude/Slope

The final model, with a AIC fit-value of 884.60, was fitted using the Factor Analytic: First Order covariance structure, with both fixed effects and subject level random effects intercepts. This final model included all interaction possibilities of the 4 fixed-effects variables, with insignificant higher level interactions removed from the final model. The following the following fixed effects terms were significant: Intercept, main effect of Age, as well as a two-way interaction of Emotion X Sex. For the two-way interaction of Emotion X Sex, estimates of fixed effects indicated that angry significantly differed by sex, and fear and happy had a trend level effect by sex. Specifically, for females, the N2 slope for the Angry prime was smaller (less negative) than the N2 slope to the scrambled prime. In other words, the magnitude of set size related modulations of the N2 following Angry primes was smaller than following a scrambled prime (**Figure 10f-g**). For males, the opposite was true: the N2 slope for the Angry prime was larger (more negative) than the N2 slope to the scrambled prime. In other words, the magnitude of set size related modulations of the N2 following an Angry prime was greater than following a scrambled prime (**Figure 10f-g**). The trend level effect for emotions fear and happy and sex followed the same pattern.



A
Average N2 Amplitude at Cz
Angry
Fear
Happy
Scrambled
Set Size 1
Set Size 5
Set Size 30
B
Average N2 Amplitude at Fz
C
Set Size 1
Set Size 5
Set Size 30
255-295ms
280-320ms
D
Average N2 Slope (log)
Cz
Fz





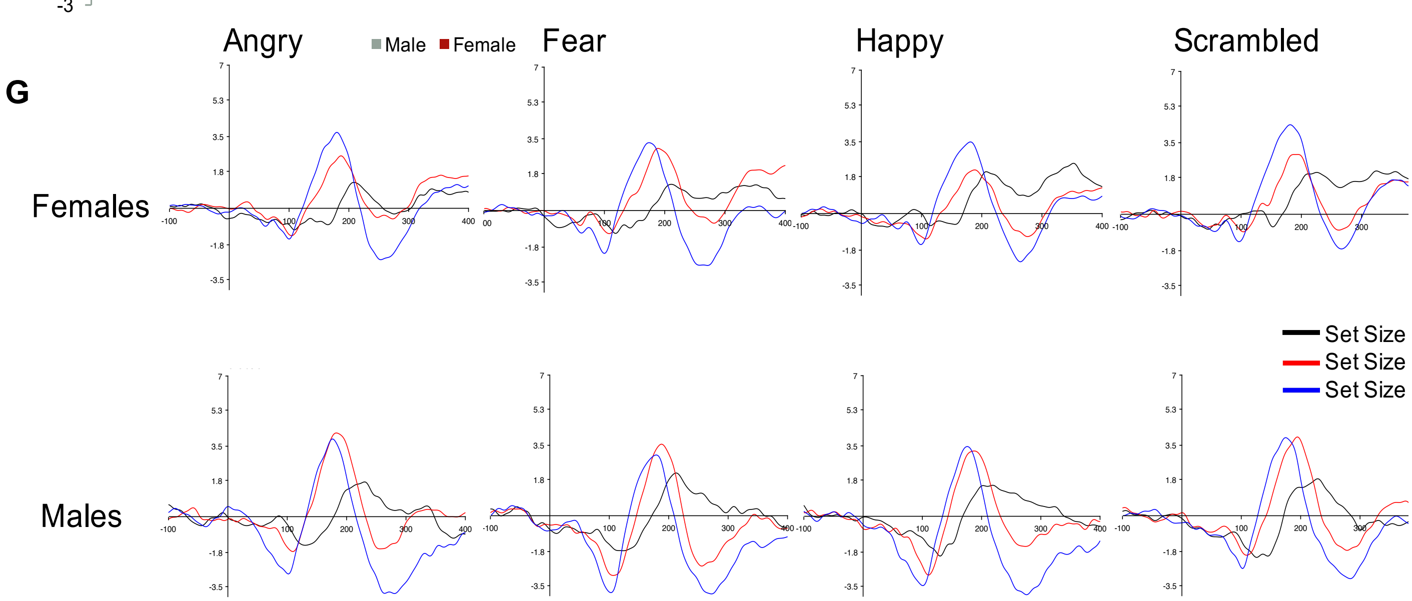



**Figure 10.** Relations between Average N2 Amplitude, Emotion, Sex, and Age (a) N2 by emotion and set size at Cz (b) N2 by emotion and set size at Fz (c) Scalp Distribution at Cz ar Fz optimal latencies (d) N2 Slope by emotion at Cz and Fz (e) Waveforms by emotion and set size at Cz and Fz (f) N2 slope by Sex and emotion at Cz (g) Waveforms by emotion, set size, and sex at Cz.

**A2. Examining the relations of N2 Amplitude variability and behavior**

The final model, with a AIC fit-value of 2058.67, was fitted using the Factor Analytic: First Order covariance structure, with both fixed effects and subject level random effects intercepts. This final model included all 5 fixed-effects variables with insignificant terms removed. The following the following fixed effects terms were significant predictors of visual search reaction time slope: Intercept, main effect of Age, Sex, and N2 slope. As well, there were two 2-way interaction: Emotion X N2 slope, N2 slope X Sex, as well as one three-way interaction: Emotion x Sex X Average SCARED. These were superseded a four-way interaction of Emotion X N2 slope X Average SCARED Score X Sex.

Estimates of fixed effects indicated the following for the main effect of N2 slope: across all emotion prime conditions, the larger the magnitude of set size related modulations of the N2 (e.g. more negative slope value), the larger the reaction time visual search. This effect is significantly larger in males than (**See Figure 12a**). The Emotion X Average SCARED interaction was driven by anxiety related difference in the fear condition (**See Figure 12b**). Compared to the scrambled condition, reaction time slopes to the fear condition significantly increased as a function of higher anxiety. The Emotion X Average SCARED X Sex interaction was driven by anxiety and sex differences for the angry and fear conditions compared to scrambled. For males, compared to the scrambled condition, reaction time slopes for the angry and fear conditions significantly increased as a function of higher anxiety scores. In females, the reaction time slope for the angry slope did not vary as a function of anxiety, however the fear slopes increased as a function of anxiety.

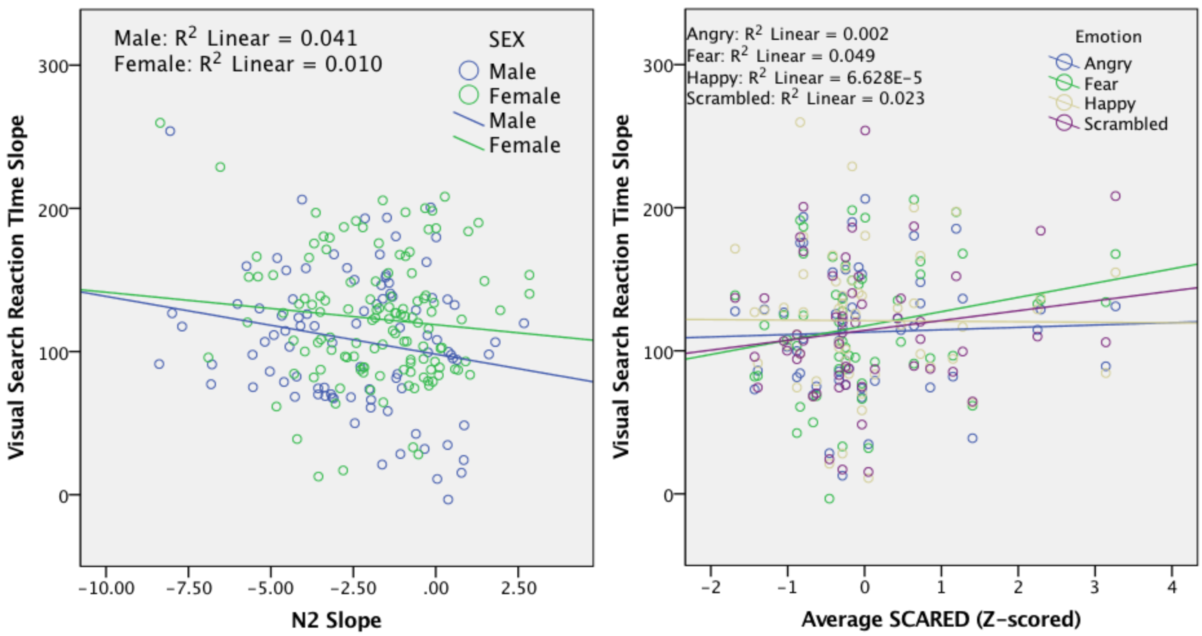



**Figure 12.** Relations between Average N2Slope, Emotion, Sex, Anxiety and Visual Search Reaction time slope.

### *Appendix B: Path Model with all components*

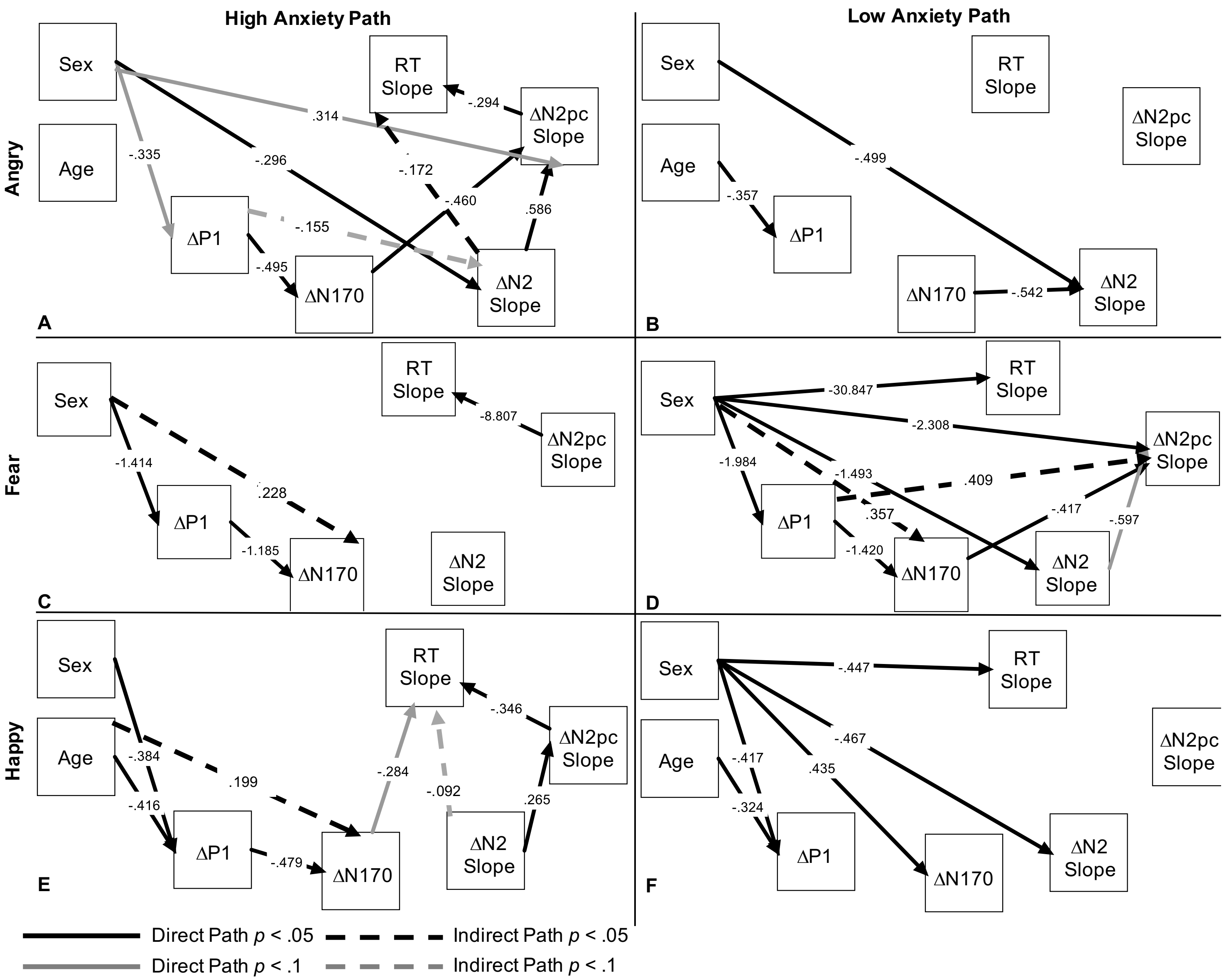
Given the numerous interactions across Aims 1 & 2, several path models were constructed, with the overarching goal of informing a comprehensive theoretical model of the present findings. To examine how age, sex, and anxiety relate to the effects of the fear, angry, and happy primes on the P1, N170, N2 and N2pc ERPs, as well as predict reaction time, several additional data processing steps were applied. First, given the limited applications of path SEM models to repeated categorical predictors, differences scores (e.g. Scrambled – Angry) were calculated for each of the dependent variables: P1 amplitude, N170 amplitude, N2 Slope, N2pc Slope, and Reaction Time slope. We added an anxiety group variable to more easily examine anxiety related effects; a median split was used to create two groups such that one group represented half of the participants with the highest anxiety scores, while the second represented the half of the participants with the lowest anxiety scores. These anxiety-specific groupings were used to aid in interpretation of resulting pathways using (Muthén & Muthén) by directly testing whether path estimates for each group significantly differed. Thus, each of the models included data from all 54 participants with usable EEG and RT data, compared model findings from each anxiety half of the sample ($n$ = 27 per group), and included the independent variables age (centered) and sex (coded as 0 or 1), and the following predictors in the specified order (all difference scores for each condition in relation to scrambled): P1, N170, N2, N2pc, Low Anxious: P1, N170, N2pc, with a final dependent variable of reaction time slope. For each model, insignificant terms and paths above $p$ = .2 were removed, and all indirect effects were examined.

**B1. Path Model Results**

Across the three emotion comparisons, there were several consistent paths for both the high and low anxious halves of the sample. Sex was a significant predictor of ΔP1 for the fear and happy comparisons; moreover, this path was at trend level for the angry comparison in the high anxious half of the sample. Group comparisons of these paths indicated that the path estimates across each of the three model comparisons did not differ significantly between the high and low anxious halves of the sample. Thus, across the entire sample, males had larger positive differences in p1 amplitudes to scrambled compared to each emotion, angry fear, and happy, while females had differences closer to zero. These results mirror sex-related P1 differences found in *Aim 1*.

The path from Sex to ΔN2 Slope was consistent across the entire sample for the Angry and Fear models. Here, males had larger N2 Slope to angry and fear compared to scrambled, while females had larger amplitudes to scrambled compared to both Angry and Fear. While this was also the case in the happy model for the low anxious half of the sample, there were no sex-related differences in ΔN2 slope for the high anxious half of the sample.

While age was not a significant predictor in the fear model, there were consistent findings in the Angry and Happy models for the age to ΔP1 paths for both halves of the sample as well. The significant paths from Age to ΔP1 predicted significantly larger ΔP1 in younger participants, specifically with P1 amplitudes to scrambled larger than to angry or happy, and these differences becoming increasingly smaller, and reversed with increasing age. While this path wasn't significant for the high anxious sample for the angry model, tests of the path estimates indicated that the path did not significantly differ from the low anxious half of the sample, and was still consistent with the above findings.




Across all three models, the high anxious half of the sample had a significant path from ΔP1 to ΔN170. For each of these three models, larger P1 amplitudes to any of the emotion primes compared to the scrambled primes predicted larger N170 amplitudes to emotion primes compared to scrambled primes. The low anxious half of the sample only displayed this pattern for the fear condition, and interestingly, the effect was significantly more dramatic (e.g. the differences in the ΔP1 lead to significantly larger differences in ΔN170 compared to the high anxious half of the sample). While the ΔP1 to ΔN170 paths for the happy and angry models did not reach significance for the low anxious half of the sample, group comparisons of the path estimates indicated that these two paths did indeed significantly differ from the high anxious half of the sample. Specifically, for the low anxious participants, *larger* P1 amplitudes to the angry or happy primes compared to the scrambled primes predicted *smaller* N170 amplitudes to angry or happy primes compared to scrambled primes.

The ΔN170 very interestingly related to ΔN2pc in the high anxious half of the sample in the angry model. Specifically, for the ΔN170 to ΔN2pc path, larger N170 to the scrambled prime compared to the angry prime led to increased N2pc slope following an angry prime compared to the scrambled prime. Furthermore, the same pattern was observed in the low anxious half of the sample in the fear model, and while this path did not reach significance for the high anxious half of the sample, comparisons of parameter estimates indicated that there were no group differences for the ΔN170 to ΔN2pc Slope path in the fear model.

**B2. Summary of Model Findings**

Sex- and age- related differences across the models appear to function similarly in both low and high anxious halves of our sample. However, significant behavioral paths with the N2pc, only appear to be present in the high anxious portion of our sample. For both low and anxious participants, there are sex differences in the magnitude of the ΔP1, with males having larger P1 amplitudes to scrambled compared to other emotions. Moreover, for the high anxious half of the sample only, larger P1 amplitudes to each of the emotion primes compared to scrambled primes are associated with larger N170 amplitudes to the emotions primes compared to scrambled. Interestingly, for the angry condition in high anxious participants only, larger N170 amplitudes lead to attenuated N2pc slopes after angry primes compared to scrambled. For the fear model, the same was true but only reached significance for the low anxious participants.

For the high anxious participants across all emotions, and for the low anxious participants during the fear condition only, there appeared to be a reliable neural flow predicting behavior. Larger P1 amplitudes to the scrambled prime compared to any of the emotion primes predicted larger N170 amplitudes to scrambled primes compared to the other emotions. Subsequently, this larger N170 to the scrambled prime compared to the emotion primes led to increased N2pc slope following an emotion prime compared to the scrambled prime. Finally, across all emotion conditions for the high anxious half of the sample, and for the fear condition for the low anxious half of the sample, greater N2pc slopes to the emotion prime compared to scrambled resulted in less efficient reaction time slopes for the emotion compared to scrambled. These findings suggest that in high anxious individuals, both positive and negative emotions have the potential to disrupt attentional neural processes, and affect subsequent behavior, while in low anxious individuals, modulations in related neural processes may be subtler, and differences appear to be emotion specific. Moreover, appropriate initial neural responses during the emotion and face recognition phases may determine the efficiency of subsequent attention related processes, and thus behavior. These findings will be further discussed in the context of related literature in the next chapter.

## *Appendix C: Benjamini-Hochberg FDR Corrections*

### C1. Examining variability in P1 Amplitude

**Table C1** Estimates of Fixed Effects: P1 Amplitude

| Parameter | Est. | SE | df | t | *Sig.* | -95% CI | + 95% CI | B-H Crit: *p* < .05 | *FDR Sig.* |
|---|---|---|---|---|---|---|---|---|---|
| Angry (Female) | 0.556 | 0.347 | 50.344 | 1.603 | 0.115 | -0.14 | 1.252 | 0.050 | *NS* |
| Fear x Age | 0.285 | 0.132 | 51.389 | 2.16 | 0.035 | 0.02 | 0.549 | 0.046 | *p* < .05 |
| Angry x Age | 0.276 | 0.118 | 50.344 | 2.332 | 0.024 | 0.038 | 0.514 | 0.042 | *p* < .05 |
| Fear (Female) | 0.972 | 0.386 | 51.389 | 2.522 | 0.015 | 0.198 | 1.746 | 0.038 | *p* < .05 |
| Happy x Age | 0.349 | 0.106 | 57.959 | 3.286 | 0.002 | 0.136 | 0.561 | 0.033 | *p* < .05 |
| Happy (Female) | 1.099 | 0.311 | 57.959 | 3.536 | 0.001 | 0.477 | 1.721 | 0.029 | *p* < .05 |
| Contrast: Scrambled x Age | -0.82 | 0.242 | 51.468 | -3.392 | 0.001 | -1.306 | -0.335 | 0.025 | *p* < .05 |
| Int./Contrast: Scrambled (Male) | 10.72 | 0.882 | 51.468 | 12.156 | 0 | 8.95 | 12.489 | 0.021 | *p* < .05 |
| Angry (Male) | -1.877 | 0.432 | 50.344 | -4.345 | 0 | -2.745 | -1.01 | 0.017 | *p* < .05 |
| Fear (Male) | -2.168 | 0.48 | 51.389 | -4.512 | 0 | -3.132 | -1.204 | 0.013 | *p* < .05 |
| Happy (Male) | -2.76 | 0.387 | 57.959 | -7.129 | 0 | -3.535 | -1.985 | 0.008 | *p* < .05 |
| Contrast: Scrambled (Female) | -3.483 | 0.708 | 51.468 | -4.921 | 0 | -4.903 | -2.062 | 0.004 | *p* < .05 |

### C2. Examining variability in RT (P1 Amplitude)

**Table C2** Estimates of Fixed Effects: Visual Search Slope (P1)

| Parameter | Est. | SE | df | t | *Sig.* | -95% CI | + 95% CI | B-H Crit: *p* < .05 | *FDR Sig.* |
|---|---|---|---|---|---|---|---|---|---|
| Contrast: Scrambled x Age (All) | -1.90 | 12.44 | 79.67 | -26.65 | 0.879 | 22.85 | -0.15 | 0.050 | *NS* |
| Happy x Averaged SCARED (Male) | 12.46 | 19.92 | 86.88 | -27.13 | 0.533 | 52.06 | 0.63 | 0.049 | *NS* |
| Contrast: Scrambled x Averaged SCARED (Male) | 32.03 | 48.85 | 105.67 | -64.81 | 0.513 | 128.88 | 0.66 | 0.047 | *NS* |
| Angry x Age x P1 (All) | -1.47 | 2.10 | 53.76 | -5.67 | 0.487 | 2.74 | -0.70 | 0.046 | *NS* |
| Angry x Averaged SCARED (Male) | 23.43 | 24.26 | 57.61 | -25.13 | 0.338 | 72.00 | 0.97 | 0.045 | *NS* |
| Happy x Averaged SCARED (Female) | 41.23 | 41.69 | 72.44 | -41.87 | 0.326 | 124.34 | 0.99 | 0.044 | *NS* |
| Happy x Averaged SCARED x Age (All) | -11.18 | 10.53 | 74.43 | -32.17 | 0.292 | 9.81 | -1.06 | 0.042 | *NS* |
| Angry x Age (All) | 13.30 | 12.28 | 53.26 | -11.34 | 0.284 | 37.93 | 1.08 | 0.041 | *NS* |
| Angry x P1 (All) | 6.82 | 6.27 | 53.01 | -5.75 | 0.282 | 19.39 | 1.09 | 0.040 | *NS* |
| Happy x Age x P1 (All) | 2.04 | 1.86 | 89.18 | -1.66 | 0.276 | 5.75 | 1.10 | 0.038 | *NS* |
| Fear x Age (All) | -15.33 | 12.94 | 80.69 | -41.08 | 0.240 | 10.42 | -1.19 | 0.037 | *NS* |
| Average SCARED x P1 (Males) | -7.03 | 5.92 | 106.21 | -18.77 | 0.238 | 4.71 | -1.19 | 0.036 | *NS* |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Happy x Age (All) | -15.18 | 12.44 | 96.22 | -39.87 | 0.225 | 9.51 | -1.22 | 0.035 | *NS* |
| Angry (All) | -55.81 | 44.08 | 52.16 | -144.25 | 0.211 | 32.64 | -1.27 | 0.033 | *NS* |
| Happy x P1 (All) | -7.52 | 5.61 | 91.39 | -18.66 | 0.183 | 3.62 | -1.34 | 0.032 | *NS* |
| Happy x Averaged SCARED x Age x P1(All) | 2.65 | 1.96 | 82.03 | -1.25 | 0.180 | 6.54 | 1.35 | 0.031 | *NS* |
| Angry x Averaged SCARED x Age x P1(All) | 3.40 | 2.46 | 52.81 | -1.54 | 0.173 | 8.34 | 1.38 | 0.029 | *NS* |
| Angry x Averaged SCARED x P1 (All) | -12.28 | 8.84 | 51.51 | -30.03 | 0.171 | 5.47 | -1.39 | 0.028 | *NS* |
| Fear x Age x P1 (All) | 2.53 | 1.79 | 90.04 | -1.03 | 0.162 | 6.08 | 1.41 | 0.027 | *NS* |
| Happy x Averaged SCARED x P1 (All) | -9.46 | 6.66 | 78.74 | -22.71 | 0.159 | 3.79 | -1.42 | 0.026 | *NS* |
| Angry x Averaged SCARED (Female) | 79.39 | 53.20 | 51.52 | -27.39 | 0.142 | 186.17 | 1.49 | 0.024 | *NS* |
| Fear x Averaged SCARED (Male) | 29.15 | 19.60 | 104.86 | -9.72 | 0.140 | 68.01 | 1.49 | 0.023 | *NS* |
| Happy (All) | 60.91 | 36.63 | 76.20 | -12.04 | 0.100 | 133.85 | 1.66 | 0.022 | *NS* |
| Angry x Averaged SCARED x Age (All) | -22.75 | 13.29 | 51.30 | -49.43 | 0.093 | 3.92 | -1.71 | 0.021 | *NS* |
| Fear (All) | 63.91 | 36.04 | 89.57 | -7.68 | 0.080 | 135.51 | 1.77 | 0.019 | *NS* |
| Fear x P1 (All) | -9.41 | 5.29 | 88.83 | -19.92 | 0.079 | 1.11 | -1.78 | 0.018 | *NS* |
| Contrast: Scrambled x P1 (All) | 10.32 | 5.69 | 91.56 | -0.98 | 0.073 | 21.63 | 1.81 | 0.017 | *NS* |
| Contrast: Scrambled x Age x P1(All) | -3.51 | 1.87 | 94.35 | -7.22 | 0.063 | 0.19 | -1.88 | 0.015 | *NS* |
| Fear x Averaged SCARED x Age (All) | -21.33 | 10.48 | 91.80 | -42.15 | 0.045 | -0.50 | -2.03 | 0.014 | *NS* |
| Age (Males) | 23.07 | 10.25 | 46.02 | 2.43 | 0.029 | 43.70 | 2.25 | 0.013 | *NS* |
| Fear x Averaged SCARED (Female) | 92.05 | 40.76 | 93.46 | 11.12 | 0.026 | 172.98 | 2.26 | 0.012 | *NS* |
| Sex | -80.02 | 32.87 | 48.32 | -146.11 | 0.019 | -13.93 | -2.43 | 0.010 | *NS* |
| Fear x Averaged SCARED x Age x P1(All) | 4.77 | 1.96 | 90.76 | 0.88 | 0.017 | 8.67 | 2.43 | 0.009 | *NS* |
| Contrast: Scrambled x Averaged SCARED (Female) | -129.62 | 52.55 | 76.64 | -234.26 | 0.016 | -24.97 | -2.47 | 0.008 | *NS* |
| Contrast: Scrambled x Averaged SCARED x Age (All) | 33.61 | 12.67 | 76.89 | 8.37 | 0.010 | 58.85 | 2.65 | 0.006 | *NS* |
| Fear x Averaged SCARED x P1 (All) | -17.85 | 6.65 | 88.54 | -31.07 | 0.009 | -4.63 | -2.68 | 0.005 | *NS* |
| Contrast: Scrambled (All) | 115.21 | 42.38 | 76.87 | 30.81 | 0.008 | 199.60 | 2.72 | 0.004 | *NS* |
| Contrast: Scrambled x Averaged SCARED x Age x P1 (All) | -5.83 | 2.13 | 84.15 | -10.08 | 0.008 | -1.59 | -2.73 | 0.003 | *NS* |
| Contrast: Scrambled x Averaged SCARED x P1(All) | 22.65 | 7.84 | 80.45 | 7.05 | 0.005 | 38.25 | 2.89 | 0.001 | *NS* |

## C3. Examining variability in N170 Amplitude

**Table C3** Estimates of Fixed Effects: N170 Amplitude

| Parameter | Est. | SE | df | t | *Sig.* | -95% CI | + 95% CI | B-H Crit: *p* < .05 | *FDR Sig.* |
|---|---|---|---|---|---|---|---|---|---|
| Fear x Age (Male) | 0.01 | 0.34 | 93.46 | 0.02 | 0.99 | -0.66 | 0.67 | 0.050 | *NS* |
| Happy (Male) | -0.13 | 0.84 | 116.4 | -0.16 | 0.87 | -1.79 | 1.52 | 0.048 | *NS* |
| Fear x Age (Female) | -0.08 | 0.46 | 93.46 | -0.17 | 0.87 | -0.98 | 0.83 | 0.047 | *NS* |
| Contrast: Scrambled x Age (Female) | -0.14 | 0.79 | 57.98 | -0.18 | 0.86 | -1.73 | 1.44 | 0.045 | *NS* |
| Happy (Female) | -0.26 | 1.19 | 116.4 | -0.22 | 0.83 | -2.62 | 2.1 | 0.044 | *NS* |
| Angry (Female) | 0.49 | 1.41 | 53.86 | 0.35 | 0.73 | -2.33 | 3.3 | 0.042 | *NS* |
| Fear (Female) | -0.5 | 1.36 | 93.46 | -0.37 | 0.72 | -3.2 | 2.2 | 0.041 | *NS* |
| Contrast: Scrambled x Average SCARED x Age (Male) | -0.47 | 1.05 | 57.98 | -0.45 | 0.66 | -2.58 | 1.63 | 0.039 | *NS* |
| Fear (Male) | 0.44 | 0.95 | 93.46 | 0.46 | 0.65 | -1.45 | 2.34 | 0.038 | *NS* |
| Angry x Age (Female) | -0.32 | 0.47 | 53.86 | -0.68 | 0.5 | -1.26 | 0.63 | 0.036 | *NS* |
| Contrast: Scrambled x Average SCARED x Age (Female) | 0.77 | 1.12 | 57.98 | 0.69 | 0.49 | -1.46 | 3.01 | 0.034 | *NS* |
| Contrast: Scrambled x Average SCARED (Male) | 2.49 | 2.94 | 57.98 | 0.85 | 0.4 | -3.41 | 8.38 | 0.033 | *NS* |
| Fear x Average SCARED x Age (Male) | 0.54 | 0.6 | 93.46 | 0.89 | 0.38 | -0.66 | 1.74 | 0.031 | *NS* |
| Angry (Male) | -0.9 | 0.99 | 53.86 | -0.91 | 0.37 | -2.88 | 1.08 | 0.030 | *NS* |
| Happy x Age (Female) | -0.39 | 0.4 | 116.4 | -0.97 | 0.33 | -1.18 | 0.4 | 0.028 | *NS* |
| Contrast: Scrambled x Age (Male) | 0.63 | 0.58 | 57.98 | 1.08 | 0.29 | -0.54 | 1.8 | 0.027 | *NS* |
| Fear x Average SCARED x Age (Female) | -0.68 | 0.64 | 93.46 | -1.06 | 0.29 | -1.96 | 0.59 | 0.025 | *NS* |
| Contrast: Scrambled x Average SCARED (Female) | -3.84 | 3.21 | 57.98 | -1.2 | 0.24 | -10.26 | 2.58 | 0.023 | *NS* |
| Angry x Age (Male) | 0.42 | 0.35 | 53.86 | 1.2 | 0.24 | -0.28 | 1.11 | 0.022 | *NS* |
| Happy x Age (Male) | 0.43 | 0.29 | 116.4 | 1.45 | 0.15 | -0.16 | 1.01 | 0.020 | *NS* |
| Angry x Average SCARED (Male) | -2.64 | 1.75 | 53.86 | -1.51 | 0.14 | -6.15 | 0.86 | 0.019 | *NS* |
| Angry x Average SCARED x Age (Male) | 0.93 | 0.63 | 53.86 | 1.49 | 0.14 | -0.32 | 2.18 | 0.017 | *NS* |
| Fear x Average SCARED (Male) | -2.56 | 1.69 | 93.46 | -1.51 | 0.13 | -5.91 | 0.8 | 0.016 | *NS* |
| Fear x Average SCARED (Female) | 3.21 | 1.84 | 93.46 | 1.75 | 0.08 | -0.44 | 6.87 | 0.014 | *NS* |
| Contrast: Scrambled (Female) | 4.57 | 2.37 | 57.98 | 1.93 | 0.06 | -0.17 | 9.31 | 0.013 | *NS* |
| Angry x Average SCARED x Age (Female) | -1.27 | 0.66 | 53.86 | -1.91 | 0.06 | -2.6 | 0.06 | 0.011 | *NS* |
| Angry x Average SCARED (Female) | 3.96 | 1.9 | 53.86 | 2.08 | 0.04 | 0.14 | 7.78 | 0.009 | *NS* |
| Happy x Average SCARED (Male) | -3.29 | 1.48 | 116.4 | -2.22 | 0.03 | -6.23 | -0.36 | 0.008 | *NS* |
| Happy x Average SCARED x Age (Male) | 1.14 | 0.53 | 116.4 | 2.14 | 0.03 | 0.09 | 2.18 | 0.006 | *NS* |
| Happy x Average SCARED (Female) | 4.47 | 1.61 | 116.4 | 2.77 | 0.01 | 1.27 | 7.66 | 0.005 | *NS* |
| Happy x Average SCARED x Age (Female) | -1.4 | 0.56 | 116.4 | -2.49 | 0.01 | -2.51 | -0.28 | 0.003 | *NS* |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Int./Contrast: Scrambled (Male) | -11.12 | 1.66 | 57.98 | -6.69 | 0 | -14.45 | -7.79 | | 0.002 | *p* < .05 |

## C4. Examining variability in RT (N170 Amplitude)

**Table C4** Estimates of Fixed Effects: Visual Search Slope (N170)

| Parameter | Est. | SE | df | t | *Sig.* | -95% CI | + 95% CI | Index | B-H Crit: *p* < .05 | *FDR Sig.* |
|---|---|---|---|---|---|---|---|---|---|---|
| Happy (Male) | 6.36 | 72.13 | 73.55 | 0.09 | 0.93 | -137.37 | 150.1 | | 0.050 | *NS* |
| Happy x Average SCARED (Female) | 11.32 | 36.76 | 73.57 | 0.31 | 0.76 | -61.92 | 84.57 | | 0.049 | *NS* |
| Happy x Age (Female) | 4.42 | 14.4 | 73.85 | 0.31 | 0.76 | -24.27 | 33.12 | | 0.048 | *NS* |
| Happy (Female) | 21.89 | 49.51 | 75.31 | 0.44 | 0.66 | -76.73 | 120.51 | | 0.047 | *NS* |
| Happy x N170 (Female) | -3.66 | 7.78 | 76.44 | -0.47 | 0.64 | -19.15 | 11.83 | | 0.046 | *NS* |
| Happy x Age (Male) | -13.48 | 24.58 | 76.27 | -0.55 | 0.59 | -62.44 | 35.47 | | 0.045 | *NS* |
| Happy x Average SCARED x Average SCARED x Age (All) | -6.09 | 9.8 | 76.55 | -0.62 | 0.54 | -25.61 | 13.43 | | 0.044 | *NS* |
| Fear x Average SCARED (Female) | 23.11 | 35.46 | 87.73 | 0.65 | 0.52 | -47.36 | 93.58 | | 0.043 | *NS* |
| Contrast: Scrambled x Average SCARED (Male) | -17.98 | 24.15 | 64.76 | -0.74 | 0.46 | -66.22 | 30.26 | | 0.042 | *NS* |
| Happy x Average SCARED (Male) | 18.61 | 20.33 | 66.74 | 0.92 | 0.36 | -21.97 | 59.2 | | 0.041 | *NS* |
| Happy x N170 (Male) | 8.63 | 9.29 | 74.43 | 0.93 | 0.36 | -9.88 | 27.13 | | 0.040 | *NS* |
| Happy x Age x N170 (Female) | 2.43 | 2.41 | 74.25 | 1.01 | 0.32 | -2.37 | 7.23 | | 0.039 | *NS* |
| Fear x Average SCARED x Average SCARED x Age (All) | -11.09 | 9.2 | 87.03 | -1.21 | 0.23 | -29.38 | 7.2 | | 0.038 | *NS* |
| Happy x Age x N170 (Male) | -4.2 | 3.37 | 74.86 | -1.25 | 0.22 | -10.92 | 2.51 | | 0.038 | *NS* |
| Happy x Average SCARED x Average SCARED x N170 (All) | 8.16 | 6.13 | 77.92 | 1.33 | 0.19 | -4.04 | 20.36 | | 0.037 | *NS* |
| Happy x Average SCARED x Average SCARED x N170 x Age (All) | -2.54 | 1.89 | 80.56 | -1.34 | 0.18 | -6.31 | 1.22 | | 0.036 | *NS* |
| Contrast: Scrambled x N170 (Female) | 10.16 | 7.12 | 83.61 | 1.43 | 0.16 | -4.01 | 24.33 | | 0.035 | *NS* |
| Angry x Age (Male) | -40.01 | 27.88 | 47.55 | -1.44 | 0.16 | -96.08 | 16.06 | | 0.034 | *NS* |
| Angry x Average SCARED (Male) | 38.54 | 25.01 | 46.24 | 1.54 | 0.13 | -11.8 | 88.88 | | 0.033 | *NS* |
| Fear x Average SCARED (Male) | 30.49 | 19.79 | 84.12 | 1.54 | 0.13 | -8.88 | 69.85 | | 0.032 | *NS* |
| Fear (Female) | -74.79 | 45.75 | 82.71 | -1.64 | 0.11 | -165.79 | 16.22 | | 0.031 | *NS* |
| Contrast: Scrambled x Age x N170 (Female) | -4.05 | 2.41 | 78.68 | -1.68 | 0.1 | -8.86 | 0.75 | | 0.030 | *NS* |
| Angry (Male) | 144.65 | 84.65 | 48.8 | 1.71 | 0.09 | -25.48 | 314.77 | | 0.029 | *NS* |
| Fear x Average SCARED x Average SCARED x N170 (All) | 10.2 | 5.86 | 89.66 | 1.74 | 0.09 | -1.43 | 21.84 | | 0.028 | *NS* |
| Contrast: Scrambled x N170 (Male) | -16.04 | 8.95 | 83.19 | -1.79 | 0.08 | -33.85 | 1.77 | | 0.027 | *NS* |
| Fear x Age (Male) | -40.61 | 23.1 | 82.46 | -1.76 | 0.08 | -86.57 | 5.35 | | 0.026 | *NS* |
| Angry x Average SCARED x Average SCARED x N170 x Age (All) | -3.83 | 2.17 | 53.6 | -1.77 | 0.08 | -8.17 | 0.52 | | 0.025 | *NS* |
| Contrast: Scrambled x Average SCARED (Female) | -68.4 | 37.65 | 78.79 | -1.82 | 0.07 | -143.34 | 6.54 | | 0.024 | *NS* |
| Angry x Age x N170 (Male) | -6.78 | 3.67 | 48.62 | -1.85 | 0.07 | -14.15 | 0.58 | | 0.023 | *NS* |
| Angry x Average SCARED (Female) | 80.01 | 42.11 | 61.73 | 1.9 | 0.06 | -4.18 | 164.2 | | 0.022 | *NS* |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Contrast: Scrambled x Age x N170 (Male) | 6.2 | 3.3 | 80.47 | 1.88 | 0.06 | -0.38 | 12.77 | 0.021 | *NS* |
| Angry x Average SCARED x Average SCARED x Age (All) | -23.13 | 11.9 | 54.83 | -1.94 | 0.06 | -46.97 | 0.71 | 0.020 | *NS* |
| Contrast: Scrambled (Male) | -147.53 | 73.09 | 78.62 | -2.02 | 0.05 | -293.02 | -2.03 | 0.019 | *NS* |
| Fear (Male) | 136.52 | 68.05 | 83.43 | 2.01 | 0.05 | 1.19 | 271.85 | 0.018 | *NS* |
| Fear x Age (Female) | 26.77 | 13.53 | 82.21 | 1.98 | 0.05 | -0.14 | 53.68 | 0.017 | *NS* |
| Contrast: Scrambled x Age (Male) | 49.97 | 23.98 | 77.81 | 2.08 | 0.04 | 2.24 | 97.71 | 0.016 | *NS* |
| Angry x N170 (Male) | 22.41 | 10.29 | 51.06 | 2.18 | 0.03 | 1.75 | 43.06 | 0.015 | *NS* |
| Angry x Average SCARED x Average SCARED x N170 (All) | 15.07 | 6.73 | 64.52 | 2.24 | 0.03 | 1.62 | 28.51 | 0.014 | *NS* |
| Fear x N170 (Female) | -16.8 | 7.32 | 85.32 | -2.3 | 0.02 | -31.34 | -2.25 | 0.013 | *NS* |
| Fear x Age x N170 (Female) | 5.5 | 2.28 | 84.72 | 2.41 | 0.02 | 0.96 | 10.03 | 0.013 | *NS* |
| Contrast: Scrambled x Average SCARED x Age (All) | 24.33 | 9.93 | 75.85 | 2.45 | 0.02 | 4.55 | 44.11 | 0.012 | *NS* |
| Fear x Average SCARED x Average SCARED x N170 x Age (All) | -3.96 | 1.72 | 89.74 | -2.3 | 0.02 | -7.37 | -0.54 | 0.011 | *NS* |
| Angry (Female) | -150.28 | 56.71 | 49.25 | -2.65 | 0.01 | -264.24 | -36.33 | 0.010 | *NS* |
| Angry x N170 (Female) | -21.67 | 8.48 | 51.87 | -2.56 | 0.01 | -38.7 | -4.65 | 0.009 | *NS* |
| Fear x N170 (Male) | 25.4 | 8.7 | 83.92 | 2.92 | 0.01 | 8.1 | 42.7 | 0.008 | *NS* |
| Contrast: Scrambled x Age (Female) | -37.92 | 14.89 | 72.76 | -2.55 | 0.01 | -67.59 | -8.24 | 0.007 | *NS* |
| Angry x Age (Female) | 47.13 | 16.76 | 47.96 | 2.81 | 0.01 | 13.44 | 80.82 | 0.006 | *NS* |
| Angry x Age x N170 (Female) | 6.85 | 2.68 | 49.84 | 2.56 | 0.01 | 1.48 | 12.23 | 0.005 | *NS* |
| Fear x Age x N170 (Male) | -8 | 3.06 | 82.37 | -2.61 | 0.01 | -14.09 | -1.91 | 0.004 | *NS* |
| Contrast: Scrambled x Average SCARED x N170 (All) | -14.92 | 5.68 | 78.52 | -2.63 | 0.01 | -26.23 | -3.62 | 0.003 | *NS* |
| Contrast: Scrambled x Average SCARED x N170 x Age (All) | 4.82 | 1.76 | 81.81 | 2.73 | 0.01 | 1.31 | 8.33 | 0.002 | *NS* |
| Int./Contrast: Scrambled (Female) | 218.19 | 48.52 | 77.2 | 4.5 | 0 | 121.58 | 314.8 | 0.001 | *p* < .05 |

## C5. Examining variability in N2pc Slope

**Table C5** Estimates of Fixed Effects: N2pc Slope

| Parameter | Est. | SE | df | t | *Sig.* | -95% CI | + 95% CI | B-H Crit: *p* < .05 | *FDR Sig.* |
|---|---|---|---|---|---|---|---|---|---|
| Fear x Age (Male) | 0.04 | 0.47 | 59.32 | 0.08 | 0.94 | -0.9 | 0.97 | 0.050 | *NS* |
| Happy x Age (Female) | 0.06 | 0.55 | 79.84 | 0.1 | 0.92 | -1.04 | 1.16 | 0.048 | *NS* |
| Angry (Male) | -0.15 | 1.11 | 84.95 | -0.13 | 0.89 | -2.35 | 2.05 | 0.047 | *NS* |
| Fear x Average SCARED (Female) | 0.34 | 2.56 | 59.32 | 0.14 | 0.89 | -4.77 | 5.46 | 0.045 | *NS* |
| Fear (Male) | -0.24 | 1.33 | 59.32 | -0.18 | 0.86 | -2.89 | 2.42 | 0.044 | *NS* |
| Happy (Female) | -0.52 | 1.65 | 79.84 | -0.31 | 0.75 | -3.8 | 2.76 | 0.042 | *NS* |
| Fear x Average SCARED x Age (Female) | -0.29 | 0.89 | 59.32 | -0.32 | 0.75 | -2.07 | 1.5 | 0.041 | *NS* |
| Fear x Average SCARED (Male) | -0.9 | 2.35 | 59.32 | -0.38 | 0.7 | -5.59 | 3.79 | 0.039 | *NS* |
| Angry x Age (Female) | -0.23 | 0.53 | 84.95 | -0.43 | 0.67 | -1.28 | 0.82 | 0.038 | *NS* |
| Contrast: Scrambled (Female) | -0.63 | 1.35 | 138.88 | -0.46 | 0.64 | -3.31 | 2.05 | 0.036 | *NS* |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fear x Average SCARED x Age | 0.41 | 0.84 | 59.32 | 0.49 | 0.63 | -1.27 | 2.09 | 0.034 | *NS* |
| Contrast: Scrambled x Age (Female) | 0.29 | 0.45 | 138.88 | 0.64 | 0.52 | -0.61 | 1.19 | 0.033 | *NS* |
| Happy (Male) | 0.77 | 1.16 | 79.84 | 0.66 | 0.51 | -1.54 | 3.07 | 0.031 | *NS* |
| Contrast: Scrambled x Average | 1.25 | 1.84 | 138.88 | 0.68 | 0.5 | -2.38 | 4.88 | 0.030 | *NS* |
| Angry x Age (Male) | -0.29 | 0.39 | 84.95 | -0.74 | 0.46 | -1.06 | 0.49 | 0.028 | *NS* |
| Contrast: Scrambled x Average | -0.51 | 0.64 | 138.88 | -0.8 | 0.43 | -1.78 | 0.75 | 0.027 | *NS* |
| Contrast: Scrambled x Average | 0.48 | 0.6 | 138.88 | 0.8 | 0.42 | -0.71 | 1.68 | 0.025 | *NS* |
| Contrast: Scrambled x Average | -1.42 | 1.68 | 138.88 | -0.84 | 0.4 | -4.75 | 1.91 | 0.023 | *NS* |
| Happy x Age (Male) | -0.35 | 0.41 | 79.84 | -0.86 | 0.39 | -1.16 | 0.46 | 0.022 | *NS* |
| Happy x Average SCARED (Female) | -2.05 | 2.23 | 79.84 | -0.92 | 0.36 | -6.5 | 2.39 | 0.020 | *NS* |
| Angry (Female) | 1.48 | 1.58 | 84.95 | 0.94 | 0.35 | -1.65 | 4.62 | 0.019 | *NS* |
| Contrast: Scrambled x Age (Male) | 0.33 | 0.33 | 138.88 | 0.98 | 0.33 | -0.33 | 0.99 | 0.017 | *NS* |
| Happy x Average SCARED x Age | 0.83 | 0.78 | 79.84 | 1.07 | 0.29 | -0.72 | 2.38 | 0.016 | *NS* |
| Happy x Average SCARED (Male) | 2.4 | 2.05 | 79.84 | 1.17 | 0.25 | -1.68 | 6.48 | 0.014 | *NS* |
| Happy x Average SCARED x Age | -0.87 | 0.73 | 79.84 | -1.19 | 0.24 | -2.33 | 0.59 | 0.013 | *NS* |
| Fear x Age (Female) | -0.88 | 0.63 | 59.32 | -1.4 | 0.17 | -2.15 | 0.38 | 0.011 | *NS* |
| Int./Contrast: Scrambled (Male) | -1.36 | 0.95 | 138.88 | -1.43 | 0.16 | -3.24 | 0.52 | 0.009 | *NS* |
| Fear (Female) | 3.36 | 1.89 | 59.32 | 1.78 | 0.08 | -0.41 | 7.13 | 0.008 | *NS* |
| Angry x Average SCARED x Age | 1.7 | 0.74 | 84.95 | 2.28 | 0.03 | 0.22 | 3.18 | 0.006 | *NS* |
| Angry x Average SCARED (Female) | -5.28 | 2.13 | 84.95 | -2.47 | 0.02 | -9.52 | -1.04 | 0.005 | *NS* |
| Angry x Average SCARED x Age | -1.66 | 0.7 | 84.95 | -2.37 | 0.02 | -3.05 | -0.26 | 0.003 | *NS* |
| Angry x Average SCARED (Male) | 4.97 | 1.96 | 84.95 | 2.54 | 0.01 | 1.07 | 8.86 | 0.002 | *NS* |

### C6. Examining variability in RT (N2pc Slope)

**Table C6** Estimates of Fixed Effects: Visual Search Slope (N2pc)

| Parameter | Est. | SE | df | t | *Sig.* | -95% CI | + 95% CI | B-H Crit: $p < .05$ | *FDR Sig.* |
|---|---|---|---|---|---|---|---|---|---|
| Fear x Age (Female) | -0.7 | 9.5 | 90.23 | -0.07 | 0.94 | -19.56 | 18.17 | 0.050 | *NS* |
| Fear x Age (Male) | 0.7 | 6.13 | 88.44 | 0.11 | 0.91 | -11.49 | 12.88 | 0.049 | *NS* |
| Fear (Female) | 5.47 | 30.14 | 92.05 | 0.18 | 0.86 | -54.39 | 65.34 | 0.048 | *NS* |
| Happy x Age (Male) | -1.32 | 7.53 | 73.41 | -0.18 | 0.86 | -16.32 | 13.68 | 0.046 | *NS* |
| Happy x N2pc (Male) | 1.02 | 5.55 | 137.92 | 0.18 | 0.85 | -9.96 | 12.01 | 0.045 | *NS* |
| Fear x N2pc (Female) | -1.46 | 6.37 | 97.69 | -0.23 | 0.82 | -14.1 | 11.17 | 0.044 | *NS* |
| Happy (Male) | 5.72 | 24.19 | 76.46 | 0.24 | 0.81 | -42.46 | 53.9 | 0.043 | *NS* |
| Fear (Male) | 5.23 | 20.12 | 90.6 | 0.26 | 0.8 | -34.73 | 45.2 | 0.042 | *NS* |
| Contrast: Scrambled x Age (Male) | 2.49 | 7.98 | 87.63 | 0.31 | 0.76 | -13.37 | 18.35 | 0.040 | *NS* |
| Fear x Averaged SCARED x Age (All) | -1.51 | 4.86 | 94.95 | -0.31 | 0.76 | -11.15 | 8.13 | 0.039 | *NS* |
| Happy x Averaged SCARED x Age | -2.08 | 5.79 | 88.77 | -0.36 | 0.72 | -13.59 | 9.43 | 0.038 | *NS* |
| Angry x Age (Male) | -3.42 | 6.7 | 101.69 | -0.51 | 0.61 | -16.72 | 9.88 | 0.037 | *NS* |
| Contrast: Scrambled x Average | 11.09 | 20.7 | 84.01 | 0.54 | 0.59 | -30.08 | 52.25 | 0.036 | *NS* |
| Happy x Average SCARED (Female) | -14.74 | 19.73 | 72.68 | -0.75 | 0.46 | -54.06 | 24.58 | 0.035 | *NS* |
| Happy x Average SCARED (Male) | 18.88 | 23.95 | 86.11 | 0.79 | 0.43 | -28.73 | 66.49 | 0.033 | *NS* |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Happy x Age (Female) | -9.8 | 11.64 | 76.74 | -0.84 | 0.4 | -32.98 | 13.37 | 0.032 | *NS* |
| Angry (Male) | 19.06 | 22 | 107.12 | 0.87 | 0.39 | -24.55 | 62.67 | 0.031 | *NS* |
| Angry x Average SCARED (Female) | -18.1 | 17.33 | 99.5 | -1.04 | 0.3 | -52.48 | 16.29 | 0.030 | *NS* |
| Angry x N2pc (Male) | 5.17 | 4.98 | 123.58 | 1.04 | 0.3 | -4.69 | 15.03 | 0.029 | *NS* |
| Angry x Age (Female) | 12.08 | 10.2 | 102.87 | 1.18 | 0.24 | -8.15 | 32.3 | 0.027 | *NS* |
| Age x N2pc (Male) | 1.97 | 1.57 | 111.13 | 1.26 | 0.21 | -1.14 | 5.07 | 0.026 | *NS* |
| Angry (Female) | -44.3 | 32.19 | 105.93 | -1.38 | 0.17 | - | 19.52 | 0.025 | *NS* |
| Happy (Female) | 50.89 | 36.44 | 78.7 | 1.4 | 0.17 | -21.65 | 123.42 | 0.024 | *NS* |
| Fear x N2pc (Male) | 7.27 | 5.28 | 110.51 | 1.38 | 0.17 | -3.2 | 17.74 | 0.023 | *NS* |
| Contrast: Scrambled x Average | -36.22 | 25.15 | 103.26 | -1.44 | 0.15 | -86.08 | 13.65 | 0.021 | *NS* |
| Contrast: Scrambled x Averaged | 9.51 | 6.01 | 104.33 | 1.58 | 0.12 | -2.41 | 21.42 | 0.020 | *NS* |
| Contrast: Scrambled x Age (Female) | -21.16 | 12.19 | 90.12 | -1.74 | 0.09 | -45.38 | 3.05 | 0.019 | *NS* |
| Angry x Averaged SCARED x N2pc | 8.86 | 4.94 | 121.47 | 1.79 | 0.08 | -0.92 | 18.65 | 0.018 | *NS* |
| Angry x N2pc (Female) | 11.77 | 6.44 | 113.63 | 1.83 | 0.07 | -0.99 | 24.53 | 0.017 | *NS* |
| Happy x N2pc (Female) | 13.78 | 7.42 | 134.08 | 1.86 | 0.07 | -0.89 | 28.45 | 0.015 | *NS* |
| Contrast: Scrambled (Female) | 73.94 | 37.91 | 92.11 | 1.95 | 0.05 | -1.34 | 149.23 | 0.014 | *NS* |
| Fear x Average SCARED (Male) | 39.46 | 19.83 | 93.48 | 1.99 | 0.05 | 0.09 | 78.82 | 0.013 | *NS* |
| Fear x Average SCARED (Female) | -33.04 | 15.99 | 88.37 | -2.07 | 0.04 | -64.82 | -1.26 | 0.012 | *NS* |
| Contrast: Scrambled x N2pc (Female) | 17.45 | 8.01 | 121.42 | 2.18 | 0.03 | 1.59 | 33.32 | 0.011 | *NS* |
| Contrast: Scrambled x N2pc (Male) | -12.78 | 5.6 | 117.6 | -2.28 | 0.02 | -23.87 | -1.7 | 0.010 | *NS* |
| Angry x Averaged SCARED x Age | -12.66 | 5.2 | 114.51 | -2.44 | 0.02 | -22.96 | -2.37 | 0.008 | *NS* |
| Age x N2pc (Female) | -5.66 | 2.26 | 124.63 | -2.51 | 0.01 | -10.14 | -1.19 | 0.007 | *NS* |
| Angry x Average SCARED (Male) | 57.24 | 22.04 | 115.75 | 2.6 | 0.01 | 13.59 | 100.89 | 0.006 | *NS* |
| Happy x Averaged SCARED x N2pc | 15.11 | 5.38 | 135.68 | 2.81 | 0.01 | 4.47 | 25.75 | 0.005 | *NS* |
| Int./Contrast: Scrambled (Male) | 97 | 25.44 | 91.19 | 3.81 | 0 | 46.48 | 147.53 | 0.004 | $p < .05$ |
| Contrast: Scrambled x Averaged | -12.23 | 3.79 | 114.29 | -3.23 | 0 | -19.74 | -4.72 | 0.002 | $p < .05$ |
| Fear x Averaged SCARED x N2pc (All) | 15.89 | 5.36 | 125.53 | 2.97 | 0 | 5.29 | 26.49 | 0.001 | $p < .05$ |

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