INTERACTION OF ATTENTION AND EMOTION ACROSS DEVELOPMENT AND DISORDER

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This dissertation examines how attention and emotion interact in early visual processing across typical development and in Attention Deficit/Hyperactivity Disorder (ADHD). To investigate early visual processing, we utilized the attentional blink (AB) paradigm. The AB is the loss of awareness of a target immediately following detection of a first target. However, the AB does not occur if the second target contains emotional information. This modulation of the AB indicates that emotional information has privileged access to early visual attention. Chapter 2 reports that independent of the emotional expression, children showed a larger AB than adults for human faces, suggesting reduced attentional resources in early visual processing. There was, however, no developmental difference in the extent to which the AB was reduced for angry faces, indicating that early visual attention to emotionally salient information is mature in children. Further, typically developing children who were more anxious, displayed a reduced AB for faces with neutral expression, indicating heightened early visual attention to socially important information. Chapter 3 reports that children with ADHD were similar to controls in the magnitude of the AB for neutral faces and its reduction for angry faces. Thus, early visual attention to human
faces and its modulation by emotional expression is intact in ADHD. Further, ADHD children with more inattention symptoms showed a larger modulation of the AB by emotional information. These results have implications for models of how attention and emotion interact in early visual attentional processing in typical development and ADHD.
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CHAPTER 1: INTRODUCTION

Emotional events capture our attention instantly. A mundane drive home from work can become memorable when there is a car accident on the side of the road. A stern face looking at us in a crowd immediately draws our attention to that person and makes us more likely to remember that person more than anyone else in that crowd. When emotional value is added to a stimulus, that stimulus becomes more significant. The increased significance allows us to remember it more. Attention can be facilitated by emotion such that emotionally charged stimuli can be consolidated into our memory faster. The facilitation by emotion may arise from the evolutionary need to identify important stimuli in the environment, whether it is negative, like a snake, or positive, like a mother’s face. In this dissertation, I will investigate how emotion influences attention at the perceptual level across typical development and in a common attentional disorder of development, Attention Deficit Hyperactivity Disorder (ADHD).

**Attention**

Attention is the process by which we reduce the flow of information into the sensory system of the brain by enhancing the relevant or important components of the input stream while eliminating the distracting ones (Taylor & Fragopanagos, 2005). Attention can be voluntary and controlled by either top-down or bottom-up processes (Corbetta & Shulman, 2002). Top down processes are more goal-directed and rely on a dorsal brain network (Corbetta, Patel, & Shulman, 2008; Corbetta & Shulman, 2002). Bottom up processes on the other hand are reflexive, sensory driven and rely on a
ventral brain network. The ventral network underlies emotional arousal and motivational processes (Weissman & Prado, 2012). When we study for an exam we engage our dorsal network to focus on only the material that is necessary for us to know for the exam. The ventral network is engaged when we see bright neon shirt or when we see someone crying in a crowd. The difference between these two networks is the effort required, when we engage our dorsal network, it is more effortful—we must direct our attention voluntarily, (endogenous). Engaging the ventral network is less effortful; stimuli capture our attention even if we do not want to direct our attention to it (exogenous). There has been an increasing interest among researchers to understand the types of stimuli that capture attention but also how they do it as well.

Attention processing is believed to have two components, an early and late stage of processing (Corbetta et al., 2008; Corbetta & Shulman, 2002). In the early stage, information enters through sensory inputs and is selected without full perceptual analysis. An example of this would be the cocktail party effect, where in a busy and confusing environment we are alerted by our name being called out; however, we do not know who or where our name was called from (Kuyper, 1972). In the late stage of attention processing, information can only be selected on after full perceptual analysis and recoding into a semantic or categorical representation. A gating mechanism is believed to be present between early and late stage processing that determines what information pursues later stage processing (D. Broadbent & Broadbent, 1990).
Attention processing is limited in its capacity to process information (Johnston, 1986; Posner, 1993). Information cannot be simultaneously processed if multiple inputs are receiving large amounts of information. When this does happen, a bottleneck is believed to occur while determining what is selected for extended processing to gain awareness and what is not selected (D. Broadbent & Broadbent, 1990). In the presence of high priority information, a mechanism has been established early on to overcome the limited capacity of attention processing (Anderson, 2005). Information that is identified as high priority like emotional information, can be selected or filtered rather easily so that it gain access and pass the bottleneck efficiently (Pratto & John, 1991). The bottleneck is manifested in the attentional blink (AB) phenomenon when one target is being processed and subsequent target is presented immediately after the first target. There is a quick influx of information and the second target cannot be detected. However if the second target is of high priority like one containing emotional information, the AB effect can be reduced or even abolished. Therefore, it is important to understand what makes emotional information gain a priority status in attention processing.

*Emotion*

Emotion can be thought of as states that coordinate homeostasis in a complex environment (Kuyper, 1972). The experience of emotions or the states of emotional consciousness are what we commonly call “feelings” (Taylor & Fragopanagos, 2005). When studying selective attention “emotion” can refer to the emotional quality of a
stimulus or emotional state of an individual (Yiend, 2010). In this dissertation, emotion refers to the emotional quality of the stimulus.

Emotion has been densely studied and certain structures and circuits have emerged as areas important in the processing of emotion. Both cortical and subcortical structures have been implicated in processing emotions. Higher order sensory cortices are involved in the perceptual representation of the stimuli and its features. Cortical structures like the ventrolateral (VLPFC), orbitofrontal (OFC), and prefrontal cortices are involved in modulating emotional responses in subcortical structures like the amygdala and ventral striatum. The VLPFC cortex is a modulator of the emotional responses in the amygdala. When there is reduced activation in the VLPFC it is thought to reflect a reduced top-down control of the amygdala (Marsh, Gerber, & Peterson, 2008). The OFC along with the amygdala and ventral striatum mediate the association of the perceptual representation with an emotional response, cognitive processing and behavioral motivation (Adolphs, 2003). The amygdala in particular is suggested to be the encoder of emotional value before or even without the full object-level perception of the stimuli that permits the conscious awareness of a stimuli (Taylor & Fragopanagos, 2005). Therefore an extensive circuit is utilized in processing emotion.

Faces have been used ubiquitously in researching emotion as experimental stimuli for several reasons. Faces contain not only information about identity, gender, or age but also convey information about emotion (Ekman & Oster, 1979; Patrik
Vuilleumier & Pourtois, 2007). A primary means of communication is done through the emotional expressions on the face (Ekman & Oster, 1979; Somerville, Fani, & McClure-Tone, 2011). Basic emotions like anger, fear, disgust, happiness, sadness and surprise are easily identified across cultures and ages (Ekman & Friesen, 1971). Faces can be controlled for visual characteristics and because of this there are several normalized sets readily available to researchers (Somerville et al., 2011). Emotional faces can be easily used across different age groups and clinical populations because they do not require semantic processing and do not contain graphic images that can be disturbing for younger research participants. The availability and ease of using faces has produced a large literature that allows us to further understand emotion with different techniques from behavioral to electrophysiological to neuroimaging.

The human brain has developed a way to process emotional faces because of their evolutionary and social significance early in development. Animal research shows that among primate species there is a relationship between the size of their neocortex and their social group (Adolphs, 2003; Dunbar, 2009). The evolutionary hypothesis is that the larger the social group the greater the need for social skills and cognitive processes and thus greater brain development to subserve social cognition (Dunbar, 2009; Whiten, 1997). Human developmental research shows the importance of faces from infancy in the development of early preference for faces and face-like stimuli (Batty & Taylor, 2006; Cohen Kadosh & Johnson, 2007). At birth, infants rely on high contrast features to detect face-like shapes (Lamb & Sherrod, 1981). Infants at
3 months, cannot discriminate between emotional expressions, (Nelson, 1987) but will change their behavior in response to different emotional expressions (Montague & Walker-Andrews, 2001). By 4 months, infants are able to discriminate between expressions (T. M. Field, Woodson, Greenberg, & Cohen, 1982). Longer looking times were seen in 7 month olds in response to fearful faces, (de Haan, Belsky, Reid, Volein, & Johnson, 2004). Discrimination of emotional expression improves dramatically throughout the first year of life, (Nelson, 1987; Somerville et al., 2011). Emotional faces are evolutionarily and developmentally important stimuli in the environment.

Facial expressions of emotion are so inherently salient that the human brain has developed a way to process faces that is independent of basic object recognition. Components of a face are initially processed individually and subsequently integrated to perceive a face and its emotional expression (Haxby, Hoffman, & Gobbini, 2000). Neuroimaging studies have outlined an extensive network that supports face processing, comprised of visual object processing regions: inferior occipital gyrus, superior temporal sulcus, anterior temporal pole and the fusiform face area, (LeDoux, 2000; Pessoa, 2002; Patrik Vuilleumier, 2005). Regions traditionally associated with the ventral network of attention, like the amygdala, posterior cingulate and orbitofrontal cortex, are also believed to process some aspects of faces (Blagrove & Watson, 2010; Blasi et al., 2009; Hariri, Bookheimer, & Mazziotta, 2000; LeDoux, 2000). Electrophysiological studies have identified certain potentials in the parts of
these regions to be indicative of face processing (Darque, Del Zotto, Khateb, & Pegna, 2012; M. J. Taylor, Batty, & Itier, 2004). Event related potentials (ERPs) are measured using electroencephalography (EEG) that measure the electrical activity over time using electrodes placed on the scalp. ERPs have different waveforms that are either positive or negative which are called components. In the early stages of face processing, intracranial ERPs recorded from the cortical surface of the inferior temporal and fusiform gyri have shown that a negative component occurs 200 ms after the presentation of faces (N200). Another potential has been found with intracranial depth recordings that is specific to faces, the P180, in the basal occiptotemporal cortex. One more signal is the N170 that is recorded at the scalp from the occipito-temporal cortex. The N170 in both adults and children is largest at parieto-temporal locations, however the latencies decrease from childhood to adulthood. The decrease in latency with increasing age suggests a faster and more efficient face processing mechanism. In addition to the N170 there is a positive component that is involved in early face processing, the “P1”. In children it is rather large and can be found earlier than the N170. Like the N170, the P1 decreases with age. The amplitudes of these potentials also differ between adulthood and childhood. The P1’s amplitude decreases with age while the N170 decreases from early childhood (approximately 4 years of age) to mid childhood and then increases again from the teenager to adulthood. Collectively all these results suggest an extensive face processing network that matures over time to be able to detect finer details, (Somerville et al., 2011; Taylor et al., 2004).
It is therefore important to understand how the emotional face processing mechanism develops and how it might be affected in a developmental disorder.

*Attention Deficit Hyperactivity Disorder*

Attention Deficit/Hyperactivity Disorder, ADHD, is one of the most common neuropsychiatric disorders in childhood, affecting 3-7% of school-aged children. ADHD was first described as “hyperkinesis disorder of childhood,” then Attention Deficit Disorder, (ADD) and as it currently identified in the DSM-IV, ADHD. ADHD is characterized by symptoms of inattention, hyperactivity and impulsivity. Depending on the ratio of symptoms, the DSM-IV recognizes three subtypes, a hyperactive-impulsive (more hyperactive/impulsive symptoms), inattentive (more symptoms of inattention), and combined (presence of both hyperactive/impulsive and inattention symptoms) subtype. ADHD’s symptoms interfere with scholastic and social functioning and significantly impact quality of life. For over 20 years, ADHD has been conceptualized as a disorder of the prefrontal cortex and is still diagnosed on behavioral reports from educators, parents, and clinicians. Children with ADHD are known to have problems filtering information, selective visual attention, (the ability to focus on relevant information while ignoring irrelevant distractors) (Mason, Humphreys, & Kent, 2005) all related to a core cognitive deficit in a top down process, executive control (Schachar, Tannock, Marriott, & Logan, 1995). Executive control is ascribed to a nigrostriatal network, which utilizes a similar structure like the dorsal network of attention, the lateral frontal cortex. Recently, researchers have questioned
the belief that ADHD is exclusively a result of the deficit in executive control.
Evaluation of early studies of selective visual attention, showed that children with
ADHD despite being distracted by irrelevant stimuli were no more vulnerable to
irrelevant information than controls (Castel, Lee, Humphreys, & Moore, 2011).
Children with ADHD have a stronger preference for small immediate rewards over
larger delayed rewards (E. J. S. Sonuga-Barke, 2002) and high-rate intrusive and
impulsive behavior (excessive talking, interruptions, obnoxious behavior), deficient
communication skills (including eye contact and motor regulation), biased and
deficient social cognitive skills (decreased self-awareness, deficient social problem-
solving skills, biased attributions of others’ intentions, inattentiveness to social cues),
and poor emotional regulation (Guevremont & Dumas, 1994; Hoza, 2007; Nixon,
2001; Soliva et al., 2009; Wheeler & Carlson, 1994). All these behaviors cannot be
explained exclusively from a deficit in executive control, therefore a deficit or atypical
process must be present in an area outside of executive control.

Current ADHD research has begun to consider investigating bottom-up
processes like those involved in the ventral network of attention as a potential site of a
deficit for children with ADHD. The mesolimbic network, comprised of the
orbitofrontal cortex, anterior cingulate, ventral striatum, and amygdala, are believed to
contribute to an emotional and motivation dysfunction in ADHD (E. J. S. Sonuga-
Barke, 2003). Of particular concern for this dissertation is the amygdala because of its
role both in the ventral network of attention and mesolimbic emotional dysfunction in ADHD.

ADHD is mainly known by its executive control deficits but there is also behavioral evidence for emotional dysfunction in ADHD. Boys with ADHD have more difficulty on tasks that match emotions to situations even when impulsive responding was controlled (Yuill & Lyon, 2007). This suggests emotional dysregulation above and beyond executive dysfunction. Social functioning and emotional regulation vary across ADHD subtypes, such that the combined subtype is characterized by being less popular, more aggressive, and being more negative after being disappointed (Maedgen & Carlson, 2000). A performance measure of impulsivity (Stop Signal Task) accounted for only a small amount of variability in emotional regulation when a child with ADHD performed a task that was designed to make the child frustrated (Kühle et al., 2007). In addition, Stop-signal performance did not change from before to after performing the frustration-inducing task even when the children with ADHD were told to regulate their emotions explicitly. In a different study, medication treatment with either methylphenidate or atomoxetine (whose action influences both the top down and bottom up networks) improved positive emotion expression on a parent-rated Expression and Emotion Scale for Children (Kratochvil et al., 2007). Together these studies provide evidence that emotional dysfunction in ADHD is not accounted for by executive control mediated by dorsal top down
processes. Direct investigation of emotional processing in ADHD is necessary to further provide a comprehensive view of ADHD pathophysiology.

Studies assessing the bottom-up processes directly in ADHD have mainly utilized rewards. Tangible rewards like money, tokens, or food incentives (Konrad, Gauggel, Manz, & Schöll, 2000; Luman, Oosterlaan, & Sergeant, 2005), have been used to improve ADHD’s executive control deficits. However recently there is an emerging literature indicating the increased salience of socio-emotional information and its effect on executive control tasks. One group directly compared the effect of non-social (money) and social (smiling faces) rewards in typically developing children and adolescents on a response inhibition task. Interestingly they found that both types of reward increased performance on the response inhibition task and the degree of influence of the social reward depended on how empathetic a child or adolescent is (Kohls, Peltzer, Herpertz-Dahlmann, & Konrad, 2009). This provides one of the first pieces of evidence that socio-emotional information is salient and can enhance performance in children. Among ADHD children, when a social motivation condition (children were made to believe they were competing with other children) was introduced in an interference suppression task (a child adapted flanker), children with ADHD were able to perform equally well as controls (Geurts, Luman, & van Meel, 2008). Lastly when both monetary and social (positive faces) rewards were directly compared in children with ADHD, social rewards were found to be more salient and produced greater improvements than monetary rewards on a response inhibition task.
Socio-emotional information is just as salient as rewards that engage bottom up processes that recruit the mesolimbic network in ADHD. By using socio-emotional stimuli we also have insight into how emotional information is processed by children with ADHD. It is therefore, necessary to study early emotional processing in ADHD to understand whether the emotional dysfunction is a by-product of increased bottom up processes that overload the top-down process of executive control of children with ADHD or if bottom up processes are intact and the dysfunction present is the result of a weak executive control.

**Attentional Blink Paradigm**

When the visual system is presented with a large amount of information, it is only capable of perceiving and consciously remembering a small selection. Think of the last time you went to a wedding, you can remember parts of the party, the dress the bride wore, the cake, the tossing of the garter and bouquet. But can you remember: whether the groom wore a bow tie or tie, whether the flower girl had a colored sash, whether the bouquet had colored ribbon or not. The selection of the information involves attention, and if allocation of attentional resources is insufficient, “inattentional blindness” can occur. If it was a large elaborate wedding you may not have paid enough attention to the little details because there were too many. A task that elucidates this phenomenon is the rapid serial visual presentation paradigm (RSVP), also known as the attentional blink paradigm (Raymond, Shapiro, & Arnell, 1992). In this task, stimuli are presented quickly at about a rate of 10 stimuli per
second (100ms). In the RSVP stream, there are two targets, T1 and T2 that are presented among distractors, with T2 appearing always after T1 at different time lags. There is a reduced number of T2 targets that are consciously reported when they occur between 200 and 500ms after T1, resulting in the attentional blink. The attentional blink demonstrates the temporal limitation of the attentional resources readily available for information to reach consciousness.

The attentional blink is believed to reflect the transient impairment of post perceptual attentional mechanisms active at a late stage (after the identification of the stimulus) at the top-down process level. Attentional resources are depleted while T1 is being processed. However if there is a salient T2, attentional capture occurs via the reflexive allocation of attention toward the salient T2 reallocating attentional resources so that it is processed (Anderson, 2005). Bottom-up processes like that of the ventral network of attention are believed to be responsible for this enhanced early attentional processing. Emotional T2s are an example of salient T2s that can be perceived at early lag intervals, because of the allocation of attentional resources available that reduce the attentional blink effect. The amygdala has been implied for the preferential processing of emotion with the attentional blink paradigm (Anderson & Phelps, 2001), when the amygdala has been compromised due to brain insult, there is no allocation of attentional resources so that T2 can be fully processed. The attentional blink paradigm through the use of emotional stimuli can provide insight into how attentional capture occurs across development and ADHD.
Faces can convey various emotions making them even more efficient in capturing visuo-spatial attention, to the extent that early stages of face processing are considered to be automatic (Pessoa, 2002; Patrik Vuilleumier, 2005). Because of the influence that emotional faces exert in early visual processing, it is believed that they have a preferred status in the perceptual processing stream. Relative to other visual objects, faces elicit an early enhanced negative component in the lateral occipital scalp at about 170ms after stimulus presentation which is said to be face specific (Darque et al., 2012). Therefore for this dissertation, faces will be used in the emotional attentional blink paradigm.

The use of emotional faces in the attentional blink paradigm has facilitated the study of how anxiety influences early perceptual processing. Angry schematic faces reduce the AB effect in normal adults (Maratos, Mogg, & Bradley, 2008). Among anxious individuals there is heightened sensitivity to negative emotions like anger and fear (de Jong & Martens, 2007; B. De Martino, Kalisch, Rees, & Dolan, 2008; Fox, Russo, & Georgiou, 2005). Highly anxious individuals show a reduced AB effect with fearful faces compared to happy faces (Fox et al., 2005). Women with higher trait anxiety also show a reduced attentional blink when T2 targets are faces with anger compared to happy faces (de Jong & Martens, 2007; Fox et al., 2005). Anxious individuals therefore perceive emotional faces as more salient and thus are processed more efficiently because less competition is present for attentional resources (B. De Martino et al., 2008; Fox et al., 2005; Maratos et al., 2008). It is unknown, however,
how anxiety influences early emotional perceptual processing across development and in a disorder that suffers from attentional problems.

The attentional blink has been successfully adapted to investigate early perceptual processing in children and in ADHD (Garrad-Cole, Shapiro, & Thierry, 2011; Li, Lin, Chang, & Hung, 2004). However to date there is no study investigating the role emotion plays in early perceptual processing in children and in ADHD.

Research Goals & Rationale

The influence of emotion on attention and how they interact has been a major focus in cognitive neuroscience. While there is a considerable amount of literature on how emotion and attention interact across development, little is known on how emotion captures attention in the perceptual stage of processing. Even less is known about how this process may be affected in a developmental disorder in which attentional function is disrupted, such as ADHD. In Study 1, we used the Attentional blink paradigm to examine the effect of emotional faces on early visual attention in children and adults. We also investigated whether these effects are associated with anxiety in children and adults. Study 2 used the Attentional blink paradigm to examine the effect of emotional faces on early visual attention in children with ADHD. We also examined whether these effects are associated with ADHD symptoms and anxiety.
CHAPTER II: DEVELOPMENTAL DIFFERENCES IN THE EMOTIONAL MODULATION OF THE ATTENTIONAL BLINK

Abstract

We examined developmental differences in early stages of attention processing for socio-emotional information. Adults and children (8–14 years) performed an attentional blink task that required identification of a dog face (T1) and either an angry or neutral face (T2) among scrambled face distractors. The anticipated attentional blink phenomenon was found with both neutral faces and angry faces, reduced detection at earlier lags that increased across later lags, in both adults in children. We found a developmental difference such that children took more time to detect faces than adults. Among children, those with higher trait anxiety showed a smaller magnitude of the attentional blink. Emotional stimuli reduced the attentional blink, as expected, but this effect did not differ developmentally. However, overall detection of emotional stimuli was higher for emotional than neutral stimuli, to a larger extent in children relative to adults. Together, these findings are the first to reveal developmental differences in early stages of attention processing and its modulation by emotion.
**Introduction**

When a person blinks, there is information that the visual system will not perceive and therefore not process; like an eye blink, attention appears to blink as well. When a person is asked to search for a specific target within a rapid series visual presentation (RSVP) of irrelevant stimuli (~100ms), upon successful detection of that target, a second subsequent target will not be perceived nor processed, therefore resulting in an attentional blink (D. E. Broadbent & Broadbent, 1987; Raymond et al., 1992). Detection of the second subsequent target improves when there is more time in between the presentation of the first and second target (e.g. 600ms) than less time (e.g. 200ms). The attentional blink is a natural phenomenon that occurs and has been instrumental in studying early stages of attention processing.

Theoretical models of the attentional blink suggest a two-stage process that has its limitations. Detection of a second subsequent target decreases because attentional resources are depleted when the first target is being processed (Shapiro, Caldwell, & Sorensen, 1997). All items in the RSVP stream are processed at stage 1, in order to identify target features. Target selection occurs at Stage 2 and requires short-term memory. Decreased T2 detection occurs because Stage 1 has priority and therefore Stage 2 processing cannot begin until Stage 1’s is complete. A bottleneck effect is said to occur at Stage 2 because it cannot process additional items from Stage 1 until it is done processing (Arnell, Helion, Hurdelbrink, & Pasieka, 2004; Marvin M. Chun & Potter, 1995; Jolicoeur, 1998; Martens & Wyble, 2010). It is believed that more
efficient consolidation of the first target should reduce the wait at the bottleneck, resulting in a smaller attentional blink (Arnell, Howe, Joanisse, & Klein, 2006). The more unique a target is among the distractors, the easier and thus faster processing that occurs at Stage 2, which results in increased T2 detection at earlier lags (M M Chun, 1997; Marvin M. Chun & Potter, 1995). Recent research has begun to focus on using salient stimuli like emotions as targets in the attentional blink to investigate early perceptual processes.

Emotional information has been shown to influence the attentional blink. When emotional information is introduced as the second subsequent target in the attentional blink paradigm, the blink is reduced such that the second emotional stimuli can be detected at earlier time points, (e.g. before 500ms), (Anderson & Phelps, 2001). One hypothesis for the attenuated attentional blink with emotion is that the increased salience of an emotional face among non-emotional face results in a low threshold for detecting the emotional face, reducing the bottleneck effect (de Jong & Martens, 2007). Another explanation for the reduced attentional blink is evidence suggesting an alternate pathway that is faster in processing emotional stimuli that engages the amygdala to reduce the need for attentional resources (Anderson & Phelps, 2001; Pessoa, 2002). The reduced attentional blink has been confirmed with various types of emotional stimuli: words (Benedetto De Martino, Strange, & Dolan, 2007), scenes (B. De Martino et al., 2008), schematic faces (Maratos et al., 2008) and photographs of
faces (Stein, Peelen, Funk, & Seidl, 2010). The reduced attentional blink for emotional information suggests emotion is prioritized in early stages of attention processing.

Developmental studies confirm that emotional information is prioritized in later stages of attention processing, however little is known about earlier stages. Infants prefer faces over other stimuli (Grossmann & Johnson, 2007; Johnson, 2005) and are biased towards happy faces (Faroni, et al., 2007) indicating that full brain maturation is not necessary to detect and prefer an emotional stimuli. A bias for angry faces emerges later in early childhood, between 1-3 years, (Vaish, Grossman, & Woodward, 2008), suggesting that a bias for negative emotions develops from a very young age.

In older children (ages 10 to 13 years old) the bias for angry faces created more interference, on an executive control task that used emotion as irrelevant stimulus, than in young children (ages 6 to 9 years old) and adults (K. A. Barnes, Kaplan, & Vaidya, 2007). This study suggests that emotional information will compete for attentional resources even when it is not relevant to the task. This competition for attentional resources by emotion appears to be more vulnerable in older children than in adults. Therefore it is necessary to examine developmentally whether emotional information has a preferred status at early stages of attention processing.

While a few studies have examined early stages of attention processing using the attentional blink phenomenon in children, none have investigated whether the magnitude of the attentional blink changes across development with socio-emotional information. Only one study has looked at how the attentional blink changes across
age (Garrad-Cole et al., 2011). In this study, children of seven, twelve, and adolescents of fifteen years of age were compared to adults on an attentional blink task that used shapes as targets. All but children of seven years of age recovered from the attentional blink by 600 ms, these children took over 1000 ms to recover. This study demonstrated that with increasing age, the attentional blink is reduced. This study suggests that the profound blink found amongst younger children is due to inefficient processing at Stage 2, where the bottleneck occurs, and that by 12 years of age children are showing a similar attentional blink pattern to adolescents and adults. We expect to replicate with our emotional attentional blink paradigm, that with increasing age the attentional blink is reduced.

More insight about the attentional blink in children can be drawn from studies that have focused upon two developmental disorders, Attention Deficit Hyperactivity Disorder (ADHD; (Mason et al., 2005) and dyslexia (Visser, Boden, & Giaschi, 2004). Children with ADHD show mixed results with one study showing no differences in the attentional blink relative to gender-matched controls when letters were used as both targets and distractors (Mason et al., 2005). Another study has demonstrated evidence for a prolonged blink using letters as target and distractors as well (Li et al., 2004). Relative to their age-matched controls, children with dyslexia had a larger attentional blink when shapes were used as targets among random dot distractors (Visser et al., 2004). Thus, the attentional blink phenomenon occurs in children as young as 8 years and developmental disorders with attentional and language problems appear to alter it.
In healthy children, individual differences in the magnitude of the attentional blink are associated with impulsivity, a trait associated with ADHD (Chhabildas, Pennington, & Willcutt, 2001; Gomez, 2003; Oades, Slusarek, Velling, & Bondy, 2002). Specifically, higher levels of impulsivity in adolescence were related to two characteristics of the attentional blink: worse subsequent target detection at early lags and a prolonged blink (Ray Li, Chen, Lin, & Yang, 2005). Thus, children with higher levels of impulsivity were characterized as having a larger and more long-lasting attentional blink. Impulsivity is characteristic of immaturity and therefore, it is possible that younger children will show a larger and prolonged attentional blink relative to older children and/or adults. Currently, there is no study investigating differences in early stages of attention processing using the emotional attentional blink in children.

Differences seen in early stages of attention processing, through the use of the emotional attentional blink paradigm, have been attributed to individual differences among healthy adults in their levels of anxiety. One study assessed healthy females who either scored high or low on measures of anxiety and revealed a bias for a specific emotion among anxious individuals (Fox et al., 2005). Highly anxious females have a shortened attentional blink for fearful faces while less anxious females have a shortened attentional blink for both fearful and happy faces. In another similar study, selecting high and low socially anxious healthy females, both high and low socially anxious women had a shortened attentional blink in the presence of an angry face, (de Jong & Martens, 2007). This study further established the anger superiority effect,
which is the tendency for healthy individuals to selectively attend to angry faces, (Hansen & Hansen, 1988), seen in other studies with other paradigms (Bradley, Mogg, White, Groom, & de Bono, 1999; Schutter, Putman, Hermans, & van Honk, 2001). It is unknown whether individual differences in anxiety may also explain the differences in early stages of attention processing in healthy children with emotional information.

In the present study, we examined developmental differences in the attentional blink for faces with and without emotional expressions. We hypothesized that children would have a larger attentional blink with neutral faces than adults because their brains are still developing and thus are less efficient than adult brains to process a subsequent target. With regards to the influence of emotion, we hypothesize that children will benefit the most from the emotional information resulting in a smaller attentional blink than adults. Lastly, we hypothesize that both state and trait anxiety will be related to the size of emotional attentional blink, such that more anxious individuals will be more sensitive to emotional faces and thus have a smaller attentional blink.

Methods

Participants

Thirty eight 7-14 year old children were recruited from the Washington DC metropolitan area through advertisements. Thirty five undergraduate students (16 female; mean age = 19.3, SD = 1.1 years) were recruited from Georgetown University Psychology classes. The final sample included 31 children (15 female; mean age =
11.5, SD = 1.9 years, Range= 8-14; mean IQ = 111, SD = 14.3, Range= 91-138) and 33 adults (16 female; mean age = 19.4, SD = 1.1 years, Range= 18-22) following exclusion of 7 children and 2 adults who did not meet performance criteria (see below in results). All participants were paid $10 for participation. Written informed consent from adults and parents of children, and assent from children were obtained according to Georgetown University Institutional Review Board guidelines.

Participants with neurological and psychiatric conditions were excluded by self-report for adults and standardized measures for children. Exclusion criteria for children was: 1) Full scale IQ below 85 (estimated using Vocabulary and Block Design subtests of the Wechsler Abbreviated Scale of Intelligence, (WASI; (Weschler, n.d.). 2) Presence of neurological disorder by parent-report and psychiatric disorder based upon the Behavior Assessment System for Children (BASC; (Reynolds & Kamphaus, 1992) including conduct disorder. 3) Score below 50 on the Word Attack and Letter Word Identification subtests of the Woodcock-Johnson reading test to screen for reading problems (WJ III; (R.W. Woodcock, K.S. McGrew, & N. Mather, 2000).

Stimulus materials
All stimuli were displayed on a white background at a viewing distance of 60 cm on a 17 inch monitor using E-Prime version 1.1 (Psychology Software Tools Inc., Pittsburg, PA). Twenty color face photographs of adult faces (10 with neutral facial expressions and 10 with angry facial expressions) were obtained from the NimStim set, www.macbrain.org; faces did not overlap across tasks. The Emotional Identification
Task consisted of six colored photographs of adults with angry and neutral facial expressions (three of each gender). The Attentional Blink Task consisted of three classes of stimuli: 1) Two color photographs of dogs, from the website www.dogbreedinfo.com, were used as the first target stimuli (T1). 2) Twenty eight colored photographs of scrambled faces were used for the distractor stimuli. Faces of seven females and seven males with neutral expressions were scrambled with the face outline preserved and the interior portion scrambled using the scramble feature from the website http://www.faceresearch.org. 3) Fourteen colored photographs of faces with angry and neutral expressions (seven of each gender) were used for the second target stimuli (T2).

Procedure

First, participants completed the State-Trait Anxiety Inventory questionnaire [STAI Form Y for adults, and STAI-CH for children; (Spielberger, Edwards, Montuori, & Lushene, 1983)]. Then, participants completed the Emotional Identification Task followed by 20 practice trials and 188 test trials of the Attentional Blink (AB) task.

Emotional Identification Task

The goal of the task was to assess whether participants recognized the emotional valence of faces accurately. The task consisted of 6 trials. Participants began the task by pressing the space bar in response to the words “Get Ready!” on the screen. Either an angry face or neutral face was presented centrally for 2000 ms,
following which the participant had to press the number “1” key for “angry” or the number “2” key for “no emotion” in answer to the question “Is this person:”. Participants could take as long as they needed to record their response. Recognition accuracy of 70% or higher was required to move on to complete the AB task. All subjects achieved this criterion at first attempt.

Attentional Blink task

The AB task consisted of 188 trials divided into four blocks of 47 trials each. Participants pressed the space bar in response to the words “Get Ready!” on the screen to start each block; they could take a self-paced break in between blocks. Each trial began with the presentation of a fixation cross for 750 ms followed by a rapid serial visual presentation (RSVP) stream of 15 stimuli presented for 100 ms each (see Figure 1). Participants were instructed to look for a dog and informed that sometimes a face would appear and to pay attention because the pictures came on the screen very fast. Each trial ended with the a question on the screen “Did you see a dog?”. Participants pressed “1“ for “yes” or “2” for “no” on the number pad of the keyboard. Following their response, a second question “Did you see a face?” appeared on the screen. Once again, participants indicated their response by using the number pad. For each question, participants had 5000 ms to respond.

The AB task consisted of eight types of trials, two types of catch trials, and six types of AB trials varying in the facial expression of the T2 stimulus, at each of three lags. Specifically, catch trials included: 1) 30 T1-only trials, in which only the T1, a
dog, appeared in the RSVP stream but no T2 appeared; 2) 32 T2-only trials, in which a T2 (either an angry or neutral face) appeared in the RSVP stream without a preceding T1. These trials were included in order to ‘catch’ children with a bias to respond with “yes” to both questions at the end of the RSVP stream.

On the remaining AB trials, a T2 was either a face with a neutral or angry expression and followed the T1 with three lags: 1) 21 trials with a neutral T2 appearing 200 ms after the T1, (termed Neutral-Lag 2); 4) 21 trials with an angry T2 appearing 200 ms after the T1, (termed Angry-Lag 2); 5) 21 trials with a neutral T2 appearing 400 ms after the T1 (termed Neutral-Lag 4); 6) 21 trials with an angry T2 appearing 400 ms after the T1, (termed Angry-Lag 4); 7) 21 trials with a neutral T2 appearing 800 ms after the T1 (termed Neutral-Lag 8); 8) 21 trials with an angry T2 appearing 800 ms after the T1 (termed Angry-Lag 8). Further, within the RSVP stream, the serial position of T1 was varied among stimuli 4, 5, and 6 in the trial sequence. The position of T1 was varied at these points to minimize missing the T1 because it occurred too early in the sequence that individuals would not have enough time to adapt to the RSVP presentation and to minimize working memory demands of remembering they saw the T1 by the end of the trial. Thus, T2 followed each of these positions at the three lags described above such that it was either the second (Lag 2), fourth (Lag 4), or eighth (Lag 8) stimulus after the T1. All the trials were pseudorandomized into blocks so that no more than two successive trials were of the same type within each block. Blocks were created to allow breaks after 47 trials, and
were balanced to include the same number of each trial types. Two versions of the task were created to counterbalance block presentation order.
Figure 1. Rapid serial visual presentation (RSVP) stream for the Attentional Blink Task. Participants monitored two target stimuli (T1 & T2) embedded among 13 distractor stimuli, each presented for 100ms with no interstimulus interval. The first target stimulus (T1) was a dog face and the second target stimulus (T2) was a human face (either neutral or angry). The distractors were scrambled faces. a) T1-only catch trials in which only the dog face was presented, b) T2-only catch trials in which only an angry or neutral face was presented, c) Double target trials in both T1, the dog face, and T2, the human face, were presented. The two targets were separated by either 2, 4 or 8 distractors, (200ms, 400ms, or 800ms, respectively). At the end of the RSVP stream, participants indicated by key press whether they had seen saw a dog and a face.
Results

Participants who performed worse than chance (50%) on the T2 catch trial were excluded from analysis. This criterion resulted in the exclusion of seven children and two adults from the total cohort of participants. A response was scored as correct if the participant correctly identified first the T1 and then the T2, as for T1 incorrect trials the source of T2 errors is unknown (Marvin M. Chun & Potter, 1995). For each participant, percentage of accurate T2 trials was computed for each of the six types of AB trials. Percent accuracy was analyzed in a mixed analysis of variance with Group (Children, Adults) as the between-subjects factor and emotion (T2 - angry, neutral) and lag (2, 4, 8) as within-subjects factors. Measures of effect size (partial eta-squared for analyses of variance [ANOVA], Cohen’s $d$ for means, $r^2$ for correlations) are presented for the attentional blink effects. Figure 2 summarizes the results by trial type and groups.
We found three main effects. Overall, T2 accuracy was higher in adults than in children (main effect of group), $F(1,62) = 21.77$, $p< .001$, $\eta^2=.26$ and both groups were more accurate when the T2 was a face with angry than neutral expression (main effect of emotion), $F(1,62) = 39.84$, $p < .001$, $\eta^2=.10$. Further, T2 accuracy differed by lag (main effect of lag), $F(2,61) = 25.99$, $p< .001$, $\eta^2=.17$. Post-hoc tests showed that T2 detection at lag 2 was lower than at lag 4, $t(63) = 4.51$, $p < .001$, $d= 0.80$, and lag 8,
t(63), = 6.75, p < .001, d= 1.76. T2 detection at lag 4 was also lower than lag 8, t(63), = 4.48, p < .001, d= 0.82. These findings indicate that our paradigm produced the expected attentional blink phenomenon, decreased accuracy at the shortest lag relative to longer lags.

In addition to these main effects, several key interactions were observed. First, a significant lag X group interaction was obtained, F(2,61) = 5.39, p < .01, η²=.03, suggesting that the magnitude of the overall attentional blink (neutral and emotional) differed by age. Paired t-tests revealed that both groups showed improvement in overall T2 detection with each increasing lag: Adults - lag 2 versus lag 4, t(32), = 3.45, p < .005, d= 1.53; lag 4 versus lag 8, t(32), = 3.22, p < .001, d= 0.68, and lag 2 versus lag 8, t(32), = 4.70, p < .005, d= 2.18; Children - lag 2 versus lag 4, t(30), = 3.06, p < .01, d= 0.78; lag 4 versus lag 8, t(30), = 4.02, p < .001, d= 1.13, and lag 2 versus lag 8, t(30), = 5.44, p < .001, d= 2.11. These results demonstrate that both adults and children had an attentional blink effect, poor T2 accuracy at shorter lags that improved as the lag increased. However, adults’ accuracy was better at each lag. Independent samples t-test revealed that adults had higher T2 detection at lag 2, t(62), = 4.52, p < .001, d= 1.15, lag 4, t(62)= 4.18, p < .001, d= 1.02 , and lag 8, t(62)= 3.84, p < .001, d= .97. When a difference score was calculated to assess the magnitude of the blink, (i.e. lag 8 performance minus lag 2), there was a larger magnitude of blink in children than in adults, t(62), = 2.63, p < .05, d= 0.67, such that children had a more profound blink, (lower T2 accuracy) than adults.
Second, there was also a significant lag X emotion interaction, F(2,61) = 10.97, p < .001, η² = .05, suggesting that the magnitude of the attentional blink differed by the nature of the T2. Collapsing across groups, paired t-tests showed a higher T2 accuracy for angry trials relative to neutral trials at lags 2 and 4 but not lag 8: lag 2, t(63), = 6.37, p < .001, d = 1.52, lag 4, t(63) = 3.25, p < .005, d = 1.02 , and lag 8, t(63) = 1.72, p = .09, d = .23. Thus, better T2 detection for emotional faces was limited to earlier lags. Among the angry trials, T2 detection improved from lag 2 to lag 8, t(63) = 3.05, p < .005, d = 0.93 and also from lag 4 and lag 8, t(63) = 2.74, p < .01, d = 0.59, but not from lag 2 to lag 4, t(63) = 1.47, p = .15, d = 0.36. Among the neutral trials, T2 detection improved with increasing lag length: lag 2 and lag 4, t(63), = 5.18, p < .001, d = 1.06; lag 4 and lag 8, t(63), = 4.29, p < .001, d = 0.89, and lag 2 and lag 8, t(63), = 7.45, p < .001, d = 2.14. This finding was further substantiated when a difference score was calculated to assess the magnitude of blink (lag 8 minus lag 2), a significantly larger blink was found on neutral trials than on angry trials, t(63), = 4.71, p < .001, d = 1.56. These findings indicate that we observed the expected effect of emotional stimuli on the attentional blink phenomenon, a shorter blink for angry than neutral faces.

Third, a significant Emotion by Group interaction was found, F(1, 62) = 5.67, p < .05, η² = .01. Independent sample t-tests revealed better T2 detection (when collapsing across all lags) in adults than children for angry trials, t(62) = 4.18, p < .001, d = 1.06 and neutral trials, t(62) = 4.61, p < .001, d = 1.17. Paired t-tests revealed a significantly higher T2 accuracy for angry than neutral trials in both adults, t(32)=
3.61, \( p < .001, d= 1.47 \), and children, \( t(30)= 5.09, p < .001, d= 1.26 \). When a difference score was calculated to assess the influence of emotion, (i.e. angry face trials’ performance minus neutral face trials), children had a larger difference score than adults, \( t(62), = 2.38, p < .05, d= 0.60 \), indicating that accuracy improved much more with the emotional face in children. Figure 3 summarizes graphically that adults had better detection of T2 for both angry and neutral faces than children, however children had a greater improvement in accuracy when an emotional face was presented as T2. Most importantly, the Group X Lag X Emotion interaction was not significant, \( F(2,61) = .632, p =.54, \eta^2=.033 \) indicating that the effect of the facial expression of the T2 stimulus did not influence the magnitude of the attentional blink differently in the two age groups.

![Figure 3. Means percentage correct scores for emotional face of T2 (angry vs neutral) and group (adult vs. child).](image_url)
In order to assess individual differences in state and trait anxiety, both the adult and child STAI, raw scores were converted to Z-scores. There was a difference in trait anxiety between adults (raw: mean = 37.4, SD = 12.2; Z-score: mean = 0.27, SD = 1.23) and children (raw: mean = 31.6, SD = 5.14; Z-score: mean = -0.31, SD = .52), t(60)= 2.37, p < 0.05, d= 0.96) such that adults were more anxious than children. In lieu of the difference, we then assessed individual differences in the size of the attentional blink, (indexed by subtracting T2 accuracy for neutral at lag 8 from T2 accuracy for neutral at lag 2), separately in each group. A negative correlation between the size of the attentional blink and trait anxiety level was shown in children, such that more anxious children had a smaller attentional blink, (r= -0.41, p < .05, r²= 0.16); this relationship was not significant in adults (r= 0.21, p = 0.25, r²= 0.04). Lastly to assess whether trait anxiety was associated with the emotional attentional blink (indexed by subtracting T2 accuracy for neutral from T2 accuracy for angry faces at Lag 2). No significant correlations were found in either group with trait anxiety. Furthermore, state anxiety was also higher in adults (raw: mean = 33.0, SD = 8.68; Z-score: mean= 0.28, SD= 1.18) than children (raw: mean = 28.2, SD= 3.57; Z-score: mean= -0.38, SD= .49), t(55)= 2.55, p < .001, d= 0.70, but was not associated with either the size of the attentional blink or its modulation by emotion.
Figure 4. Correlation between STAI Trait Anxiety and the size of the attentional blink in children.

**Discussion**

We examined developmental differences in early stages of attention processing and its modulation by emotional stimuli. We found a developmental difference in the magnitude of the attentional blink for faces such that it was larger in children than in adults regardless of the nature of T2. Among children, those with higher trait anxiety showed a smaller magnitude of the attentional blink. Emotional stimuli reduced the
attentional blink, as expected, but this effect did not differ developmentally. However, overall detection of emotional stimuli was higher for emotional than neutral stimuli, to a larger extent in children relative to adults. Together, these findings are the first to reveal developmental differences in early stages of attention processing and its modulation by emotion.

The introduction of socio-emotional information in our paradigm is central to understanding our findings. Attentional blink paradigms that have been used in children to date have used non-social stimuli: words, (Anderson & Phelps, 2001), chinese characters, (Ray Li et al., 2005), letters, (Marois & Ivanoff, 2005), numbers, (Colzato, Slagter, Spapé, & Hommel, 2008), shapes, (Garrad-Cole et al., 2011). We do see a larger more profound blink with children than adults as the previous developmental study that used non-social stimuli, shapes, (Garrad-Cole et al., 2011). We do not however see a developmental difference between neutral and emotional faces for the magnitude of the attentional blink, despite seeing the attentional blink phenomenon (main effect of lag) and a difference among adults and children in the nature of the emotional face, (significant Emotion x Group interaction). Therefore it is important to look at our study more closely to understand the influence of emotion across development in early stages of attention processing. The introduction of social information, as is the case of with neutral faces, reveals a developmental difference in early stages of attention processing seen in children having a larger attentional blink than adults, (a significant Group X Lag interaction is observed when a repeated
measures ANOVA is analyzed with the neutral face trials alone). However when emotional information is introduced, as in the case of the angry faces, we see no difference in the size of the attentional blink between children and adults, (there is also no longer a Group x Lag interaction present when a repeated measures ANOVA is run with only the angry face trials). It maybe that neutral faces are salient and the introduction of an emotion is not as salient to produce a strong effect or difference in early stages of attention processing, when comparing neutral and angry faces together. In order to better assess the influence of emotion a non-social stimulus like shapes, (that have been previously used), could be additionally incorporated to the task to better distinguish between the influence of social and emotional information. Another alternative to assess the influence of emotion in the attentional blink would be to use the emotional information as the first target. This “reverse” version of the attentional blink has been used more recently to assess how long an emotional stimulus engages early attentional processes (de Jong & Martens, 2007). In conclusion the specifics of our paradigm may in fact explain our lack of a specific developmental difference in the emotional modulation of early stages of attention processing.

The developmental difference found in the attentional blink can be explained by recent research showing developmental differences in event-related potential (ERPs) indicators of early face processing. Developmental ERP studies have shown the presence of two components that are indicative of early face processing, the N170 and the P1 (M. J. Taylor et al., 2004). The N170, in young children between 4 and 7 years
of age, is found to be bifid, (two peaks) and between 10 and 13 years of age, (our sample included children ranging from 8 to 14 years of age), the bifid pattern merges to one, looking more like the single peak adult N170. The bifid N170 in childhood is reflective of a slower inefficient process that is distributed across different areas, and as the brain matures, the processing of faces is localized to one region. The P1, the positive component preceding the N170, is an indicator of earlier stage processing than the N170. The P1 latency has been shown to decrease with age among a group of children ranging from 4 to 13 and adults. The larger latency in young children (4 years to 10 years old) reflects a slower processing speed. In adulthood, myelination, facilitates neurotransmission that results in faster and more efficient processing (Luna & Sweeney, 2004; Rubia et al., 2000; Toga, Thompson, & Sowell, 2006). The presentation of a larger blink by children maybe a result of a larger distributed set of regions trying to encode each face and thus require more time to not only encode but communicate to each other in order to successfully identify T2, indicating an immature face processing network.

Our study continues to show converging evidence for the preferential treatment for emotion in early attention processing in both adults and children. Emotion modulated the attentional blink at early lags but its effect is reduced at later lags. The modulation of emotion was an expected finding since it has been previously shown with other emotional attentional blink studies (Jefferies, Smilek, Eich, & Enns, 2008; Maratos et al., 2008; Srivastava & Srinivasan, 2010; Stein et al., 2010). One key difference
between our paradigm and previous studies’ is the high accuracy present on the lag 2 trials in the adult group, approximately 87% for the neutral faces and 95% for angry faces, other studies using faces have ranged from 30%-50% for neutral faces and 65%-88% for angry faces (de Jong & Martens, 2007; Maratos et al., 2008). In the later lags, adults perform at near ceiling, over 90%. The higher accuracy could be a result of an adaptation to our paradigm, the initial target, T1, is a dog face, that is salient enough to facilitate faster processing of T1 allowing attentional resources to become readily available for a subsequent target to be processed. The use of a dog face was done to make the task child-friendly. Both adults and children improved with the presentation of an angry face as the T2 at any time point, this finding is consistent with other literature showing a benefit from angry or threatening faces in performance on various tasks in children (Hadwin et al., 2003; Heim-Dreger, Kohlmann, Eschenbeck, & Burkhardt, 2006; Perez-Edgar et al., 2010) and adults (Mogg, Bradley, de Bono, & Painter, 1997; Schub, Meinecke, Abele, & Gendolla, 2006; Schutter et al., 2001).

Lastly, our study provides correlational evidence for a vigilant-avoidant bias among more anxious individuals for ambiguous emotion (Amir, Foa, & Coles, 1998; MacLeod & Cohen, 1993; Stopa, 2000). In our study, the neutral faces appeared to be more salient to highly anxious children, than angry faces in our sample, as indicated by a smaller attentional blink with neutral faces. Emerging literature suggests that a critical discriminate among anxious individuals is in how they process ambiguous information. Anxious individuals appear to perceive ambiguity as threatening and
therefore avoid any ambiguous information and it is evident from childhood, (A. P. Field & Lester, 2010). Neutral faces are considered to provide ambiguous information in previous child studies, (for review(Leppanen & Nelson, 2009). In our study of early attentional processing, we see that the neutral faces are very salient to highly anxious children, since their attentional blink is reduced. It maybe the case that in early stages of attention processing children are vigilant towards ambiguous stimuli and when assessed in later stages of attention, they actually display the avoidant bias traditionally seen in emotion studies (Perez-Edgar et al., 2010). Important to note is that adults did not show the heightened response to neutral faces. One explanation is that adults understood that these were neutral faces and thus did not perceive any ambiguity.

Most of the adult studies assessing the role of anxiety in early attentional processing have selected those adults who score higher on measures of anxiety. In our study we did not select the more anxious individuals, none of our subjects met the criteria for an anxiety disorder. In conclusion, further research should be done to confirm this early vigilant, later avoidant pattern of behavior in more anxious children and investigate if this pattern might be present in adults as well.

Further studies should continue to investigate early automatic attentional processes. It is important to differentiate whether the differences we see with emotion are due to overall salience difference or truly a preference for emotion. The reason we must distinguish this is because the size of the attentional blink varies depending on the relationship between the targets and the distractors in the trials, the greater difference
between the targets and distractors, the smaller the blink, and increased sensitivity (Anderson, 2005; Marvin M. Chun & Potter, 1995). Lastly, within the realm of individual differences, presence of a short allele for the serotonin transporter corresponds with an increased reactivity to threatening stimuli in an individual on an emotional go-no-go task (Hariri, 2002; Hariri et al., 2000). Therefore genetic differences in the serotonin transporter may help explain individual differences in early automatic attention processing. In conclusion, our study is one of the first pieces of evidence for developmental differences in the early automatic attention processing and the increased saliency of both social and emotional information in early attention processing.
CHAPTER III: EMOTIONAL MODULATION OF THE ATTENTIONAL FUNCTION IN CHILDHOOD ATTENTION DEFICIT/HYPERACTIVITY DISORDER

Abstract

The attentional blink (AB) phenomenon was used to assess the modulation of emotion in early visual attention in children with Attention Deficit/Hyperactivity Disorder (ADHD). The AB effect is the temporary loss of perceptual awareness that follows successful target identification in a rapid serial visual presentation. Emotional stimuli can either attenuate or abolish the AB effect, which suggests that there is a preferential access to early visual attention processing for emotional information. In the present study, we examined the AB effect with neutral and angry faces in 7-14 year old children with and without an ADHD diagnosis. Children with ADHD exhibited an AB effect for neutral faces and it was reduced for angry faces to the same extent as control children. Children with ADHD who were more inattentive benefitted the most from the presentation of an angry face in early lags. Control children who were more anxious had a smaller AB effect with neutral faces. Thus, early visual attentional processing and its modulation by emotion are intact in ADHD, however individual differences in anxiety and inattention symptoms influence it.
Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most common neuropsychiatric disorders in childhood, affecting 3-7% of school-aged children and continues to affect between 30% and 60% of adults (Wender, Wolf, & Wasserstein, 2001). ADHD is characterized by symptoms of inattention, hyperactivity and impulsivity, which are believed to be indicative of a core cognitive deficit in executive functioning (Barkley, 1997; Cubillo, Halari, Smith, Taylor, & Rubia, 2012). More recently, emotional problems exhibited by children with ADHD have gained attention and are thought to contribute to ADHD pathophysiology (Johansen, Aase, Meyer, & Sagvolden, 2002; Nigg & Casey, 2005; Sonuga-Barke, 2005). Individuals with ADHD have difficulties in establishing and maintaining social interactions and relationships (Biederman et al., 1996; Friedman et al., 2003), and the same medications that aid executive dysfunction in ADHD also reduce emotional dysfunction (Reimherr et al., 2005; Williams et al., 2008). However, emotional dysfunction in ADHD is not well characterized currently.

There are differences in the perception of emotional stimuli by individuals with ADHD. When a positive word was read in a dichotic listening task, children with ADHD did not respond faster when the word was presented in the right ear, indicating reduced reactivity to positive stimuli (Becker, Doane, & Wexler, 1993). Adults with ADHD showed a reduced startle response to pleasant picture scenes, suggesting that positively valenced stimuli are not salient in ADHD (Conzelmann et al., 2009).
Adolescent ADHD boys had more signs of emotional impairment in that they had higher anxiety and depression levels and difficulty correctly identifying negative (e.g., angry and fearful) emotional faces than controls (Williams et al., 2008). These children also exhibited an atypical ERP response: reduced occipital lobe activity during early perceptual analysis of the emotional expression (within 120ms), followed by an exaggerated amount of activity associated with structural encoding (120-220ms) and lastly a slowed and reduced amount of temporal brain activity indicative of context processing (300-400ms). Upon receiving methylphenidate treatment, the boys’ ability to identify the negative emotions improved and a more normalized ERP response to emotional faces was observed. Further, adults with ADHD who self reported a heightened negative response to the emotional face which subsequently interfered with their ability to successfully categorize an emotional face (Rapport, Friedman, Tzelepis, Van Voorhis, & Friedman, 2002). Together, these studies suggest that negative emotional stimuli produce a greater response than positive emotional stimuli in ADHD.

The attentional blink paradigm is a tool that allows the assessment of early visual attentional processing with minimal executive control demands. The paradigm requires a person to search for a specific target within a rapid serial visual processing (RSVP) stream of irrelevant stimuli (~100ms). Upon successful detection of that target, a second subsequent target will not be perceived; this effect is referred to as an attentional blink, AB, (D. E. Broadbent & Broadbent, 1987). Detection of the second
subsequent target improves when there is more time in between the presentation of the first and second target (e.g. 600ms) than less time (e.g. 200ms).

Theoretical models posit that the AB effect indexes information processing limitations in a two-stage process. Detection of a second subsequent target decreases because attentional resources are depleted when the first target is being processed (Shapiro et al., 1997). All items in the RSVP stream are processed at stage 1, in order to identify target features. Target selection occurs at Stage 2 and requires short-term memory. Decreased T2 detection occurs because Stage 1 has priority and therefore Stage 2 processing cannot begin until Stage 1’s is complete. A bottleneck effect is said to occur at Stage 2 because it cannot process additional items from Stage 1 until it is done processing (Arnell, Helion, Hurdelbrink, & Pasieka, 2004; Chun & Potter, 1995; Jolicoeur, 1998; Martens & Wyble, 2010). It is believed that more efficient consolidation of the first target should reduce the wait at the bottleneck, resulting in a smaller AB (Arnell et al., 2006). Newer models that incorporate neuroimaging evidence believe that the bottleneck is caused by an attentional filter under executive control in frontal regions (Maratos et al., 2008; Martens & Wyble, 2010).

Emotional information has been shown to influence the AB. When emotional information is introduced as the second subsequent target in the AB paradigm, the blink is reduced such that the second emotional stimuli can be detected at earlier time points, before 500ms (Anderson & Phelps, 2001). The reduced AB has also been confirmed with socio-emotional stimuli like schematic faces (Maratos et al., 2008) and
photographs of faces (Stein et al., 2010). Reduction of the AB for socio-emotional information suggests a prioritization in early attentional processing that eliminates the bottleneck effect.

Studies of the AB in ADHD show mixed results. There is evidence in both children and adults with ADHD that the AB is intact with non-social stimuli like letters (Carr, Henderson, & Nigg, 2006; Mason, Humphreys, & Kent, 2005). Other studies report an atypical AB with non-social stimuli. In adults with ADHD, a prolonged blink has been reported with letters in which there is below chance detection of T2 and an increased amount of lags before recovering from the blink (Hollingsworth, McAuliffe, & Knowlton, 2001). Increased gaze instability has been proposed to explain the prolonged blink with letters in adults with ADHD (Armstrong & Munoz, 2003). Children with ADHD have also shown a prolonged blink with numbers and Chinese characters (Li et al., 2004). Increased symptoms of impulsivity have been related to a prolonged AB in control children with numbers and Chinese characters (Li, Chen, Lin, & Yang, 2005) and children with ADHD (Chhabildas et al., 2001; Gomez, 2003; Oades et al., 2002). In contrast, adolescents with the inattentive subtype of ADHD did not show the expected AB effect with letters such that they had increased detection at early lags but as the lag interval increased, detection of T2 did not increase suggesting attentional filtering problems (Carr et al., 2006). Therefore differences in the AB effect are related to symptoms of ADHD. To date there is no study investigating the influence of socio-emotional information on the AB in ADHD.
Anxiety is a common symptom that is comorbid with ADHD and is associated with differences in the emotional modulation of the AB. Individuals with increased anxiety levels have consistently shown more sensitivity to emotional information and thus exhibited a smaller AB for emotional stimuli (Amir, Taylor, Bomyea, & Badour, 2009; de Jong & Martens, 2007; Fox et al., 2005; Srivastava & Srinivasan, 2010). It is also important to investigate the influence of anxiety in ADHD because up to 25% of the child ADHD population display one or more anxiety conditions (Brown, 2009).

Deficits in the self-regulation of emotion are evident in a substantial number of children with ADHD and these deficits play an important role in determining functional impairment and the risk of developing comorbid anxiety disorders (Anastopoulos et al., 2010).

In the present study, we investigated the influence of socio-emotional information on the AB in children with ADHD and age and IQ matched controls. It is hypothesized that both controls and children with ADHD would have a reduced AB with emotional faces. Children with ADHD would be more sensitive to the emotional face and thus exhibit a smaller AB effect than controls, since they are more susceptible to attend to negatively valenced faces (Williams et al., 2008) and are more vulnerable to salient information with the AB as seen with Mason et al. (2005). In addition, as reported by Li et al. (2005), symptoms of impulsivity would be related to a larger AB with neutral faces. Based on findings from Carr, et. al. (2010), symptoms of inattention would be related to an increased detection of emotional information at early
lags and therefore, a smaller emotional AB. Lastly symptoms of anxiety would be related to increased detection of emotional faces at the early lags and a smaller emotional AB as well as previously found with De Martino et. al. (2008) and Fox et al. (2005).

**Methods**

**Participants**

Thirty-one children with a diagnosis of ADHD and 35 control children, aged 7-14 years were recruited from the Washington DC metropolitan area through advertisements. The final sample included 31 control children (15 female; mean age = 11.5, SD = 1.9 years; mean IQ = 110, SD = 13.9, Range= 91-138) and 27 children with ADHD (12 female; mean age = 11.0 , SD = 1.8 years; mean IQ = 114, SD =14.9, Range= 87-140) following exclusion of 7 children who did not meet performance criteria (see below in results). Children with ADHD consisted of ten inattentive and seventeen combined subtypes. All participants were paid $10 for participation.

Written informed consent from parents of children, and assent from children were obtained according to Georgetown University Institutional Review Board guidelines.

Participants with neurological and psychiatric conditions were excluded by parent-report and the Behavior Assessment System for Children (BASC; (Brown, 2009) including conduct disorder. Additional exclusion criteria for children was: 1) Full scale IQ below 85 (estimated using Vocabulary and Block Design subtests of the
Wechsler Abbreviated Scale of Intelligence, (WASI; (Weschler, n.d.). 2) Score below 50 on the Word Attack and Letter Word Identification subtests of the Woodcock-Johnson reading test to screen for reading disability (WJ III; (R.W. Woodcock et al., 2000). All participants with ADHD provided documentation from the diagnosing clinician (either a physician or a psychologist) which was reviewed by a clinical psychologist (PL) to confirm DSM-IV criteria were met (i.e., presence of 6 out of 9 symptoms of inattention and 6 out of 9 symptoms of hyperactivity/impulsivity in more than one setting, present before age 7 years and causing impairment). Further, a parent for each child completed the ADHD Rating Scale (DuPaul, 1998) to characterize ADHD symptoms of hyperactivity and inattention.

Age (p = 0.30) and Full Scale IQ (p = 0.43) did not differ between ADHD (Mean age = 11.0 years, SD = 1.76; Mean IQ = 114.11, SD = 14.94) and control children (Mean age = 11.5 years, SD = 1.91; Mean IQ = 110.45, SD = 13.86). Relative to controls, ADHD children had higher symptoms of hyperactivity (ADHD: Mean = 12.5, SD= 5.26; Controls: Mean = 4.05, SD = 3.70; t(40)= 6.04, p < .01) and inattention (ADHD: Mean = 16.2, SD= 5.39; Controls: Mean = 5.62, SD = 3.92; t(45)= 7.73, p < .001). At the time of testing, six ADHD children were stimulant medication naïve and the remaining withheld medication for over 24 hours.

Stimulus materials

All stimuli were displayed on a white background at a viewing distance of 60 cm on a 17 inch monitor using E-Prime version 1.1 (Psychology Software Tools Inc.,
Pittsburg, PA). Twenty color face photographs of adult faces (10 with neutral facial expressions and 10 with angry facial expressions) were obtained from the NimStim set, www.macbrain.org.

All face stimuli were drawn from the NimStim set and did not overlap across tasks. The Emotional Identification Task consisted of six colored photographs of adults with angry and neutral facial expressions (three of each gender). The AB Task consisted of three classes of stimuli: 1) Two color photographs of dogs, from the website www.dogbreedinfo.com, were used as the first target stimuli (T1). 2) Twenty eight colored photographs of scrambled faces were used for the distractor stimuli. Faces of seven females and seven males with neutral expressions were scrambled with the face outline preserved and the interior portion scrambled using the scramble feature from the website http://www.faceresearch.org. 3) Fourteen colored photographs of faces with angry and neutral expressions (seven of each gender) were used for the second target stimuli (T2).

Procedure

First, participants completed the State-Trait Anxiety Inventory questionnaire [STAI-CH for children; (Spielberger et al., 1983)] to assess both state and trait anxiety. Then, participants completed the Emotional Identification Task followed by 20 practice trials and 188 test trials of the AB task.

Emotional Identification Task
The goal of the task was to assess whether participants recognized the emotional valence of faces accurately. The task consisted of 6 trials. Participants began the task by pressing the space bar in response to the words “Get Ready!” on the screen. Either an angry face or neutral face was presented centrally for 2000 ms, following which the participant had to press the number “1” key for “angry” or the number “2” key for “no emotion” in answer to the question “Is this person:”. Participants could take as long as they needed to record their response. Upon successful recognition of at least 70% of the emotional faces, they went on to complete the AB task.

Attentional Blink task

The AB task consisted of 188 trials divided into four blocks of 47 trials each. Participants pressed the space bar in response to the words “Get Ready!” on the screen to start each block; they could take a self-paced break in between blocks. Each trial began with the presentation of a fixation cross for 750 ms followed by a rapid serial visual presentation (RSVP) stream of 15 stimuli presented for 100 ms each (see Figure 1). Participants were instructed to look for a dog and informed that sometimes a face would appear and to pay attention because the pictures came on the screen very fast. Each trial ended with the a question on the screen “Did you see a dog?”. Participants pressed “1“ for “yes” or “2” for “no” on the number pad of the keyboard. Following their response, a second question “Did you see a face?” appeared on the screen. Once
again, participants indicated their response by using the number pad. For each question, participants had 5000 ms to respond.

The AB task consisted of eight types of trials, two types of catch trials, and six types of AB trials varying in the facial expression of the T2 stimulus, at each of three lags. Specifically, catch trials included: 1) 30- T1-only trials, in which only the T1, a dog, appeared in the RSVP stream but no T2 appeared; 2) 32- T2-only trials, in which a T2 (either an angry or neutral face) appeared in the RSVP stream without a T1 preceding it. These trials were included in order to ‘catch’ any response biases to answering “yes” to both questions at the end of the RSVP stream.

On the remaining AB trials, a T2 was either a face with a neutral or angry expression and followed the T1 with three lags: 1) 21 trials with a neutral T2 appearing 200 ms after the T1, (termed Neutral-Lag 2); 4) 21 trials with an angry T2 appearing 200 ms after the T1, (termed Angry-Lag 2); 5) 21 trials with a neutral T2 appearing 400 ms after the T1 (termed Neutral-Lag 4); 6) 21 trials with an angry T2 appearing 400 ms after the T1, (termed Angry-Lag 4); 7) 21 trials with a neutral T2 appearing 800 ms after the T1 (termed Neutral-Lag 8); 8) 21 trials with an angry T2 appearing 800 ms after the T1 (termed Angry-Lag 8). Further, within the RSVP stream, the serial position of T1 was varied among stimuli 4, 5, and 6 in the trial sequence. Thus, T2 followed each of these positions at the three lags described above such that it was either the second (Lag 2), fourth (Lag 4), or eighth (Lag 8) stimulus after the T1. All the trials were pseudorandomized into blocks so that no more than
two successive trials were of the same type within each block. Blocks were created to allow breaks after 47 trials, and were balanced to include the same number of each trial types. Two versions of the task were created to counterbalance block presentation order.

Figure 5. Rapid serial visual stream presentation (RSVP) stream for the AB Task. Participants monitored two target stimuli (T1 & T2) embedded among 13 distractor stimuli, each presented for 100ms with no interstimulus interval. The first target stimulus (T1) was a dog face and the second target stimulus (T2) was a human face (either neutral or angry). The distractors were scrambled faces. a) T1-only catch trials in which only the dog face was presented, b) T2-only catch trials in which only an angry or neutral face was presented, c) Double target trials in both T1, the dog face, and T2, the human face, were presented. The two targets were separated by either 2, 4
or 8 distractors, (200ms, 400ms, or 800ms, respectively). At the end of the RSVP stream, participants indicated by key press whether they had seen saw a dog and a face.

**Results**

Participants who performed worse than chance (50%) on the T2 catch trial were excluded from analysis. This criterion resulted in the exclusion of seven children and two children with ADHD from the total cohort of participants. A response was scored as correct if the participant correctly identified first the T1 and then the T2, as for T1 incorrect trials the source of T2 errors is unknown (Marvin M. Chun & Potter, 1995). For each participant, percentage of accurate T2 trials was computed for each of the six types of AB trials. Percent accuracy was analyzed in a mixed analysis of variance with Group (Children, Adults) as the between-subjects factor and emotion (T2 - angry, neutral) and lag (2, 4, 8) as within-subjects factors. Measures of effect size (partial eta-squared for analyses of variance [ANOVA], Cohen’s $d$ for means) are presented for the AB effects. Figure 2 summarizes the results by trial type and groups.
We found two main effects. Both groups were more accurate when the T2 was a face with angry than neutral expression (main effect of emotion), $F(1,56) = 36.77, p < .001, \eta^2=.04$. Further, T2 accuracy differed by lag (main effect of lag), $F(2,56) = 21.42, p< .001, \eta^2=.08$. Post-hoc tests showed that T2 detection at lag 2 was lower than at lag 4, $t(58) = 3.90, p < .001, d= 1.71$, and lag 8, $t(58), = 6.66, p < .001, d= 1.93$. T2 detection at lag 4 was also lower than lag 8, $t(58), = 3.89, p < .001, d= 0.98$. These
differences by lag indicate that our adapted paradigm produced the expected AB phenomenon, decreased accuracy at the shortest lag relative to longer lags.

In addition to these main effects, one key interaction was observed, a significant Lag X Emotion interaction, $F(2,56) = 3.51, p<.001, \eta^2=.01$, indicating that the magnitude of the AB differed by the nature of the T2. Collapsing across groups, paired $t$-tests showed a higher T2 accuracy for angry trials relative to neutral trials at each lag: lag 2, $t(58)= 4.89, p < .001, d= 1.40$, lag 4, $t(58)= 2.97, p < .005, d= 0.72$, and lag 8, $t(58)= 2.82, p < .01, d= 0.79$. Among the angry trials, there was an improvement in T2 detection from lag 2 to lag 8, $t(58)= 3.97, p < .001, d= 1.31$, and another from lag 4 and lag 8, $t(58)= 3.54, p < .001, d= 1.13$. Lag 2 and lag 4 did not show an improvement for the angry faces, $t(58)= 1.59, p = .12, d= 0.46$. Among the neutral trials, all the lags were different from each other: lag 2 and lag 4, $t(58)= 4.10, p < .001, d= 1.10$; lag 4 and lag 8, $t(58)= 6.06, p < .001, d= 0.81$, and lag 2 and lag 8, $t(58)= 2.81, p < .01, d= 2.01$, showing improved T2 detection with increasing lag length. This finding was further substantiated when a difference score was calculated to assess the magnitude of the AB, (i.e. lag 8 performance minus lag 2) which was significantly larger on neutral trials than on angry trials, $t(58)= 2.49, p < .05, d= 0.94$. This finding indicates that we observed the expected effect of emotional stimuli on the AB phenomenon, a shorter blink for angry than neutral faces.
Most importantly, the Group X Lag X Emotion interaction was not significant, \( F(2,56) = 0.72, p = .49, \eta^2 = .001 \) indicating that the effect of the facial expression of the T2 stimulus did not influence the magnitude of the AB differently in both groups.

We examined whether the magnitude of the AB was associated with anxiety. In order to assess the magnitude of the AB, the neutral face performance (T2 accuracy) from lag 2 was subtracted from lag 8. In order to assess the influence of emotion in early attentional processing, neutral face performance (T2 accuracy) for lag 2 was subtracted from angry face performance at lag 2.

Trait anxiety, as measured with the STAI-C, was higher in children with ADHD (mean = 37.6, SD = 5.69) relative to control children (mean = 31.6, SD = 5.14, \( t(41) = 3.99, p < .001, d = 1.11 \)); no child met the criteria for the presence of a clinical anxiety disorder. A negative correlation between the magnitude of the AB and trait anxiety level was shown across control and ADHD children combined, such that more anxious children had a smaller AB (\( r = -0.24, p < .05 \)). Examining the groups separately, trait anxiety correlated significantly with the magnitude of the AB in control children, (\( r = -0.41, p < .05 \)), but not ADHD children, (\( r = -0.04, p = .43 \)). Therefore, the correlation in the full group was driven by the control children. Results are shown in Figure 3. There were no correlations between trait anxiety and the influence of emotion on the AB across both groups, (\( r = -0.13, p = .18 \)), or within each group, (ADHD: \( r = .05, p = .40 \); Controls: \( r = -.25, p = .09 \)).
No significant correlations were found with state anxiety and the magnitude of the AB across both groups (r = .16, p = .13) or within ADHD (r = .30, p = .09) or Controls: r = .06, p = .38.  No significant correlations were found between state anxiety and the influence of emotion on the AB across both groups (r = .11, p = .21) or within ADHD (r = .25, p = .13) or Controls (r = .01, p = .48).

Lastly, we investigated whether the magnitude of the AB or its modulation with emotion was associated with symptoms of hyperactivity/impulsivity and inattention.
measured with the ADHD Rating Scale. A positive correlation was found between symptoms of inattention and the size of the emotional AB (r = 0.38, p < .05) in children with ADHD, such that the more inattentive children benefitted more from an angry face at lag 2 relative to a neutral face. Results are shown in Figure 4. This finding was exclusive to the ADHD group since it did not appear in control children (r = -0.25, p = .12) and across both groups (r = .02, p = .43). The magnitude of the AB did not correlate with inattention symptoms, (r = -0.14, p = .17). Further, symptoms of hyperactivity/impulsivity did not show association with either the magnitude of the AB (r = -0.11, p = .23) or the influence of emotion on the AB (r = -0.02, p = .43) across both groups. Neither group alone showed a relationship with hyperactive/impulsivity symptoms for the magnitude of the AB, (ADHD: r = .09, p = .35; Controls: r = -0.18, p = .19), and influence of emotion on the AB (ADHD: r = .35, p = .05; Controls: r = -0.09, p = .35).
Figure 8. Correlation between the Influence of Emotion on Early Attentional Processing and Inattention symptoms as measured by the ADHD Rating Scale.

**Discussion**

We assessed early attentional processing and its modulation by emotional stimuli in children with ADHD and age and IQ matched controls using the AB paradigm. The magnitude of the AB was similar in both groups with neutral faces. Both groups also showed a similar reduction of the AB with angry faces. Thus, early
attentional processing was preserved for socio-emotional stimuli in ADHD. The magnitude of the AB varied by individual differences in anxiety such that children who were more anxious had a smaller AB with neutral faces. The influence of emotion on the AB effect varied by individual differences in symptoms of inattention among children with ADHD such that more inattentive children showed a larger effect of angry faces on the AB. Together, these findings further the understanding of early attentional processing in ADHD and typical development.

The present study extends our knowledge of early attention processing in ADHD in four ways. First, our study is the first to examine the AB effect for socio-emotional stimuli in ADHD. Prior to this study, the AB had been investigated with non-social stimuli such as letters (Carr et al., 2006), letters with asterisks, (Mason et al., 2005), and numbers among Chinese characters (Li et al., 2004), with mixed results. Our study demonstrates that the AB effect with socio-emotional information is similar in children with ADHD and controls.

Second, we demonstrate preserved AB effect for both neutral and emotional faces in both controls and ADHD. One probable explanation for the absence of differences between groups with our study is our task design. A bottleneck effect normally occurs at Stage 2 because it cannot process additional items from Stage 1 until it is done processing (Arnell, Helion, Hurdelbrink, & Pasieka, 2004; Chun & Potter, 1995; Jolicoeur, 1998; Martens & Wyble, 2010). When the first target can be more efficiently processed because its uniqueness amongst distractors, a smaller AB is
seen because there is no bottleneck effect (Arnell et al., 2006). Thus, the more unique a target is among the distractors, like in our study that required a dog and human face to be detected among scrambled faces, the easier and thus faster processing that occurs at both Stage 1 and 2, which results in increased T2 detection at earlier lags (Chun, 1997; Chun & Potter, 1995). We see how the increased contrast between targets and non-targets improved performance, since our control children had better T2 detection, above 70% for neutral faces and above 85% for angry faces at lag 2, than previous non-emotional AB studies that have performance for lag 2 between 50% and 60%, (Carr, Henderson, & Nigg, 2010; Mason et al., 2005). In conclusion, our task design may have facilitated early attentional processing of both neutral and emotional stimuli in both controls and ADHD.

An alternative explanation for our lack of group differences in the emotional AB arises from the networks responsible for processing emotional information. Preferential emotion processing is believed to be dependent on the amygdala, since patients with amygdala lesions do not show a reduction in the AB when emotional words are presented as the second target (Anderson & Phelps, 2001). The amygdala is part of the mesolimbic network involved in emotional processing (Sonuga-Barke, Bitsakou, & Thompson, 2010) and has been highlighted recently in ADHD research. Increased amygdala activation has been found during making judgments regarding nose width and perceived hostility of a face. The altered amygdala functioning may relate to later stages of emotional attention processing since the task required an
evaluative judgement (Brotman et al., 2010). In our study, we only required detection of a face without any evaluation of valence. We can only infer from our study that behaviorally, amygdala functioning is intact in children and ADHD during early attentional processing.

Third, our study shows a reduced AB with neutral faces in more anxious control children. This finding is different from previous studies revealing individuals with higher anxiety levels have a smaller AB with emotional faces (de Jong & Martens, 2007; B. De Martino et al., 2008; Fox et al., 2005). We propose that the neutral faces were perceived as ambiguous, and thus, those who were more anxious perceived them more negatively and were more vigilant towards these faces. Emerging literature suggests that anxious individuals process ambiguous information differently (Becker & Detweiler-Bedell, 2009; Heim-Dreger, Kohlmann, Eschenbeck, & Burkhardt, 2006; MacLeod & Cohen, 1993; Stopa, 2000). Anxious children appear to perceive ambiguity as threatening and therefore avoid any ambiguous information (A. P. Field & Lester, 2010). Faces with neutral expressions are perceived as ambiguous in children (for review Leppanen & Nelson, 2009). It maybe the case that in early stages of attention processing children are more vigilant towards ambiguous stimuli and when assessed in later stages of attention, they actually display the avoidant bias traditionally seen in emotion studies (Perez-Edgar et al., 2010). Children with ADHD despite reporting higher levels of trait anxiety did not show the same phenomenon as controls. Controls’ anxiety scores seem more evenly distributed across
the full range while children with ADHD’s range is smaller if the outliers are dropped, as seen in Figure 3. Therefore in ADHD, the absence of correlation between anxiety and the magnitude of the attentional blink is the result of a reduced range of scores.

Fourth, children with ADHD who are more inattentive had a larger effect of emotion on the AB (i.e., higher accuracy for detecting angry relative to neutral faces immediately after detection of T1). The inattentive subtype is believed to have a defective attentional filter (gate) and therefore, poor interference suppression (Diamond, 2005). In our study, children with ADHD with more inattentive symptoms benefitted the most from an emotional T2. Emotional stimuli are more salient and therefore, may have been more difficult to suppress for those with more severe inattention. This is inline with a previous study indicating that inattention in ADHD is related more to early-stage information control (attention-gating) instead of response inhibition (Carr et al., 2006). There are neuroimaging studies suggesting that the deficit in attention filtering seen in the inattentive subtype is related to a dysfunction in fronto-parietal cortical attention networks, while the combined and hyperactive/impulsive subtypes possess late stage control deficits subserved by frontal-subcortical circuits related to executive control (Adams, Derefinko, Milich, & Fillmore, 2008; Diamond, 2005; Milich, Balentine, & Lynam, 2006).

It is important to note the limitations of our study. First, ADHD is a heterogenous disorder comprised of different subtypes and it maybe important to study more closely subtype differences especially in lieu of our finding that inattentive
symptoms relate to the emotional AB effect and the previous inattentive subtype study that only found a difference in the AB effect among the inattentive subtype (Carr et al., 2006). Second, our task was manipulated to enhance child engagement and subsequently performance. It is possible that by making our task too child-friendly, we lost the ability to detect more subtle differences between controls and ADHD. Lastly, we only investigate negative and neutral faces, it maybe the case that positive emotions may should a greater AB since there is evidence that positive emotions are not as salient as negative emotions in ADHD (Becker et al., 1993; Conzelmann et al., 2009).

In summary, early visual attention processes were sensitive to socio-emotional information in children with ADHD. Furthermore, both anxiety and inattention influence early visual attention processes, anxiety reduces the overall magnitude of the blink while in ADHD inattention symptoms were related to greater sensitivity to angry faces.
CHAPTER IV: GENERAL DISCUSSION

This dissertation presented results that extend the understanding of the role of socio-emotional information in early visual attention processing in typical development and in a developmental disorder, Attention Deficit/Hyperactivity Disorder (ADHD). Chapter 2 and 3 reported the results from studies, which are the first to use the attentional blink (AB) paradigm to examine early visual attention to human faces with neutral and negative emotional expression. We found two novel findings: First, independent of emotional expression, typically developing children showed a larger attentional blink than adults, indicating reduced attentional resources in early visual processing. However, the extent to which early visual attention is influenced by emotionally salient information did not differ between typically developing children and adults as there were no developmental differences in the attentional blink effect for angry faces. This finding suggests that processing of emotional stimuli as salient is mature in late childhood. Second, early visual attention to neutral faces and to emotionally salient information was intact in ADHD as children with ADHD showed a similar magnitude of the attentional blink for neutral and angry faces as age and IQ matched control children. Therefore, attentional deficits observed in ADHD do not appear to stem from early visual attention, at least, for socio-emotional information.

Anxiety was found to enhance early attention processing in typically developing children. Prior adult work had shown a reduced AB effect among anxious individuals with emotional words, faces and scenes (Jefferies et al., 2008; Maratos et
al., 2008; Tibboel, Van Bockstaele, & De Houwer, 2011). Our study did not replicate the reduced AB effect with faces in anxious adults but did find a reduced AB effect using neutral faces in more anxious children. Neutral faces are high priority information as there is evidence that they are perceived as ambiguous and therefore negative for anxious individuals (MacLeod & Cohen, 1993; Leppanen & Nelson, 2009). In this dissertation we suggest that vigilant bias is present among anxious children for neutral (ambiguous) faces and it would disappear as the brain matures into adulthood. The perception of the neutral faces as negative among the anxious children reduced the bottlenecking in attentional processing because they were considered to be highly important information to process.

In children with ADHD, symptoms of inattention were related to early attention processing of emotional information. Inattentive subtype of ADHD had been characterized as showing a lack of the AB effect because of an inefficient attentional filter (Carr, Henderson, & Nigg, 2010). We show that in the presence of high priority information like faces, the AB effect is not only intact but in the early lags (early stages of attentional processing) angry faces reduce it. Our study suggests that the attentional filter is aided possibly by a subcortical structure like the amygdala to normalize the AB effect and reduces the bottlenecking effect at the early lags when a high priority stimulus like an emotional face is presented. Collectively from both studies, individual differences in anxiety and inattention can influence early attentional processing in the presence of socio-emotional information.
Neural substrates of the Attentional Blink effect

Attentional processing has been shown to be mediated via a dorsal and ventral pathway. The AB task has furthered our understanding of early attention processing to include more specific neural substrates. A distributed network across the occipital, parietal and frontal areas is implicated in the non-emotional AB effect (Martens & Wyble, 2010). Early visual areas like V1 are activated by both T1 and T2 (Hein, Alink, Kleinschmidt, & Müller, 2009). When T2 is not reported, there is reduced activity in the fronto-parietal cortex, specifically the anterior cingulate, lateral prefrontal, and parietal regions (Kranczioch, Debener, Schwarzbach, Goebel, & Engel, 2005; Marois & Ivanoff, 2005; Marois, Yi, & Chun, 2004). The lateral frontal and parietal regions are believed to be the neural substrates for the AB bottleneck (Marois & Ivanoff, 2005) and under top-down control. Our findings from Chapter II suggest selection for high priority information in early attention processing is critical for humans therefore a mechanism is established early in childhood in order to detect threatening or important information in the environment.

The emotional AB recruits other neural substrates than the nonemotional AB. When faces are used in the emotional AB, the fusiform face area (FFA) is more activated for correct identification of a face (B. De Martino et al., 2008). The recruitment of the FFA was related more to the presence of a face in T2 than to whether the face had a positive or negative emotion. Interestingly the ventral striatum is more active when T2 is a fearful face than with a neutral face T2, consistent with
previous research showing ventral striatum activation during aversive or unpleasant visual stimuli (Paradiso et al., 1999). When attentional resources are limited, rostral anterior cingulate cortex (rACC) shows increased activation when T2 is an emotional face (B. De Martino et al., 2008). The rACC activation correlated with successful identification of T2. Interesting to note is that the rACC has been shown previously to have reciprocal connections with areas of emotion processing (ventral striatum, anterior insula, orbitofrontal cortex, and amygdala) that are also part of the ventral pathway of attention processing (Bush, Luu, & Posner, 2000; B. De Martino et al., 2008). Therefore, the rACC is an important structure in the selection of high priority emotional information under limited attentional resources (B. De Martino et al., 2008).

One critical structure in the interaction of attention and emotion is the amygdala (Phelps, 2006). The amygdala is strategically positioned in the brain to communicate with various structures and thus has influence on various stages and types of processing. The amygdala has reciprocal connections with sensory cortical processing areas, like the visual cortex (Amaral, Behniea, & Kelly, 2003). Because of its location it is able to receive emotional information input before gaining awareness of the emotional information (Romanski & LeDoux, 1992; Whalen, 1998). In ADHD the amygdala is also a key structure in the mesolimbic pathway responsible for emotional and motivational dysfunctioning (E. J. S. Sonuga-Barke, 2003). Early attentional processing requires the amygdala (Anderson & Phelps, 2001) to be intact for the attentional capture of emotion to occur. From our findings, we suspect that the
amygdala is working efficiently to detect emotional information in the environment quickly. Both emotional influences from the amygdala and attentional influences from fronto-parietal areas appear to act to amplify emotion or task-relevant information in a stimulus-specific manner, producing similar increases in fMRI and EEG responses (Lang et al., 1998; Sabatelli, Lang, Bradley, Costa, & Keil, 2009). Emotion and attention effects have distinct sources, they may occur in a parallel or competitive manner and produce additive (or occasionally interactive) effects on sensory responses (Brosch, Pourtois, Sander, & Vuilleumier, 2011; Keil, Moratti, Sabatelli, Bradley, & Lang, 2005; Pourtois, Schettino, & Vuilleumier, 2012; Rossi & Pourtois, 2012; P Vuilleumier & Schwartz, 2001). Therefore in our emotional AB effect with adults, children and ADHD we see an enhanced bottom-up signal that facilitates detection of emotional information in very early stages of attention processing. Therefore, we continue to confirm behaviorally an important status for emotional information in early attention processing.

**Future Directions**

Of central importance to this dissertation was the behavioral investigation of the early attentional processing of socio-emotional information. A logical next step is to investigate the neural mechanism of how socio-emotional information is processed in early attentional stages. By investigating the neural mechanism, we can enhance our understanding of brain development by shedding light on how early attentional
processing may be an immature process in childhood and evidenced as such by a
distributed network of regions. We can also continue to provide evidence for the
emotional dysfunction seen in ADHD. There are several pieces of evidence that the
amygdala is not normal in ADHD, however our behavioral study in Chapter III would
suggest otherwise. For normal behavioral functioning of the amygdala in ADHD,
certain neural compensations may be made such as the development of a
volumetrically smaller amygdala when compared to controls (Frodl & Skokauskas,
2012) or the hyper activation of the amygdala when rating subjective fear of neutral
faces (Brotman et al., 2010)).

To address the notion that salient information has a preferred status of
attentional processing that utilizes a ventral network of attention, a direct investigation
of non-social and social-emotional stimuli in early attentional processing should be
conducted. There is behavioral evidence emotional value is not the sole contributor to
an enhanced early attentional processing, but aspects of arousal and salience can
produce similar results (Anderson, 2005). Therefore, bottom-up processes that utilize
the ventral network of attention may in fact not be coding for emotion but instead a
more global feature like arousal or salience.

Another potential avenue for future research is to investigate the role of
genetics in early attentional processing. Serotonin (5-hydroxytrptamine; 5-HT), is a
monoamine neurotransmitter synthesized in the raphe nucleus and released all through
out the brain (N. M. Barnes & Sharp, 1999). The serotonin transporter protein (5-
HTT) is located on the pre-synaptic terminal, and is responsible terminating the action of 5-HT. A polymorphism in the serotonin transporter long promoter region, 5-HTTLPR, of the serotonin transporter gene (SLC6A4) influences 5-HTT mRNA transcription. A short “S” allele is linked with reduced expression of the serotonin transporter mRNA relative to the long “l” allele (Hu et al., 2006). Given that polymorphisms in the serotonin transporter gene have been found to contribute to individual differences in emotional reactivity, it is likely that the individual differences we see in anxiety may have its origin in the genetic expression of the serotonin transporter gene. Expression of the S allele is associated with heightened emotional reactivity (Pérez-Edgar et al., 2010), higher scores of anxiety-related behaviors (Lesch et al., 1996), and increased amygdala activation to more negative stimuli (Munafò, Brown, & Hariri, 2008). Therefore the serotonin transporter gene may help differentiate between those individuals who are more susceptible to socio-emotional information in earlier lags of the attentional blink. Another gene of interest would be the catechol-O-methyltransferase (COMT) gene. COMT is the enzyme that degrades catecholamines like dopamine in the synapse. A single nucleotide polymorphism (SNP) in the COMT gene, Val158Met, which substitutes a methionine for valine, results in lower levels of COMT in the synapse, which in turn leads to less dopamine breakdown. Individuals with two inherited copies of the met allele (met/met) have less COMT and more dopamine functioning in the synapse compared to those with two copies of the val allele (val/val) (Chen et al., 2004). Children and adults who are
homozygous for the met allele tend to have better performance on attentional tasks while also possessing reduced control for emotionally salient stimuli (Blasi et al., 2005; Diamond, Briand, Fossella, & Gehlbach, 2004). Therefore by investigating the role of the COMT gene, we can determine if dopamine has a role in the gating mechanism of the attentional filter in ADHD in early attentional processing. Therefore genetic studies of early attentional processing should be conducted.

**CONCLUSION**

Emotional information has the ability to capture attention quickly. We know that emotion can draw our attention through a ventral pathway of attention that utilizes bottom-up processing. The amygdala appears to be the center for the attentional capture of emotion because of its location in the brain and its reciprocal connections with sensory cortices and prefrontal cortices. The AB paradigm has allowed us to gauge what and how emotion captures attention. Through the use of the AB we can continue to further understand the mechanism by which emotion and other salient information captures our attention.

To our knowledge, these are the first studies to utilize an AB with neutral and angry faces to assess the early visual attention processing across development and in ADHD. We found that independent of the emotional expression of a face, children show a larger AB than adults. We also found that children with ADHD have an intact AB like control children with both angry and neutral faces. We also found that
individual differences can influence early attention processing. Based on our findings, more research should investigate the development of the AB in children and its neural substrates. Individual differences in gene expressions should be also investigated to further understand how one’s genetic code can make one more sensitive to emotional information.


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Brosch, T., Pourtois, G., Sander, D., & Vuilleumier, P. (2011). Additive effects of emotional, endogenous, and exogenous attention: behavioral and


de Haan, M., Belsky, J., Reid, V., Volein, A., & Johnson, M. H. (2004). Maternal personality and infants’ neural and visual responsivity to facial expressions of


