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Visual Attention Shifting in Autism Spectrum Disorder

by

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ABSTRACT

Much research to date has been devoted to understanding the neurocognitive abnormalities characteristic of autism spectrum disorders (ASD). Abnormalities in visual attention are particularly notable in ASD and have the potential to inform an understanding of the aberrant neural networks underlying this disorder. The current study utilized a model integrating components of both a two-stage model of perceptual binding and Posner's model of attention in order to provide a coherent account of previous findings of both enhanced and impaired visual attention abilities in ASD. To investigate a potential deficit in attention shifting underlying a variety of observed attentional abnormalities in ASD, the present study employed experimental paradigms requiring attentional shifting at two levels of visual information processing. Aims of the current study were (1) to investigate a general deficit in shifting attention at the level of both preattention and focused attention in ASD as compared to age- and gender-matched NT controls, as measured by both a visual search task with a dimensional shift component and a Navon-type letter task requiring participants to shift attention between global and local levels of a visual stimulus; and (2) to investigate the degree to which deficits in attention shifting as measured by these tasks in ASD as compared to age- and gender-matched NT are related to social functioning. Results were not consistent with a general deficit in attention shifting, but rather showed a qualitatively similar shifting response in ASD and neurotypicals. Preliminary support was found for a relationship between measures of social functioning and attention shifting at the level of both preattention and focused attention. Hypothesized relationships with underlying neural networks and directions for future research are discussed.

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Chapter 1: Introduction

Autism spectrum disorders[1] (ASD) are characterized by impairments in social functioning, communication, and restricted range of behaviors and interests, with severity ranging from minimal social and academic or occupational impairment to profound disability. The increasingly high incidence of these disorders (recently estimated at 1 in 68 children; Centers for Disease Control and Prevention, 2012), coupled with the large amount of resources needed to care for many of these individuals, necessitates heightened efforts to determine the etiologies, neurological and cognitive bases, and effective prevention strategies and interventions for ASD. In particular, a thorough understanding of the neurocognitive abnormalities underlying ASD has the potential to improve assessment, early and accurate diagnosis, and treatment. Though a significant body of research to date has been devoted to understanding the neurocognitive abnormalities characteristic of these disorders, a cohesive account of the various perceptual and cognitive strengths and deficits observed in this population has remained elusive. However, one area that has emerged as a potential window into a unifying construct for ASD is the process of visual attention.

While many of the earlier psychological theories of ASD focused on a single aspect of the disorders, such as impairments in executive function or theory of mind, newer models have adopted a developmental perspective that takes into account potential cascading effects that small abnormalities in early, basic perceptual or cognitive processes may have on the development of higher-order cognitive functions (Belmonte et al., 2004; Rippon, Brock, Brown, & Boucher, 2007). Thus, relatively small abnormalities at an early stage of processing, such as

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[1] Although ASD has not been an official diagnostic category prior to DSM-V, this classification has been widely used in research contexts and generally refers to individuals diagnosed with Autistic Disorder, Asperger's Disorder, or Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS). The term "ASD" will hereafter be defined in this way unless otherwise noted.

visual perception, may be observed to have effects throughout successive stages of information processing, such as visual attention and executive function. In fact, this hypothesis has been supported by, for example, recent evidence suggesting that deficits in face processing in ASD are due at least in part to basic visual perceptual deficits rather than simply a deficit in social motivation (Behrmann, Thomas, & Humphreys, 2006). This neurodevelopmental view of ASD holds particular significance for intervention; while current behavioral interventions are almost exclusively aimed at downstream manifestations of these basic deficits, such as social functioning, early interventions to address basic perceptual or cognitive abnormalities (including pharmacotherapy, psychotherapy, or a combination of the two) may prove to be more effective in preventing these downstream effects.

In order to gain insight into the neurocognitive underpinnings of the heretofore incoherent pattern of findings of enhanced and impaired visual perception and attention in ASD, the current study utilized a model integrating components of both a two-stage model of perceptual binding and Posner's model of attention. The following review will explicate current models of perceptual binding, Posner's model of attention, selected tasks believed to index the components of interest of these models, and current evidence for the neurophysiological basis of the components of interest. A common process with the potential to explain disparate findings of abnormal visual perception and attention in ASD will be proposed, and an integrative model of visual perception and attention will be presented, on which the current study will be based.

Chapter 2: Theories of Perceptual Binding and Visual Search Behavior

One of the most basic tasks of the visual system is to integrate elements of a percept into a unified whole. It has long been established that various aspects of a percept (e.g., color, shape, motion) are registered and processed by discrete brain regions, and yet the phenomenological experience is perception of a unified object. Despite the fundamental nature of this process to the experience of the outer world, a consensus has not yet been reached on how this "binding problem" is solved from either a cognitive or a neuroscientific standpoint. In fact, multiple investigators (Humphreys, Allen, & Mavritsaki, 2009; Quinlan, 2003) have proposed that the controversy surrounding this problem is inherently unresolvable by reference to behavioral markers alone and must be resolved through collaboration with neuroscience. This process has begun to take place relatively recently, as the three prevailing cognitive models of perceptual binding and/or visual search (feature integration theory, guided search theory, and attentional engagement theory) have each undergone multiple revisions in order to incorporate emerging neuropsychological and neurophysiological evidence. Each model will be reviewed here, the common underlying concepts will be discussed, and current evidence for the neural basis of these processes in neurotypicals and ASD will be presented.

Feature Integration Theory

This model was originally proposed by Anne Treisman, along with Garry Gelade, in 1980. Since its original incarnation the model has undergone several revisions, including points added in response to challenges made by data that were inconsistent with the original theory. However, despite some lingering concerns about phenomena that cannot be completely explained by this model, it remains one of the most influential theories of perceptual binding, and continues to be supported by more recent research (e.g., Chan & Hayward, 2009).

In its most current form (Treisman, 1998), feature integration theory (FIT) proposes that visual processing consists of two stages: in the first stage, stimuli over a broad range of the visual field are processed in parallel, and in the second stage, focused attention is directed at a particular location, allowing the features present in the attended object to be "bound" and thus experienced as belonging to the same object. The process of moving from the "preattentive" to the "focused attention" stage relies on two types of mental representation: a "master map" of locations of objects in the visual field, and "feature maps" which indicate both the presence or absence of a particular feature somewhere in the visual field (e.g., "green" or "vertical") as well as vague information about the general location of that feature. Focused attention serves to "bind" these free-floating features to the "master map" of locations, thus determining which features are present at the same location.

Thus, FIT proposes that simple tasks requiring only information about whether a feature is present or absent (e.g., identifying a green item amongst an array of gray items) can be done at a preattentive level, while tasks that require more complex information about whether two features are present in the same object (e.g., a green square amongst green triangles and red squares) require focused attention. While much data have been gathered in support of this theory, some of the most compelling includes studies in which individuals who are prevented from focusing their attention on any one of an array of objects display the phenomenon of "illusory conjunctions," in which they report having seen an object containing two features which actually belonged to two separate objects (Treisman & Schmidt, 1982). Though FIT is most often associated with the phenomenon of visual search, it is important to note that FIT is also able to explain other psychological phenomena, such as these illusory conjunctions. In contrast, the other models which will be discussed here have been presented as models of visual search only, and do not explain principles of visual perception and attention beyond this circumscribed area.

The most recent version of the model has been updated from the originally proposed version by the addition of coarse spatial information to the “feature maps,” explaining evidence that illusory conjunctions are more likely to occur when the objects in question are located close together (Cohen & Ivry, 1989). Furthermore, on the basis of evidence that individuals are able to search for a target much more quickly when they have prior knowledge of its features and the features are highly discriminable (Wolfe, Cave, & Franzel, 1989), the model was updated to include the potential for top-down inhibition of irrelevant features. Thus, the excitation of various features by preattentive detection in the visual field is counterbalanced by inhibition of those features that are *a priori* known to be irrelevant, thus allowing faster search for the relevant features. This concept of top-down influences on preattentive visual perception underlines FIT’s conceptual integration of perceptual and attentive processes; perception is seen to influence attention in the role of the “master map” in guiding focused attention, and attention influences perception in the role of focused attention in creating the perception of unified objects as well as top-down influences on the ease with which objects are perceived. This interaction of perception and attention, and specifically the role of top-down influences, will be particularly relevant for the model proposed for the current study to describe perceptual and attentional abnormalities in ASD.

Guided Search

The guided search (GS) model of visual search was originally proposed by Wolfe, Cave, and Franzel (Wolfe et al., 1989) to account for some aspects of visual search that were not accounted for by the FIT model. Like FIT, this model has undergone multiple revisions to accommodate new evidence on visual search phenomena (Wolfe, 1994; Wolfe, 2007); the current review will describe the most recent iteration of this model. As noted above, GS has not been presented as a model of perceptual binding like FIT, but rather as a model of visual search specifically. Thus, the current review of the GS model is presented in order to address some of the objections to FIT that have been raised, though FIT is generally recognized as a more comprehensive model.

The GS model (Wolfe, 2007) is predicated on the basis that at the early, preattentive stage of visual processing, stimuli from a wide area of the visual field are processed in parallel. Various top-down "guidance" processes, which incorporate information derived from both early visual processing and object recognition processes, operate to influence visual information processing at multiple levels, from early perceptual processes through behavioral response. Specifically, GS proposes two separate limiting factors on behavioral output in visual search tasks: the first, visual selective attention, limits access of early visual information to "object recognition processes," the second, the "attentional blink," is a phenomenon in which a stimulus cannot be detected when presented rapidly succeeding (i.e. 200-500 ms after) a previous stimulus presented in the same location, thus preventing the second stimulus from influencing behavioral responses. Though the current model allows for some cases in which early visual information is able to bypass selective attention, such information is still subject to the "attentional blink." This accounts for cases in which strong top-down influences are able to guide visual search without the need for selective attention but nevertheless are limited by another type of attentional capacity. Another important feature of the GS model is the concept of multiple attentional processes, exemplified by the distinction between attention at the level of selection for object recognition and selection for influencing behavioral responding and/or conscious awareness.

It is noted in the most recent version of this model that some limitations remain that prevent it from accounting for all visual search phenomena, such as how search strategies are adapted based on learning from previous trials and how selective attention is directed toward objects, rather than features. However, more notable for the purpose of the present study is that the sole purpose of this model is to account for visual search specifically, rather than capturing broader perceptual and attentional processes.

Attentional Engagement Theory

The third prevailing theory of visual search, attentional engagement theory (AET), has also undergone several revisions since it was first introduced (Duncan & Humphreys, 1992, 1989). Like GS, AET has been put forth as a model of visual search specifically, not as a model of perceptual binding. The original form of this theory proposed that search difficulty is modulated by similarity of targets to non-targets and by dissimilarity of non-targets from each other. In contrast, FIT and GS had proposed that stimuli were selected based only on previous knowledge of target features. Though AET was purported to be distinct from the previous two models in that it did not have a two-stage structure, its description of an early parallel processing stage followed by the entry of selected information into visual short-term memory, which corresponds to the subjective experience of focused attention, appears largely similar to the other models' preattentive/focused attention structure. The AET model also proposed a continuum of search difficulty based on the relationships between targets and non-targets, rather than a two-stage model with fast, parallel search at the preattentive stage and slow, serial search at the focused attention stage. Search would be efficient when non-targets could be grouped together based on similar features and rejected simultaneously through a process of "spreading suppression." This concept was not represented in the early FIT and GS models; it has been noted, however, that more recent versions of these models have incorporated elements of top-down inhibition of non-target features (Humphreys et al., 2009).

Common Features of These Models

Not surprisingly, FIT, GS, and AET have grown to resemble each other more as each has attempted to accommodate emerging data in support of the other two models. As functional neuroimaging methods have become more widely accessible, all three models have also evolved to align with evidence of brain functions associated with perceptual binding and visual search, the details of which will be discussed in the following section. The result has been that the fundamental structures of the three models are similar in a number of ways. Though AET attempts to distinguish itself from two-stage models, its format does not appear to be hugely discrepant from such models, as noted above. All three models propose an early stage of parallel processing of visual information, followed by selection of specific information to inform behavioral responses. Furthermore, all three models now recognize the importance of top-down influences on early stages of visual perception. For the purposes of the current study, these two broad concepts will be sufficient to inform a model of abnormal visual perception and attention in ASD, as will be explained in Chapter 5, “Rationale and Theoretical Model for the Present Study.” For the sake of clarity, the FIT model alone will be referenced from this point forward, as this model is most relevant to an investigation of relationships between visual perception and attention rather than visual search specifically.

Chapter 3: Behavioral and Neural Correlates of Visual Search Task Performance in ASD and Neurotypicals

Task Description

A wide range of visual search tasks have been used to investigate the two stages of perceptual binding proposed by FIT, as well as to investigate perceptual and cognitive abnormalities in ASD. Generally, these tasks involve the presentation of an array of discrete stimuli among which the participant is required to search for one stimulus designated as a target, with non-target stimuli generally referred to as “distractors.” Reaction time is most often the dependent measure of interest, as reaction times generally show a wider range than measures such as error rates or accuracy both within and between participants, as well as showing more clear differences between commonly used task conditions. In addition to visual perception and attention abilities, within-subject factors that determine reaction time include processing and psychomotor speed. These tasks can have a wide range of difficulty based on various stimulus and response factors, such that they can be modified for use with very young children or the cognitively impaired, but can also be made relatively difficult for use with unimpaired adults and individuals with unusually well-developed visual perceptual abilities (e.g., ASD). Stimulus factors that can be varied in visual search tasks include prior knowledge of the target, display size, whether the target has feature(s) in common with distractors, and color, shape, size, texture, and orientation of target and distractors. Different types of responses can also be required in these tasks, including target-present and/or target-absent responses and target type responses. The effects of such task variations on neurotypical performance is discussed below.

Performance in Neurotypicals

One of the most common variations in classic visual search tasks is feature search versus conjunction search. This distinction refers to whether the target has any feature(s) in common with any of the distractors; in feature search, the target has no features in common (e.g., a red square among green circles), whereas in conjunction search, the target does have features in common with distractors (e.g., a red square among red circles and green squares). This distinction has been particularly important in the history of visual search research primarily due to the FIT model, which understands feature search to be conducted at the preattentive level and conjunction search to require focused attention. Extensive evidence supports this view that feature search is conducted at the preattentive level and is thus relatively easy, while conjunction search requires focused attention and thus requires relatively more cognitive resources. Namely, it has been repeatedly shown that individuals perform significantly better on feature search tasks than on conjunction search tasks, as indicated by faster reaction times (Chan & Hayward, 2009; Humphreys et al., 2009; Treisman, 1982; Treisman & Gelade, 1980; Treisman & Schmidt, 1982).

Although neurotypicals generally show faster reaction times on feature search tasks than conjunction search tasks, it has also been noted that reaction times are slower within a feature search task when the target can be defined within more than one dimension and the participant is required to switch attention between dimensions. In this version of visual search, the participant is unaware of what the target will be before beginning the task, but is simply informed that they are to respond based on whether they see one stimulus that is different from the others. Targets are then presented which differ from the distractors in more than one dimension, for example, a diagonal black bar or a red vertical bar among black vertical bars. Participants have been found to be slower in responding to a target defined in one dimension (e.g., orientation) when the previous trial included a target defined in another dimension (e.g., color; Chan & Hayward, 2009; Found & Muller, 1996; Müller, Heller, & Ziegler, 1995; Treisman & Gormican, 1988). It should be noted that the reference here to switching of "attention" between stimulus dimensions may appear contradictory, as feature search is purported to be accomplished by preattentive processes. However, "attention" here refers not to the same process of "focused attention" as described by FIT, but rather, specifically to top-down influences on preattentive processes. This conceptualization will be explored in greater depth in Chapter 5, "Rationale and Theoretical Model for the Present Study."

Another well-documented factor in visual search task difficulty is display size, or the number of stimuli presented in a display. Generally, neurotypical performance decreases as display size increases, as indicated by slower reaction times with increasing display sizes. It is of note that while reaction times increase somewhat with display size on feature search tasks, the increase is greater for conjunction search tasks (Humphreys et al., 2009; Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman, 1982). This is consistent with the FIT model, which proposes that feature search can be conducted with parallel processing of stimuli, while conjunction search must be conducted by serial processing of stimuli (Treisman & Gelade, 1980). Thus, feature search tasks do not require significantly more time to process an increasing number of stimuli, while conjunction search requires more time with each additional stimulus.

Another well-established finding in visual search tasks is that, in neurotypicals, reaction times increase with increasing similarity between targets and distractors. Though this and similar phenomena formed the basis of the original AET of visual search (Duncan & Humphreys, 1989), contemporary versions of FIT and the GS model have both evolved to accommodate evidence that search for a target among similar distractors is more difficult than among dissimilar distractors. This is accounted for in the FIT model by the proposal that features that are similar enough within a given dimension (e.g., pink and red) primarily activate the same feature detectors, thus necessitating serial rather than parallel processing of stimuli. This account is supported by evidence that in feature search tasks in which the target is not sufficiently different from distractor stimuli, reaction times increase with increasing display size similar to conjunction search, rather than remaining relatively stable as in easier feature search tasks (Treisman & Gormican, 1988).

While the majority of the research on visual search in neurotypicals has been conducted with adult samples, there is a more modest body of literature on the typical developmental trajectory of performance on visual search tasks in younger individuals. There is a considerable amount of evidence supporting a general decrease in search times from young childhood to young adulthood. Samples including children from age 6 to age 18 have consistently found a decrease in reaction times on both feature and conjunction search with increasing age (Day, 1978; Gibson & Yonas, 1966; Hommel, Li, & Li, 2004). Furthermore, performance on conjunction search specifically has been found to improve throughout childhood as measured by decreased reaction times. Studies have confirmed this trend with children ages 6 through 22, at which time age-related improvements in reaction times have been shown to level off (Hommel et al., 2004; Trick & Enns, 1998). However, despite overall faster performance with age, the relationship between performance on feature and conjunction search has been shown to be similar across the developmental trajectory. Using a within-subjects design, one sample of very young children (1- to 3-year olds) found that the increase in reaction times for feature and conjunction search with increasing numbers of distractors was the same as that observed in adults; namely, little to no increase in feature search versus steady increase in conjunction search (Gerhardstein & Rovee-Collier, 2002).

Neural Correlates of Visual Search Task Performance in Neurotypicals

Neural activation in neurotypicals during performance of visual search tasks has been extensively studied. Due to the wide range of cognitive, perceptual, and motor processes involved in the activity of visual search, neural activity related to all of these processes cannot be covered exhaustively here. Rather, the current review will focus on aspects of neural activation during visual search that are relevant to the core principles of FIT, namely the neural bases of perceptual binding, preattentive versus attentive visual processing, and top-down influences on visual search behavior. The processes discussed here are also some of those that have been found to be disordered in ASD and will be relevant to the current investigation, as will be discussed in the following sections.

Perceptual binding. To provide context for the current discussion, FIT is based on an enduring problem in perception and neuroscience; that is, how does the brain create a unified percept from the activation of discrete populations of neurons that each represent a single feature? It has long been known that different areas within the primary visual cortex are responsible for coding individual features of a visual percept, for example, color, orientation, and movement, and that populations of neurons also exist that code particular combinations of features (e.g., Hubel & Wiesel, 1968). A logical extension of these findings would be that neurons exist which code successively more complex combinations of features, such that one cell exists for every possible visual percept, or at least for every percept which an individual has encountered. This has come to be known as the “grandmother cell hypothesis,” so called because it would suggest that there exists a single neuron representing the image of one’s grandmother. This hypothesis, however, has been found to be unworkable, due in part to the combinatorial explosion in the number of neurons necessary to code each possible percept (Quiroga, Kreiman, Koch, & Fried, 2008). In need of an alternative mechanism for perceptual binding, neuroscience has found some promising clues but has yet to come to a consensus on how the brain is able to solve this problem.

The currently proposed alternative to the grandmother cell hypothesis is the temporal binding hypothesis. This theory proposes that feature binding is achieved by temporal correlations in neural firing patterns. This theory has received support from a body of research showing increased EEG activity in the gamma frequency band (~30-100 Hz) during viewing of a coherent object as opposed to a non-coherent visual pattern (e.g., Kanizsa triangles vs. control stimuli; Tallon, Bertrand, Bouchet, & Pernier, 1995; Tallon-Baudry, Bertrand, Delpuech, & Permier, 1997). Specifically, there appears to be an increase in neural synchrony at 40 Hz during perception of a coherent object. While this phenomenon was originally demonstrated in adults, it has also been found that 8-month-old infants show an increase in 40 Hz activity during viewing of a Kanizsa figure as compared to a control stimulus (Csibra, Davis, Spratling, & Johnson, 2000).

Despite the well-established correlation between neural synchrony in the gamma frequency band and perception of a coherent object, controversy remains about whether temporal binding is a sufficient explanation for the binding problem. Ghose and Maunsell (1999) have proposed that neural synchrony could be a result of binding rather than the causal mechanism, a concern that was echoed by Treisman in a recent version of FIT (1998). It was noted that while neural synchrony could be a mechanism for tracking which features belong together in the same object once they have been identified, it must first be determined which features belong to which object. Treisman proposes that this function is achieved by focused attention at the location of an object, then allowing features to be identified and tracked as belonging together. However, this account is complicated by the fact that increased gamma-band synchrony has also been found to be associated with selective visual-spatial attention (Fries, Reynolds, Rorie, & Desimone, 2001; Gruber, Müller, Keil, & Elbert, 1999). While it is as yet unclear how focused attention and perceptual binding processes are differentially represented in the brain, the presence of increased neural synchrony during both of these processes can be seen to provide support for FIT’s claim that they are intimately linked (i.e., that perceptual binding is achieved through focused attention).

In addition to neural synchrony, the role of the parietal cortex in perceptual binding has been well-established. Some of the earliest evidence came from case studies of individuals with lesions of the parietal lobe who showed difficulty binding features together into a coherent object, as indicated by much higher than normal rates of illusory conjunctions (Friedman-Hill, Robertson, & Treisman, 1995; Robertson, Treisman, Friedman-Hill, & Grabowecky, 1997; Treisman, 1998). Further support has been provided by several studies showing increased activation of the superior parietal cortex during conjunction search and other tasks with visuo-spatial attention requirements (Corbetta & Shulman, 1998; Petersen, Corbetta, Miezin, & Shulman, 1994; Shafritz, Gore, & Marois, 2002), as well as one study showing that transcranial magnetic stimulation (TMS) applied over the parietal cortex interferes with the feature binding necessary for conjunction search, without affecting performance on feature search (Ashbridge, Walsh, & Cowey, 1997).

Preattentive versus attentive visual processing. The distinction between the neural bases of preattentive and attentive visual processing is particularly difficult to determine due to the highly overlapping nature of both their behavioral manifestations and their neural mechanisms. The aforementioned difficulty in distinguishing the neural bases of perceptual binding and focused attention is analogous to the difficulty in distinguishing preattentive and attentive visual processing. Thus far, the only method that has succeeded in distinguishing the two has been intracranial recording in monkeys, which provides high resolution data in both the spatial and temporal dimensions. Some evidence for the neural basis of focused attention specifically has also been provided by magnetoencephalography (MEG) of humans, which also provides high spatial and temporal resolution relative to other imaging methods, though not as high as intracranial recording.

Intracranial recording in monkeys during performance of a visual search task has provided support for a combination of serial and parallel search strategies in both feature and conjunction search tasks. Recordings from the V4 area of the visual cortex showed that throughout search, neurons showed increased activity and gamma-band synchronization when a stimulus within the visual field matched a feature of the target stimulus (Bichot, Rossi, & Desimone, 2005). This finding is consistent with preattentive or parallel processing of stimuli as proposed by FIT, in that neurons were activated in response to a certain feature without specifically focused visual attention. Furthermore, neurons also showed increased activity when potential targets were selected for focused visual attention, consistent with a serial processing stage. Recordings from the frontal eye fields during conjunction search also provided support for a parallel, preattentive stage of processing by showing that neurons were differentially activated by targets, distractors, and distractors that shared a feature with the target (Bichot & Schall, 1999).

An MEG study in humans had the aim of localizing the source of a previously identified event-related potential (ERP) component, called N2pc, that was found to be associated with focusing of visual attention on a stimulus in a visual search task (Eimer, 1996). This component consists of a negative deflection in the electroencephalographic (EEG) signal that occurs between 180-280 ms after presentation of a visual search stimulus array which is most pronounced over posterior scalp regions contralateral to the position of the attended stimulus in the visual field. Eliciting the N2pc component by presenting participants with a visual search task while undergoing MEG recording allowed for localization of the cortical sources of the component, which was found to arise from activity in two separate areas. Findings of earlier activation in the parietal cortex (180-200 ms) followed by later occipio-temporal activation (220-240 ms) were consistent with visual cortex activity associated with focused attention as demonstrated in Bichot et al. (2005), as well as evidence for parietal involvement in orienting of attention, which will be discussed in Chapter 4, "Posner Attention Model."

Top-down influences on visual search behavior. Top-down influences on visual search have been shown to operate at both the preattentive and attentive level, consistent with the current version of FIT. At the preattentive level, these top-down influences have been shown to affect attentional capture by a singleton "pop-out" target as well as creating priming effects that influence performance when switching between dimensions in which the target is defined. At the attentive level, top-down influences affect selection of targets for focused attention as well as facilitating serial search and inhibition of return.

Attentional capture within a feature search task has been found to be significantly influenced by prior knowledge of, and thus top-down control over, which dimension will define the target. Thus, performance is slowed when a target is defined within a dimension other than that which is expected based on previous information (Müller et al., 1995). Furthermore, fMRI evidence has shown that while attentional capture by a singleton distractor is associated with involuntary shifts of attention mediated by the superior parietal cortex, thus interfering with target search, activation of the frontal cortex is negatively associated with interference by such distractors (de Fockert, Rees, Frith, & Lavie, 2004). Thus, higher levels of top-down control by the frontal cortex help to prevent attentional capture by an irrelevant stimulus dimension.

Expectation of the dimension in which a target will be defined also exerts significant influence over performance on feature search tasks. An fMRI investigation has shown that feature-based cue information about the color of a potential target was represented in frontal, parietal, and cingulate regions, indicating that cue information induced preparation for top-down control of subsequent visual search (Egner et al., 2008). This interpretation was supported by improved search performance corresponding to increasing amounts of cue information. Another fMRI investigation found that when the dimension in which a target was defined switched (e.g., color target to shape target), there was a resulting increase in activity in the left frontopolar cortex as well as in posterior regions implicated in higher-order visual processing (Pollmann, Weidner, Müller, & von Cramon, 2000). This was understood to reflect top-down control over the attended visual dimension by the frontopolar cortex, which induced a modulation of activity in visual cortical areas. EEG evidence has also supported the role of left frontopolar activation in shifting attention between stimulus dimensions, which occurred very early in visual processing (within 110 ms; Gramann, Töllner, & Müller, 2010).

When visual search is conducted at the attentive level, as in conjunction search, top-down processes influence selection of targets for focused attention. During intracranial recording in monkeys, increased activity in neurons in the inferior temporal cortex (associated with high-level visual processing) has been observed during selection of a target for focused attention based on previously presented cue information that was held in working memory (Chelazzi, Miller, Duncan, & Desimone, 1993). In addition to activating information related to potential targets, top-down influences also function to inhibit attention to previously attended stimuli in a serial search task, as demonstrated by behavioral responses to cues at previously attended locations within a visual search array (Klein, 1988).

Performance in ASD

It has long been understood that individuals with ASD display areas of relative strengths and weaknesses within various cognitive domains in relation to neurotypical performance. One of the earliest identified areas of relative strength was in visual-spatial processing, as indicated by various sources of evidence including consistently high performance on the Wechsler block design task (Lincoln, Courchesne, Kilman, Elmasian, & Allen, 1988; Prior, 1979; Rumsey & Hamburger, 1988) and case studies of autistic “savants” who display extraordinary drawing abilities.

Subsequent investigations of visual search abilities in ASD as compared to neurotypicals have consistently found ASD to show superior performance on both feature and conjunctive visual search tasks. Plaisted, O’Riordan, and Baron-Cohen (1998) found faster reaction times on a conjunctive search task, but not in a feature search task, in children with ASD (ages 7-10) as compared to verbal IQ-matched neurotypicals (ages 6-9). O’Riordan and colleagues proposed that the lack of group differences on the feature search task in this study were essentially due to a ceiling effect, and thus conducted two studies in which a more difficult feature search task was included. These later studies found faster performance on both feature and conjunction search in both children (ages 6-9) and adults (ages 17-27) with ASD as compared to age- and IQ-matched neurotypicals, with between-group differences increasing with larger display sizes (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; O'Riordan, 2004). No between-group differences in accuracy were found, consistent with the literature on visual search in neurotypicals, in which accuracy rates are uninformative of performance.

A follow-up to O'Riordan's 2001 study was conducted as a test of a possible mechanism for enhanced visual search performance in ASD. Several potential explanations had been proposed including: (1) that ASD are better able to discriminate between stimuli, (2) that ASD are better able to excite target stimuli and/or inhibit distractor stimuli, or (3) that ASD are better able to inhibit return to previously searched items. To test for enhanced discrimination of stimuli in ASD, task conditions in which target-distractor similarity was manipulated were administered to age- and IQ-matched children with ASD and neurotypical controls, both ages 6-11. Results showed that while reaction times of both neurotypicals and ASD were slowed by increased target-distractor similarity, ASD were slowed less than neurotypicals in the high similarity condition (O'Riordan & Plaisted, 2001). This finding was thought to provide support for an increased ability to discriminate between stimuli in ASD. Similar results were later found with an adult sample (ages 17-27), providing evidence that enhanced stimulus discrimination in ASD persists into adulthood (O'Riordan, 2004).

Another related study investigated the possibility of enhanced top-down excitation of target stimuli or inhibition of distractor stimuli in ASD as an explanation for superior visual search performance. This study employed a positive and a negative object-based priming paradigm within a conjunction search task, in which the effect of changing either the target or the distractor stimuli, respectively, within a task condition was analyzed (O'Riordan, 2000). Results showed that individuals with ASD showed faster reaction times overall, consistent with other studies. However, while both groups showed slower reaction times on task conditions in which either the target or distractors were variable from trial to trial, as opposed to conditions in which targets and distractors remained the same, there was no group by condition interaction in either the positive or negative priming paradigms. Thus, individuals with ASD showed neither enhanced nor impaired top-down excitation of target stimuli or inhibition of distractor stimuli as compared to neurotypicals, which was thought to provide further support for enhanced low-level perceptual discrimination.

Another line of investigation has also provided evidence of enhanced stimulus discrimination in ASD as a means of accounting for faster visual search times. In order to distinguish this possibility from the possibility of more efficient search strategies in ASD, Kemner, van Ewijk, van Engeland, and Hooge (2008) utilized eye-tracking during performance of a visual search task by age- and IQ-matched adult males with and without ASD. While ASD participants showed the expected advantage in reaction time over neurotypical participants, eye-tracking data revealed no evidence of alternative search strategies in those with ASD, though they did perform fewer eye movements. These results were understood to provide further evidence of enhanced stimulus discrimination in those with ASD.

As noted above, a possible alternative explanation for enhanced visual search in ASD is what is known as enhanced “inhibition of return,” or an improved ability to avoid returning to previously attended stimuli. To test this hypothesis, Joseph et al. (2009) compared performance on a standard visual search task to one in which the distractors and targets randomly changed locations during search in order to control for memory of distractor locations. In this sample of age-matched 8- to 19-year-old ASD and neurotypical children, those with ASD showed faster reaction times than neurotypicals, but did not show less efficient performance on the dynamic search task, suggesting that enhanced memory for distractor locations could not account for faster performance in those with ASD. Furthermore, eye-tracking data showed that the number and locations of visual fixations were similar for those with ASD and neurotypicals, but that individuals with ASD showed significantly shorter fixation times. Faster reaction time on the search task was also associated with greater symptom severity among the ASD group. Taken together, these results provide further support for enhanced stimulus discrimination in ASD, as well as suggesting that the degree of this enhanced perceptual ability is related to severity of pathology.

Another possible explanation for atypical visual search performance in those with ASD is abnormal eye movement. In a review of the literature on visual search among individuals with ASD, Brenner, Turner, and Müller (2007) conclude that while there is only tentative evidence for abnormal eye movements in those with ASD, there is also no evidence of the presence or absence of oculomotor abnormalities preceding the development of perceptual and cognitive abnormalities in ASD. Furthermore, any available evidence of abnormal eye movements in individuals with ASD is in adults only, and in many cases is confounded with perceptual and cognitive processes, Thus, abnormal eye movement cannot yet be ruled out as a precipitating factor for ASD symptoms observed later in the developmental trajectory.

Neural Correlates of Visual Search in ASD

To date, no imaging studies of ASD have been conducted during performance of a visual search task. However, evidence of structural and functional brain abnormalities in neural processes that have been implicated in visual search performance in neurotypicals can inform hypotheses about potential contributing factors to atypical visual search in those with ASD.

Perceptual binding. Evidence has been accumulating that neural synchrony in the gamma frequency band is abnormal in individuals with ASD. Given the apparent role of gamma band synchrony in visual perception and attention in neurotypicals, it has been hypothesized that such abnormalities may play a role in the characteristically elevated perceptual discrimination abilities that are thought to contribute to enhanced visual search performance in those with ASD. Such a hypothesis is made more plausible by the majority of evidence which shows higher gamma power in posterior cortical regions involved in visual perception and attention in those with ASD as compared to neurotypicals, suggesting a possible neural basis for enhanced perceptual abilities. For example, EEG studies in children have found higher midline gamma power in individuals with ASD than in neurotypicals during a sustained visual attention task (Orekhova et al., 2007), higher parietal gamma power in individuals with ASD than mentally retarded (MR) controls during viewing of illusory figures (Brown, Gruber, Boucher, Rippon, & Brock, 2005), and higher temporal gamma power in infant siblings of children with ASD (who thus are considered to belong to the broader ASD phenotype) than in neurotypicals (Elsabbagh et al., 2009). In addition, another EEG study of children with ASD found impaired sensory gating as compared to neurotypicals (Orekhova et al., 2008). This was indicated by a failure by the ASD group to appropriately modulate the amplitude of the auditory event-related potential in response to repeated clicks, suggesting an impaired ability to habituate (i.e., down-regulate the physiological response to familiar stimuli) in individuals with ASD. Most recently, a MEG study of ASD adolescents during viewing of Mooney faces (thought to index perceptual binding) found that gamma power during perceptual binding was primarily concentrated in visual cortical regions, as compared to the pattern of gamma power in neurotypicals which was distributed throughout a fronto-parietal network (Sun et al., 2012).

Top-down influences on visual search behavior. Since no studies of neural activity specifically during visual search in individuals with ASD have been carried out, inferences must be made from related paradigms to determine potential abnormalities in top-down influences on visual search in ASD. Impairments in higher-order processes mediated by association cortices (i.e., frontal lobe, certain parietal and temporal regions) have been well-established in ASD in the context of many different paradigms indexing many aspects of executive function and other top-down processes. Top-down processes that are particularly relevant to visual search include top-down control over spatial shifting of attention, inhibition of distractor stimuli, and excitation of target stimuli. Though it is well-established that spatial shifting of attention is abnormal in ASD (Haist, Adamo, Westerfield, & Townsend, 2010; Renner, Klinger, & Klinger, 2006), this body of literature is outside the scope of this project and will not be discussed further. The current review will focus on top-down inhibition and excitation of stimulus features both within and between dimensions.

As discussed in Chapter 2, normal excitation of a relevant stimulus dimension and inhibition of irrelevant dimensions result in significant dimension-switching costs, or increased time to identify a target defined in a different dimension. While this phenomenon has not been specifically investigated in ASD, there is evidence that the frontal cortical region implicated in dimension-switching in neurotypicals shows abnormal function in those with ASD. The frontopolar cortex, part of a region of the frontal cortex known as Brodmann area (BA) 10, has been found to be specifically involved in dimension switching (but not in target changes within a dimension) during fMRI investigations of feature search in neurotypicals (Gramann et al., 2010; Pollmann et al., 2000; Pollmann, 2001; Weidner, Pollmann, Müller, & von Cramon, 2002). Evidence is beginning to accumulate that frontopolar cortex, and more generally BA 10, show hypoactivation in those with ASD during tasks requiring top-down control. For example, an fMRI study of cognitive control in adolescents with ASD showed hypoactivation of anterior frontal regions (i.e., BA 10) during a cognitive control task as compared to neurotypicals, as well as hypoconnectivity between frontal and occipital areas in response to cues predicting the need to exercise cognitive control (Solomon et al., 2009). Cognitive control was measured with the "preparing to overcome prepotency" task, which consists of a red or a green box followed by an arrow pointing left or right; participants are to press a key in the same direction as the arrow following a green box, and the opposite direction following a red box. Thus, top-down control is required to respond correctly in the red box/high-control condition, similar to the top-down control required to switch attention between stimulus dimensions. Reduced functional connectivity between frontopolar cortex and other cortical areas in those with ASD as compared to neurotypicals was also found in another fMRI study during a simple visuomotor coordination task, suggesting that frontopolar cortex lacks appropriate coordination with other brain regions even in the absence of demands on top-down control. Theoretical justification of impaired function of BA 10 in ASD is provided by evidence that this region has a particularly long developmental period extending through adolescence, making it more likely to be susceptible to abnormal developmental processes (Dumontheil, Burgess, & Blakemore, 2008). Thus, it is hypothesized that abnormal function of BA 10 is likely involved in many disorders of neurodevelopment including ASD, ADHD, and schizophrenia.

Of note is evidence that switching within a stimulus dimension, rather than between dimensions, is subserved not by frontopolar but by frontomedian cortex in neurotypicals (Pollmann et al., 2007; Weidner et al., 2002). While a meta-analysis of fMRI studies indicates that there is consistent evidence of hypoactivation of frontomedian cortex in those with ASD during social cognitive tasks (Sugranyes, Kyriakopoulos, Corrigall, Taylor, & Frangou, 2011), there is some evidence that individuals with ASD nevertheless show intact performance on visual search tasks involving within-dimension stimulus changes. For example, an ASD group showed overall slowing of reaction times that were comparable to neurotypicals in a conjunction search task involving switching of either targets or distractors within a stimulus dimension, indicating intact top-down excitation and inhibition of stimulus features within a dimension (O'Riordan, 2000). Another study employing a negative priming task in which inhibition of irrelevant stimulus features (defined by either location or color) was required showed intact inhibition of locations, but impaired inhibition of color, in those with ASD as compared to neurotypicals (Brian, Tipper, Weaver, & Bryson, 2003). Thus, more research is required to clarify the presence or absence of deficits in within-dimension switching among those with ASD.

Left frontopolar cortex has been found to be specifically involved in dimension switching during feature search (Weidner et al., 2002), and though no imaging research has addressed the function of left frontopolar cortex in ASD specifically, there is reason to believe that it may be implicated in some observed attentional abnormalities. One study examined the effect of *within*-dimension changes in a conjunctive target in ASD and found reaction times comparable to those of neurotypicals (O'Riordan, 2000), but this does not provide information about possible slowing related to *between*-dimension changes. In neurotypicals, within-dimension changes produce less slowing of reaction times than between-dimension changes do; thus, if individuals with ASD do in fact have an impaired ability to switch attention between dimensions, this deficit may be more evident in a paradigm requiring between-dimension changes. Furthermore, O'Riordan (2000) examined average reaction times for a task condition including both switching and non-switching trials, which may have reduced the sensitivity of the measure to potential between-group differences in within-dimension switching costs.

While FIT as discussed above provides an important framework for conceptualizing preattentive versus attentive visual processes, it does not provide an account of the various functions that fall under the umbrella of visual attention. Such an account is provided by Posner’s model of attention, which will be explicated in the following section, and which has provided the framework for a significant body of research on attention abnormalities in ASD.

Posner Attention Model

Overview of the Model

One of the most currently and influential models of attention is the one originally developed by Michael Posner. While other models of attention have been based on factor analyses of data derived from traditional neuropsychological tests (Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991), Posner's model is distinguished by its basis in neuroscience and conceptualization of the various elements of attention as forming a system within the brain. As originally conceived, Posner's model of attention consisted of three components: maintaining an alert state, orienting to locations, and detecting signals for conscious processing (Posner & Petersen, 1990). Though the model has since evolved to conceptualize the latter process as "executive attention" (Posner & Fan, 2008), the basic premises remain the same while details have continued to evolve as evidence from cognitive neuroscience accumulates. The following explication of Posner's model is drawn from more recent iterations (Fan, 2013; Fan, Gu, Guise, Liu, & Fossella, 2009; Posner & Fan, 2008).

Alert. Alertness or vigilance ensures the ability to respond to a stimulus. Alertness is subdivided into intrinsic, or tonic, alertness, which refers to wakefulness and arousal, and phasic alertness, which refers to the ability to increase readiness to respond to a target, often cued by an external stimulus. The alerting system of the brain is associated with cortical projections of the noradrenergic system (Coull, Sahakian, & Hodges, 1996), which originates in the locus coeruleus. The alerting function of the brain is associated with thalamic, right frontal, and parietal cortical regions (Marrocco, Witte, & Davidson, 1994).

Orient. The brain's orienting function involves selecting specific information from among all sensory inputs. Orienting is also subdivided into two types: exogenous orienting, which occurs when a sudden onset of a stimulus draws attention, and endogenous orienting, which occurs when attention is voluntarily directed to a new location. Within these, orienting can also be described as overt, or involving head and/or eye movements, or covert, or without head and/or eye movements. Orienting has also been found to involve three sub-stages: disengaging from the currently attended stimulus, moving attention to the new stimulus, and engaging attention to the new stimulus (Posner & Cohen, 1984). Orienting of attention has been widely studied in neurotypicals and patient populations with a paradigm in which a cue is presented which is either spatially congruent or incongruent with a subsequent target (Posner, 1980). Attention is oriented to the cue location, and thus enhances processing of the subsequent target if it appears in the same location, but impairs processing if the target appears in a different location and attention must be reoriented. The orienting system of the brain is associated with cortical cholinergic projections originating in the basal forebrain (Davidson & Marrocco, 2000). The frontal eye fields, thalamus, midbrain, and parietal cortex are all associated with orienting attention (Corbetta & Shulman, 1998b; Petersen, Corbetta, Miezin, & Shulman, 1994b; Posner & Petersen, 1990).

Executive attention. Executive control of attention involves monitoring and resolving conflict between processes mediated by different brain areas. Executive attention can be indexed with various tasks that require, for example, responding to one dimension of a stimulus that conflicts with a more strongly attended dimension, such as a Stroop task (Stroop, 1935). Executive attention is associated with cortical dopaminergic projections originating in the ventral tegmental area (Fan, Fossella, Sommer, Wu, & Posner, 2003), and with activation of the lateral prefrontal cortex and the anterior cingulate cortex (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Matsumoto & Tanaka, 2004).

Attentional network abnormalities in ASD. To index each of the three components of Posner’s attentional model, as well as the interactions between the three components, the attentional network test (ATN) was developed. This is a relatively complex task involving multiple cue conditions, a cue validity manipulation (congruent versus incongruent cues), and multiple cue-target intervals (see Fan et al., 2009 for a detailed description of the ATN). Most notably in neurotypicals, this task elicits a tradeoff between response speed and executive control, where higher alertness produces faster response speed and lower executive control, and vice versa. When applied to ASD, this task provides evidence for impairment in the orienting component of attention, but not in the alert or executive attention components (Keehn, Lincoln, Muller, & Townsend, 2010). While findings of impairment in orienting are consistent with previous research (Courchesne et al., 1994; Harris, Courchesne, Townsend, Carper, & Lord, 1999; Renner et al., 2006; Townsend et al., 1999), the lack of impairment in the executive control domain is in contrast to extensive findings of impaired executive function in those with ASD (Happé, Booth, Charlton, & Hughes, 2006; Johnson et al., 2007; Ozonoff, Pennington, & Rogers, 1991; Ozonoff, Strayer, McMahon, & Filloux, 1994). However, the executive attention component of the ANT measures primarily response inhibition; even in studies in which response inhibition has been found to be intact in ASD, other components of executive function such as set shifting have been found to be impaired (Luna, Doll, Hegedus, Minshew, & Sweeney, 2007; Ozonoff et al., 1994).

In light of a variety of mixed findings indicating abnormalities in both the orienting and executive attention functions in ASD in some conditions but not in others, Fan (2013) suggests that an abnormal interaction between the orienting and executive control functions may explain such an inconsistent pattern of performance. Thus, the following section will describe two cognitive functions that incorporate aspects of both orienting and executive attention and observed abnormalities of these functions in ASD.

Attentional Functions Incorporating Orienting and Executive Attention

While some functions clearly fall within one of Posner's three components of the attention system, others involve two or more of these components. Fan et al. (2009) note that while some regions and functions are specific to each of the three attentional components, there is also substantial overlap and interaction between them. One function that incorporates elements of two components is endogenous spatial orienting, which incorporates orienting to location as well as voluntary, executive control over the locations to which attention is oriented. Another such function is referred to as the "spotlight of attention," which involves broadening or narrowing the area of the circumscribed area of the visual field being attended. Like endogenous orienting, the spotlight of attention involves a spatial orienting component but is also under voluntary control.

Endogenous spatial orienting. As noted above, endogenous spatial orienting is defined as voluntary orienting to a location, most often measured in cognitive paradigms by use of a central directional cue such as an arrow. Imaging studies have provided evidence that endogenous orienting is mediated by a neural network that partly overlaps the network mediating exogenous, or involuntary, shifts of attention, with endogenous attention involving intraparietal and superior frontal cortex and exogenous attention involving temporoparietal and inferior frontal cortex (Corbetta & Shulman, 2002). Findings on endogenous spatial orienting in ASD have been mixed, with impairment generally seen with shorter cue-target intervals and intact orienting seen with longer intervals (Landry, Mitchell, & Burack, 2009; Wainwright-Sharp &

Bryson, 1993), though one study has found intact endogenous orienting in those with ASD at a short cue-to-target interval (Senju, Tojo, Dairoku, & Hasegawa, 2004).

Only one study to date has investigated the neural correlates of endogenous shifts of attention in individuals with ASD, utilizing an fMRI paradigm in which participants were required to shift attention back and forth between two lateral spatial locations rather than a standard Posner paradigm (Belmonte & Yurgelun-Todd, 2003). Though the task was designed to create a ceiling effect, and thus ASD and neurotypical performance was not significantly different, individuals with ASD showed higher activation in visual cortical regions (i.e., ventral occipital and striate cortex) and lower activation in regions normally associated with the orienting network (i.e., superior parietal, middle temporal, inferior and medial frontal cortex). Consistent with other imaging studies which have found intact behavioral performance but abnormal neural activation in ASD, this suggests that in some tasks, individuals with ASD are able to utilize compensatory neural mechanisms to achieve normal performance.

Spotlight of attention. Posner's conceptualization of the nature of attention has historically relied on the metaphor of a beam or spotlight. Processing of stimuli that fall within the spotlight is facilitated, while processing of stimuli outside the spotlight is inhibited (Posner, Snyder, & Davidson, 1980). In addition to orienting the spotlight to a different location, the spotlight can also be broadened or narrowed, facilitating processing of either local or global aspects of a stimulus. The process of broadening or narrowing the spotlight of attention is voluntary and effortful, as evidenced by longer reaction times when attention must be redirected from global to local features of a stimulus, or vice versa (Robertson, Egly, Lamb, & Kerth, 1993; Ward, 1982). Studies of patients with parietal lesions (Robertson, Lamb, & Knight, 1988; Townsend & Courchesne, 1994) and one study of TMS applied over parietal cortex (Stone &

Tesche, 2009) have shown impaired ability to adjust the size of the spotlight of attention, and fMRI investigations of neurotypicals have confirmed that the parietal cortex is involved in control of the size of the attentional spotlight (Fink et al., 1996). It has been widely theorized that an abnormal balance between attention to global and local features of stimuli may underlie ASD symptomatology, often conceptualized as “weak central coherence,” or impaired ability to perceive a whole stimulus rather than its separate parts (Happé & Frith, 2006). Evidence for and against this theory is presented below, in the context of the cognitive paradigms most often used to measure global versus local visual attention.

Selected Tasks Indexing Spotlight of Attention

Embedded figures task.

Task description. The standardized Embedded Figures Test involves presenting a complex geometric figure, which the participant is asked to describe. This is followed by presentation of a simple geometric “target” figure, followed again by the original complex figure, within which the participant was required to trace over the simple target figure (Witkin, Oltman, Raskin, & Karp, 1971). Performance is measured by mean time to detect the embedded figures, with a time limit of three minutes to correctly trace the simple figure, after which the item is scored as incorrect. A standardized Children’s Embedded Figures Test (CEFT; Karp & Konstadt, 1963) and a Group Embedded Figures Test (GEFT; Oltman, Raskin, & Witkin, 1971) have also been developed. The children’s version is modified to include only two simple figures, a “tent” and a “house,” each of which is presented in the form of a cardboard cutout. Complex figures are representations of objects, which the child is asked to name upon the first presentation rather than describing the figure. The adult version of the EFT has been adapted for use in functional imaging studies as a computerized task in which participants are presented with a simple and complex figure simultaneously and instructed to press one button if the simple figure is present within the complex figure and another button if it is not (Manjaly et al., 2003, 2007). To control for neural activity associated with viewing the geometric figures, Manjaly et al. (2003, 2007) have also included a control task with minimal local search requirements.

Performance in neurotypicals. The EFT is considered to be a measure of the "cognitive style" of field dependence or independence, and as such, was not developed with clinical populations in mind. Field dependence/independence refers to the tendency to solve a problem with or without reference to the external context in which it is presented. Thus, a "field independent" individual should perform better than a "field dependent" individual on the EFT. Though there were several early reports of males performing better than females, both in children (Cairns, Malone, Johnston, & Cammock, 1985) and adults (Witkin, 1950), this claim has not held up in a meta-analysis (Voyer, Voyer, & Bryden, 1995) or in studies in which participants were given practice opportunities (Johnson, Flinn, & Tyer, 1979; Lusk & Wright, 1981). Developmentally, children's performance has been found to improve throughout childhood and adolescence, leveling off around age 17 (Amador-Campos & Kirchner-Nebot, 1997; Witkin, Goodenough, & Karp, 1967).

Performance in ASD. Individuals with ASD have consistently been shown to perform better than neurotypicals (Jarrold, Gilchrist, & Bender, 2005; Jolliffe & Baron-Cohen, 1997; Keehn, Brenner, & Ramos, 2009; Shah & Frith, 1983) and MR controls (Shah & Frith, 1983) on the EFT as indicated by faster completion times. Of note are three fMRI studies which utilized modified versions of the EFT and did not find performance in those with ASD to be different from neurotypicals (Lee et al., 2007; Manjaly et al., 2007; Ring et al., 1999). Though all of these studies utilized relatively low sample sizes (17, 12, and 6 ASD participants, respectively), and task requirements were subtly altered due to adaptation to the imaging environment, another non-imaging study utilizing a sample size of 12 ASD participants and a version of the EFT very similar to that of Manjaly et al. (2003, 2007) did find group differences (Keehn et al., 2009). A possible explanation for this pattern of findings is that characteristics of the imaging environment (e.g., high noise volume, constricted space) differentially affected performance in the two groups, such that ASD participants' performance was slowed more than neurotypicals. However, despite a lack of group differences in behavioral performance in these imaging studies, neural activity was consistently found to be substantially different in those with ASD than neurotypicals, as will be discussed below.

One potential explanation for faster EFT performance in ASD is enhanced perceptual functioning, as has also been proposed to explain faster visual search times. Evidence in support of this theory has been provided by a study which utilized eye tracking during performance of the embedded figures test (Keehn et al., 2009). In this study, ASD participants showed shorter fixation times overall, indicating a need for less time to encode each stimulus as compared to neurotypicals. Interestingly, those with ASD also showed similar fixation times on EFT and control trials, indicating that they perceived the target stimulus as equally salient in each condition. This result was taken as support for the weak central coherence theory of ASD, in which local stimulus features are perceived more easily than global features. Potential support for enhanced perceptual discrimination and/or weak central coherence is also provided by Jarrold et al. (2005), who found that while EFT performance was correlated with performance on a conjunction search task in neurotypicals, it was correlated with feature search performance in those with ASD. This suggests that in ASD, EFT performance is achieved by enhanced perception of the target stimulus and/or impaired perception of the global, complex stimulus, such that a target figure in the EFT “pops out,” similar to a target in a feature search task, while in neurotypicals the EFT requires more effortful search, similar to a conjunction search task.

Neural correlates of EFT performance in neurotypicals. Manjaly et al. (2003) have applied their modified version of the EFT, including a control condition, in an fMRI study of neurotypical adults. This investigation found that areas of activation specific to the EFT (as compared to the control task) were superior and inferior parietal cortex, and inferior frontal/premotor cortex. These regions were also found to be activated during EFT performance in the adult neurotypical sample of an earlier study of ASD, though this study did not include a control task condition (Ring et al., 1999). Manjaly et al.’s paradigm applied to neurotypical adolescents also elicited increased activation in posterior parietal cortex and inferior frontal/premotor cortex (Manjaly et al., 2007), while a sample of neurotypical children who performed the EFT compared to a simple shape matching task showed activation in regions including inferior and middle frontal cortex, premotor cortex, and superior and inferior parietal cortex (Lee et al., 2007).

Neural correlates of EFT performance in ASD. The above mentioned studies have found generally similar patterns of activation in children, adolescents, and adults with ASD, with some differences. Lee et al. (2007) found that children with ASD failed to activate medial and lateral frontal cortex, ventral temporal cortex, and inferior parietal cortex as neurotypicals did. In adolescents with ASD, Manjaly et al. (2007) found increased activation in visual cortical regions (i.e., primary visual and striate cortex) as compared to neurotypicals. In adults, Ring et al. (1999) found lower activation of dorsolateral prefrontal and parietal cortices and higher activation of ventral occipital and inferior temporal cortices in those with ASD as compared to neurotypicals. Collectively, these results suggest that in comparison to neurotypicals, individuals with ASD rely more on visual processes and less on higher cognitive processes such as executive attention and working memory.

Navon task.

Task description. First utilized by David Navon, the so-called "Navon task" involves presentation of stimuli consisting of a large letter composed of smaller letters (Navon, 1977a). The global and local levels can be congruent (e.g., a large X made up of small X's) or incongruent (e.g., a large X made up of small H's). In one of the most common variations on this task, participants are directed to respond to either the global or the local level of the stimulus, i.e., the large letter or the small letters which make up the large letter. However, participants may also be directed to indicate whether a certain letter or letters are present or absent, whether at the global or the local level. Responses can be defined by verbal identification of the letter, a button push in which two buttons are designated for responding to specific letters, or a button push indicating whether a target letter is present or absent. The primary measure of performance is reaction time, though accuracy can also be examined.

Performance in neurotypicals. Navon's original study utilizing this task found an overall bias toward perception of the global level in neurotypical adults, as indicated by faster overall reaction times in identifying global letters and slower identification of the local letter when the global letter was incongruent (Navon, 1977b). An overall bias towards global processing has been challenged, however, by evidence that factors such as stimulus size (Lamb & Robertson, 1990), stimulus level previously attended to (Ward, 1982), and even affective states such as anxiety or sadness (Gasper & Clore, 2002) have an influence over bias towards processing of global or local stimulus features. Another relevant feature of neurotypical performance on Navon tasks is that reaction times are generally slower when a switch of attention from the global to the local stimulus level, or vice versa, is required, as opposed to maintaining attention at the same level (Ward, 1982).

Developmentally, children ages 7 to 14 have been found to show more interference from incongruent features at younger ages, as indicated by slower reaction times when the unattended level is incongruent with the attended level of the stimulus (Roe, Moses, & Stiles, 1997a). Furthermore, the youngest subjects showed the greatest interference from the global stimulus level, indicating a bias towards processing the global stimulus level. Presentation of stimuli to the right and left visual fields produced increasing asymmetry in response times to global and local levels with increasing age, such that the oldest children showed significantly faster reaction times to the local level when a stimulus was presented to the right visual field and faster reaction times to the global level when a stimulus was presented to the left visual field, while younger children showed less of a difference in reaction times.

Performance in ASD. Performance on Navon tasks has been extensively studied in individuals with ASD. A recent review concluded that existing evidence has supported superior processing of the local stimulus level in those with ASD, with mixed evidence for impaired processing of the global stimulus level (Dakin & Frith, 2005). In fact, despite two studies showing no differences in performance between ASD and neurotypical groups on a Navon task (Mottron, Burack, Stauder, & Robaey, 1999; Ozonoff et al., 1994), there is a substantial amount of evidence for differences in local and global processing.

One of the more consistent findings in studies of Navon task performance in ASD is increased local-to-global interference, such that those with ASD show lower accuracy and/or slower reaction times when required to identify a global letter that is incongruent with the local letters compared to neurotypicals (Behrmann, Avidan, et al., 2006; Rinehart, Bradshaw, Moss, Brereton, & Tonge, 2000; Wang, Mottron, Peng, Berthiaume, & Dawson, 2007). Some of these studies have also observed an overall bias towards local processing, with higher accuracy and/or faster reaction times to local letters than global letters (Rinehart et al., 2000; Wang et al., 2007). One study has employed both a selective and a divided attention condition, in which a target would appear at only one level or could appear at either level, respectively (Plaisted, Swettenham, & Rees, 1999). ASD participants did not perform differently from neurotypicals in the selective attention condition, but showed a local bias in the divided attention condition. These results were thought to support the hypothesis that individuals with ASD are able to process global features normally with focused attention, but that in the absence of focused attention to global features, they are less able to inhibit local information. Further support for local bias is provided by evidence that while global bias in neurotypicals is modulated by task constraints such as visual angle and exposure time, ASD performance consistently shows local bias despite manipulation of task constraints (Wang et al., 2007).

Despite the amount of research into global versus local processing in ASD, uncertainty remains about whether these abnormal patterns of processing are best understood as a potential deficit in global processing, as in the theory of weak central coherence, or as a strength in, or bias toward, local processing (Happé, 1999). What the evidence clearly supports at this time is that there is an abnormal balance in global and local processing in individuals with ASD, with a greater tendency toward local processing at the expense of global processing in comparison to patterns seen in neurotypicals.

An aspect of performance on Navon tasks in ASD that has been underrepresented in the literature is the ability to adjust the spotlight of attention, thus shifting attention from the local to the global level or vice versa. Some preliminary evidence for difficulty adjusting the spotlight of attention in those with ASD has been provided by studies utilizing paradigms other than a Navon task. Specifically, one study employing a paradigm in which participants were required to respond to a target while ignoring varying numbers of distractors found that ASD adults required higher numbers of distractors than neurotypicals to successfully narrow their spotlight of attention and ignore distractors, though their reaction times and accuracy were not impaired (Remington, Swettenham, Campbell, & Coleman, 2009). These findings provide support for both enhanced perceptual processing and difficulty adjusting the spotlight of attention in individuals with ASD. Another study employed a paradigm in which participants were required to judge the length of two lines comprising a crosshair, which changes in size from trial to trial. ASD children and adolescents were slower and less accurate in their judgments than neurotypicals and learning disordered controls when the crosshair was adjusted to a larger size, but not when adjusted to a smaller size (Mann & Walker, 2003). Again, these findings provide support for difficulty adjusting the spotlight of attention in those with ASD. Finally, one study has investigated ability to adjust the spotlight of attention in ASD using a Navon task. This study found that children and adolescents ages 6-15 who were diagnosed with autism without MR, but not children diagnosed with Asperger’s disorder, showed slower reaction times on trials in which a target appeared at the global level when the previous target had appeared at the local level (Rinehart, Bradshaw, Moss, Brereton, & Tonge, 2001). This provides further evidence for difficulty adjusting the spotlight of attention in ASD, though only in children with autism as opposed to Asperger’s disorder.

Ability to adjust the spotlight of attention has been found by one existing study to be impaired in individuals with autism, though no impairment was found in individuals with Asperger’s disorder (Rinehart et al., 2001). The paradigm employed in this study involved an important shortcoming, however, that may have limited its sensitivity to differences between the Asperger's and neurotypical groups. Namely, target stimuli in this paradigm were displayed until a response was made. There is evidence that in endogenous orienting tasks with short cue-target intervals those with ASD show more difficulty shifting attention between spatial locations (Landry, Mitchell, & Burack, 2009b; Wainwright-Sharp & Bryson, 1993b), and that in Navon tasks with short exposure times, those with ASD show local precedence while neurotypicals show global precedence (Wang et al., 2007). Thus, individuals with ASD seem to show more impairment in shifting attention when time limits are imposed, suggesting that a Navon paradigm with shorter stimulus exposure may elicit more significant between-group differences.

Neural correlates of Navon task performance in neurotypicals. One of the most well-established findings in imaging studies of Navon task performance in neurotypicals is the relative lateralization of processing of global and local aspects of visual stimuli by the right and left hemispheres, respectively. This finding has been replicated in both fMRI (Martinez et al., 1997; Moses et al., 2002a; Weissman & Woldorff, 2005a) and EEG (Romei, Driver, Schyns, & Thut, 2011; Romei, Thut, Mok, Schyns, & Driver, 2012; Volberg, Kliegl, Hanslmayr, & Greenlee, 2009a) studies, and can also be roughly replicated by non-imaging studies by presenting a stimulus to only the right or left visual field, as in the study presented above by Roe, Moses, and Stiles (1997).

In addition to the global/local lateralization phenomenon, fMRI studies have provided more specific information about the localization of neural processes underlying Navon task performance. Specifically, the process of redirecting attention to the local or global level of a Navon stimulus has been found to be associated with activation in the intraparietal sulcus, while actual perception of the local or global stimulus features has been found to be associated with left or right inferior parietal and superior temporal activation, respectively (Weissman & Woldorff, 2005b). It has also been found that in a sample of 12- to 14-year-olds, perception of local features in younger children with less mature processing styles was associated with less hemispheric asymmetry and overall higher activation than their older peers with more mature processing styles (Moses et al., 2002b). These findings are consistent with Roe, Moses, and Stiles' (1997) findings that lateralization of global and local processing develops through adolescence.

EEG studies have produced interesting findings on the role of neural synchrony in processing of local and global features of Navon stimuli. Higher power in the alpha frequency band has been associated with inhibiting representations of global or local stimulus features, as indicated by higher alpha activity over right parietal cortex associated with fast reaction times to local stimulus aspects, while higher alpha over left parietal cortex was associated with fast reaction times to global stimulus aspects (Volberg, Kliegl, Hanslmayr, & Greenlee, 2009b). These findings suggest that the parietal cortex exerts top-down control over attention to global or local aspects of a stimulus. This theory was further supported by another EEG study in which posterior alpha activity was shown to be modulated specifically by shifts of attention to high or low spatial frequency stimulus features (i.e., local or global features; Flevaris, Bentin, & Robertson, 2011).

Studies utilizing TMS in neurotypicals have provided support for the roles of theta, beta, and alpha-band synchrony in parietal cortex in processing of local and global stimulus features. TMS over right parietal cortex in the theta frequency band has been shown to enhance global processing and inhibit local processing, while TMS over right parietal cortex in the beta frequency band has been shown to produce the opposite effect, enhancing local processing and inhibiting global processing (Romei et al., 2011). Furthermore, over right parietal cortex TMS in the alpha frequency band has been shown to impair global processing, while TMS in the alpha frequency band over left parietal cortex has been shown to impair local processing (Romei et al., 2012). Though the separate functions of parietal neural synchrony in each frequency band have not yet been parsed apart, it is apparent that neural synchrony in the left and right parietal cortex is necessary to achieve perception of local and global stimulus features, respectively.

It is less clear at this time what aspects of neural activity are necessary to adjusting the spotlight of attention, though lesion studies and fMRI studies in neurotypicals have provided preliminary findings. Lesions of the right inferior parietal lobe have been found to impair the ability to switch attention between global and local stimulus features (Robertson et al., 1988), consistent with fMRI and EEG findings that the parietal cortex is associated with adjusting the spotlight of attention (Flevaris, Bentin, & Robertson, 2011b; Weissman & Woldorff, 2005b). Adjusting the spotlight of attention has also been shown to be associated with increased activation of temporal-parietal regions, as well as anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex (DLPFC) in an fMRI study of neurotypicals (Fink et al., 1997). However, the role of the DLPFC remains unclear, as a study of patients with lesions in this area found no impairment in adjusting the spotlight of attention.

Neural correlates of Navon task performance in ASD. Despite the prevalence of studies showing abnormal processing of global and local stimuli in those with ASD, there is currently no imaging research on neural activity underlying performance of a Navon task specifically. The current understanding of neural activity underlying global and local processing in ASD primarily consists of the previously described research on neural correlates of EFT performance.

However, two imaging studies provide evidence for abnormal visual cortical function underlying abnormal perception of local and global stimulus features in individuals with ASD.

In one fMRI study employing a modified version of the Wechsler block design task (Wechsler, 1981), lower activation was noted in the V2 region of the visual association cortex in those with ASD as compared to neurotypicals, despite comparable behavioral performance (Bölte, Hubl, Dierks, Holtmann, & Poustka, 2008). This finding was interpreted as possibly reflecting decreased effort to discriminate local stimulus elements, and/or decreased top-down attention modulation to inhibit representation of global stimulus features in favor of local features. Furthermore, an EEG study of neurotypicals categorized as scoring high or low on the Autism Spectrum Quotient (ASQ) found that high ASQ individuals showed a delay in the visual evoked potential, a measure of primary visual cortex activity, as well as higher local-to-global interference on a Navon task (Sutherland & Crewther, 2010). Both measures together were highly predictive of high ASQ status as determined by discriminant analysis. It was argued that delayed processing in primary visual cortex could account for the impairment in global processing observed in the high ASQ group.

No studies have been conducted on neural activity associated with adjusting the spotlight of attention in the context of a Navon task. However, one study including neurotypicals, patients with parietal lesions, ASD participants with parietal volume loss, and ASD participants without parietal volume loss found that only participants with parietal abnormalities showed an abnormally small spotlight of attention (Townsend & Courchesne, 1994). This was indicated by enhanced responses to targets within a narrow area of the visual field and a lack of interference from distractors outside of the narrow attentional spotlight. Given the importance of abnormal global and local processing and attention shifting in ASD, further research into the neural mechanisms underlying these processes is warranted.

Chapter 5: Rationale and Theoretical Model for the Present Study

Relationship between Feature Integration Theory and Posner's Attention Model

Although the concept of "focused attention" has been discussed both in the context of two-stage models of perceptual binding and in the context of models of visual attention, little research has investigated the relationship between the two and whether they are in fact the same construct. An exception to this is a line of study by Briand (1998) and colleagues (Briand & Klein, 1987) which explored the relationship between the constructs of attention as put forth by Treisman's feature integration theory and by Posner's visual orienting model. This line of research supported the conclusion that while some functions of the constructs of attention proposed by these two models were shared, specifically in the case of involuntary shifts of attention, different functions were observable in the case of voluntary shifts of attention. This discrepancy was reconciled by reference to Posner and Peterson's (1990) proposal that the overarching construct of attention is in fact subserved by multiple neural systems whose functions interact. Thus, while involuntary shifts of attention (such as exogenous spatial orienting) are primarily mediated by the orienting network, voluntary shifts of attention (such as endogenous spatial orienting and adjusting the spotlight of attention) are mediated by both the orienting and the executive attention network. This distinction is particularly relevant to ASD, as it has been suggested that the pattern of strengths and weaknesses in visual attention in individuals with ASD may be accounted for by an abnormal interaction between the orienting and executive attention networks (Fan, 2013).

A General Deficit in Shifting Attention?

A common theme in studies of various aspects of visual attention in ASD is deficient shifting in volitional attentional processes, including endogenous spatial orienting and adjusting the spotlight of attention. This is reflected in a recent review of attentional abnormalities in individuals with ASD in which it is noted that currently available evidence points to the idea that "when there are multiple parallel inputs, the ability to process the information of the unattended input is significantly reduced in patients with ASD" (Fan, 2013). However, a specific understanding of the types of shifting that are impaired in those with ASD has yet to be achieved by the current literature. Findings on endogenous spatial orienting have been mixed, as reviewed above, with deficits primarily seen with short cue-target intervals (Landry et al., 2009b; Senju et al., 2004; Wainwright-Sharp & Bryson, 1993b). Findings on adjustment of the spotlight of attention have been more consistent, with multiple studies confirming deficits (Mann & Walker, 2003; Remington et al., 2009; Rinehart et al., 2001). Pascualvaca, Fantie, Papageorgiou, and Mirsky (1998) have argued against a general deficit in shifting attention on the basis of two unstandardized computer-adapted tests of attention shifting, but these measures may not have been sensitive enough to detect group differences. Notably, ASD children in this study did perform significantly worse than neurotypical controls on the Wisconsin Card Sorting Task (WCST; Heaton, 1981), a measure of the set-shifting component of executive function. Furthermore, a review of the literature on executive function in ASD has concluded that impairments in set-shifting are well supported (Sanders, Johnson, Garavan, Gill, & Gallagher, 2008). Further research is needed to investigate a potential deficit in specific aspects of attention shifting in ASD that may underlie observable clinical symptoms in these disorders.

Relationship between Attention Shifting and Social Functioning

It has been proposed that visual attention plays an integral role in the development of social functioning through the mediating process of joint attention, a vital social skill that typically develops in infancy (Mundy & Jarrold, 2010). Joint attention involves either following another’s gaze to an object in the environment (receptive joint attention) or using one’s gaze to direct another’s attention (initiating joint attention). Mundy, Card, and Fox (2000) present EEG evidence supporting the idea that the normal development of joint attention relies on attentional neural networks as described by Posner’s model. Specifically, they explain that receptive joint attention behavior is mediated by the posterior/orienting network, while initiating joint attention behavior is mediated by the anterior/executive attention network, and integration of these functions requires integrated activity of the anterior/executive and posterior/orienting attention networks. Thus, it may be hypothesized that a deficit in the anterior/executive attention system would be sufficient to disrupt the normal development of joint attention abilities and, in turn, higher-level social functioning. In fact, Mundy, Sullivan, and Mastergeorge (2009) have proposed a theoretical parallel and distributed processing model of ASD in which an integrated anterior and posterior attention network is necessary for the development of joint attention, and thus higher-level social functioning.

Impairments in joint attention abilities have consistently been found in individuals with ASD (Charman et al., 1997; Dawson et al., 2004; Leekam, Lopez, & Moore, 2000), with cascading effects on other areas of development such as language (Bopp & Mirenda, 2010; Charman, 2003; Dawson et al., 2004). Impairments in executive attention have also consistently been found in individuals with ASD, as reviewed in Chapter 4. A limited number of studies have investigated the relationship between executive attention and joint attention in individuals with ASD, indicating a positive correlation between the two skills (Dawson et al., 2002; Griffith & Pennington, 2003). However, to the author’s knowledge, no studies to date have investigated the relationship between executive attention and more general social functioning in children with ASD.

Model for the Present Study

To investigate a potential deficit in attention shifting underlying a variety of observed attentional abnormalities in children with ASD, the present study employed experimental paradigms requiring attentional shifting at two levels of visual information processing. A model is proposed which integrates a fundamental aspect of FIT, the two-stage model of preattentive processing and focused attention, with the three attention systems proposed by Posner's attention model. A schematic of this model, including all tasks in the present study, is presented in Figure 1. Crossing the two-level FIT model with Posner's three-level attention model gives a total of six subdomains within which between-group effects may be investigated.

While Posner's attention model is fundamentally based on functional neuroanatomy, FIT originated as a model of perception and cognition and has not been explicitly mapped onto functional neural networks. Thus, some speculation is required in order to generate hypotheses about how interactions between FIT's levels of attention with Posner's attentional networks will manifest in an ASD population. As described in Chapter 3, evidence suggests that focused attention requires more engagement of parietal areas than preattentive processing, which is more reliant on visual association areas within the occipital cortex. Thus, FIT's construct of focused attention may overlap with Posner's posterior/orient component of attention. It is important to note, as in Chapter 3, that top-down or frontal processes can influence processing at the level of either preattention or focused attention. However, there does not appear to be a necessary relationship between level of engagement of frontal processes and level of attention within FIT (i.e., preattention vs. focused attention). Based on this interpretation of the relationship between FIT and Posner's model, a general deficit in top-down frontal processes would be expected to result in deficits on tasks indexing Posner's executive component at either the preattentive or focused attention level, but would not necessarily bear a relationship to performance on tasks indexing the alert and orient components at either the preattentive or focused attention level.

Of the three levels of the Posner attention model, the orientation component has been widely examined in the ASD literature and was not incorporated in the present study. Conversely, the alert component has not generally been identified as a theoretical area of weakness in ASD (Fan, 2013); however, individuals with ASD have generally been found to show accelerated reaction times in tasks requiring simple visual detection and identification, as exemplified by the discussion of enhanced visual search in individuals with ASD presented in Chapter 3. Thus, while assessing for potentially abnormal performance on the alert component is important for the current study to dissociate the alert component from the shift component at both the preattentive and focused attention levels, the alert system will not be a main focus of the current study. However, the preattentive and focused attention levels of the alert component were included in order to control for potential abnormalities at this more basic level of processing. Specifically, measures of psychomotor and processing speed were administered, as these have consistently been found to be slowed in individuals with ASD (Goldstein, Johnson, & Minshew, 2001; Mayes & Calhoun, 2007). Thus, to ensure that performance differences are attributable to differences in frontal attention processes rather than general slowing of psychomotor or processing speed, scores from these two tasks were used to statistically control reaction times from tasks indexing executive attention.

The main focus of the current investigation was executive attention at both the preattentive and focused attention levels of visual processing. The theoretical basis for hypothesizing group differences at the level of executive attention is provided by evidence that both the frontal and posterior attention systems, associated with Posner’s executive attention and orienting systems, respectively, can be engaged at the preattentive and the focused attention levels, though to different degrees. FIT proposes that frontal-mediated executive processes can operate at the preattentive level, even though this level of processing is relatively more reliant on posterior-mediated orienting processes. Conversely, executive attention tasks that are performed at the level of focused attention rely more heavily on frontal-mediated processes than on posterior orienting processes, though posterior attention processes are still necessary. Thus, a hypothetical deficit in frontal attention processes in children with ASD would theoretically impact performance on tasks requiring frontal-mediated executive processes at both the preattentive and the focused attention level. The present study also examined the potential relationship between the hypothesized deficits in executive attention and impaired social functioning in individuals with ASD.

		Posner Attention Model		
		Alert (Subcortical)	*Orient (Parietal cortex)*	*Shift/Executive Attention (Frontal cortex)*
Feature Integration Theory	*Preattentive (Visual association cortex)*	CogState Detection	▨	Visual search task
	Focused Attention (Parietal cortex)	CogState Identification	▨	Navon task; CogState Set-shifting

Figure 1. Model for the present study. Integrating FIT and Posner’s attention model allows the examination of the intersection of preattention and focused attention with the alert, orient, and executive attention components of Posner’s model. Brain regions generally associated with each level or component are indicated, and tasks that were used in the present study to index the intersection of each of these components are noted. The present study focused primarily on the intersection of executive attention with preattention and focused attention.

Chapter 6: Aims and Hypotheses

Aims of the Current Study

(1) To investigate a general deficit in shifting attention at the level of both preattention and focused attention in children with ASD as compared to age- and gender-matched neurotypical controls (NT), as measured by both a visual search task with a dimensional shift component and a Navon-type letter task requiring participants to shift attention between global and local levels of a visual stimulus.

(2) To investigate the degree to which deficits in attention shifting as measured by these tasks in children with ASD as compared to age- and gender-matched neurotypicals are related to social functioning.

Hypotheses

Alert. (1) Individuals with ASD will show significantly slower reaction times than NT on measures indexing the alert component at the level of both preattention and focused attention.

Shift/executive attention. (2) The magnitude of differences in reaction time between "shift" and "non-shift" trials (hereafter referred to as "RT difference scores") will be significantly higher in the ASD group than the NT group on measures of executive attention at the level of both preattention and focused attention. (3) Within the ASD group, measures of executive attention at the level of both preattention and focused attention will be significantly positively correlated with each other.

Preattention. (4) On an average of all conditions on a measure of executive attention at the level of preattention, ("shift" and "non-shift"), the ASD group will show significantly faster reaction times than the NT group, consistent with previous findings (O'Riordan, 2004; O'Riordan et al., 2001; O'Riordan & Plaisted, 2001; Plaisted et al., 1998).

Focused attention. (5) On a measure indexing executive attention at the level of focused attention, the ASD group will show a bias toward local processing as indicated by significantly faster RT and significantly higher accuracy on local than global target trials. (6) Within the ASD group, RT will be significantly slower and accuracy will be significantly lower on "shift" trials than "non-shift" trials. (7) Within the ASD group, RT difference scores will be significantly larger for local-to-global shifts than global-to-local shifts. (8) Within both the ASD and NT groups, measures of executive attention at the level of focused attention will be significantly positively correlated with each other.

Relationships with social functioning. (9) NT will show significantly lower scores than the ASD group on measures of social impairment. (10) NT will show significantly higher scores than the ASD group on measures of affect recognition and theory of mind. (11) Among the ASD group, measures of executive attention at the level of both preattention and focused attention will be significantly positively correlated with measures of social impairment (i.e., higher executive attention ability will be associated with lower social impairment). (12) Among the ASD group, measures of executive attention at the level of both preattention and focused attention will be significantly negatively correlated with measures of affect recognition and theory of mind (i.e., higher executive attention ability will be associated with better affect recognition and theory of mind).

Chapter 7: Method

Participants

Participants were 20 children with ASD and 20 age- and gender-matched NT children ages 7 years, 2 months to 14 years, 1 month[2]. Sample size was chosen with consideration of recommendations by Cohen (1992) which indicate that a sample size of 26 is needed to detect a mean difference with a large effect size at $p < .05$. The chosen age range ensures eligibility for testing with a wide range of standardized clinical neuropsychological measures for children while avoiding high within-group variation due to age-related development of executive function.

There were no significant between-group differences in age ($t[38] = -.43$, $p = .67$), FSIQ ($t[38] = 1.63$, $p = .11$) or gender ($\chi^2[2, N = 40] = 0$, $p = 1$). While the groups differed significantly on WASI Vocabulary scores ($t[38] = 2.59$, $p < .05$), they did not differ on WASI Matrix Reasoning scores ($t[38] = .61$, $p = .55$). Demographic characteristics of the participants are presented in Table 1. Of those who completed testing, 19 NT and 18 ASD successfully completed the Navon task; one NT and two ASD did not complete the task as they were unable to achieve 80% accuracy after at least 4 administrations of the practice trials.

Exclusion criteria for both ASD and NT participants included functioning below the Low Average range (<80 FSIQ on Wechsler Abbreviated Scale of Intelligence; WASI; Wechsler, 1999) and any known history of head injury with loss of consciousness or other neurological disorders such as epilepsy or total color blindness. NT participants took no psychoactive medications; ASD participants who regularly took psychoactive medications remained on their regular medications on the day of testing.

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[2] Previous studies utilizing visual search and Navon tasks have included children with ASD as young as 6.

Table 1

Demographic Characteristics of NT and ASD Participants

	NT *M* (*SD*)	ASD *M* (*SD*)
Age (years)	10.2 (1.8)	10.5 (1.9)
Sex (% male)	85	85
WASI FSIQ (SS)	112.0 (13.3)	105.3 (12.9)
WASI Vocabulary (T score)*	58.8 (10.3)	50.8 (9.1)
WASI Matrix Reasoning (T score)	54.7 (6.4)	53.3 (8.0)

* Significant between-group difference (p<.05)

ASD participants. Recruitment of ASD participants was conducted through the outpatient psychiatry and ASD specialty clinics at the University of Michigan Health System Department of Psychiatry (n = 13), as well as through fliers posted in the community (n = 7). Specifically, the parents of patients presenting for evaluation at the ASD clinic were approached prior to the start of the evaluation and presented with the opportunity to participate in the current study as part of an ASD database development study. Recruitment flyers were also posted in the community. IRB approval at the University of Michigan Health Systems was obtained for experimental testing and medical record review as part of this larger ASD database development study. Following ASD participants' scheduled clinic visit, medical record review was used to obtain Child Behavior Checklist, Autism Diagnostic Observation Schedule (Lord et al., 2000), Social Responsiveness Scale (Constantino, 2002), Social Communication Questionnaire (Rutter, Bailey, Lord, & Berument, 2003), and NEPSY (Brooks, Sherman, & Strauss, 2009) scores. ASD participants were diagnosed with Autism Spectrum Disorder based on Diagnostic and Statistical Manual of Mental Disorders-Fifth Edition (DSM-V) diagnostic criteria, as determined by the

Ph.D. level neuropsychologist conducting the clinical assessment. Diagnosis was further confirmed based on ADOS.

NT participants. NT participants were recruited through childcare centers in the greater Ann Arbor area, by distribution of recruitment fliers providing information about the study and the PI's contact information to parents, as well as through fliers posted in the community. See Appendix A for recruitment flyers. IRB approval was obtained from Eastern Michigan University for testing of NT and ASD participants recruited from the community. Additional exclusion criteria for NT participants included any history of ASD in a first-degree relative and clinically significant mood, anxiety, or attention problems (*T* score ≥ 70 on an internalizing subscale or Attention Problems subscale of the Child Behavior Checklist; Achenbach, 1991).

Measures

Visual search task. The visual search task utilized in the present study is a non-standardized task designed to measure executive attention at the level of preattention, as well as visual discrimination ability. Because the visual search task is not a standardized measure, no reliability or validity indices are available. However, parameters of this task are based on those used in previous studies which have successfully elicited dimension switching effects and group differences between ASD and NT participants (Chan & Hayward, 2009; O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001).

Stimuli. Stimulus parameters for the visual search task followed Chan and Hayward (2009), with modifications based on parameters used in O'Riordan, Plaisted, Driver, and Baron-Cohen (2001). Each search item was a bar subtending 1.17° vertically and 0.22° horizontally. In color target trials, the target was red and the distractors gray. In orientation target trials, all items were gray; the distractors were vertical, and the target was rotated 30° counterclockwise. Items were presented within a 6 × 4 matrix subtending 23.8° of visual angle horizontally and 17.4° vertically, with 24 equally sized cells. One item was randomly located within each cell, with the center of each item at least 0.92° from its cell border. For target-present trials, the target could appear in any cell. Stimuli were presented on a black background. See Figure 2 for examples of color target, orientation target, and non-target stimuli. A fixation cross was presented in the center of the screen for 500 ms to 1500 ms, with duration randomly determined to avoid prediction of target onset. The fixation cross was removed for 50 ms, followed by onset of a visual search display, which was displayed for 2000 ms or until a response was made. An inter-stimulus interval with a black screen was then presented for 500 ms.

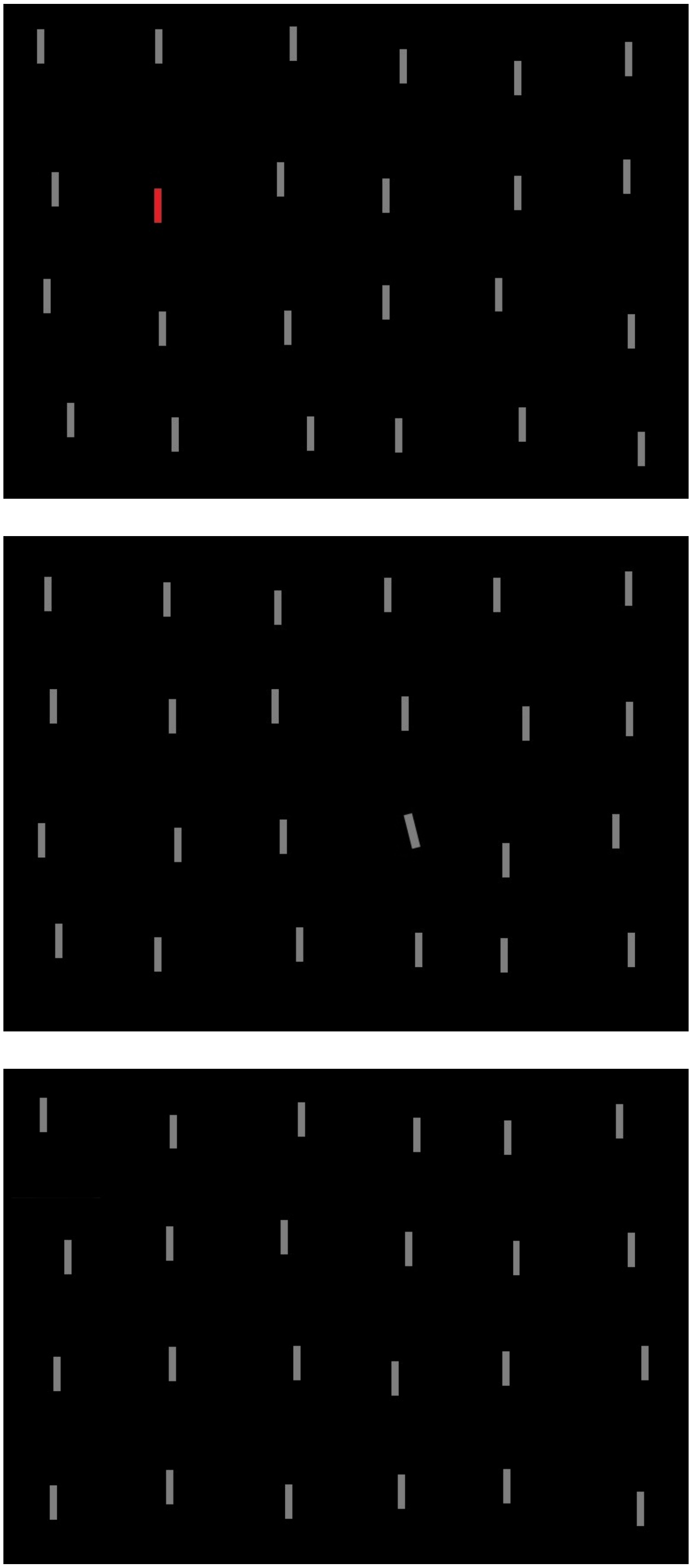

Figure 2. Examples of color target, orientation target, and non-target stimuli used in the visual search task.

Procedure. Stimuli were presented on a computer with a QWERTY keyboard. Participants were instructed to respond as quickly as they could without making mistakes. Participants were asked to push the “z” key when a target was present, and the “m” key when a target was not present. Trials were presented in pairs constituting 4 conditions: color target preceded by color target (CC), color target preceded by orientation target (OC), orientation target preceded by orientation target (OO), and orientation target preceded by color target (CO), with 20 trial pairs in each condition. Non-target trials were interspersed with target trial pairs. Four blocks including 26 target trials and 5 non-target trials each were presented in pseudorandom order, for a total of 124 trials. Participants were offered a break between blocks of the task. Accuracy and reaction times (RT) were recorded.

Performance indices. Performance on the visual search task is measured by RT, which was analyzed for correct trials only. Performance indices included RT and RT difference scores, which are calculated by subtracting RT for non-shift trials from RT for shift trials. RT for all trials is an indicator of general visual search ability, while RT difference score is an indicator of executive attention at the level of preattention.

Navon task. The Navon task utilized in the present study is a non-standardized task designed to measure executive attention at the level of focused attention, as well as global and local visual processing. Because the Navon task is not a standardized measure, no reliability or validity indices are available. However, parameters of this task are based on those used in previous studies which have successfully elicited group differences between ASD and NT participants.

Stimuli. Stimulus parameters for the Navon task followed Wang et al. (2007). Stimuli consisted of white block letter global patterns of letters A, X, H, and K, each composed of smaller letters. Global and local letters were always incongruent. Global numerals consisted of a rectangular 5x5 matrix with a height to width ratio of 1.47 to 1. Stimuli subtended visual angles of 3.17 x 4.66° for global numerals and 0.62 x 0.82° for local numerals. All stimuli were white and were presented on a black background. See Figure 3 for examples of global target, local target, and non-target stimuli. A fixation cross was presented in the center of the screen for 800 ms, the stimulus will be presented for 200 ms[3], and an inter-stimulus interval with a black screen was then presented for 2000 ms.

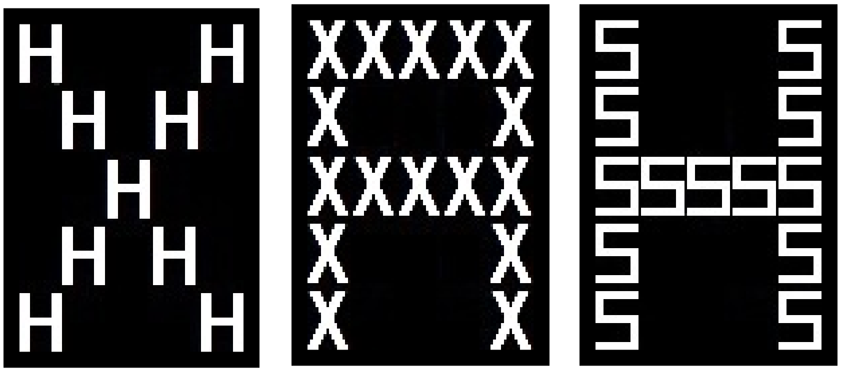

Figure 3. Examples of global stimuli, local stimuli, and non-target stimuli used in the Navon task.

Procedure. Stimuli were presented on a computer with a QWERTY keyboard. Participants were instructed to respond as quickly as they could without making mistakes. Participants were asked to push the “z” key when either the global or local letter was an X, and the “m” key when neither the global or the local letter was an X. Trials were presented in pairs constituting 4 conditions: global target preceded by global target (GG), global target preceded by local target (LG), local target preceded by local target (LL), and local target preceded by global target (GL), with 20 trial pairs in each condition. Non-target trials were interspersed with target

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[3] Stimulus exposure time will be limited to 200 ms in order to optimally elicit between-group differences.

trial pairs. Four blocks including 26 target trials and 5 non-target trials each were presented in pseudorandom order, for a total of 124 trials. Participants were offered a break between blocks of the task. Accuracy and RT were recorded.

Performance indices. Performance on the Navon task is measured by accuracy and RT. RT was analyzed for correct trials only, and accuracy was defined as percentage of correct trials out of all trials, including errors and non-responses. Performance indices included accuracy, RT, and RT difference scores, which are calculated by subtracting RT for non-shift trials from RT for shift trials. RT is an indicator of global or local processing, while RT difference score is an indicator of executive attention at the level of focused attention.

CogState tasks. The CogState test battery is a set of computerized neuropsychological measures that are administered by a trained individual. The tasks utilized in the present study (Detection, Identification, and Set Shifting) can be completed in a total of approximately 9 minutes. Performance indices for the detection and identification task are reaction times in log10 milliseconds, while the performance index for set shifting is accuracy. For the Detection and Identification tasks a lower score indicates better performance, while for the Set Shifting task a higher score indicates better performance. Test-retest reliability for the Detection and Identification tasks has been estimated at .38-.94 (Falleti, Maruff, Collie, & Darby, 2006). The Detection task has been found to be significantly correlated with scores on the grooved pegboard task, a commonly used measure of psychomotor speed, while the Identification task has been found to be significantly correlated with the Trail Making Test parts A and B, commonly used measures of processing speed (Maruff et al., 2009).

Procedure. Stimuli for all CogState tasks are images of playing cards presented in the center of the screen. Each card is first presented face down and then flips over to face up.

Stimuli were presented on a computer with a QWERTY keyboard. Participants were instructed to respond as quickly as they could without making mistakes. Feedback on whether each response is incorrect or too early was provided in the form of an error sound. RT and accuracy were recorded.

Detection. For the detection task, participants were instructed to press a designated "Yes" key as soon as each card flips over. Accuracy and reaction times were recorded. Reported scores are $\log_{10}$ of the average reaction time for correct trials.

Identification. For the identification task, participants were instructed to press a designated "Yes" key if a card is red and a designated "No" key if a card is not red. Accuracy and reaction times were recorded. Reported scores are $\log_{10}$ of the average reaction time for correct trials.

Set-Shifting. The CogState Set Shifting task is a brief, computerized version of the WCST, on which individuals with ASD have generally been shown to be impaired (Pascualvaca et al., 1998; Sanders et al., 2008). For the set shifting task, participants were instructed to press a designated "Yes" key if a card was a target card and a designated "No" key if a card was not a target card. The word "color or "number" is displayed on the screen to indicate in which dimension the target was defined, but participants initially must guess which stimulus (i.e., red or black) constitutes a target. Following a correct response, the card flipped over to reveal the next card. Following an incorrect response, an error sound was presented and the card did not flip over until a correct response was made. Following completion of one set of cards, the target dimension changed in either an intradimensional shift (e.g., red to black) or an extradimensional shift (e.g., black to 2). The participant was not informed when intradimensional shifts occur and must learn the new target dimension. Accuracy was recorded. Reported scores are the inverse sine function of percentage of trials correct.

Demographic and screening form. The demographic and screening form is a brief parent report questionnaire assessing participants' demographic characteristics, academic history, and medical history. This questionnaire was developed by Dr. Lajiness-O'Neill with modifications by the PI, and was used to confirm that participants met all eligibility criteria.

Wechsler Abbreviated Scale of Intelligence. The WASI is a brief IQ measure that is administered by a trained individual, may be completed in approximately 15 minutes, and has normative data available for children as young as age 6. The present study employed the 2-factor version of the WASI, which includes Vocabulary and Matrix Reasoning subtests. Scores on these subtests together are used to generate an estimate of full scale IQ (FSIQ), which has a reliability coefficient of .93 in children.

Child Behavior Checklist. The CBCL is a parent report measure of children's behavioral, emotional, and social problems. The CBCL can be completed independently by a parent in approximately 15-20 minutes, and provides *T*-scores for anxiety/depression, withdrawal/depression, somatic complaints, social problems, thought problems, attention problems, rule-breaking behavior, and aggressive behavior, as well as a score for total problems. Test-retest reliability of CBCL item scores is estimated at .93 to 1.0, while internal consistency is estimated at .63 to .79.

Measures of social functioning. A variety of measures and measurement approaches provided samples of a variety of components of social functioning and impairment (i.e., communication, affect recognition, theory of mind, etc.) from a variety of reporters, i.e., parent report, objective testing, and trained observer. This is intended to decrease the probability of a Type II error when assessing relationships with executive attention.

Autism Diagnostic Observation Schedule. The ADOS was administered for ASD participants only. The ADOS is a semi-structured, standardized assessment of social interaction, communication, and play designed for use with children suspected of having ASD. The ADOS is administered by a trained individual and takes approximately 30-45 minutes to complete. The ADOS provides scores for impairment in the social, communication, and restricted and repetitive behavior domains. Internal consistency of the various domains of the ADOS is estimated to be between .47 and .94. Test-retest reliability for the various domains of the ADOS is estimated to be between .59 and .82.

Social Responsiveness Scale. The SRS is a parent report measure of social impairment for children with ASD. The SRS can be completed independently by a parent in approximately 15-20 minutes, and provides a total *T*-score that indicates whether a child's social impairments fall within the normal, mild to moderate, or severe range. The SRS has a reliability coefficient estimated at .90.

Social Communication Questionnaire. The SCQ is a parent report measure of communication and social functioning designed for use with children suspected of having ASD. The SCQ can be completed independently by a parent in approximately 10 minutes, and provides a categorical indication of whether a child potentially has ASD based on a cutoff score. The SCQ has been found to have good internal consistency, ranging from .81 to .92. Receiver operating characteristic (ROC) analyses have indicated that the SCQ has good ability to discriminate ASD from NT and MR, with area under the curve (AUC) ranging from .79 to .90.

***NEPSY Affect Recognition and Theory of Mind subtests*.** The NEPSY Affect Recognition and Theory of Mind subtests are children's neuropsychological measures of social perception and cognition. These subtests are administered by a trained individual and can be completed in approximately 5-7 and 10-13 minutes, respectively. Each subtest provides a scaled score indicating affect recognition and theory of mind ability. Internal reliability is estimated .90 for Affect Recognition and at .85 for Theory of Mind. Test-retest reliability is estimated at .70 to .77 for Theory of Mind and at .50 to .61 for Affect Recognition.

Descriptive statistics for all measures are presented in Table 2.

Table 2

Scores on Measures of Attention and Social Functioning for NT and ASD Participants

Measure	Subscale	NT *M* (*SD, Range*)	ASD *M* (*SD, Range*)
Visual Search	Shift RT	811 (150, 458-1078)	913 (188, 458-1190)
	Non-Shift RT	770 (131, 465-1054)	859 (156, 579-1214)
Navon	Shift RT	549 (114, 288-760)	591 (178, 319-957)
	Non-Shift RT	512 (111, 274-791)	529 (156, 299-881)
	Shift ACC	.92 (.08, .68-1)	.85 (.13, .53-1)
	Non-Shift ACC	.94 (.07, .68-1)	.86 (.13, .54-1)
CogState	Detection	2.60 (.09, 2.48-2.79)	2.65 (.09, 2.49-2.82)
	Identification	2.80 (.08, 2.67-2.95)	2.84 (.08, 2.71-2.98)
	Set Shifting	1.08 (.11, .88-1.22)	.99 (.10, .81-1.15)
ADOS	Total	--	10.8 (4.8, 3-19)
	Social Affect	--	8.2 (4.7, 3-19)
	Restricted/Repetitive Behavior	--	2.3 (2.4, 0-8)
SRS		42.5 (5.1, 37-60)	74.6 (9.1, 63-90)
SCQ		2.2 (2.2, 0-8)	16.4 (8.2, 1-29)
NEPSY	Affect Recognition	10.3 (2.3, 6-16)	9.6 (2.3, 5-14)
	Theory of Mind†	51-75	26-50

Note: RT is in milliseconds. ACC is proportion of trials correct. CogState Detection and Identification scores are $\log_{10}$ RT. CogState Set Shifting scores are the inverse sine function of percentage of trials correct. ADOS and SCQ scores are raw scores, SRS scores are T scores, and NEPSY AR scores are scaled scores.

†NEPSY Theory of Mind scores are available as percentile ranges only. Reported scores are median percentile ranges.

General Procedure

ASD participants. Following informed consent by a parent as well as assent by participants age 10 years or older[4] on the morning of their clinic appointment, ASD participants recruited through the ASD specialty clinic completed testing following their scheduled neuropsychological testing in a private office at the University of Michigan outpatient psychiatry clinic. Testing of participants recruited through the ASD clinic took place during the regular parent interview and did not require any additional time at the clinic beyond that of their scheduled appointment. For ASD participants recruited through the community, a visit to the EMU Psychology Clinic was scheduled upon parents' response to recruitment flyers. All ASD participants completed both the visual search and Navon tasks, including a practice condition, as well as the three CogState tasks, for a total of approximately 30 minutes of testing time. ASD participants recruited through the community completed an ADOS, a 2-factor WASI, and NEPSY Affect Recognition and Theory of Mind subtests in addition to the visual search, Navon, and three CogState tasks, for a total of approximately 2 hours of testing time. For ASD participants recruited through the community, a parent completed a brief demographic and screening form, a CBCL, an SRS, and an SCQ while their child completed testing, for a total of approximately 45 minutes

NT participants. Following informed consent by a parent as well as assent by participants age 10 years or older, NT participants completed testing after school hours at the EMU Psychology Clinic. NT participants completed a 2-factor WASI and NEPSY Affect Recognition and Theory of Mind subtests in addition to the visual search, Navon, and three CogState tasks, for a total of approximately 1 hour of testing time. For NT participants, a parent

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[4] University of Michigan IRB policy indicates that assent should be obtained from children age 10 and older, while parent consent only must be obtained for children under age 10.

completed a brief demographic and screening form, a CBCL, an SRS, and an SCQ while their child completed testing, for a total of approximately 45 minutes. See Appendix B for the demographic and screening form.

All participants. Prior to testing, participants were presented with each of the four letters used in the Navon task (A, X, H, and K) and required to correctly verbally identify each letter in order to verify their ability to complete the task. Testing of both ASD and NT participants was administered by the PI and/or a trained research assistant. Immediately prior to completing each experimental task (visual search and Navon tasks), all participants completed a practice version of the task until they achieved 80% accuracy[5]. Each CogState task also includes a practice version immediately prior to the task. Order of administration of the visual search and Navon tasks was counterbalanced. For the visual search and Navon tasks, data in which 25% or more of responses within any condition are rejected due to error, no response, or reaction times below 200 ms or above 2000 ms were excluded. Participants received a small incentive for participation.

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[5] This is common practice for many experimental paradigms, in order to ensure that participants understand task instructions as indicated by performance well above chance.

Chapter 8: Results

Alert. (1) *Individuals with ASD will show significantly slower reaction times than NT on measures indexing the alert component at the level of both preattention and focused attention.* Independent samples *t*-test showed a significant between-group difference in RT on the Detection task, with ASD showing slower RT ($t(38) = -1.78$, $p < .05$). See Figure 4 for reaction times on the Detection task for ASD and NT. The between-group difference in RT on the Identification task trended toward significance, again with ASD showing slower RT ($t(38) = -1.65$, $p = .054$). See Figure 5 for reaction times on the Identification task for ASD and NT. Cohen's *d* was calculated for RT on both tasks, yielding moderate effect sizes of .57 for RT on the Detection task and .54 for the Identification task.

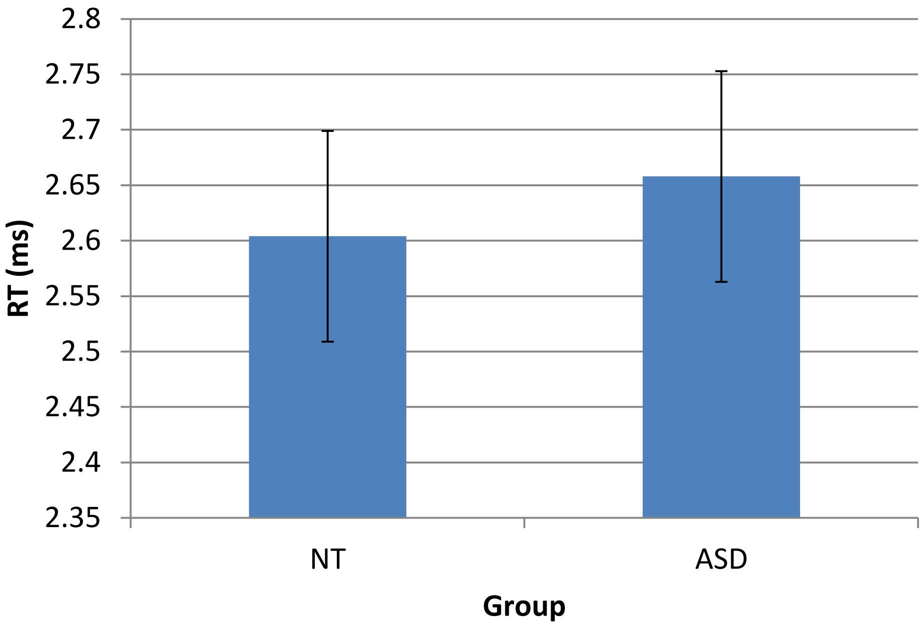

Figure 4. Mean CogState Detection normalized reaction times (Log10 milliseconds) for NT and ASD.

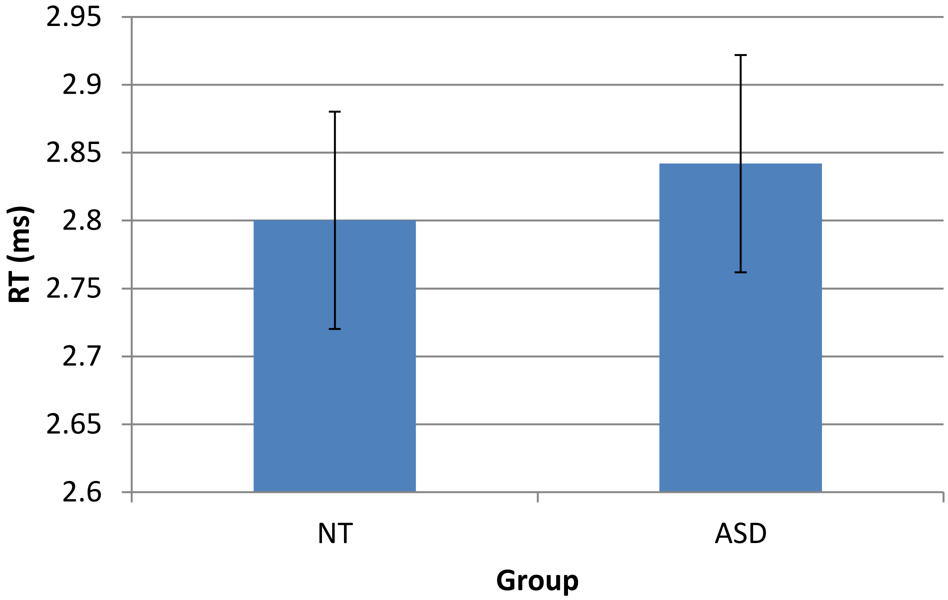

Figure 5. Mean CogState Identification normalized reaction times (Log10 milliseconds) for NT and ASD.

Shift/executive attention. (2) *The magnitude of differences in reaction time between "shift" and "non-shift" trials will be significantly higher in the ASD group than the NT group on measures of executive attention at the level of both preattention and focused attention.* Univariate ANCOVA showed no significant between-group differences in RT difference scores on the Navon (*F*(1, 33) = .16, *p* = .69) or visual search tasks (*F*(1, 36) = .09, *p* = .77) after controlling for performance on the CogState Detection and Identification tasks.

(3) *Within the ASD group, measures of executive attention at the level of both preattention and focused attention will be significantly correlated with each other.* Among ASD, RT difference scores on the visual search task were not significantly correlated with RT difference scores on the Navon task (*r* = -.13, *p* = .30) or with CogState Set Shifting scores (*r* = -.10, *p* = .33). However, post-hoc analysis showed that among NT, a positive correlation between

RT difference scores on the visual search and Navon tasks trended toward significance ($r = .39$, $p = .051$).

Preattention. (4) *On an average of all conditions on a measure of executive attention at the level of preattention, ("shift" and "non-shift"), the ASD group will show significantly faster reaction times than the NT group.* Repeated measures ANCOVA showed no significant between-group differences in RT on the Visual Search task ($F(1,36) = 1.84$, $p = .18$) after controlling for performance on the CogState Detection and Identification tasks. Post-hoc analysis using a Bonferroni correction for multiple comparisons showed that, consistent with the literature on visual search tasks, there was a significant main effect of trial type, with participants overall showing slower RT on shift than non-shift trials ($t(1, 39) = 3.80$, $p < .001$); Cohen's *d* revealed a small effect size of .27. See Figure 6 for reaction times on the visual search task. In addition, post-hoc analysis showed a significant interaction between trial type and RT on the CogState Identification task ($F(1, 36) = 6.37$, $p < .05$). Specifically, the slower a participant's RT on the Identification task, the greater the difference between their RT on shift and non-shift trials was (i.e., a greater increase in RT on shift as compared to non-shift trials).

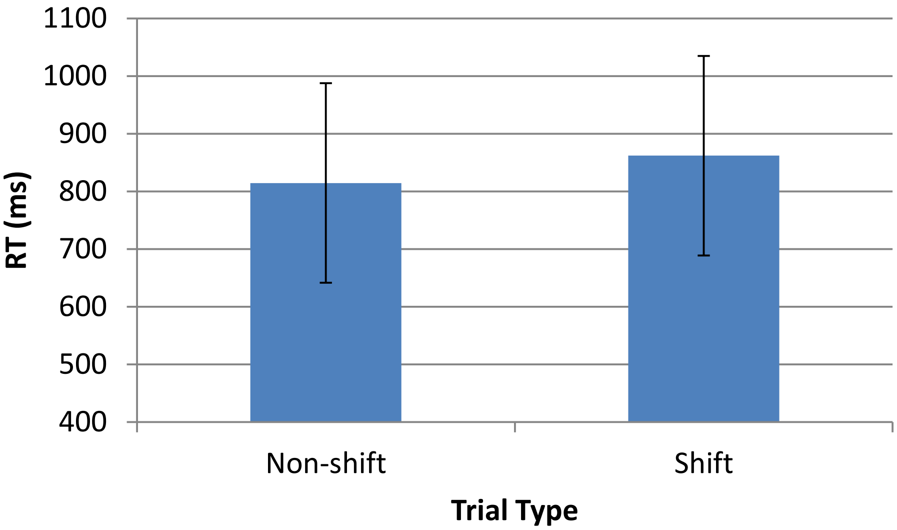

Figure 6. Mean visual search reaction times in milliseconds by trial type (shift or non-shift).

Focused attention. (5) *On a measure indexing executive attention at the level of focused attention, ASD will show a bias toward local processing as indicated by significantly faster RT and significantly higher accuracy on local than global target trials.* Repeated measures ANCOVA showed no significant main effect of level (global vs. local) on RT (F(1, 32 = .51, p = .48) or accuracy (F(1, 33) = 3.89, p = .23) on the Navon task after controlling for performance on the CogState Detection and Identification tasks.

(6) *Within the ASD group, RT will be significantly slower and accuracy will be significantly lower on "shift" trials than "non-shift" trials.* Repeated measures ANCOVA showed no significant main effect of trial type on RT for the Navon task (F(1, 32) = 1.39, p = .25), though there was a significant main effect of trial type for accuracy (F(1, 33) = 7.57, $p < .05$), with accuracy being lower for shift than non-shift trials for both ASD and NT; Cohen's d revealed a small effect size of .15 However, planned contrasts indicated no significant effect of trial type on accuracy among ASD for the Navon task. (F(1, 33) = 2.27, p = .42).

Notably, post-hoc analysis using a Bonferroni correction for multiple comparisons revealed significantly higher RT for shift than non-shift trials among all subjects on the Navon task (t(1,36) = 3.79, $p < .001$); Cohen's d revealed a small effect size of .34. See Figure 7 for reaction times on the Navon task. Furthermore, post-hoc analysis revealed a significant interaction between trial type and RT on the CogState Detection task (F(1,32) = 4.49, $p < .05$). Specifically, the slower a participant's RT on the Detection task, the greater the difference between their RT on shift and non-shift trials was (i.e., a greater increase in RT on shift as compared to non-shift trials).

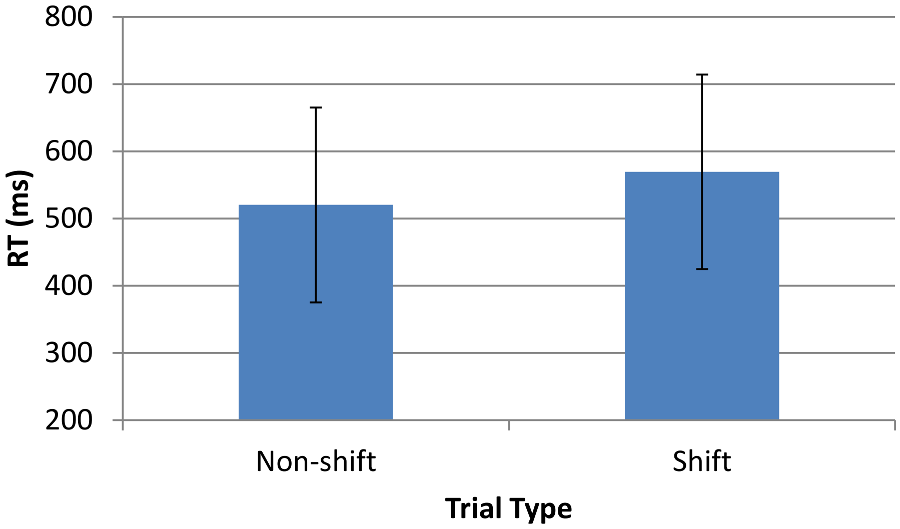

Figure 7. Mean Navon reaction times in milliseconds by trial type (shift or non-shift).

(7) *Within the ASD group, RT difference scores will be significantly larger for local-to-global shifts than global-to-local shifts.* Repeated measures ANCOVA revealed no significant main effect of condition (local to global vs. global to local) on RT difference scores on the Navon task ($F(1, 32) = .51$, $p = .48$).

(8) *Within both the ASD and NT groups, measures of executive attention at the level of focused attention will be significantly positively correlated with each other.* RT difference scores on the Navon task were significantly negatively correlated with CogState Set Shifting accuracy for the ASD group ($r = -.59$, $p < .01$), but not for NT ($r = -.10$, $p = .68$). See Figure 8 for Pearson's *r* correlations between Navon RT difference scores and CogState Set Shifting for ASD and NT groups. Post-hoc analysis confirmed that accuracy on CogState Set Shifting was higher for NT than for ASD ($t(38) = 2.70$, $p < .01$).

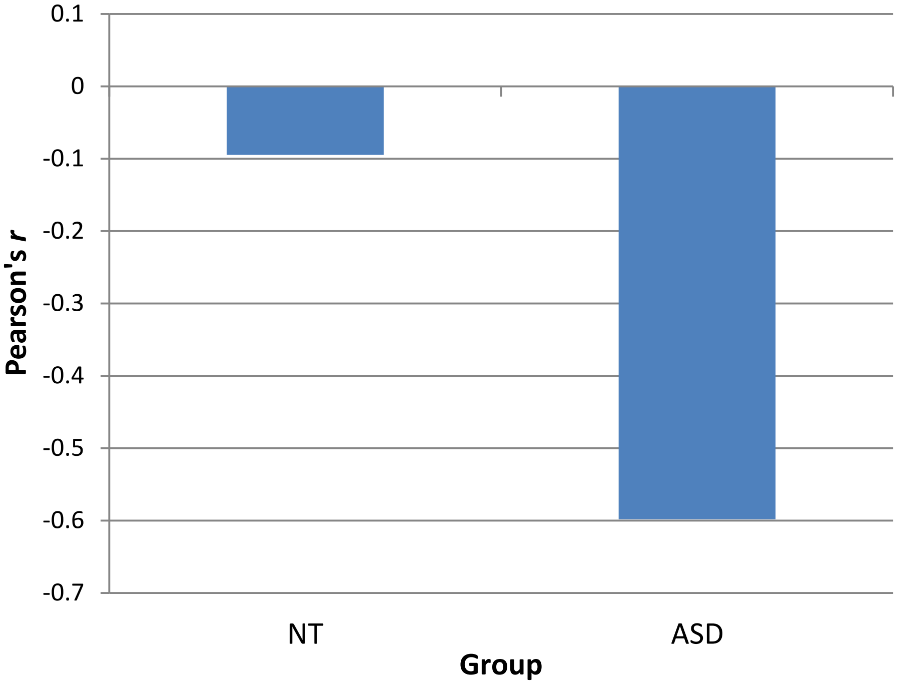

Figure 8. Correlation coefficients (Pearson's *r*) for Navon RT difference scores in milliseconds correlated with CogState Set Shifting normalized accuracy (arcsin of percentage of correct trials) for NT and ASD.

Relationships with social functioning. (9) *NT will show significantly lower scores than the ASD group on measures of social impairment.* Independent samples *t*-tests showed significant between-group differences on both the SCQ ($t(38) = -7.55$, $p < .001$) and the SRS total score ($t(38) = -6.15$, $p < .001$). Cohen's *d* revealed very large effect sizes of 2.45 for the SCQ and 2.0 for the SRS.

(10) *NT will show significantly higher scores than the ASD group on measures of affect recognition and theory of mind.* Independent samples *t*-tests showed no significant between-group difference on NEPSY Affect Recognition ($t(38) = 1.43$, $p = .08$) or Theory of Mind scores ($t(37) = 1.46$, $p = .08$).

(11) *Among the ASD group, measures of executive attention at the level of both preattention and focused attention will be significantly positively correlated with measures of*

social impairment. RT difference scores on the Navon and Visual Search tasks were not significantly correlated with SCQ (*r* = .02, *p* = .45; *r* = .23, *p* = .08, respectively) or SRS total scores (*r* = -.004, *p* = .49; *r* = .24, *p* = .07, respectively). Among the ASD group, RT difference scores on the Navon and Visual Search tasks were not significantly correlated with ADOS social functioning scores (*r* = -.11, *p* = .35; *r* = -.22, *p* = .19, respectively). However, among the ASD group, post-hoc analysis showed that RT difference scores on the Navon task were significantly positively correlated with ADOS restricted and repetitive behavior scores (*r* = .45, *p* < .05), and a positive correlation between RT difference scores on the visual search task and SRS scores trended toward significance (*r* = .37, *p* = .054).

(12) *Among the ASD group, measures of executive attention at the level of both preattention and focused attention will be significantly negatively correlated with measures of affect recognition and theory of mind.* Among the ASD group, NEPSY Affect Recognition scores were not significantly correlated with RT difference scores on the visual search task (*r* = -.09, *p* = .35), but were significantly negatively correlated with RT difference scores on the Navon task (*r* = -.53, *p* < .05). NEPSY Theory of Mind scores were not significantly correlated with RT difference scores on either the visual search (*r* = -.13, *p* = .29) or Navon tasks (*r* = .15, *p* = .27).

Chapter 9: Discussion

Results of the current study provide some support for the primary hypothesis of impaired or inefficient visual attention processes in ASD, though results do not support the specific hypothesis of a specific deficit in visual attention shifting in ASD. Specifically, ASD participants showed slower RT overall on the Detection and Identification tasks with medium effect sizes; after controlling for these effects, the ASD and NT groups did not show differing RT on either the Navon or visual search tasks, nor did the difference in RT between shift and non-shift trials differ between the groups on either task.

The lack of between-group differences on a measure of executive attention at the level of preattention, specifically that participants with ASD were not faster than NT, is inconsistent with previous findings of faster visual search times in participants with ASD compared to NT (Joseph et al., 2009; Kemner et al., 2008; O'Riordan, 2000; O'Riordan et al., 2001; O'Riordan & Plaisted, 2001), although some previous research has failed to find faster feature search times in children with ASD (Plaisted et al., 1998). It is noted that the majority of previous studies of visual search processes in ASD have employed paradigms which did not require shifting between targets, and one that did employ a shifting paradigm showed slowed RT overall in both ASD and NT groups in comparison to a paradigm without shifting requirements (O'Riordan, 2000). It is possible that the lack of group differences between ASD and NT in the present study are attributable to slowing on the task overall among those with ASD due to the shifting requirement, whereas it may be the case that faster RT would have been observed on a visual search condition with no shifting requirement (e.g., color target only or orientation target only). Future research to examine the effect of shifting vs. non-shifting requirements on visual search times in individuals with ASD as compared to NT may help to elucidate the cognitive bases of abnormal visual search performance in ASD.

At the level of preattention, all participants showed slower RT on trials that required a shift between stimulus dimensions than on those that did not, with a small effect size. However, contrary to hypothesis, the magnitude of the difference in RT between shift and non-shift trials was not greater in the ASD group than NT. Interestingly, post-hoc analysis revealed an interaction between RT on the Identification task and trial type on the visual search task, such that participants with slower RT on the Identification task showed a greater magnitude of difference in RT between shift and non-shift trials than participants with faster RT on the Identification task. Thus, slower processing speed was associated with slower shifting, and vice versa.

The observation of slower RT on trials requiring a shift between target stimulus dimensions is consistent with previous literature demonstrating this effect in NT (Chan & Hayward, 2009; Found & Muller, 1996; Müller et al., 1995; Treisman & Gormican, 1988). However, the current study is the first to demonstrate this shifting effect in ASD. While the expected difference in shifting response between ASD and NT groups was not observed, it is informative that ASD showed a shifting response that appears to be qualitatively similar to that of NT. It may be the case that individuals with ASD would show greater slowing on shift trials given a more challenging paradigm, based on previous evidence for an increase in differences in performance between ASD and NT on more challenging feature and conjunction search paradigms (O’Riordan et al., 2001). Future investigations of visual search skills in ASD employing visual search tasks of varying degrees of difficulty with shifting requirements may contribute to an understanding of the contribution of top-down processing to visual search abilities in ASD.

The interaction between processing speed and shifting effects on the visual search task may provide evidence for decreased efficiency of top-down processes during preattentive visual processing in ASD. ASD showed slower processing speed than NT, and participants with slower processing speed showed larger shifting effects on the visual search task (i.e., a greater difference between RT on shift and non-shift trials); thus, it may be the case that given greater statistical power or a more challenging visual search paradigm to elicit greater group differences, ASD would have demonstrated a larger shifting effect (i.e., less efficient top-down processes) at the level of preattentive visual processing. However, it may also be the case that slower processing speed is associated with less efficient top-down effects on preattentive visual processing regardless of diagnostic group. Comparison of multiple diagnostic groups and inclusion of larger sample sizes with a wider range of processing speed may be informative in this case.

At the level of focused attention, no group differences in RT were observed, and again, the magnitude of the difference in RT between shift and non-shift trials was not greater in ASD than NT. However, all participants showed slower RT and lower accuracy on trials that required a shift of the spotlight of attention than on those that did not, both with small effect sizes. These findings are consistent with previous findings of decreased performance in NT when a shift of the spotlight of attention is required (Ward, 1982). Furthermore, results showed that slower psychomotor speed was associated with less efficient shifting of the spotlight of attention. Similar to the relationship between processing speed and preattentive visual shifting, given that ASD showed slower average psychomotor speed, it may be the case that ASD would have demonstrated a greater shifting effect than NT given higher statistical power. Alternatively, it may be this relationship would hold regardless of diagnostic category. Interestingly, the proposed model for the current study would have predicted a relationship between psychomotor speed and preattentive visual shifting, as well as a relationship between processing speed and visual shifting at the level of focused attention, whereas the current study found that these relationships were reversed. Further investigation of the relationships between the behavioral manifestations of these components of visual attention may clarify a model of the neurocognitive relationships between these processes.

Despite the lack of observed group differences in overall RT at the level of focused attention, examination of relationships among measures of preattention and focused attention revealed different associations for NT and ASD participants. Among NT, the magnitude of the difference in RT between shift and non-shift trials at the level of preattention (visual search task) was correlated with that at the level of focused attention (Navon task), while this was not the case for ASD. On the other hand, among ASD, the magnitude of the difference in RT between shift and non-shift trials at the level of focused attention was negatively correlated with accuracy on the Set Shifting task, while this was not the case for NT.

In addition to the absence of the expected group differences in overall RT, the current study also failed to replicate previous findings of enhanced local processing in ASD (Dakin & Frith, 2005). However, it is noted that previous evidence of enhanced local processing is not unequivocal, as some studies have failed to find group differences in performance based on level of processing (Mottron et al., 1999; Ozonoff et al., 1994). With regard to the absence of differences in shifting in ASD at the level of focused attention in the current study, it is noted that only one prior study has investigated a shifting effect with a Navon task (Rinehart et al., 2001). Notably, that study found that children diagnosed with autism, but not Asperger’s disorder, had difficulty adjusting the spotlight of attention from local to global. Because the current study included primarily high-functioning individuals with ASD, who under previous diagnostic guidelines would likely have been diagnosed with Asperger’s disorder, the current findings may in fact be consistent with Rinehart et al.’s study. Another potential contributing factor to the lack of observed group differences is the choice of stimulus parameters for the Navon task. Parameters used in the current study may not have been sensitive to group differences in shifting, as they were based on a paradigm designed to evoke group differences in response time based on level of attention (i.e., global or local) rather than an effect of shifting between levels of attention (Wang et al., 2007). Although the current study employed a paradigm designed to be more sensitive to group differences by using a shorter stimulus exposure time than that employed by Rinehart et al., this did not elicit impaired performance in ASD.

Differing relationships between measures designed to index the shift component of Posner’s visual attention model suggest a potential difference in the neurocognitive bases of attention shifting in ASD as compared to NT. A correlation between shifting times on the visual search and Navon tasks in NT suggests that NT may recruit similar neural networks to accomplish these two tasks; imaging evidence would suggest that parietal cortex and frontal cortex, particularly frontopolar cortex, may be particularly important. For those with ASD, a correlation between shifting times on the Navon task and Set Shifting scores suggests that individuals with ASD may recruit different neural networks than NT in order to shift on the Navon task. Performance of tasks similar to CogState Set Shifting, such as the Wisconsin Card Sort Task, is thought to depend more heavily on regions including DLPFC rather than frontopolar cortex in NT; thus, it may be the case that individuals with ASD rely on the higher-order processing associated with regions such as DLPFC to achieve shifting of the spotlight of attention, whereas NT rely more heavily on the more basic, less effortful executive processes associated with frontopolar cortex. Alternatively, individuals with ASD may rely more heavily on other (e.g., posterior) brain regions to shift the spotlight of attention as well as for higher-order executive processing, resulting in lower efficiency for both types of tasks.

On measures of social functioning, the expected group differences were observed on parent report measures of social functioning, with higher levels of symptoms reported for ASD than NT participants, and with very large effect sizes for both measures. However, objective testing revealed no significant group differences on measures of social cognition, despite confirmation of social communication deficits among ASD participants using gold-standard criteria (i.e., ADOS). Among those with ASD, the magnitude of the difference in RT between shift and non-shift trials at the level of focused attention was not correlated with social communication deficits as measured by the ADOS, but was positively correlated with restricted and repetitive behavior scores on that measure. This measure of shifting at the level of focused attention was also negatively correlated with scores on an objective measure of social cognition, specifically affect recognition, among ASD participants only. Furthermore, among the ASD group, there was a trend toward a positive correlation between scores on a parent report measure of social responsiveness and the magnitude of the difference in RT between shift and non-shift trials at the level of preattention.

The lack of observed group differences on objective measures of social cognition, specifically affect recognition and theory of mind, raises questions about the validity and utility of these tasks. Given the fact that deficits in these skills are a hallmark of ASD, and diagnoses of the individuals included in the present study were confirmed using the gold-standard observational diagnostic measure for ASD, it is unlikely that no group differences in social cognition were present. This suggests a need for more valid objective, standardized measures of social cognition in order to investigate these skills and their relationships with other cognitive domains without relying on observer reports. Regarding the relationships between measures of social functioning and attention shifting, while NT did not show relationships between measures of attention shifting and social functioning, this is likely due to significant floor effects on parent report measures of social functioning. Because the measures employed in the current study are designed to measure ASD symptomology, they are relatively insensitive to typical variations in social skills. Regarding the ASD group, the correlation between shifting at the level of focused attention and observations of restricted and repetitive behaviors is interpreted with caution due to the restricted range of scores on the latter measure. However, it is possible that inefficient shifting at the level of focused attention is related to the tendency to maintain focus on a restricted range of sensory stimuli, behaviors, or topics of interest, as is observed in ASD. Further research to this end may clarify the relationship between these types of symptoms and the neurocognitive basis of ASD.

Chapter 10: Conclusions

Taken together, the results of the current study provide some support for abnormal or inefficient visual attentional processing in ASD, though results do not support specific deficits in visual attention shifting. While performance on tasks of attention shifting at the level of both preattention and focused attention indicated higher costs of shifting attention in terms of either speed or accuracy, these effects were comparable in ASD and NT. In addition, the observed relationship between processing speed and costs of visual attention shifting at the level of preattention, and the observed relationship between psychomotor speed and costs of shifting the spotlight of attention, are potentially informative about the neurocognitive bases of visual attention in both ASD and NT. These relationships were not different between the two diagnostic groups, suggesting that there may be a general relationship between processing speed and top-down effects on preattentive visual processing, as well as psychomotor speed and the top-down effects of visual processing at the level of focused attention, that are not specific to diagnostic group.

According to the proposed model for this study, processing speed relies on a neural network involving subcortical and parietal regions, while visual attention shifting at the level of preattention relies on a neural network involving visual association cortex and frontal (specifically frontopolar) cortex. Both require long-range connections between distal cortical regions associated with more basic sensory functioning and higher-order associative functions, respectively. On the other hand, according to the proposed model, psychomotor speed relies on a neural network involving subcortical regions and visual association cortex, while visual attention at the level of focused attention relies on a network involving parietal and frontal cortical regions. Both constitute more local-level connections between cortical and subcortical regions associated with more basic sensory functioning and higher-order associative functions, respectively. It may be the case that individuals with less efficient short- or long-range connections in one network are more likely to also have less efficient connections in other, similar networks, thus resulting in poorer performance in the domains of both processing speed and visual attention shifting at the level of preattention, or in both psychomotor speed and visual attention shifting at the level of focused attention.

Confirmation of the hypotheses proposed above will require neuroimaging research to elucidate the neural mechanisms underlying visual attention orienting and shifting in ASD as compared to NT, as well as the potential relationships between processing speed and visual attention shifting at the level of preattention, and between psychomotor speed and visual attention shifting at the level of focused attention. Little imaging research has investigated visual attention shifting in ASD, and no imaging studies of ASD have been conducted during performance of a visual search task to date, making this an area ripe for exploration. Specifically, MEG recording during performance of visual attention tasks with orient and shift demands, such as the visual search task, would provide information about both regional activation and the nature and efficiency of communication within and between cortical regions. As described above, the model for the current study suggests the hypothesis that inefficient orienting and shifting of visual attention at the level of preattention is associated with inefficient activation of and/or communication between visual association cortex, parietal cortex, and frontal cortex, specifically frontopolar cortex. To this end, a follow-up to the current study will investigate this hypothesis using MEG recordings of neural activity in NT children and those with ASD while performing the visual search task used in the present study. Other directions for future research include further investigation of the relationship between the behavioral and neural correlates of processing speed and visual attention at the level of preattention in both NT children and those with other neurodevelopmental disorders.

Limitations of the current study include the relative homogeneity of the ASD sample, specifically the high-functioning status of the majority of the ASD participants. As described above in regard to the Navon task, it may be the case that a lack of observed group differences in visual attention shifting was due to the high-functioning status and relatively low symptom severity of the majority of the ASD participants. Furthermore, the sample size employed in the current study, while comparable to that used in many studies of cognitive functioning in clinical populations, may have been too small to detect small to moderate effect sizes. Both of these factors may limit the generalizability of the present findings to other populations, including low-functioning ASD. However, the current findings regarding inefficient visual attention shifting at the level of preattention in ASD, as well as its relationship with processing speed, constitute a new direction in the literature on visual attention in ASD, as well as raising new questions for future research with the potential to illuminate the neurocognitive bases of this disorder.

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Appendix A.

Recruitment Flyer

EASTERN MICHIGAN UNIVERSITY AND UNIVERSITY OF MICHIGAN DEPARTMENT OF PSYCHIATRY ARE LOOKING FOR CHILDREN AGES 6-12 TO PARTICIPATE IN A STUDY OF ATTENTION

- The research will examine differences in attention and social functioning between healthy children and children with an autism spectrum disorder.
- This study will require children to complete one hour of thinking and attention tasks, and a parent to complete 45 minutes of questionnaires about their child's feelings and behavior.
- This study is being conducted at the Eastern Michigan University Science Complex, located at the corner of Washtenaw Ave. and Oakwood St. in Ypsilanti
- Participants will receive a $30 gift card upon completion of testing.
- Children who are eligible for this study have no history of seizures or head injury with loss of consciousness.

For more information or to find out if you are a candidate please contact:
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Renee Lajiness-O'Neill, Ph.D.

Eastern Michigan University IRB APPROVAL REF. 130402
University of Michigan IRB APPROVAL REF #HUM00068105

Appendix B.

Demographic and Screening Form

Demographic Questionnaire

Demographic Information

1. Name of participant: ____
2. Gender: *(circle)* MALE FEMALE
3. Ethnicity: ____
4. Date of Birth: ______________________
5. Age: _______________________
6. Handedness (right or left): _____________________
7. Home address: ____

   ____

   ____
8. Phone number: ____
9. Parents' level of education (for example: GED, high school diploma, bachelors degree, masters degree, doctoral degree, etc.):

   Father: ____

   Mother: ____

Academic History

10. Participant's current grade or highest grade completed: ____________________________
11. Has the participant been held back one (or more) year(s) in school? *(circle)* YES NO

    If yes, in what grade and for how many years: ________________________________

12. Has the participant obtained special services in school up to now (for example: special education, speech therapy, occupational therapy, social work, etc.)?

    ____

    ____

    ____

Medical History

13. Has any member in your family or your spouse's family been diagnosed with Autism / Asperger's / Pervasive Developmental Disorder? *(circle)* YES NO

    If yes, please explain and specify the individual's relationship to the participant (for example: mother, father, sister, brother, uncle, aunt, etc.)

    ____

    ____

    ____

14. Has any member of your family or your spouse's family been diagnosed with a psychiatric illness such as Depression, Anxiety, Bipolar Disorder (or Manic Depression), Schizophrenia, or other? *(circle)* YES NO

    If yes, please explain and specify the individual's relationship to the participant (for example: mother, father, sister, brother, uncle, aunt, etc.)

    ____

    ____

    ____

15. Place a check mark (√) in the box next to any of the following conditions for which the participant has a history: *(check all that apply)*

    ☐ birth related injuries
    ☐ developmental delay / developmental disorder
    ☐ speech/language impairment
    ☐ head injury with loss of consciousness
    ☐ seizure disorder / epilepsy
    ☐ tic disorder / Tourette's disorder
    ☐ substance use / abuse
    ☐ other neurological condition (please specify) ____________________________

    ____

    ____

16. Place a check mark (√) in the box next to any of the following diagnoses the participant has previously received: *(check all that apply)*

☐ Attention Deficit/Hyperactivity Disorder (ADHD)
☐ Autism / Asperger's / Pervasive Developmental Disorder
☐ Depression
☐ Anxiety
☐ Obsessive-Compulsive Disorder
☐ Conduct Disorder / Oppositional Defiant Disorder
☐ other mental health condition (please specify) ____________________________

____

____

17. Is the participant currently prescribed medication? *(circle)* YES NO

If yes, please name the medications and for what they are prescribed:

Medication	Condition
__________________________	__________________________
__________________________	__________________________
__________________________	__________________________
__________________________	__________________________

18. Please note in the following section any relevant medical or background information not previously mentioned (surgeries, hospital stays, imaging scans, etc.).

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