QUANTIFYING TEMPORAL ASPECTS OF LOW-LEVEL MULTISENSORY PROCESSING IN CHILDREN WITH AUTISM SPECTRUM DISORDERS: A PSYCHOPHYSICAL STUDY

By

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CHAPTER I

INTRODUCTION

Autism spectrum disorders (ASD) form a continuum of neurodevelopmental disorders that are characterized by a triad of symptoms including pervasive deficits in social understanding and reciprocity, impairments in language and communication skills, and behavioral rigidity that includes repetitive behaviors and restricted interests (American Psychiatric Association, 2000). Prevalence estimates for ASD have increased substantially over the past 10-15 years, with recent figures now estimating that 1 in every 150 children is affected by an ASD (Center for Disease Control and Prevention, 2006; Fombonne, 2003). Though not part of the diagnostic criteria for ASD, reports of sensory disturbances date back to Kanner's original description of autism (1943). In this initial report, both sensory fascinations, such as staring at light reflections, and sensory hypersensitivities, such as distress in response to loud noises, were described. Since the original description of the disorder, observations of both hypo- and hyper-arousal to sensory input, interest and preoccupation with sensory features of objects, and aversion or unusual reaction to specific sensory stimuli have been made consistently in individuals with ASD (Dawson & Watling, 2000; O'Neill & Jones, 1997; Sigman & Capps, 1997). Additionally, clinical descriptions of individuals with ASD having difficulty integrating multi-sensory stimuli into a unified percept have been reported (D. Williams, 1996).

Findings of abnormal sensory experiences spanning visual, auditory, gustatory, and tactile domains suggest that ASD may be characterized by processing alterations that cross multiple sensory systems, reflecting abnormalities in basic information processing across sensory modalities. In addition, it has been suggested that the selective integration of information from the different senses may also be impaired, in which case specific alterations in multisensory integration may exist (Iarocci & MacDonald, 2006). The ability to synthesize sensory information into unique multisensory percepts is necessary for understanding the complexities of the world around us. For instance, in trying to understand a conversation partner in a noisy party, one relies on the visual input from watching the lips to make up for reduced auditory input from spoken words in order to make out what the person is saying (Sams et al., 1991; Sumby & Pollack, 1954). Therefore, perception of and response to complex and higher-order (i.e., cognitive and/or socially-relevant) stimuli with sensory properties across modalities (i.e., multisensory) rely on intact functioning of more basic sensation and perception processes and the ability to make cross-modal associations.

Intact functioning of individual sensory systems in integrating lower-level unimodal sensory input (i.e., more basic, unidimensional stimuli without inherent social or cognitive relevance) is a necessary precursor to the ability to accurately perceive and respond to more complex or socially-relevant sensory occurrences, as seem to be impaired in ASD. However, little quantitative evidence has been gathered regarding basic unisensory and multisensory function in ASD in order to understand the nature of higher-order sensory alterations. Furthermore, whether the multisensory abnormalities reported in ASD are simply a reflection of disruptions in unisensory (e.g., visual alone, auditory alone) function, or extend to multisensory processing, remains unknown. Better characterization of fundamental sensory processing will contribute to our understanding of sensory abnormalities that are highly prevalent in individuals with ASD and likely play an important contributory role in the core social, communicative, and behavioral symptoms that characterize these disorders (Rogers & Ozonoff, 2005). Clarification of the respective roles of disrupted unisensory and multisensory function represents an important step in better elucidating the role of sensory dysfunction in autism.

Principles of Sensory Processing and Multisensory Integration

Multisensory integration is necessary for the creation of a perceptual gestalt that informs our understanding of the world around us. However, multisensory processing is subserved by processing that occurs within modality-specific sensory systems (i.e., visual system, auditory system) in response to perceptual features of incoming information. Importantly, individual sensory systems are specialized in terms of the properties of input stimuli they can best resolve (Welch & Warren, 1980). The visual system is finely tuned to process spatial aspects of the environment, and visual acuity for spatial information far exceeds auditory spatial acuity (Howard & Templeton, 1966). For instance, while one can visually discriminate minute spatial details in the environment (i.e., pick out a specific person in a crowded room of people), it is difficult to localize the source of a sound in space (i.e., figure out from where in a crowded room you hear your name being called). The ventriloquist effect provides a helpful illustration of this concept. A skilled ventriloquist can make it seem that his voice is coming from a dummy somewhere across the room. In this illusion, the visual cue of seeing the dummy's mouth move alters the apparent spatial origin of the accompanying sound such that it seems a voice is coming from the dummy (Bertelson, 1999; Howard & Templeton, 1966). Thus, the visual system has dominated the auditory system in localizing a sound in space, in this case resulting in a compelling illusion.

Conversely, the auditory system is specialized for making temporal discriminations among rapidly presented stimuli whereas the visual system has worse temporal acuity (Grondin & Rousseau, 1991; Rousseau, Poirier, & Lemyre, 1983). Perceived rate and duration of a visual stimulus can be influenced by the presence of coincident auditory input (Walker & Scott, 1981; Welch, Duttenhurt, & Warren, 1986). Thus, when temporal features of a stimulus are most prominent, audition will alter visual perception (Shams, Kamitani, & Shimojo, 2004). Findings in both the visual and auditory modalities indicate that when the nature of a certain stimulus places particular demands on fine-grained spatial or temporal discrimination, the more specialized sensory system is likely to dominate other modalities. The relative specialization of individual sensory systems and their ability to override and bias one another in processing aspects of input stimuli for which they are particularly specialized becomes important when multiple stimuli occur in close spatial or temporal proximity.

There are multiple cortical and subcortical brain regions in which sensory input from multiple modalities converges. Here, the possibility for multisensory integration of cross-modal input arises. Animal literature has provided evidence that neurons having multisensory properties integrate information across senses such that resulting neural responses differ notably from responses that would occur in response to any singular unimodal sensory input (Meredith & Stein, 1983; Wallace, Meredith, & Stein, 1998; Wallace, Wilkinson, & Stein, 1996). Multisensory integration is most likely to occur when two independent sensory inputs occur in close spatial and temporal proximity (Meredith, Nemitz, & Stein, 1987; Meredith & Stein, 1986; Stein & Meredith, 1993). Given that multisensory neurons have spatially overlapping receptive fields, if two stimuli occur in proximal locations in space, they are likely to evoke an increased, multisensory response. In the temporal domain, when two stimuli occur relatively close together in time, it is likely that they will be integrated as part of a single, multisensory representation rather than recognized as discrete entities. Thus, if two stimuli occur in close proximity in space and/or time, the probability that multisensory integration will occur increases. As the interval between the stimuli expands, the likelihood of multisensory integration declines (Hairston et al., 2003; Meredith et al., 1987).

Changes in the size of the window in which integration is likely to occur can be expected to have important consequences both for sensory functioning itself and for the higher-order cognitive processes that are dependent upon the temporal fidelity of the different sensory and multisensory systems. Indeed, the spatial and temporal windows within which integration of multiple sensory inputs is likely to occur have been examined and there is significant evidence that an atypical binding window can cause clinically relevant impairment in certain populations. For example, an increased temporal binding window is thought to play a role in the etiology of developmental dyslexia (Hairston, Burdette, Flowers, Wood, & Wallace, 2005).

The likelihood of multisensory integration also varies according to the principle of inverse effectiveness. According to this principle, the signal intensity of unimodal sensory inputs affects: a) whether multisensory integration will occur upon stimulus combination, and b) the magnitude of the gain that will be seen in response to this pairing (Stein & Meredith, 1993). When unisensory stimuli are weak in eliciting responses on their own, they are likely to induce increased multisensory responsiveness in combination with other spatially and/or temporally proximal sensory inputs (Meredith & Stein, 1986; Stein, London, Wilkinson, & Price, 1996; Wallace et al., 1996). Multisensory integration is less likely to occur when unisensory inputs are strongly effective by themselves; thus, hyper-sensitivity to unimodal input should result in decreased multisensory integration whereas hypo-sensitivity should elicit increased multisensory integration.

This review of underlying factors relating to sensory processing and multisensory integration of basic stimuli suggests three dimensions along which neural processes might go awry, possibly resulting in atypical sensory experiences as have historically been reported in ASD. First, it is possible that modality-specific sensory systems that ought to be specialized for specific discriminations (e.g., visual system for spatial discriminations, auditory system for temporal discriminations) have reduced effectiveness in performing their specialized function. Second, it is possible that the window within which multisensory information continues to be bound together despite increasing distance in space and/or time (e.g., the temporal binding window) is altered. Third, relating to the principle of inverse effectiveness, the degree or intensity to which multisensory integration occurs may be altered if unisensory input is processed to an atypical extent. However, there is a dearth of evidence examining any of these possibilities in ASD.

Sensory Experiences and Processing in ASD

Clinical, Autobiographical, and Caregiver Report of Sensory Abnormalities

While the integrity of underlying sensory and multisensory processes in ASD as it relates to basic brain functioning remains largely unexplored, the impact of sensory abnormalities in the lives of individuals with ASD is clear. Anecdotal reports written by and about individuals with ASD describe a range of sensory abnormalities including both sensory interests and sensory aversions. Clinically, children with ASD have been reported to react to sensory stimuli in idiosyncratic ways, such as smelling or licking non-edible objects or peering at objects out of the corners of their eyes (Sigman & Capps, 1997). Autobiographical reports suggest that some individuals with ASD have difficulty processing information from different sensory modalities concurrently and may experience "sensory overload" (Cesaroni & Garber, 1991; O'Neill & Jones, 1997). For instance, in an autobiographical description of her own sensory sensitivities, Grandin (2000) reports aversions and extreme sensitivity to certain everyday sounds, difficulty screening out background noises, and fascinations with watching certain objects move. In another personal account by an adult with autism, D. Williams (1994) describes perceiving objects as a collection of parts, rather than as a unified whole, as well as difficulties with processing information in the context of distracting visual input. Other anecdotal reports describing individuals with ASD suggest that input from one sense may be perceived in another sensory modality (i.e., synesthesia, in which, for example, a sound may invoke a visual sensation of color or a specific taste sensation) (Baron-Cohen et al., 2007). Thus, according to the descriptions of both individuals with ASD themselves and the clinicians who work with and observe them, atypical experience with, perception of, and response to information from the various senses are widespread.

A small literature exists that attempts to quantify and describe the rate and nature of sensory differences in ASD using questionnaires and rating scales. The Sensory Profile (SP: Dunn, 1999; Dunn & Westman, 1997), a caregiver rating form, has been used for such purposes. In a small sample of children ages 3 to 13 years old with autism, Kientz & Dunn (1997) found that 42-88% had significant hyper- and hypo- and/or paradoxical responses to sensory input, as reported by their parents on the SP. Watling, Dietz, and White (2001) found that 3 to 6 year old children with ASD were described as having significantly different profiles than age-matched typically developing children on many of the SP factors, including Sensory Seeking, Oral Sensitivity, Poor Registration, Low Endurance/Tone, and Fine Motor Perceptual. Using the Sensory Sensitivity Questionnaire – Revised (SSQ-R), Talay-Ongan and Wood (2000) found parent report of increased sensitivity across all sensory modalities relative to typically developing control children. In another study, conducted by Leekam, Nieto, Libby, Wing, and Gould (2006), over 90% of children ages 2 to 13 with autism were reported to have pervasive, multimodal sensory abnormalities using the Diagnostic Interview for Social and Communication Disorders (DISCO: Wing, Leekam, Libby, Gould, & Larcombe, 2002). Even when compared to a control group of children with developmental delay who were matched on mental age, Rogers, Hepburn, and Wehner (2003) found that 2- and 3-year old children with autism were significantly different on scales of tactile sensitivity, taste/smell sensitivity, sensory under-reactive/seeks stimulation, and auditory filtering from the short version of the SP. Furthermore, Baranek, David, Poe, Stone, and Watson (2006) found that children with autism, 69% of whom experienced sensory symptoms as rated by their parents on the Sensory Experience Questionnaire (SEQ: Baranek et al., 2006), could best be differentiated from a developmentally delayed control group by their hyposensitivity to sensory input in both social and non-social contexts.

In reviewing clinical records of 200 children with ASD between two and four years of age, Greenspan and Wieder (1997) found that 19% of the children showed primarily hyper-responsiveness to sensory input, 39% evidenced predominantly hypo-responsiveness, and 36% displayed both hyper- and hypo- responsiveness to sensory input. While studies that utilize caregiver report questionnaires and clinical chart review clearly indicate that those who interact most with children with ASD are observing differences in the outward, observable behavioral responses to sensory input, second-hand report does not allow for understanding internal processes relating to sensory sensitivity nor first-hand perception of sensory experiences. To understand how sensory information is processed and perceived by individuals with ASD, their sensitivity to and perception of sensory stimuli must be examined directly.

Experimental Studies of Lower-Level Sensory and Multisensory Functioning in ASD

A handful of studies have attempted to quantify lower-level unisensory processing of basic sensory inputs in individuals with ASD. The subsequent literature review will be limited to studies involving spatial and temporal discriminations in the visual and auditory domains, as that will be the focus of the present study. First, it is important to note that differences in processing of auditory and visual stimuli cannot simply be ascribed to deficits in hearing or vision. Klin (1993) notes that children with ASD typically test within normal limits on hearing and vision screenings and that issues of testability and compliance may interfere with the validity of tests and accuracy of screening in many of the remaining children, perhaps resulting in higher perceived rates of hearing and vision problems that may not truly exist (Baranek, Parham, & Bodfish, 2004).

Spatial discrimination abilities in the visual domain are among the best characterized aspects of sensory processing in ASD. In fact, discrimination of discrete visual details within complex spatial displays has widely been found to be a relative strength in ASD (O'Riordan & Plaisted, 2001). Research findings regarding processing of static visual information that have been used to support the claim of enhanced ability to make spatial discriminations in the visual domain include findings of enhanced ability to recognize a target shape embedded within a larger picture (Joliffe & Baron-Cohen, 1997; Shah & Frith, 1983) as well as superior ability to detect a hidden target in visual search tasks (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998). However, there is some evidence that these abilities may depend on the nature and complexity of the visual stimuli. Adolescents and adults with autism have been found to show superior orientation discrimination of luminance-defined gratings, but inferior discrimination of more complex, texture defined, gratings that are processed further along the visual processing pathway, relative to typically developing participants (Bertone, Mottron, Jelenic, & Faubert, 2005), suggesting that visual discrimination abilities may depend on stimulus complexity. Overall, though, visual processing of static spatial details is thought to be relatively spared in ASD.

In contrast, there has been some indication that the temporal aspects of information processing may be deficient in autism. Szelag, Kowalska, Galkowski, and Poppel (2004) presented children with auditory and visual stimuli of various durations and asked them to provide responses of identical lengths (e.g., press and hold a button down for the correct amount of time to produce a tone of the desired length). Results from this study revealed that children with autism had difficulty reproducing the lengths of both auditory and visual unisensory stimuli of standardized durations ranging in length from 1 to 5.5 seconds. Whereas typically developing children could reproduce durations up to 3 seconds almost veridically, children with autism typically provided responses of between 3 and 3.5 seconds, independent of the standard duration of the presented stimulus. Other studies have found atypical neural responses to low-frequency pitch changes in repeated, sequential auditory stimuli in children and adults with ASD (Gomot et al., 2006;

Tecchio et al., 2003), indicating a deficit in rapidly detecting changes in auditory input presented sequentially across time. In a study that examined the ability of 4- to 6-year old children to detect violations of temporal synchrony between intermodal (i.e., auditory and visual) stimuli, children with ASD showed impairment in detection of temporal synchrony of linguistic information in comparison to children with typical development and to those with non-autistic developmental delays (Bebko, Weiss, Demark, & Gomez, 2006). The authors hypothesized that children with ASD either do not recognize temporal asynchrony or require longer to detect it. Nonetheless, the temporal fidelity of sensory processing and the temporal binding of cross-modal stimuli have largely been overlooked in studies that have been conducted regarding perceptual processes in ASD.

Several studies have investigated cross-modal integration of auditory and visual information in ASD during higher-order cognitive processes such as speech perception, but their findings are equivocal (de Gelder, Vroomen, & van der Heide, 1991; Smith & Bennetto, 2007; J. Williams, Massaro, Peel, Bosseler, & Suddendorf, 2004). Discrepancies between study findings may relate to the confounds of using stimuli with inherent social properties and a task requiring language-related discriminations in a population with known social and language impairments. In contrast, little work has been done examining more basic facets of multisensory integration using low-level stimuli, free of social or language-based properties that confound higher-order tasks. In fact, only a single study has examined low-level integration of auditory and visual stimuli in ASD (Van der Smagt, van England, & Kemner, 2007). In this study, high functioning adults with ASD and matched controls completed a task in which they were asked to count the number of times a circle on the computer screen flashed while concurrently hearing varying numbers of beeps, which they were instructed to ignore. The number of beeps has been shown to produce the percept of additional illusory flashes (Shams, Kamitani, & Shimojo, 2002). The results of this study indicated that adults with ASD performed at equivalent levels as controls, indicating that task-irrelevant auditory information was being integrated with the primary visual input, yet it did not examine the integrity of the temporal window within which the illusion occured. Furthermore, it is worthwhile to note that the mean IQ in both groups was in the high average to superior range. While the results indicate that, at least in the highest of functioning adults with ASD, low-level multisensory integration may be intact, they do not speak to possible alterations in multisensory processing across the broad range of cognitive functioning that exists in ASD nor to the functioning of such processes across development. Thus, gaps in our knowledge about multisensory integration of low-level stimuli, a critical building block toward the ability to process and comprehend more complex information, across the autism spectrum remain largely unaddressed.

Sensory Processing and Theoretical Models of ASD

Despite clear indications of sensory abnormalities in clinical descriptions of ASD, preliminary empirical evidence for alterations in basic sensory processing, and the intuitive theoretical appeal of multisensory dysfunction in ASD, traditional theoretical models attempting to explain core deficits in ASD typically do not directly address sensory atypicalities. However, abnormal sensory processing could relate to or even underlie the core deficits posited by at least two of the models. The best popularized theories attempting to explain the core characteristics of ASD include deficits in “theory of mind”, which represents the ability to take the perspective of others (Baron-Cohen, 1995), “weak central coherence,” a difficulty in integrating information into a unified and coherent perceptual representation (Frith, 1989; Frith & Happe, 1994), and “executive dysfunction," an impairment in top-down cognitive control processes (Hughes, Russell, & Robbins, 1994; Ozonoff, Pennington, & Rogers, 1991). The theory of mind model largely ignores the sensory abnormalities that occur frequently in ASD, focusing instead on explaining social and communicative deficits. However, it could be suggested that in order to take the perspective of another person, one must be able to integrate a range of information that the other person is providing in their interaction (e.g., visually process their facial expression, aurally process tone of voice, proprioceptively process interpersonal space). In contrast, the weak central coherence model hinges on proposed differences in sensory processes; according to this theory, over-attentiveness to perceptual details causes individuals with ASD to miss the "big picture". Though the weak central coherence theory does not speak directly to abnormal sensory experiences across modalities, one might predict that hyperfocus on singular sensory or perceptual features of an object or stimulus could preclude the processing and integration of input from the other senses to create a unified whole, complete with all its multisensory features. Within the executive dysfunction hypothesis, there has been a focus on attention switching and set-shifting difficulties, in which individuals with ASD are thought to have difficulties appropriately disengaging their attention from one target in order to attend to another (Hill, 2004). While deficits in this ability are posited to relate to restricted interests and repetitive behaviors, they could also relate to sensory deficits. With regard to sensory processing within a given modality, if a child were hyperfocused on or interested in sensory aspects of objects, he might be resistant to shifting attention away from those features, regardless of the relative "real-world" importance of attending to the alternate target. Therefore, differences in the processing and integration of sensory information could potentially play central roles in causing the patterns of behavior and cognitive profiles delineated in the most popular and researched theories, despite the fact that the models have not previously been framed in a sensory context.

Newer theoretical models that have received support in the literature are more relevant to the notion of atypical multisensory processing in ASD and have begun to suggest that the functioning and communication of neural systems that support sensory processing may be impaired. For instance, suggestions that mirror neuron dysfunction may explain deficits in joint attention, imitation, and social communication in ASD (J. Williams, Whiten, Suddendorf, & Perrett, 2001) have direct relevance to multisensory processes, as mirror neurons (a class of neurons that has been discovered in frontoparietal regions of the cerebral cortex) have both multisensory and sensorimotor properties (Iacaboni & Dapretto, 2006; Rizzolatti, Fogassi, & Gallese, 2001). In an attempt to generate an all-encompassing theory of the neurological underpinnings of autism, Waterhouse, Fein and Modahl (1996) summarized evidence for dysfunction in four distinct but interacting neural systems. At the core of this theory is the recurring theme of deficits in multisensory systems, including those in the hippocampus, amygdala and neocortex that are responsible for associating stimuli across the sensory modalities.

Alterations in the structural connections and temporal relations between networks of brain regions that typically work in combination to process and make sense of complex information have also been proposed. According to the “complex information processing” model of ASD, selective impairment in the neural processing and integration of complex information across multiple domains and sensory modalities underlies core cognitive, behavioral, and social deficits that characterize ASD (Minshew, Goldstein, & Siegel, 1997). There is also some evidence from structural neuroimaging studies that the integrity of white matter connections between brain regions may be reduced in ASD, making communication between regions slower and less efficient (Barnea-Goraly et al., 2004). Furthermore, Just, Cherkassky, Keller, Kana, and Minshew (2004) introduced the possibility of reduced functional connectivity between brain regions that are synchronously activated in response to a stimulus or task demand as a potential neural mechanism for core deficits in ASD.

Related to the idea of functional underconnectivity, Brock, Brown, Boucher, and Rippon (2002) propose a temporal binding deficit in autism, wherein there is reduced communication, or temporal correlation, between brain regions that should be co-activated in processing complex stimuli. Theoretically, Brock et al.'s (2002) hypothesis most directly implicates underlying differences in temporal processing and cross-modal integration of sensory information in giving rise to core symptoms of ASD. This model builds on the weak central coherence theory and suggests that impairment in the temporal binding of information (i.e., binding together of input across senses when it is temporally proximal, thereby creating a multisensory percept) across local neural networks causes disturbances in information processing and integration, and ultimately, distorted representation of multisensory input. It is predicated on the idea that, in the typical brain, neural synchrony between interconnected sensory processing circuits may serve as the mechanism to "bind" related information (e.g., the sight and sound of a passing ambulance), thereby creating a cohesive and well-integrated perceptual gestalt (Singer, 1999; Uhlhaas & Singer, 2006).

Even if unisensory information processing were intact, impairment in the temporal binding mechanism might affect the processing of a multisensory stimulus, as individual components of the stimulus (e.g., visual, auditory) might be weakly bound, or not bound at all. Temporal integration of inputs that occur concurrently or in rapid sequential order is necessary for the creation of a perceptual gestalt (Poppel, 1997). On the other hand, processing of complex information in the real world necessarily must be completed within the temporal constraints of the stimulus duration, and proper, time-efficient processing, comprehension, and response to transient input are critical to understanding and functioning in a dynamic world. Therefore, the integrity of temporal processing and binding mechanisms is important for accurate perception in a dynamic and multisensory world.

Despite the intuitive appeal of newer models that suggest central impairments in sensory and multisensory systems, few studies have systematically examined unisensory and multisensory functioning in ASD, specifically as they relate to temporal processing, using objective, quantitative measures. A core deficit in the encoding and integration of sensory information at the neural level would likely impact downstream processes such as attention allocation, appropriate reaction to novel or unexpected stimuli or events, and comprehension of complex social information. Dysfunction in multisensory integration could therefore play an important contributory role in core social, communicative, and behavioral deficits in ASD. Furthermore, clearer understanding of the level at which sensory processing is impaired also may have important implications for intervention. In sum, a better characterization of some of the fundamental aspects of uni- and multisensory processing will represent an important step forward in our understanding of ASD.

Current Study

Prior research has established firmly that abnormalities in sensory functioning are described at high rates in ASD across sensory modalities and in the integration of multisensory input. However, many questions remain. The purpose of this study is to explore the functioning of unisensory and multisensory processing of low-level auditory and visual information in children with ASD, as compared to children with typical development. Specific emphasis is placed on the temporal aspects of sensory and multisensory processing. Information on unisensory information processing is important for understanding multisensory processing, since multisensory integration is thought to occur more strongly when input to a single modality is too weak (or too poorly processed) to convey the intended message of the input information, and because individual senses tend to dominate perception of information in other sensory modalities when they are specialized for making the discrimination of interest. The experiments described below attempt to characterize fundamental aspects of unisensory and multisensory processing using standardized psychophysical paradigms in order to shed light on some of the neural mechanisms that may underlie pervasive reports of atypical sensory processing and integration in individuals with ASD. Using standard psychophysical tasks, this study addresses the following research questions and tests related hypotheses as described below:

1) Is the ability to discriminate between two auditory stimuli presented in rapid temporal succession impaired in children with ASD, relative to children with TD? Exploring this initial question will provide a baseline understanding of the functioning of the auditory system, which should dominate the visual system in tasks requiring temporal judgments, in resolving rapidly presented stimuli.

Hypothesis #1: Children with ASD will show deficits in auditory temporal acuity when compared with children with typical development on an auditory temporal order judgment task, in line with past findings of impaired temporal processing of auditory information (Szelag et al., 2004). This alteration will manifest as a longer interstimulus interval necessary in order for children with ASD to resolve two sequential, rapidly occurring events at their perceptual threshold. If such a deficit is observed, it could affect the temporal window within which successive auditory stimuli continue to be bound together or to temporally proximal cross-modal (i.e., visual) stimuli, a question which will be explored further in research question 5.

2) Is the ability to discriminate between two visual stimuli presented in rapid temporal succession impaired in children with ASD relative to children with TD?

Hypothesis #2: Children with ASD will show deficits in visual temporal acuity when compared with children with typical development on a visual temporal order judgment task, in line with research finding impaired visual processing of motion and dynamic stimuli in ASD (Milne et al., 2002; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005; Spencer et al., 2000). This alteration will manifest as a longer interstimulus interval necessary in order for children with ASD to resolve two sequential, rapidly occurring events at their perceptual threshold.

3) Do children with TD respond in a similar manner as adults on tasks measuring multisensory processing? Specifically: a) does the addition of task-irrelevant auditory information enhance the ability to make temporal judgments regarding the onset of visual stimuli presented in rapid temporal succession in children with TD?, and b) does the addition of task-irrelevant auditory information bias visual

perception in creating the illusory percept of two visual stimuli where there is, in reality, only one? Exploring these questions will provide information regarding whether: a) children with typical development show comparable levels of multisensory integration to those seen in adults, and b) auditory information alters the ability to make visual temporal judgments, as would be predicted by the specialization of the auditory system in terms of its improved temporal acuity relative to that of the visual system and as is found in adults (Sham, Kamitani, & Shimojo, 2004).

Hypothesis #3: Children with TD will perform in a similar manner to adults. They will show enhanced accuracy in discriminating presentation order of two sequential visual stimuli separated by an interstimulus interval specified by their visual perceptual threshold with the addition of task-irrelevant auditory information. Furthermore, they will be susceptible to the creation of an illusory visual percept induced by temporally proximal auditory information. In addition to confirming the utility of these multisensory psychophysical tasks for use in children, the hypothesized observations would indicate that: a) multisensory integration of temporally proximal auditory and visual information is occurring in children with TD, and b) the auditory system is biasing the visual system in tasks that require rapid temporal discriminations, for which audition is better specialized.

4) Do children with ASD show similar patterns of multisensory integration to children with TD, in terms of combining temporally proximal, task-irrelevant auditory stimuli with target visual stimuli? Does the extent of multisensory integration differ between children with ASD and children with TD?

Hypothesis #4: If temporal binding of information processed in synchronously active brain regions is deficient in ASD, as multiple theories suggest (Brock et al., 2002; Rippon, Brock, Brown, & Boucher, 2007), we would predict decreased multisensory integration in children with ASD evidenced by decreased influence of auditory input on visual task performance.

5) If children with ASD show multisensory integration of auditory and visual information, is the temporal binding window within which such integration occurs different from that in children with TD?

Hypothesis #5: Children with ASD will differ in multisensory processing with regard to the "window" across which temporally proximal visual and auditory stimuli are bound. If structural connectivity between regions is compromised in ASD, as previous literature has suggested (Barnea-Goraly et al., 2004), neural signals responding to auditory and visual input could be predicted to be slower to reach sites of multisensory integration, thereby extending the time frame within which their signals overlap and expanding the temporal binding window.

This study is important in that it represents one of the first empirical explorations of low-level multisensory processing in ASD, using stimuli free of confounding social or communicative properties that likely represent additional processing challenges in ASD. It also explores the temporal aspects of sensory processing, which have been largely unaddressed in the experimental literature, by examining both the time necessary to discriminate among two stimuli within the same sensory modality and whether cross-modal sensory cues that occur in close temporal proximity are bound together to create a multisensory percept. This study is unique in that it examines unisensory and multisensory functioning in the same sample of individuals with ASD using parallel psychophysical tasks. Furthermore, it examines sensory functioning in children and adolescents, a period in development during which sensory difficulties are more prominent in individuals with ASD than they are at later ages (Kern et al., 2006).

CHAPTER II

METHODS

Participants

Forty children (20 with ASD and 20 with typical development [TD]) passed initial phone screening and participated in at least one session as part of this study. Participants with ASD (i.e., Autistic Disorder, Asperger's Disorder or Pervasive Developmental Disorder-Not Otherwise Specified) were recruited by: a) mailing letters to the families of children who had participated in previous Treatment and Research Institute for Autism Spectrum Disorders (TRIAD) research studies or other programs at Vanderbilt University and signed consent to be contacted for future research; b) posting flyers in the community; and c) distributing flyers at community seminars and meetings. Children with TD were recruited through a broadcast email sent to the Vanderbilt University Medical Center listserver as well as through flyers distributed in the community; 16 were selected to match already enrolled children with ASD on age and gender as closely as possible based on their dates of birth. The remaining four children with TD were initially enrolled as pilot participants, independent of enrollment of children with ASD; their data were included given that they did not alter the age, gender, or IQ distribution for the children with TD nor induce differences between groups on matching variables.

Eligibility criteria for children in both groups were as follows: a) age 8-17 years; b) normal or corrected-to-normal hearing and vision; c) Full Scale IQ above 70; and d) no evidence or past diagnosis of a specific reading disorder. Additional eligibility criteria for the ASD group required that children: a) have a confirmed diagnosis of Autistic Disorder, Asperger's Disorder or Pervasive Developmental Disorder-Not Otherwise Specified; and b) have no history of seizure disorders or known genetic disorders. Additional eligibility criteria for children with TD were as follows: a) no history of or current psychiatric, neurological, or learning disorders (e.g., ADHD, depression, epilepsy, dyslexia) or symptoms of ASD; and b) no first-degree relatives with ASD. Four children with ASD who passed the telephone screening did not meet eligibility criteria during the diagnostic session (two based on diagnosis, two based on cognitive functioning levels) and therefore did not participate in the experimental psychophysics session. Two additional children with ASD who attempted the experimental procedures were excluded from analyses due to difficulties with attention, comprehension, and compliance. The resulting sample consisted of 14 children with ASD and 20 children with TD. No group differences for chronological age, gender, Full Scale IQ, Verbal IQ, Performance IQ, or word reading abilities were found (Table 1). Higher IQ and reading scores indicate higher cognitive and reading abilities, respectively. As expected, significant group differences were found for autism symptoms, $t(32) = 9.83$, $p < 0.001$, and for sensory behaviors ($ps < 0.001$); parents of children with ASD reported significantly more autism symptoms and sensory abnormalities than did parents of children with TD. Higher scores on the SCQ represent higher levels of ASD symptomatology. Lower scores on the SP subscales indicate increased levels of sensory abnormalities.

Table 1: Sample Characteristics.

Measure	Group		Statistic	p-value
	ASD (n=14)	**TD** (n=20)		
Chronological Age (mo): Mean (SD)	144.7 (28.9)	144.7 (30.8)	t= .001	p=1.0
Gender: Number Male (%male)	11 (78.6%)	16 (80%)	$\chi 2$= .01	p=.92
WASI Full Scale IQ: Mean (SD)	108.7 (19.7)	109.0 (9.8)	t= -.05	p=.96
WASI Verbal IQ: Mean (SD)	107.2 (17.9)	111.2 (12.4)	t= -.75	p=.46
WASI Performance IQ: Mean (SD)	107.9 (19.0)	104.7 (8.4)	t= .58	p=.57
WJA Letter-Word ID: Mean (SD)	104.3 (16.6)	108.6 (8.0)	t= -.91	p=.41
WJA Word Attack: Mean (SD)	103.2 (10.2)	104.8 (5.6)	t= -.55	p=.62
SCQ Total Score: Mean (SD)	20.8 (7.9)	2.6 (2.3)	t= 8.06	p<.001
SP Auditory Processing: Mean (SD)	22.6 (6.3)	35.6 (3.1)	t= -6.92	p<.001
SP Visual Processing: Mean (SD)	31.2 (5.2)	41.2 (4.1)	t= -6.14	p<.001
SP Multisensory Processing: Mean (SD)	23.2 (3.1)	32.0 (2.8)	t= -8.30	p<.001

The intake diagnoses of the 14 children with ASD who successfully completed the experimental session were: Asperger's Disorder (n=7), Pervasive Developmental Disorder – Not Otherwise Specified (n=5), Autistic Disorder (n=2); updated formal clinical diagnoses were not issued as part of this study. Detailed clinical characterization (i.e., ADOS and ADI-R scores, clinical diagnosis) is reported in Appendix A.

Procedures

Potential participants were initially screened for eligibility using a phone interview with parents who expressed interest in having their child participate in the study; those who were eligible according to the initial phone screening were subsequently enrolled. Adequate cognitive functioning for inclusion in the study (i.e., FSIQ above 70) was confirmed at a research appointment using the Wechsler Abbreviated Scale of Intelligence (WASI: Wechsler, 1999) unless a child had completed cognitive testing in the past year and the parents could provide the scores. Reading abilities were screened using the Letter-Word Identification and Word Attack subtests of the Woodcock-Johnson Tests of Achievement – Third Edition (WJA-III: Woodcock, McGrew, & Mather, 2001), since differences in multisensory processing have been demonstrated in individuals with reading disorders (Hairston et al., 2005). All children in both groups were required to have reading standard scores above 70 on both subtests.

Children with ASD participated in two visits: 1) an initial visit during which diagnostic and cognitive screenings were completed to confirm eligibility for further participation in the experimental procedures; and 2) a second visit during which the child participated in experimental procedures and completed the two reading subtests while the parent completed a structured diagnostic interview. Children with TD participated in a single visit at which they completed both experimental psychophysics procedures and cognitive and reading screening measures. All sessions lasted between two and three hours. Parents of all participants gave informed consent and all children in both groups gave assent prior to participation in any component of this study. All children received compensation for their participation at each visit. Procedures were approved by the Vanderbilt University Institutional Review Board.

Children with ASD who passed the telephone screening were seen for an initial diagnostic confirmation appointment. At this appointment, they were administered the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000), Module 3 by a research-reliable examiner. All children included in the ASD group met criteria for autism or autism spectrum on the ADOS and also had prior clinical diagnoses of ASD confirmed by the clinical impressions of a licensed clinical psychologist. Two of the 20 children with prior ASD diagnoses were not included for the psychophysics session because they did not meet cut-off scores on the ADOS or present with clinical profiles entirely consistent with an ASD diagnosis. Children with ASD also completed the cognitive screening component of this study at this initial appointment given the rate of cognitive impairment that occurs in individuals with ASD; two additional children with confirmed ASD diagnoses were not included for the psychophysics session because they obtained WASI IQ scores below 70. Children with TD did not participate in an initial diagnostic session and were therefore administered the WASI during the experimental session. No children with TD obtained IQ scores below 70; thus, all were eligible for continuation with experimental procedures. Following eligibility determination, the sample consisted of 16 children with ASD and 20 children with TD, all of whom participated in the experimental session described below and attempted the psychophysics tasks.

During the experimental session, parent(s) of children with ASD completed the Autism Diagnostic Interview – Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994) with a trained, research-reliable interviewer to confirm history of ASD while their child participated in the experimental procedures. While their child completed the psychophysics tasks during the experimental session, parents of participants in both groups completed the Lifetime version of the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003) to provide a brief indication of autism-related concerns across all children, including those with typical development. Parents of children in both groups also completed the Caregiver Rating Form of the Sensory Profile (SP; Dunn, 1999) as well as the Sensory Experience Questionnaire (SEQ; Baranek et al., 2006) to provide independent information regarding children's sensory interests, aversions, and experiences.

For the experimental session, participants sat in a light- and sound-attenuated room, wearing headphones through which auditory stimuli were presented. They indicated their responses to task stimuli, presented on a computer monitor, through button presses on a response box. Visual stimuli were presented in white against a black background on a PC monitor (NEC Multisync FE992, 22 inch screen; 150 Hz refresh rate; 640x480 pixel resolution); specifics of visual stimuli for each task are described below. Auditory stimuli were presented via noise-canceling extra-aural headphones to both ears and were of equal binaural amplitude across all tasks that included auditory input. Volume of auditory stimuli was constant across participants within each task. Stimuli were presented using E-Prime presentation software (Psychology Software Tools Inc., Pittsburgh, PA., USA). Responses (i.e., accuracy and response time) were recorded via a Serial Response box compatible with E-prime software.

Participants were monitored by the experimenter through closed-circuit video cameras to ensure they were engaged in the tasks. In the infrequent instance that a participant was not on-task, a variety of strategies were implemented to increase engagement (e.g., reminders to stay on tasks, additional breaks, parent in the testing room, etc). Participants completed all experimental tasks within a single session in a fixed order; tasks are described in detail below. Participants were allowed to take breaks between tasks as necessary to increase compliance and maintain effort, motivation, and on-task behavior.

Measures

Clinical Tools

Social Communication Questionnaire (SCQ; Rutter et al., 2003): The SCQ is a 40-question caregiver report form inquiring about symptoms related to core diagnostic features of autism, designed to assess risk status for autism spectrum disorders. The Lifetime Version of the SCQ, which inquires about whether specific behaviors or features have ever been present across a child's lifetime as well as between the specific time period between four and five years of age, was used for this study. Parents of children both with and without ASD completed this questionnaire. A cutoff score of 15 typically indicates at-risk status for an ASD. No child with typical development exceeded this cutoff.

Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000): The ADOS is considered to be a 'gold standard' measure for autism diagnosis and involves an approximately 45- minute semi-structured interaction with a trained examiner in which the child's social interaction, play, and communication skills are observed and assessed. The ADOS is organized into four modules designed for use with individuals functioning at different developmental levels. All children with ASD who participated in this study were administered Module 3, which is intended for children and adolescents who are verbally fluent (i.e., have expressive language skills at or above the level expected of a typical four-year-old child) and for whom playing with toys is age-appropriate. Each module provides a set of behavioral ratings divided into five domains (i.e., Communication, Reciprocal Social Interaction, Imagination/Creativity, Restricted Interests and Repetitive Behaviors, and Other Abnormal Behaviors) as well as an algorithm that can be used to determine whether a child exceeds cut-off scores for autism or autism spectrum in Communication and/or Reciprocal Social Interaction domains, or on the Total Score. All children included in the ASD group exceeded the autism spectrum cutoff on the Total Score. The ADOS was not administered to children with TD.

Autism Diagnostic Interview – Revised (ADI-R; Lord et al., 1994): The ADI-R is a structured diagnostic interview that assesses the presence and degree of various symptoms and behaviors associated with ASD. It is administered to a parent or guardian by a trained examiner and inquires about current and lifetime concerns and symptom presentation across social, communication, and behavior domains. For this study, the ADI-R was only administered to parents of children with ASD and only the algorithm items (i.e., those included in the scoring algorithm to determine whether a child meets designated cutoff scores for an ASD diagnosis) were administered. All children included in the ASD group who participated in the experimental procedures met criteria for an autism spectrum disorder according to the Lifetime cutoff scores.

Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999): The WASI was administered to children with ASD who had not received cognitive evaluations in the past 12 months and to all children with TD. The WASI is a standardized and reliable instrument designed to obtain a brief assessment of general cognitive functioning in children and adults ages 6 to 89 years. It is composed of four subtests (i.e., Vocabulary, Similarities, Block Design, and Matrix Reasoning) that parallel subtests of the comprehensive Wechsler intelligence scales (i.e., WAIS-III, WISC-IV) and yields a Full Scale IQ score, as well as Verbal and Performance IQ scores. This measure was used to ensure that all children in both groups had sufficient cognitive capacity to understand experimental instructions and task demands, operationally defined here as having Full

Scale IQ scores above 70. The WASI was also used to ensure that ASD and TD groups were matched on intellectual functioning.

Sensory Profile (SP; Dunn, 1999): The SP Caregiver Questionnaire is a standardized rating form designed to measure sensory processing abilities of children ages 3 to 10 years old using a caregiver's report of the frequency with which behaviors across multiple sensory domains occur. According to the technical manual (Dunn, 2005), it has been used with clinical groups extending beyond the upper age limit for which it has been validated. The questionnaire consists of 125 items grouped into fourteen sections. The full SP was administered to parents of children in both groups to describe the day-to-day sensory functioning of the children and adolescents whose sensory and multisensory functioning we would empirically characterize using psychophysical tasks. Sections most relevant to the sensory and multisensory processes are: Auditory Processing, Visual Processing, and Multisensory Processing.

Experimental Tasks

The experimental tasks described below and summarized in Table 2 represent a series of psychophysical tasks that address temporal aspects of visual processing independently and in the presence of co-occurring, but task-irrelevant auditory stimuli. First, temporal acuity of the auditory system is examined to establish baseline auditory temporal resolution abilities using an auditory temporal order judgment (TOJ) task. Second, temporal resolution is examined in the visual system in terms of the ability to make judgments about stimulus onset order of visually presented stimuli in a visual TOJ task. Third, the ability of task-irrelevant auditory information to enhance or bias performance on two visual tasks is examined; observations of such enhancements or biases indicate that multisensory integration has occurred. In these multisensory tasks, auditory information is presented in combination with visual stimuli in two visual discrimination tasks: a) the multisensory TOJ task examines performance on a visual TOJ task with task-irrelevant auditory signals added; and b) the Flash/Beep task involves visual presentation of one or two flashing circles in conjunction with one or two beeps, presented aurally. While the auditory information in these two tasks contains no inherent information pertaining to the visual task demands and participants are instructed that they can ignore anything they hear, the auditory stimuli do provide task-irrelevant temporal information.

Table 2. Summary of Experimental Tasks

	Task (modality)	Examines:	Target Variables
Unisensory Temporal Processing	**Auditory TOJ** (A)	Temporal interval between two auditory stimuli needed to discriminate order of presentation (i.e., left vs. right ear first)	Interstimulus interval (SOA; reported in ms) at which discrimination accuracy is nearest 75%, termed "perceptual threshold"
	Visual TOJ (V)	Temporal interval between two visual stimuli needed to discriminate order of presentation (i.e., top vs. bottom first)	Interstimulus interval (SOA; reported in ms) at which discrimination accuracy is nearest 75%, termed "perceptual threshold"
Multisensory	**Multisensory TOJ** (V Task + additional A information)	1) Whether the addition of task-irrelevant auditory stimuli to the Visual TOJ task improves the accuracy with which presentation order of two visual stimuli, separated by a temporal interval fixed at the individual's visual perceptual threshold, can be discriminated 2) Contiguous window of delayed onsets of the second auditory stimulus, relative to the second visual stimulus (SOAs), for which discrimination accuracy is improved (termed "temporal binding window")	1) At each SOA condition: "accuracy gain" = % accuracy in an individual multisensory SOA condition minus % accuracy on a visual alone (i.e., no auditory input) baseline condition 2) Range of SOA values (in ms) at which significant accuracy gains are observed (see Multisensory TOJ variable #1)
	Flash/Beep (V Task + additional A information)	1) Degree to which two beeps presented with one flash creates the illusory visual percept of two flashes, termed the "double flash illusion" 2) Degree to which two flashes are reported on a 1-flash/1-beep control condition, termed "response bias" 3) Contiguous window of delay (SOA) conditions of the second auditory stimulus, preceding and following a synchronous 1-flash/1-beep stimulus presentation within which the flash/beep illusion occurs	1) At each 1-flash/2-beep SOA condition: strength of illusion = proportion of trials on which the illusory percept was reported (i.e., mean # of flashes reported; range=1-2) 2) Mean # of flashes reported on the 1-flash/1-beep control condition 3) Range of SOA values in the 1-flash/2-beeps conditions (in ms) at which the mean # of flashes reported was significantly greater than the mean # reported for the 1-flash/1-beep control condition

Auditory TOJ task: The Auditory TOJ task was designed to test auditory temporal acuity to establish baseline functioning of temporal resolution in the auditory system, which is uniquely specialized for making rapid temporal discrimination in the typical brain. In the auditory TOJ task, participants heard two identical tones, one presented to each ear in close temporal proximity, and were asked to determine in which ear the first tone was presented. Following instructions, a white fixation cross appeared on a black screen for 1000 ms. Immediately following the 1000 ms fixation, the first of two auditory stimuli was presented through headphones to either the right or left ear. Following a variable stimulus onset asynchrony (SOA), a second identical auditory stimulus was presented through the headphones to the opposite ear. The fixation cross then turned red and participants were able to respond. Participants indicated via button presses on the response box which ear they heard the first auditory stimulus (i.e., “left first” or “right first”). Following a response, a new trial began. Participants completed 10 practice trials, which included feedback regarding response accuracy, prior to completing the full task. All participants who successfully completed the full task did well on a majority of practice trials and appeared to comprehend the task demands, indicated by adequate performance on the practice run.

After practicing the task, participants were administered an adaptive staircase procedure to determine the SOA (i.e., time between the two auditory stimuli) necessary to perform the auditory TOJ task at threshold. An adaptive staircase procedure, in which three independent staircases ran concurrently, was used. All three staircases started at an SOA of 100 ms. The initial step size was 10 ms (i.e., amount by which the interstimulus interval was adjusted), which was decreased to 5 ms after five response reversals (i.e., reversals in response accuracy) and decreased again to 1 ms after an additional nine reversals to narrow in on the perceptual threshold. The SOA increased one step (i.e., became longer) after each incorrect response, and decreased one step (i.e., became shorter) after two consecutive correct responses. Each staircase terminated after sixteen reversals in response accuracy and an average was calculated from the last ten reversal values to produce the output threshold SOA. An average threshold value was calculated from the three staircase output values to yield a threshold value for the Auditory TOJ task. This thresholding procedure converged on a threshold SOA at which the participant performed at rates of 70-75% accuracy. Following the staircase procedure, participants performed a shorter confirmation procedure with SOA values set relative to their individual threshold, as determined from the staircase procedure. Three SOAs were used relative to this threshold: 0 ms (i.e., threshold), 10 ms above, 10 ms below. Each of these SOAs was repeated 20 times in a random order; at each SOA, the first auditory stimulus occurred in the left ear on half of the trials. If results of the confirmation procedure did not indicate that 70-75% accuracy rates had been produced for any of the three SOAs (i.e., performance was not near threshold for any of the SOA values), the confirmation procedure was repeated with higher or lower SOA values, depending on whether accuracy rates were too low or too high in the initial confirmation procedure.

Visual TOJ task: The visual TOJ task is designed to test temporal acuity of the visual system. In this task, participants were asked to determine which of two circles (above and below a fixation cross) presented in close temporal proximity (5-250 ms) appeared on the screen first. It is important to note that the decision participants were asked to make had both temporal (i.e., which stimulus was presented first?) and spatial (i.e., top or bottom?) demands. Following instructions, a white fixation cross appeared on a black screen. For each trial, after a delay of 1000 ms in which only the fixation cross was on the screen, the first of two circles appeared on the screen, either 7 cm above or below the fixation cross and remained on the screen. Following a variable stimulus onset asynchrony (SOA), a second circle appeared at the location opposite the first circle (e.g., above the fixation if the first circle came on below). Participants indicated via button presses on the response box which of the two circles appeared first (i.e., "top first" or "bottom first"). Following a response, both circles disappeared and a new trial began. Participants completed 10 practice trials, which included feedback regarding response accuracy, before completing the full task.

After practicing the task, participants were administered a staircase procedure to determine the SOA (i.e., time between the two visual stimuli) necessary to perform the visual TOJ task at threshold. An adaptive staircase procedure, in which three independent staircases were run concurrently, was used. One staircase started at an SOA of 80 ms, the second started at an SOA of 1 ms, and the third started at an SOA of 50 ms. The initial step size (i.e., amount by which the interstimulus interval was adjusted), was 28 ms, which was decreased to 14 ms after five response reversals (i.e., reversals in response accuracy) and decreased again to 7 ms after an additional nine reversals. The SOA increased one step (i.e., became longer) after each incorrect response, and decreased one step (i.e., became shorter) after two consecutive correct responses. Each staircase terminated after sixteen reversals in response accuracy and an average was calculated from the last five reversal SOA values to produce the output threshold SOA. An average threshold value was calculated from the three staircase output values and rounded to the nearest value compatible with the vertical scan rate of the monitor (i.e., multiple of 7). This procedure converged on the threshold SOA at which the participant performed at rates of 70-75% accuracy. Following the staircase procedure, participants performed a shorter confirmation procedure with SOA values set relative to their individual threshold, as determined from the staircase procedure. Three SOAs were used relative to this threshold: 0 ms (i.e., threshold), 7 ms above, 7 ms below. Each of these SOAs was repeated 20 times in a random order; at each SOA, the first visual stimulus appeared on the top on half of the trials. If results of the confirmation procedure did not indicate that 70-75% accuracy rates had been produced for any of the three SOAs (i.e., performance was not near threshold for any of the SOA values), the confirmation procedure was repeated with higher or lower SOA values, depending on whether accuracy rates were too low or too high in the initial confirmation procedure.

Multisensory TOJ task: In the multisensory TOJ task, task-irrelevant auditory stimuli were added to the visual TOJ task. This paradigm capitalized on previous work demonstrating that the addition of task-irrelevant auditory stimuli can improve performance on the visual TOJ task (i.e., enable individuals to discriminate between the two visual stimuli when they are presented temporally closer together) if presented within a particular temporal window (Hairston, Hodges, Burdette, & Wallace, 2006; Morein-Zamir, Soto-Faraco, & Kingstone, 2003). This phenomenon is thought to relate to the ability of the auditory system, which is more specialized for resolving temporal information relative to the visual system, to dominate and modify visual perception when stimuli present with temporal components (Shams et al., 2002; Shimojo et al., 2001). For this experiment, visual stimuli were presented as described above for the Visual TOJ task except that, on each trial, the interstimulus interval between the two visual stimuli was fixed according to each individual's threshold value, as derived from the visual TOJ staircase and confirmation procedures described above. Two identical sounds were also presented on 89% trials through extraaural headphones, with the first sound always occurring synchronously with the first visual stimulus onset. The second sound was delayed by 0-500 ms relative to the onset of the second visual stimulus (SOA increments were as follows: 0, 50, 100, 150, 200, 300, 400, 500 ms) (Figure 1). A randomly interleaved no-sound (i.e., visual only) condition provided baseline performance and represented the remaining 11% of trials.

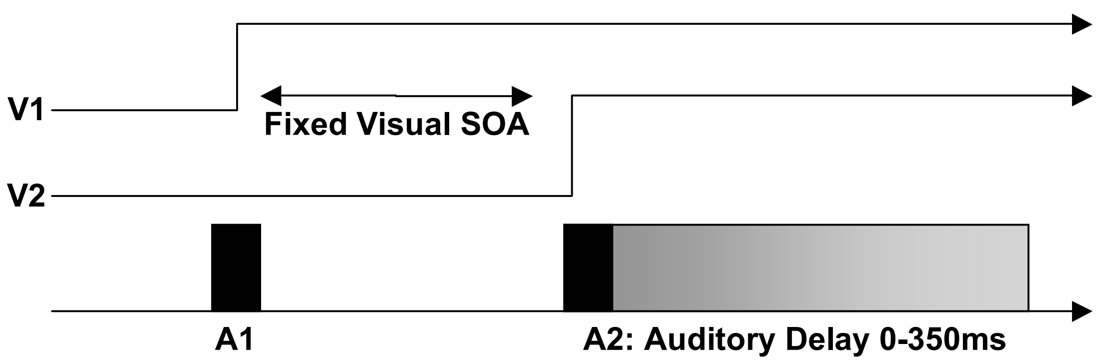

Figure 1. Schematic of the Multisensory TOJ task trial sequence. Two visual stimuli (V1 and V2) appeared on the screen, one above the fixation cross and one below, with an SOA fixed according to individual participants' visual threshold as determined in the Visual TOJ task; participants reported which visual stimulus appeared first. Two auditory stimuli (A1 and A2) were presented; A1 coincided with the onset of V1, while A2 was presented with variable delay (0-500 ms) following the onset of V2.

Each auditory SOA condition and the no-sound condition was presented 16 times in random order; at each SOA, the first visual stimulus appeared on the top on half of the trials. Participants were told from the outset that while they often would be hearing sounds through the headphones, the task was the same as in the visual TOJ (i.e., determine whether the top or bottom circle appears first) and they could ignore the sounds. Given that sounds were presented binaurally through headphones with no interaural timing or amplitude level differences, they did not provide any task-relevant spatial information that would provide clues as to whether the “top” or “bottom” circle occurred first. However, though not relevant for making spatial discriminations as is required in this task, the auditory cues did provide temporal information.

Flash/Beep Task: The second multisensory task, termed “Flash/Beep”, explored the double-flash illusion, wherein the addition of multiple auditory stimuli presented in conjunction with a single visual stimulus results in perception of a visual illusion. Instead of measuring the potential for multisensory integration of task-irrelevant auditory information to induce performance *gains* on a unisensory visual task, this task examines the extent to which distracting auditory information *interferes* with performance (i.e., induces an illusion) on a task in which the primary demands are unisensory and visual. Previous research in healthy adults has shown that when a single flash of light is paired with multiple auditory stimuli (i.e., beeps), people will often report experiencing the illusory percept of seeing multiple flashes of light (Shams et al., 2002). Importantly, the relative timing of the flash and beeps is crucial to the perception of the illusion in typical adults. Given that the flash presentation is brief in duration, counting the number of flashes places demands on temporal resolution abilities. The demands for optimized temporal acuity in discerning the number of flashes presents a situation in which the more temporally-sensitive auditory system could dominate and modify visual perception. In this task, participants were asked to count the number of flashes they perceived visually while they also heard beeps presented through headphones. Following instructions, a fixation cross appeared at the center of the screen. The visual stimulus was a white disk (4.2 cm in diameter) that appeared 4 cm directly below the fixation cross. The white disk was presented either once (with a duration of 17 ms) or twice (17 ms duration per presentation, with a 50 ms inter-stimulus interval between flashes); flashes were presented with zero, one, or two beeps dependent on condition. The auditory stimuli (i.e., beeps) always had a duration of 7 ms. Conditions containing one flash and two beeps were used to explore the nature of the double-flash illusion in ASD. In the 1-flash/2-beep conditions, two beeps were present at varying SOAs along with a single flash to determine the temporal window in which multisensory integration (i.e., the illusory percept) occurred. One beep always coincided with the onset of the single flash. The second beep was either delayed by 0-500 ms relative to the offset of the flash presentation (i.e., positive SOA values) or occurred 0-500 ms prior to the onset of the coinciding flash and beep (i.e., negative SOA values); SOA increments in both directions (i.e., additional beep occurring either before or after the coincident flash/beep presentation) were as follows: 25, 50, 100, 150, 200, 300, 400, 500 ms (Figure 2). For each condition, 10 trials were randomly presented. Because of the length of time required to present all the trials, the task was divided into two blocks with a break in the middle; participants were allowed to take a break and could restart the task with a button press. Five trials for each condition were presented both before and after the break.

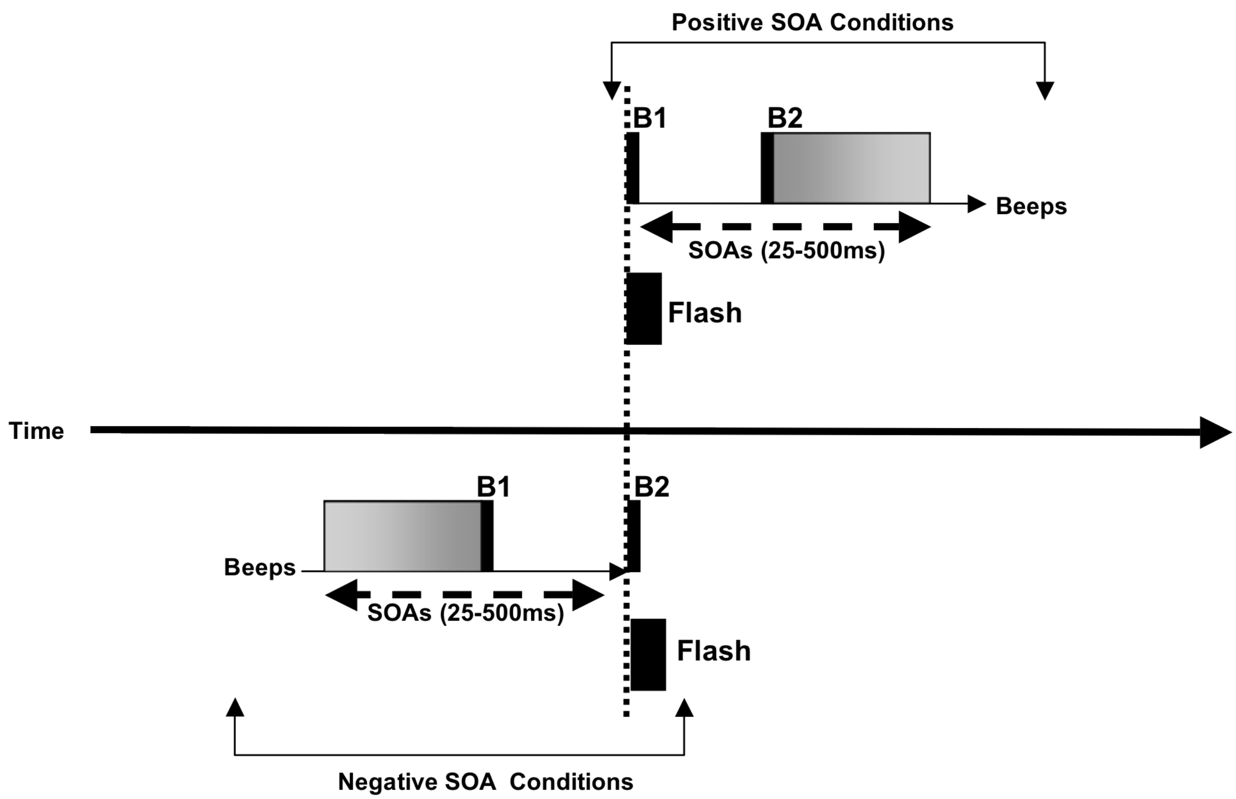

Figure 2. Schematic of Flash/Beep task. Two beeps (B1 and B2) were presented with a single flash (F1). One beep (B1 for positive SOA conditions, B2 for negative SOA conditions) was presented coincidently with the single flash. For positive SOA conditions, a second beep (B2) was presented with variable delay (25-500 ms) following the onset of the coincident F1/B1 presentation. For negative SOA conditions, an initial beep (B1) was presented preceding the onset of the coincident F1/B2 presentation by variable temporal increments (25-500 ms).

Participants indicated their response (i.e., how many flashes they perceived) by pressing buttons labeled “1” and “2”. Prior to completing the task, participants completed 6 practice trials in which they counted flashes presented without any auditory stimuli; they were subsequently reminded that their task was to count the flashes they visually perceived, not the beeps they heard; they were explicitly told they could “ignore the beeps.”

Data analysis

Response accuracy data were recorded for each trial within each task. Data from each experiment were first analyzed using independent samples t-tests to examine any between group differences on the dependent variables of interest (see Table 2). For the auditory and visual TOJ tasks, t-tests were used to explore potential group differences in threshold SOA values, as produced from the adaptive staircase and confirmation procedures, to determine whether children with ASD have altered auditory and/or visual temporal acuity compared to typically developing children.

For the Multisensory TOJ task, accuracy gains at each SOA were defined by subtracting the accuracy rate for the visual-alone baseline condition from the accuracy rate at each of the multisensory delay conditions (i.e., SOA conditions). Independent-sample t-tests were conducted with the accuracy gain values at each SOA to determine whether the magnitude of multisensory integration-related accuracy gains differed between groups at any of the delay conditions. The temporal binding window for integration, defined by consecutive SOA conditions at which there were significant gains in accuracy, was then examined separately for each group. To determine the delay conditions at which significant accuracy gains were observed (i.e., temporal binding was evident), one-sample t-tests were conducted for each SOA condition, comparing percent accuracy gain to an alternative value of 0, representing no gain in accuracy relative to the visual-alone baseline condition. This analysis was run separately for the ASD and TD groups in order to examiner group-specific windows.

For the Flash/Beep task, the mean number of flashes perceived at each SOA condition was calculated separately for each individual. Differences in the magnitude of multisensory integration, defined by the proportion of trials on which an illusory flash was reported (i.e., the participant indicated seeing two flashes when only one was presented), were examined between groups using independent samples t-tests at each SOA. Performance differences on the one-flash/one-beep control condition from this task were examined in a similar manner in order to examine any response biases. The temporal window over which multisensory integration continued to occur, evidenced by reported perception of the second flash, was determined separately for each group using paired-sample t-tests to determine the SOA conditions at which the mean number of flashes perceived differed significantly from the mean number reported on the one-flash/one-beep control condition.

CHAPTER III

RESULTS

Overall, 14 children with ASD and 20 children with typical development successfully participated in the experimental session. Data were not available and/or useable for all participants across all tasks and individual participant's data were excluded from each task according to criteria specific to each task (described below). Even after exclusion of data within individual tasks, the remaining subsets of children with ASD and TD did not differ on age, gender, IQ, or reading ability for any task (all p's > 0.22). Final participant numbers for each task are presented in Table 3.

Table 3. Final participant sample sizes by psychophysical task.

Task	Number of Participants (% of total)	
	ASD (n=14)	**TD (n=20)**
Auditory TOJ	11 (79%)	16 (80%)
Visual TOJ	14 (100%)	20 (100%)
Multisensory TOJ	13 (93%)	20 (100%)
Flash/Beep	13 (93%)	15 (75%)

Auditory TOJ Task

Eleven of fourteen children with ASD (78.5%) and 16 of 20 children with TD (80%) were included in analyses for the auditory TOJ task. The three children with ASD who were excluded from auditory TOJ task analyses attempted the task but were unable to comply with task instructions to a sufficient degree to yield a threshold at which their performance was near 75% accuracy. Four children with TD were not included in analyses for this task because they completed an earlier version of the auditory TOJ task that was subsequently modified. On average, children with ASD required an interstimulus interval of 109.0 ms (SD=30.8), while children with TD required 68.4 ms (SD=30.2) between stimuli to determine the ear (i.e., left or right) to which the first auditory stimulus was presented (Figure 3). This difference was statistically significant, t (25) = 3.40, p = .002, Cohen's d = 1.36. Cohen's d indicated a large effect size for this difference in auditory temporal threshold between ASD and TD groups (Cohen, 1988). Whereas children with TD perform at an auditory threshold similar to that seen in adults (Kanabus, Szelag, Rojek, & Poppel, 2002), children with ASD require significantly longer interstimulus intervals to differentiate two auditory stimuli.

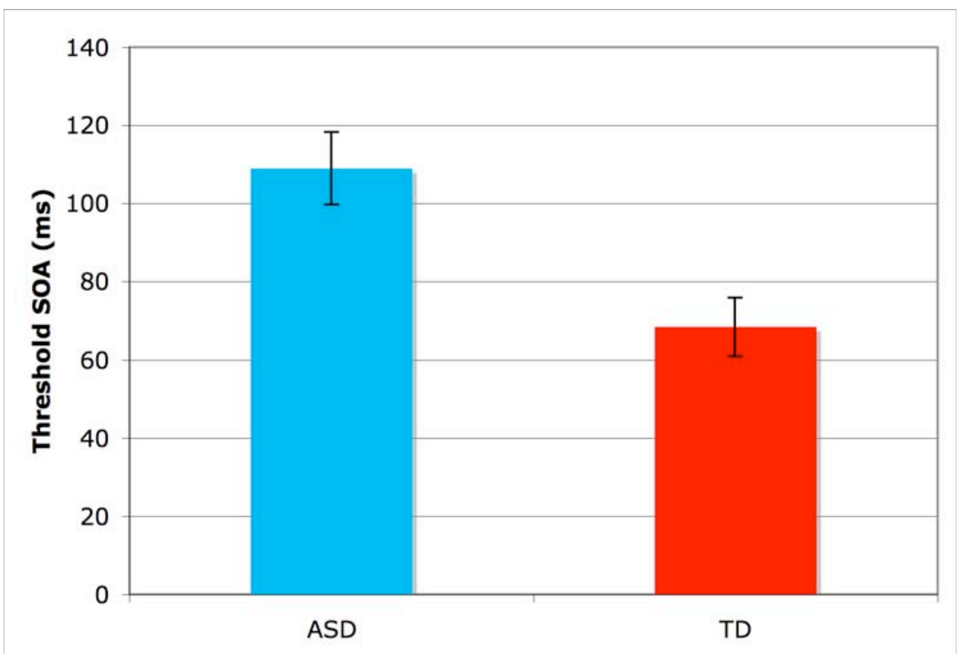

Figure 3. Auditory TOJ task: Differences in auditory TOJ threshold between ASD and TD groups. The average threshold SOA for the auditory TOJ task was longer for the ASD group (blue bar) than for the TD group (red bar) and reached statistical significance. To perform at an equivalent perceptual threshold (i.e., at approximately 75% accuracy), children with ASD required 59% more time than did children with TD.

The perceptual threshold at which children could reliably report presentation order of auditory stimuli was 59% longer in ASD than in TD. In other words, children with ASD required a 59% longer temporal interval between two auditory stimuli to perform at the same level of accuracy on the task than did children with TD. This finding suggests that temporal resolution in the auditory system is impaired in children with ASD.

<u>Visual TOJ Task</u>

All children in both groups completed the visual TOJ task and were able to comply with task instructions to a sufficient degree to yield a threshold at which their performance was near 75% accuracy. On average, children with ASD required an interstimulus interval of 65.0 ms (SD=36.4), while children with TD required 45.5 ms (SD=20.6) between stimuli to determine which stimulus (i.e., top or bottom circle) was presented first (Figure 4). This difference approached significance, $t(32) = 1.991$, $p = .055$ Cohen's $d = 0.70$. Cohen's d indicated a medium to large effect size for this difference in visual temporal threshold between ASD and TD groups. Whereas children with TD perform at a visual threshold similar to that seen in adults (Kanabus et al., 2002), children with ASD require significantly longer interstimulus intervals to differentiate two visual stimuli.

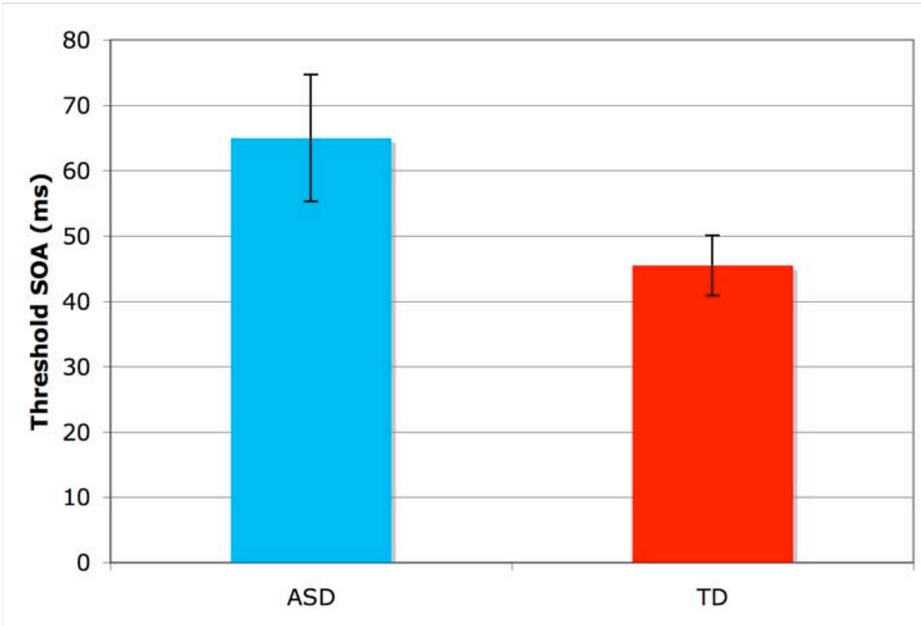

Figure 4. Visual TOJ task: Differences in visual TOJ threshold between ASD and TD groups. The average threshold SOA for the visual TOJ task was longer for the ASD group (blue bar) than for the TD group (red bar) and approached statistical significance. To perform at an equivalent perceptual threshold (i.e., at approximately 75% accuracy), children with ASD required 43% more time than did children with TD.

The perceptual threshold at which children could reliably report stimulus presentation order was 43% longer in ASD than in TD. In other words, children with ASD required 43% longer temporal intervals between visual stimuli to perform at the same level of accuracy on the task as did children with TD.

Multisensory TOJ Task

All children in both groups who completed the visual TOJ task also completed the multisensory TOJ task. However, one child with ASD was not included due to examiner error in specifying the interstimulus interval. As a result, the total numbers of children included in the ASD and TD groups for this task were 13 and 20, respectively. The interstimulus interval used for the Multisensory TOJ task was fixed according to each participant's individual visual threshold, as determined by the Visual TOJ staircase confirmation procedure. Accuracy on the visual-alone (i.e., baseline) trials did not differ significantly between groups, t (31) = -1.45, p = 0.16, Cohen's d = 0.52, though the effect size was moderate. Accuracy gains were computed by subtracting an individual's percent accuracy on the visual-alone condition from the percent accuracy at each SOA condition separately. Comparing accuracy gains at each SOA across groups revealed no significant differences, indicating that the magnitude of multisensory enhancements did not differ between groups at any auditory delay condition (all p's > 0.28).

The temporal window of multisensory integration can be defined by the range of consecutive SOAs at which percent accuracy for judging the temporal order of the visual stimuli in the context of additional task-irrelevant auditory stimuli, is significantly greater than percent accuracy on control trials without auditory stimuli. Using single-sample t-tests, accuracy gains at each multisensory SOA condition were compared to zero, which represented no multisensory gain (see Table 4 for statistics).

Table 4. Multisensory TOJ task: accuracy gains by group (full sample).

	ASD (n=13)			**TD (n=20)**		
SOA	accuracy gain	t-statistic	p-value	Accuracy gain	t-statistic	p-value
0 ms	0.091	2.204	.048	0.079	1.828	.083
50 ms	0.135	2.027	.065	0.123	4.111	.001
100 ms	0.101	2.007	.068	0.123	4.055	.001
150 ms	0.202	3.732	.003	0.131	3.401	.003
200 ms	0.143	4.880	.000	0.095	3.039	.007
300 ms	0.105	2.282	.042	0.091	2.174	.043
400 ms	0.067	1.200	.253	0.070	2.791	.012
500 ms	0.032	.641	.534	0.069	1.885	.075

In children with TD, significant improvements in accuracy above visual-alone baseline were seen at the following SOAs: 50ms, 100ms, 150ms, 200ms, 300ms, and 400ms, and gains at SOAs of 0ms and 500ms also approached statistical significance. In children with ASD, significant multisensory enhancements above visual-alone baseline were seen at SOAs of 0ms, 150ms, 200ms, and 300ms, while gains at SOAs of 50ms and 100ms also approached statistical significance (Figure 5).

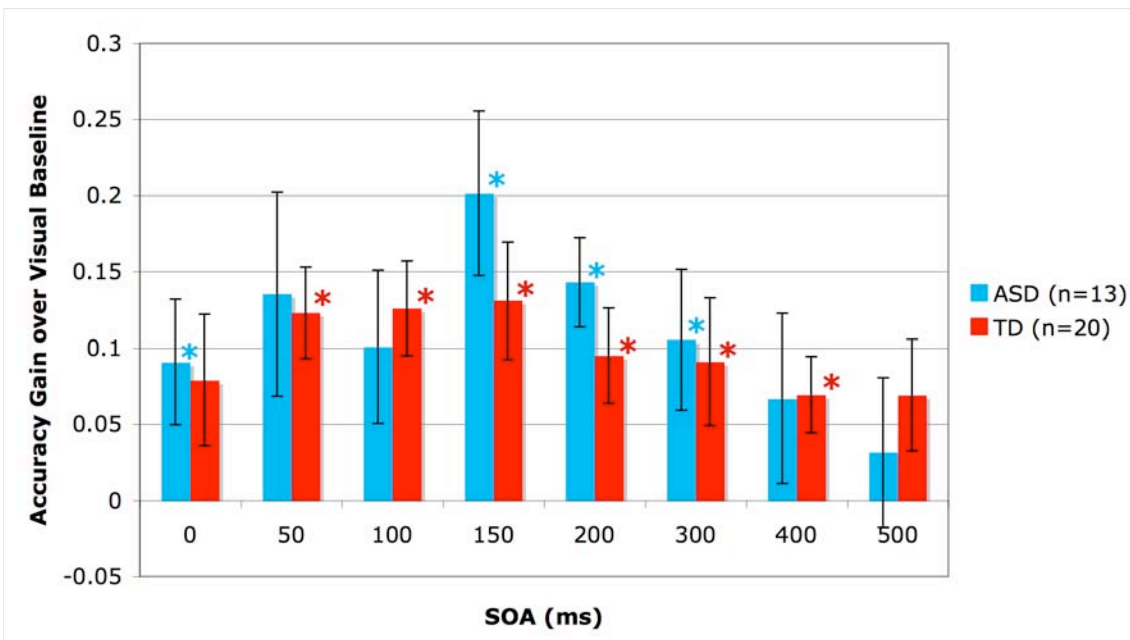

Figure 5. Multisensory TOJ task: Defining the temporal binding window (full sample). Significant accuracy gains over visual-alone baseline conditions (asterisks represent single-sample t-tests at $p < 0.05$) across a range of SOA conditions representing various temporal delays for the second auditory stimulus. Across both groups, the extent of accuracy gain above visual-alone baseline depended on the amount of auditory delay.

Post-Hoc Analyses for the Multisensory TOJ Task

Data for individual participants were subsequently examined more closely and a number of children (i.e., 6 children with ASD and 11 with TD) were ultimately excluded from follow-up analyses based on two observations. First, several children showed a pattern of consistent lack of improvement in accuracy of visual discrimination across all SOAs, including declines in performance on many conditions. These children also were performing at very high accuracy levels on visual-alone trials, indicating that the chosen threshold from the Visual TOJ task was likely too high and their performance was too close to ceiling, thus minimizing the opportunity for accuracy gain. Based on this observation, it was determined that children would be excluded from the follow-up analysis if they did not show gains on at least 25% of SOA conditions (i.e., 2 of 8). One child with ASD and three children with TD were excluded based on this criterion.

Second, an additional subset of children across both groups was noted to be performing at a much lower accuracy rate on the visual-alone baseline trials than would be expected, given that the interval between visual stimuli was fixed based on the SOA in the Visual TOJ task at which the individual child had been performing near 75% accuracy. Because these children's performance was so close to chance (i.e., 50% accuracy), the task was likely too difficult and resulted in guesses across both the visual-alone and the multisensory conditions. For the final analyses, data from participants whose accuracy scores on the visual-alone baseline condition were below 60% were excluded. This second criterion eliminated an additional five children with ASD and seven children with TD from the final analyses.

The remaining sample included seven children with ASD and 10 children with TD. While the final sample size was ultimately significantly reduced relative to the full sample, this reduced sample represents a group of children for whom the task was most clearly assessing multisensory integration as it was intended, in that they were performing above chance at their perceptual threshold, yet had room for gains in accuracy related to multisensory integration. All analyses conducted with the original sample were repeated on this reduced sample. For the Auditory TOJ task, while group differences were non-significant in this subset of participants, $t\ (15) = 1.291$, $p = .22$, Cohen's $d = .67$, the general pattern of children with ASD requiring longer interstimulus intervals to differentiate stimulus presentation order held and Cohen's d indicated that the effect size remained medium to large. The children with ASD in this sample required 34% longer to reliably discriminate auditory stimulus order, relative to children with TD (ASD: M=91.67 ms, SD=31.5; TD: M=68.62 ms, SD=34.1). A similar pattern was found for the Visual TOJ task. While group differences were again non-significant, $t\ (15) = 1.171$, $p = .26$, Cohen's $d = .60$, children with ASD in this sample required 35% longer to reliably discriminate stimulus order relative to children with TD (ASD: M=50.00 ms, SD=29.5; TD: M=37.10 ms, SD=15.8) and the effect size remained medium to large.

In this reduced sample, accuracy on the visual-only (i.e., baseline) trials of the Multisensory TOJ task did not differ between groups, $t\ (15) = -0.879$, $p = 0.39$, Cohen's $d = -.45$. In contrast to the full sample, within which there were no group differences in the degree of multisensory integration at any SOA condition, significant group differences in accuracy gains were revealed at the 200ms SOA, $t\ (15) = 2.18$, $p = .046$, with group differences at the 50ms SOA approaching statistical significance, $t\ (15) = 1.90$, $p = .077$. No group differences were revealed at other SOA conditions. This finding indicates that, at some SOA intervals, performance on a visual TOJ task was improved by spatially non-informative auditory input to a greater extent in children with ASD than in children with TD (i.e., children with ASD were integrating auditory and visual information more than children with TD), but this difference was not seen consistently and differences must be interpreted cautiously. The temporal window of multisensory integration was examined separately for children with ASD and TD in this reduced sample, again using single-sample t-tests to compare accuracy gains at each multisensory SOA condition to zero (Table 5 for statistics).

Table 5. Multisensory TOJ task: accuracy gains by group (reduced sample).

SOA	ASD (n=7)			TD (n=10)		
	accuracy gain	t-statistic	p-value	accuracy gain	t-statistic	p-value
0 ms	0.089	2.129	.077	0.068	1.846	.098
50 ms	0.160	5.211	.002	0.068	1.987	.078
100 ms	0.089	2.187	.071	0.113	3.175	.011
150 ms	0.223	6.301	.001	0.143	4.680	.001
200 ms	0.133	5.151	.002	0.062	3.043	.014
300 ms	0.097	1.816	.119	0.019	0.536	.605
400 ms	0.043	1.015	.349	0.055	2.323	.045
500 ms	0.077	1.535	.176	0.055	1.928	.086

In children with TD, significant multisensory enhancements above visual-alone baseline were seen at the following SOAs: 100ms, 150ms, 200ms, and 400ms, while gains at SOAs of 50ms and 500ms also approached statistical significance (Figure 6). In children with ASD, significant multisensory enhancements above visual-alone baseline were seen at the following SOAs: 50ms, 150ms, 200ms, while gains on SOAS of 0ms and 100ms also approached statistical significance (Figure 6). While significant accuracy gains were observed at many SOA conditions for both groups, the consecutive window of multisensory-related performance enhancement is difficult to define, likely related to the reduced sample size in this analysis. Though multisensory integration is clearly occurring in both groups of children, the temporal binding window within which this is occurring cannot be defined with certainty.

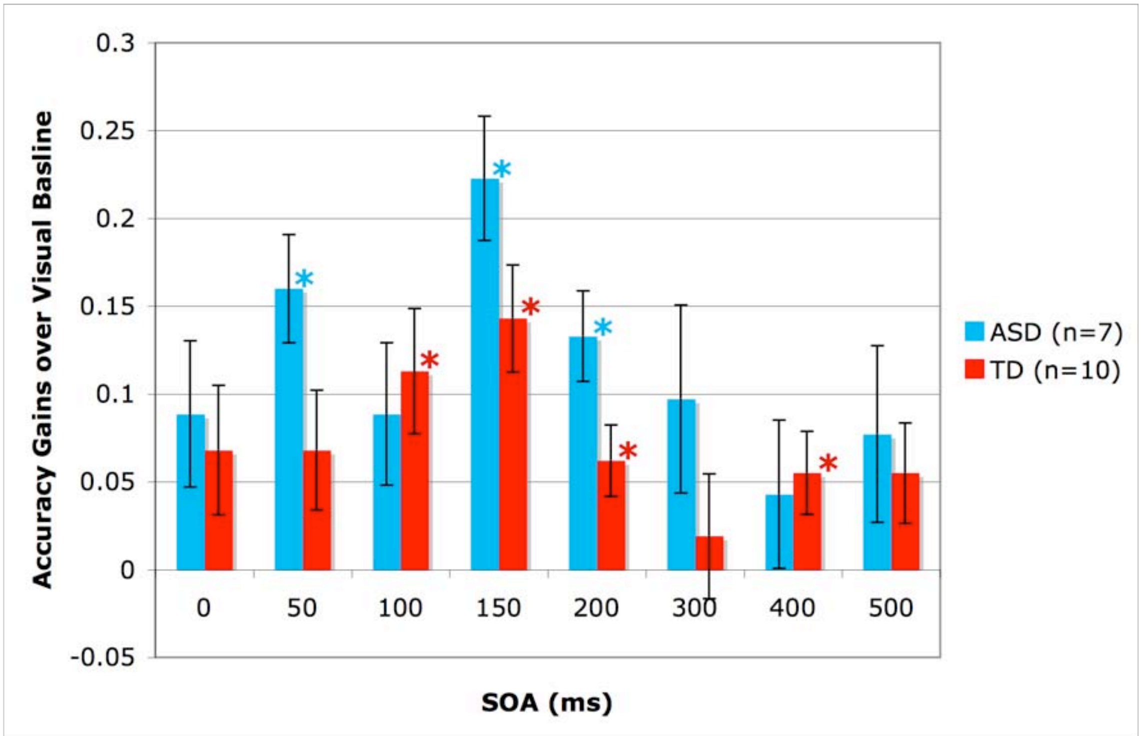

Figure 6. Multisensory TOJ task: Defining the temporal binding window (reduced sample). Significant accuracy gains over visual-alone baseline conditions (asterisks represent single-sample t-tests at $p < 0.05$) across a range of SOA conditions representing various temporal delays for the second auditory stimulus. Across both groups, the extent of accuracy gain above visual-alone baseline depended on the amount of auditory delay.

Flash/Beep Task

Thirteen of 14 children with ASD (93%) and 15 of 20 children with TD (75%) were included in analyses for the flash/beep task. Given that the task was administered to examine the strength and temporal window of the illusion, it was decided a priori that children who showed no evidence of the illusion would be excluded from analyses. One child with ASD was excluded from analyses based upon this criterion. Four children with TD who participated in the overall experimental session but are not included in this analysis completed an older version of the flash/beep task in which the range of SOA values only extended to 300ms in both directions; since it was impossible to determine what these children's performance would have been at the longer SOA intervals, their data were excluded from analyses for this task. An additional child with TD did not complete this task.

The mean number of perceived flashes was computed at each 1-flash/2-beeps SOA condition for each child and ranged from 1 (i.e., report of a single flash on all trials within a given condition) to 2 (i.e., report of two flashes on all trials within a given condition). Means closer to 2 indicate greater strength of illusion. Between group comparisons in the number of flashes reported were conducted for each SOA of the 1-flash/2-beeps conditions as well as for the 1 flash/1 beep condition. On the 1-flash/1-beep condition, children in both groups did not always report a single flash, indicating some degree of response bias. In fact, the mean number of flashes reported was significantly different from 1 in both groups, ASD group ($M=1.19$ flashes; $SD=.21$): $t(12) = 3.145$, $p = .008$; TD group ($M=1.09$ flashes; $SD=.14$): $t(14) = 2.475$, $p = .03$. However, these values did not differ between groups, $t(26) = 1.403$, $p = .18$, Cohen's $d = 0.55$, though the effect size was moderate.

Between group comparisons of the strength of the illusion (i.e., proportion of trials on which the illusory second flash was reported) were conducted at each SOA for the 1-flash/2-beeps conditions. Significant group differences in the mean number of flashes reported were observed, with children with ASD more frequently reporting two flashes than children with TD, at the following SOAs: -500ms, -300ms, -50ms, -25ms, +25ms, +200ms, +300ms, and +400ms (p's < .05), and group differences approaching significance at SOAs of -400ms, -150ms, +50ms, and +100ms (ps < .10). This result indicates that children with ASD experienced the double-flash illusion to a greater extent, suggestive of increased strength of multisensory integration (Figure 7).

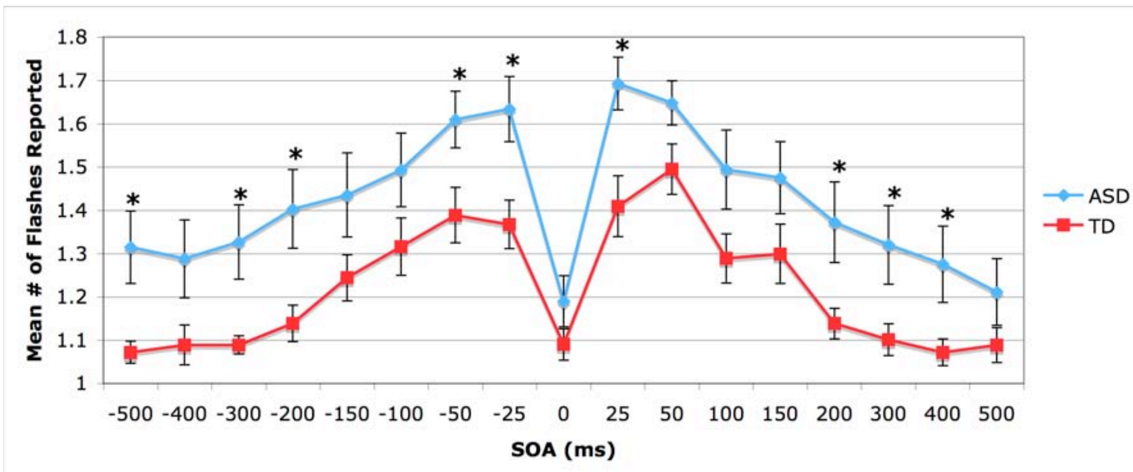

Figure 7. Flash/Beep task: Strength of visual illusion in ASD and TD across SOA conditions. The mean number of flashes reported by children with ASD was greater than the mean number reported by children with TD across a range of SOA conditions, representing various temporal delays between one beep and the coincident 1flash/1beep presentation (asterisks represent independent-sample t-tests at p < 0.05). The number of flashes reported for the 1Flash/1Beep control condition (represented here as an SOA of 0 ms) did not differ between groups. Across SOA conditions where there were 2 beeps presented, children with ASD reported the illusory second flash to a greater extent than did children with TD.

The temporal window within which the illusion occurs can be defined by the contiguous span of consecutive SOAs at which the mean number of flashes reported is significantly greater than the mean number of flashes reported on the 1-flash/1-beep condition. To examine the temporal window of this multisensory illusion in children with ASD and TD, paired-sample t-tests comparing each 1-flash/2-beeps SOA condition to the 1-flash/1-beep condition were conducted separately for the ASD and TD groups (Table 6).

Table 6. Flash/Beep task: Multisensory illusion-related increases in mean number of flashes reported over mean report for a 1-flash/1-beep (1F/1B) control condition. Reported separately for each 1-flash/2-beeps SOA condition.

	ASD			**TD**		
		Increase over 1F/1B report			Increase over 1F/1B report	
SOA	Mean # flashes	t-statistic	p-value	Mean # flashes	t-statistic	p-value
-500	1.315	2.676	.020	1.072	-.574	.575
-400	1.288	1.709	.113	1.089	.000	1.000
-300	1.327	2.509	.027	1.089	-.012	.990
-200	1.403	3.243	.007	1.139	1.034	.319
-150	1.435	3.552	.004	1.244	4.099	.001
-100	1.493	5.105	.000	1.316	4.483	.001
-50	1.609	5.354	.000	1.389	5.854	.000
-25	1.634	5.070	.000	1.367	4.248	.001
+25	1.692	6.531	.000	1.409	4.342	.001
+50	1.648	6.375	.000	1.495	7.796	.000
+100	1.494	3.503	.004	1.289	3.308	.005
+150	1.475	3.928	.002	1.299	3.268	.006
+200	1.372	3.113	.009	1.138	1.322	.207
+300	1.320	2.519	.027	1.101	0.460	.652
+400	1.275	1.450	.173	1.072	-.864	.402
+500	1.212	0.494	.630	1.089	-.024	.981

In children with TD, significant increases in the proportion of trials on which two flashes above the 1-flash/1-beep baseline were reported were seen at the following 1-flash/2-beeps SOAs: -150ms, -100ms, -50ms, +25ms, +25ms, +50ms, +100ms, and +150ms. In children with ASD, significant increases in the proportion of trials on which two flashes above the 1 flash/1 beep baseline were reported were seen at the following 1-flash/2-beeps SOAs: -500ms, -300ms, -200ms, -150ms, -100ms, -50ms, -25ms, +25ms, +50ms,

+100ms, +150ms, +200ms, and +300ms. (see Table 6 for statistics). These findings indicate that while the contiguous window for the illusion extends from –150ms to +150ms in TD, it is much wider in ASD, extending from –300ms to +300ms (Figures 8 and 9, respectively).

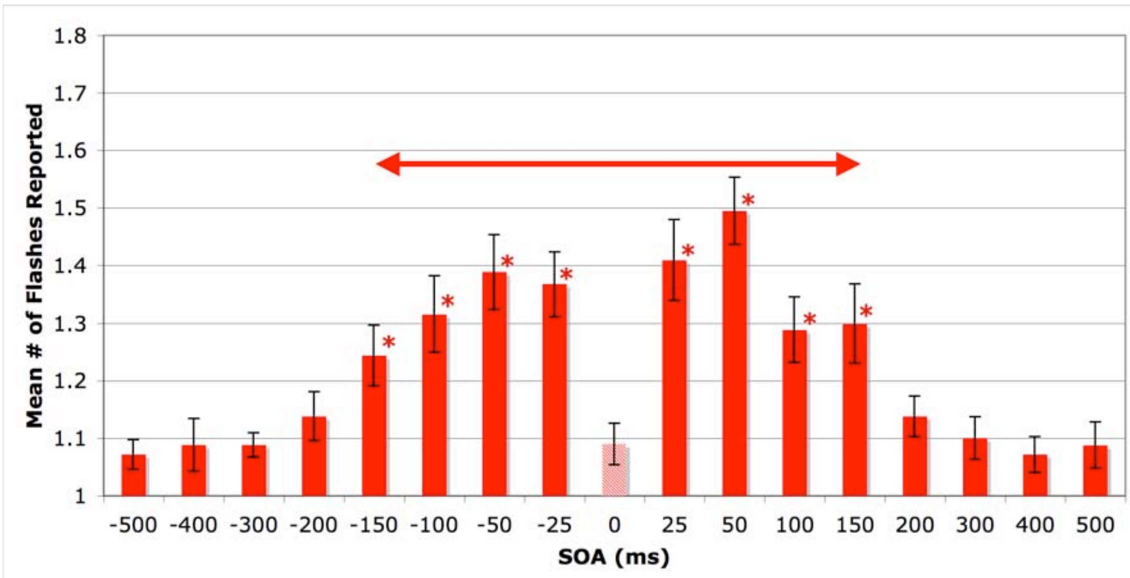

Figure 8. Flash/Beep task: Defining the temporal binding window in children with TD. Significant increases in the mean number of flashes reported on 1-flash/2-beeps trials, relative to the mean number reported on a 1-flash/1-beep control conditions (represented here as an SOA of 0 ms) were observed across 1-flash/2-beeps SOA conditions representing temporal delays between auditory stimuli ranging from -150 ms to +150 ms (asterisks represent single-sample t-tests at $p < 0.05$).

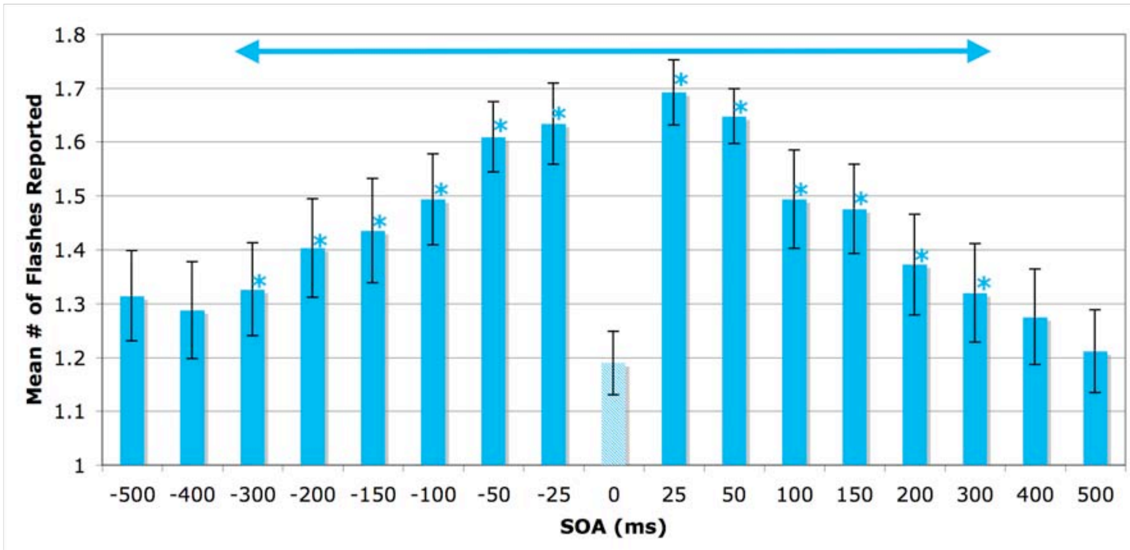

Figure 9. Flash/Beep task: Defining the temporal binding window in children with ASD. Significant increases in the mean number of flashes reported on 1-flash/2-beeps trials, relative to the mean number reported on a 1-flash/1-beep control conditions (represented here as an SOA of 0 ms) were observed across 1-flash/2-beeps SOA conditions representing temporal delays between auditory stimuli ranging from -300 ms to +300 ms (asterisks represent single-sample t-tests at $p < 0.05$).

Thus, in addition to experiencing the double-flash illusion to a greater extent, children with ASD also experienced the illusion over a wider temporal window than did children with TD, suggesting an increased temporal binding window in ASD for integration of auditory and visual input.

<u>Post-Hoc Correlations with IQ</u>

Because a previous study demonstrated a relation between IQ and the extent of multisensory integration in individuals with ASD (Cascio et al., 2008), follow-up analyses were conducted to examine the relation between IQ and the relevant dependent variables for each task in our sample of children with and without ASD. Bivariate correlations were conducted separately for the ASD and TD groups with the final samples used for each task. In the two unisensory tasks, correlations between IQ and threshold SOA values were explored. In the two multisensory tasks, IQ correlations were conducted with the mean values (i.e., mean accuracy gains in the multisensory TOJ task, mean number of flashes reported in the Flash/Beep task) across all SOA conditions combined. Where correlational analyses revealed significant relations between IQ and target variables, univariate and multivariate analyses of covariance were conducted to partial out the effects of IQ.

Perceptual threshold in the visual domain, as determined in the visual TOJ task, was not correlated with IQ in either children with ASD, $r(13) = -.47$, $p = .11$, or children with TD, $r(19) = .17$, $p = .47$. Perceptual threshold in the auditory domain, as determined in the auditory TOJ task, was also not correlated with IQ in either children with ASD, $r(10) = -.02$, $p = .97$, or children with TD, $r(15) = .23$, $p = .39$. In analyses with the reduced sample for the Multisensory TOJ task, IQ was not correlated with mean accuracy gains, averaged across all SOA conditions, in either children with ASD, $r(6) = -.63$, $p = .18$, or children with TD, $r(9) = -.46$, $p = .18$.

Correlations between IQ and mean number of flashes reported in the Flash/Beep task, averaged across all 1-flash/2-beeps conditions, were significant in children with ASD, $r(12) = -.84$, $p = .001$. In children with ASD, increased report of the double-flash illusion was associated with lower IQ. However, this pattern was not seen in children with TD, $r(14) = .32$, $p = .25$. Follow-up analyses examining correlations with IQ separately at each 1-flash/2-beeps SOA condition for children with ASD revealed significant negative correlations at the following SOA conditions: -500ms, -400ms, -300ms, -200ms, -150ms, -100ms, +150ms, +200ms, +300ms, +400ms, +500ms (r's < -.58, p's < .05).

Correlations were not significant in the ASD group at the remaining five SOA conditions. Because of the potential confounding influence of IQ, a follow-up multivariate analysis of covariance (MANCOVA) was conducted, comparing the mean number of flashes reported between groups at each SOA condition, with WASI Full Scale IQ entered as a covariate. Results of the MANCOVA revealed that between group differences remained at the following SOA conditions: -500ms, -300ms, -200ms, -50ms, -25ms, +25ms, +200ms, +300ms, and +400ms (p's < .05). These findings suggest that, even with the effects of IQ on perception of the double flash illusion partialed out, differences between groups in strength of multisensory integration remain across Flash/Beep SOA conditions representing both short and long temporal delays for the second auditory stimulus, relative to the coincident audiovisual flash-beep presentation.

CHAPTER IV

DISCUSSION

Based on consistent reports of alterations in sensory processing in individuals with ASD (Rogers & Ozonoff, 2005) and the suggestion that impairment in the temporal binding of cross-modal sensory input may be central to other core deficits in ASD (Brock et al., 2002), this study investigated temporal aspects of sensory and multisensory processing in children with ASD, in comparison to children with TD. To this end, we first examined the ability to make temporal order discriminations among rapidly presented low-level stimuli in the auditory and visual domains. Second, we examined the ability of task-irrelevant auditory input to influence performance on visual tasks with acute temporal resolution demands by way of multisensory integration, and attempted to characterize the temporal window within which this phenomenon could be observed. Characterization of processing, temporal discrimination, and cross-modal integration of low-level sensory stimuli in ASD represents an important step toward exploring whether atypicalities in basic sensory processing represent a core difference in ASD that may underlie higher-level cognitive, language, social, and behavioral abnormalities in ASD.

In terms of unisensory functioning, this study used standardized psychophysical tasks to examine the minimum interstimulus interval (i.e., temporal delay) necessary for reliable order discrimination between two stimuli presented within the same sensory modality. First, it is important to note that children with TD performed at levels similar to those seen in typical adults, with regard to the temporal delay between two stimuli necessary to discriminate presentation order in the auditory and visual domains (Kanabus et al., 2002). Literature examining basic modality-specific sensory functioning and system specialization in animals and humans indicates that the auditory system has better temporal acuity than does the visual system, and is therefore best equipped to make rapid temporal discriminations and judgments. In the auditory domain, our results indicate that children with ASD required significantly longer interstimulus temporal intervals between two auditory stimuli than did children with TD in order to accurately report on presentation order of the stimuli. Specifically, they required a 59% longer temporal delay between stimuli to reliably report on which of two auditory stimuli was presented first, consistent with our prediction (Hypothesis 1) that children with ASD would show impairments in auditory temporal processing. This difference represents a large effect size and suggests that auditory temporal acuity is significantly compromised in children with ASD, relative to children with TD.

Our finding of decreased auditory temporal acuity in ASD has important consequences for discrimination of rapidly-presented auditory information in the real world, such as in speech processing and comprehension. It could contribute to difficulties reported in ASD related to making sense of information in a noisy environment, as well as to descriptions of "sensory overload" in such situations. In terms of more basic sensory processing, compromised temporal acuity in the auditory system could have additional implications in terms of the specialized ability of audition to provide temporal information about complex, multisensory events and to influence other sensory modalities when temporal resolution demands are high. Furthermore, if requiring a longer interstimulus interval to discriminate between two auditory stimuli represents an increased temporal gap necessary to recognize the two stimuli as discrete events, the temporal window within which stimuli would be perceived as unitary, or at least conjoined, could be proportionally longer as well.

Decreased temporal acuity for resolving two rapidly presented stimuli was also observed in the visual domain in children with ASD, relative to those with TD. This finding confirmed our hypothesis regarding visual temporal processing in ASD (Hypothesis 2). Specifically, although differences did not reach statistical significance ($p=0.055$), children with ASD required a 43% longer interstimulus interval than did children with TD to discriminate presentation order of two visual stimuli, representing a medium to large effect size. The current findings of decreased performance in discriminating visual information differ from much of the experimental literature with regards to unisensory visual processing of simple stimuli, which has typically found intact or enhanced perception in ASD. Enhanced detection and discrimination of visuospatial details, such as in Embedded Figures and visual search tasks, have been used to support the Weak Central Coherence theory, which posits that discrete pieces of information are processed separately, perhaps resulting in difficulty integrating complex information into a meaningful higher-order gestalt. However, most of the evidence supporting intact perception of unimodal visual stimuli comes from tasks that involve discriminating *spatial* details in static pieces of information, presented one at a time, whereas the current study examined the ability of children with and without ASD to resolve presentation order of a series of simple stimuli occurring in rapid temporal succession. It is possible that while processing of static details requiring spatial discriminations is relatively spared in ASD, processing of changing stimuli requiring rapid temporal resolution is impaired.

In fact, there is some previous evidence that, while processing of local visual details in static spatial displays is preserved in ASD, processing of dynamic stimuli, which require rapid temporal processing of changing visual input, may be altered. For instance, individuals with ASD have been observed to be impaired in their ability to detect global motion of moving dots (Milne et al., 2002; Pellicano et al., 2005; Spencer et al., 2000) as well as to detect biological motion (Blake, Turner, Smoski, Pozdol, & Stone, 2003). While these studies speak primarily to impaired motion detection, it may be that a more general impairment in rapid temporal discrimination of information, as was observed in the current study, causes secondary impairment in motion detection and in proper processing and integration of dynamic stimuli. It is also possible that thorough processing of static visual details, as has been reported in other studies, prevents rapid shifting to and processing of successive stimuli.

If rapid temporal processing is impaired in ASD, it may be the case that discrete pieces of information will not be dissociated fully or processed separately as successive input continue to occur. Meaning conveyed in the temporal relationship between rapidly presented series of information bits might be muddled or missed. Behaviorally, this could result in sensory overload. It could also lead to difficulties, for example, in picking up on subtleties carried in the dynamic properties of social information, such as brief and subtle shifts in facial expression, eye gaze, or body posture that should provide clues to another person's mental state and intention. Future studies should further investigate the impact of temporal aspects of information presentation as it may relate to impaired perception of and response to dynamic social and non-social events.

It is important to note that, while the unisensory tasks used in this study suggest impaired temporal resolution of rapidly presented unimodal sensory stimuli in both the auditory and visual domains, they do not provide information about the perceptual threshold for detecting basic sensory input. That is, they are not designed to test whether unisensory processing mechanisms are hypo- or hyper- sensitive to incoming stimuli in ASD. They also do not allow direct predictions about the degree to which multisensory integration will occur based on the inverse effectiveness relation between uni- and multi-sensory processing. However, if it takes longer to process and resolve consecutive unimodal sensory input, the duration of the neural response to such input may also be longer. If multisensory integration occurs in the temporal window where there is overlap between the neural responses to two stimuli, then our unisensory findings might predict an extended temporal window for multisensory integration.

The multisensory TOJ task examined whether the addition of task-irrelevant auditory information enhanced the accuracy with which children could discriminate the temporal order of two visual cues, given that the auditory system is better specialized for processing temporal information than is the visual system (Hirsh & Sherrick, 1961; Welch & Warren, 1980). It is important to note that the interstimulus interval between visual stimuli was set according to each individual's visual perceptual threshold, thereby correcting for unisensory differences observed in ASD and equating potential for multisensory gains across participants, independent of their unisensory temporal discrimination abilities. First, both children with ASD and children with TD showed accuracy gains with the addition of the auditory input, indicating the engagement of multisensory processes and suggesting that audition was biasing and improving visual perception, as would be expected based on the specialization of the auditory system for temporal discriminations. With regard to typically developing children, this finding is consistent with our hypothesis (#3) that children with TD would evidence multisensory performance enhancements on primarily visual tasks with the addition of auditory input containing temporal information, in keeping with results of studies using similar tasks in adults (Hairston et al., 2006).

Second, while results from the Multisensory TOJ did not provide clear support for either more or less multisensory integration in ASD or for either a longer or shorter temporal window within which such integration occurs, the ambiguity in these results may relate to the small sample size remaining after participants with questionable performance were removed. For many children in both groups, performance on the visual-alone baseline condition (which should have been near 75% accuracy given that the interstimulus interval between visual stimuli was set at the child's perceptual threshold as provided by the visual TOJ staircase) was much lower in the context of this task. This observation was unexpected given that adults typically perform at similar accuracy rates on visual-alone trials within the multisensory TOJ task as they had on the visual TOJ staircase procedure, from which the visual threshold was derived (Hairston et al., 2006). It is possible that, in children, decreased performance on visual-alone trials in the context of the multisensory TOJ task is related to difficulty with cognitive set-shifting between differing task demands. Whereas in the visual TOJ task, all trials had only visual input, 89% of trials (i.e., eight of nine conditions) within the multisensory TOJ task had additional auditory input to which children might have become accustomed, regardless of their task relevance.

It may be the case that the novelty of low-frequency visual-alone trials caused children's attention to orient to the missing auditory component to which they had become accustomed, thus distracting their attention from the actual task (i.e., deciding which circle came first). The low-frequency shift in whether or not auditory input was present may have presented an additional task demand (i.e., to shift sets without losing focus on the goal of the task) that was more difficult for children than it likely is for adults, for whom this pattern of decreased accuracy on visual-alone trials in the multisensory TOJ task is not seen. A neural basis for this discrepancy may be that set-shifting and top-down cognitive control processes are mediated by prefrontal cortex, which matures late in development (Giedd, 2004). In the end, results of the Multisensory TOJ task, with the sample size markedly reduced relative to that in other tasks within this study, did not clearly indicate group differences in the strength of multisensory integration nor provide solid information about the nature of the temporal binding window for auditory and visual information. However, results from the Flash/Beep task suggest that, with more participants, a similar pattern of results (i.e., increased integration over a longer temporal window in ASD) might emerge for the Multisensory TOJ task.

Indeed, on the Flash/Beep task, we found compelling evidence for increased susceptibility to the influence of task-irrelevant auditory input in a primarily visual task in children with ASD. This task highlights the fact that, in addition to being able to improve visual temporal resolutions (e.g., in the Multisensory TOJ task), accompanying sounds can also induce deterioration in performance on a visual discrimination task, as is reflected in heightened rates of perceived visual illusion in the Flash/Beep task. Children with ASD reported perceiving an illusory second flash on a higher proportion of trials than did children with TD across all SOA conditions. This finding suggests increased susceptibility to incorporating temporally proximal auditory information when processing visual information, that is, increased multisensory integration.

Our findings with regard to increased multisensory integration were neither in keeping with our research hypothesis (#4) nor in line with Brock et al.'s (2002) temporal binding hypothesis for ASD, from which the most direct theoretical predictions about our experimental questions could be made. The temporal binding hypothesis suggests that decreased coupling between synchronously activated brain regions in ASD results in decreased binding of concurrent input and causes information to be processed in relative isolation, rather than being integrated into a complex and meaningful multisensory gestalt. Results of the current study indicate that, when presented in close temporal proximity, not only do auditory and visual information get bound together (as opposed to being processed in isolation as the temporal binding hypothesis might predict), they are actually integrated to a *greater* extent and continue to be bound together even when the temporal interval between stimuli is larger than would allow for binding in the brain of typical children. These results suggest that neural regions specialized for processing of auditory and visual information are not working in isolation as Brock et al.'s hypothesis would predict.

Though contrary to our predictions, increased multisensory integration could in fact provide a brain basis for many of the sensory abnormalities reportedly experienced by individuals with ASD. For instance, if integration is occurring to an inappropriately large degree, it could cause difficulty with responding to input from one modality if there is concurrent input from other modalities. Normally, concurrent information would be filtered out or processed separately, but instead it may be integrated into the perception of the unimodal stimulus on which the individual is trying to focus. D. Williams' (1996) autobiographic reports suggest that this has been her experience. Difficulties identifying the source modality of information, as have been reported in ASD, could also be explained by a pattern of too much multisensory integration. Furthermore, too much integration could cause otherwise innocuous stimuli to become overwhelming or aversive.

With respect to the "inverse effectiveness" relation between unisensory and multisensory processing, enhanced multisensory processing, as observed in this study, suggests that sensory input within a single modality may be processed to a lesser extent or perceived as weaker in children with ASD. This study did not test simple detection thresholds for stimuli within a single modality in terms of the minimum intensity or duration of an individual stimulus presentation necessary for detection of its presence. However, given findings of increased strength of multisensory integration of low-level stimuli, it will be important for future studies to explore whether simple stimulus detection abilities are impaired in ASD. Such investigation should clarify whether enhanced multisensory processing is simply due to unisensory/multisensory tradeoff related to inverse effectiveness relations responding to weakly perceived unisensory input or whether the observed differences reflect alterations in multisensory processing mechanisms themselves.

With regard to the temporal window within which integration occurs, examination of responses of children with ASD at individual SOA conditions in the Flash/Beep task indicated that perception of the illusory second flash persisted even as the second beep was separated by up to 300ms from the coincident single flash/single beep presentation.

The temporal window (i.e., -300ms to +300ms) for this illusion in children with ASD was double the window seen in children with TD. Consistent with our hypothesis (#5) regarding an increased temporal binding window in ASD, this finding suggests that the window of time across which auditory and visual information interact to influence and alter perception is expanded in ASD.

A wider temporal window within which multisensory integration occurs has important implications for how incoming sensory information is experienced and understood. Stimuli that are temporally disparate to a degree that they should be processed dichotomously as separate occurrences may instead be bound as part of a single multisensory percept that could be inaccurate and confusing. While in some instances audio-visual integration can be helpful (e.g., watching lips during speech perception in a noisy room to make up for decreased ability to hear the speaker), if it continues to occur as the temporal gap between inputs expands, it can interfere with accurate representations of incoming information. This type of interference might occur when two stimuli are separated by an interval such that they would typically be perceived as discrete pieces of information with independent meaning, but instead are not differentiated. Out-of-sync information would be integrated inappropriately, thus confusing the intended message. Indeed, according to clinical report, many individuals with ASD experience difficulty with processing and understanding complex cross-modal events, often times resulting in avoidant behaviors or experiences of sensory overload. Impairments in low-level multisensory processing and integration could underlie these clinically-relevant sensory difficulties.

Findings of enhanced multisensory integration and an expanded window in which it occurs, on the Flash/Beep task in particular, highlight the fact that increased multisensory integration is not always a good thing and can actually exacerbate the degree to which distracting information biases perception and decreases the ability to perform a task and accurately perceive information. Therefore, the ability to cognitively or behaviorally control one's interpretation and response to inappropriately integrated cross-modal stimuli might be an important strategy for coping with abnormal multisensory experiences. Follow-up analyses on the Flash/Beep task examining the relation between IQ and susceptibility to the double-flash illusion are relevant to the question of whether basic sensory and multisensory processes are open to the influence of top-down control. Results of these analyses revealed an interesting pattern of relations. First, strength of illusion at the shortest SOA conditions (i.e., those where the second auditory stimulus is presented at very short temporal delays relative to the coincident flash/beep presentation) did not correlate with IQ even in children with ASD, perhaps because of decreased variability in whether the illusion was perceived (i.e., it was almost always reported). This finding lends support to the notion that, at least at short temporal delays, the double-flash illusion is truly a low-level one, occurring as a bottom-up process that, under these temporal constraints, is immutable by top-down, volitional, or cognitive control.

At longer SOA conditions, however, IQ was inversely related to susceptibility to the illusion in children with ASD (but not TD). That is, higher IQ was related to less frequent report of the illusory percept. This finding suggests that what is, at short temporal intervals, a purely bottom-up perceptual illusion may, at longer temporal intervals, become open to the influence of top-down cognitive control. As the temporal gap between the coincident flash/beep presentation and the second auditory stimulus becomes increasingly long, children with ASD with higher IQ may become aware that they are being "tricked" and therefore attempt, and evidently successfully manage, to exert volitional control in cognitively inhibiting the influence of the second auditory stimulus on their attention to and counting of the flash(es). Though they may have remained aware of their "being tricked" even on trials from shorter SOA conditions, their cognizance could not prevent the occurrence of the illusory percept at the shorter temporal delays.

The role of intellectual ability of individuals with ASD in controlling their response to multisensory experiences appears to be an interesting avenue for future research to explore more directly. However, as it relates to the present results, the relation between IQ and susceptibility to the double-flash illusion does not compromise our findings of increased strength and temporal window of this multisensory illusion in children with ASD relative to children with TD, given that group differences across both long and short SOA conditions remained significant even with IQ entered as a covariate.

This study represents one of the first empirical explorations into whether basic sensory and multisensory processes are atypical in ASD, with a specific focus on the temporal aspects of such processes. Our findings indicate that: 1) children with ASD require greater interstimulus temporal intervals than do children with TD to discriminate presentation order of consecutive stimuli within both the auditory and visual domains; 2) children with ASD show increased strength of multisensory integration of temporally proximal auditory and visual stimuli (i.e., greater performance enhancements on a visual task with auditory information added; increased rates of reported perception of the double/flash illusion); and 3) children with ASD evidence an expanded temporal window across which they bind cross-modal information into a unified, multisensory percept (i.e., audio-visual performance enhancements and biases continue to occur despite lengthy temporal intervals between stimuli). Given these findings, it will be interesting for future research to use electrophysiological and neuroimaging approaches, such as ERP and fMRI, to examine the neural correlates of these alterations in sensory processing and integration in ASD. Furthermore, as sensory processes mature quite early in prenatal and infant development and sensory abnormalities are among the first observed in children who will later go on to receive ASD diagnoses (Baranek, 1999; Dawson, Osterling, Meltzoff, & Kohl, 2000), studying the development of basic sensory processes in infants and young children at increased risk for ASD will be an important area for future research.

One limitation of this study is that it does not examine the effectiveness of sensory processing in individual modalities with regard to detection thresholds for simple stimuli and thus does not allow direct predictions about multisensory processes or the degree of integration that could be expected based on unisensory functioning according to the principle of inverse effectiveness. Future studies should investigate multisensory processing in conjunction with examination of basic stimulus detection abilities within targeted modalities. Also, this study examined multisensory integration and temporal acuity of sensory processing in the auditory and visual domains only. Clinical reports indicate that sensory abnormalities span other sensory modalities; thus empirical exploration of low-level information processing in other senses and interaction across other cross-modal pairings will be important in better understanding underlying sensory processing and integration deficits in ASD.

The sample size in this study was relatively small, especially for the multisensory TOJ task after participants with questionable data were removed from the analyses. The high rate of data loss can be attributed to the challenges of conducting research with children, particularly with children who have ASD and often present with complicating attentional and behavioral challenges that impact the ability to produce reliable data. Nevertheless, an increased sample size would likely clarify the results of this study, particularly those related to whether children with ASD experience differences in the degree and temporal window of multisensory integration in the multisensory TOJ task. Finally, this study was limited to relatively high functioning children with ASD, namely those with cognitive functioning levels that enabled them to understand task instructions and to provide button-press responses, and to those with sufficient attentional abilities to complete the tasks. Future studies should explore methods that are more amenable for use with a broader range of children with ASD that more accurately reflects the functioning spectrum encompassed within these disorders.

In summary, our findings of difficulties resolving stimuli that occur in close temporal succession, increased strength of multisensory integration, and an expanded cross-modal temporal binding window provide empirical evidence for underlying sensory and multisensory processing deficits that may relate to the sensory abnormalities reported clinically in individuals with ASD. Atypicalities in the temporal resolution and integration of low-level information at a sensory processing level may also have broader implications for the ability of individuals with ASD to process and react appropriately to more complex combinations of sensory information, such as occur in conversation or social interaction. Though additional research is needed to clarify the nature and extent of sensory abnormalities in children with ASD, the present findings clearly implicate sensory processing as an important area for future examination in the search for underlying deficits contributing to core social, communicative, and behavioral impairments.

APPENDIX

Appendix A. Clinical characterization of participants with ASD (n=14).

	Clinical diagnosis (at intake)	**ADOS**		**ADI**		
		Communication	Reciprocal Social	Communication	Reciprocal Social	Repetitive Behaviors
1	Asperger	3	8	9	21	6
2	Asperger	4	7	16	15	5
3	Autism	4	12	23	29	8
4	PDD-NOS	5	13	18	24	8
5	Asperger	2	9	16	27	2
6	Autism	6	13	15	20	6
7	PDD-NOS	7	13	20	27	10
8	Asperger	5	10	12	18	12
9	Asperger	2	8	20	26	9
10	Asperger	3	5	22	23	4
11	Asperger	2	8	19	21	7
12	PDD-NOS	5	8	19	27	5
13	PDD-NOS	2	8	9	19	4
14	PDD-NOS	3	6	21	27	12

ADOS Cutoff Scores:
Communication (Autism = 3; ASD = 2)
Reciprocal Social Interaction (Autism = 6; ASD = 4)

ADI-R Cutoff Scores:
Communication (Lifetime Diagnostic = 7)
Reciprocal Social Interaction (Lifetime Diagnostic = 10)
Restricted, Repetitive, Stereotyped Patterns of Behaviors (Lifetime Diagnostic = 3)

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