VISUAL AND AUDITORY SENSITIVITY

IN AUTISM SPECTRUM DISORDERS

by

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ABSTRACT

Individuals with an autism spectrum disorder (ASD) often cannot tolerate certain sights and sounds, such as fluorescent lights, vacuum cleaners, and babies crying, which affects their ability to engage in activities at home and in the community. One theory that may account for these sensory impairments is the Enhanced Perceptual Functioning theory, which posits that individuals with ASD are more sensitive to auditory and visual stimuli. Previous studies in support of this theory found that individuals with ASD demonstrated an enhanced ability to detect differences in pitch, discriminate changes in visual stimuli, and detect novel targets in visual arrays. The response type and task demands differed greatly among these studies, making it difficult to draw firm conclusions. Furthermore, no studies have compared visual and auditory perception directly.

The current study sought to fill these gaps by examining visual and auditory perception in a sample of 13 children with ASD and 13 children with typical development aged 8-12 years. It was predicted that individuals with ASD would show increased sensitivity in both auditory and visual domains. To assess perceptual abilities, participants completed an auditory discrimination task examining pitch and volume and a visual discrimination task examining hue and luminance.

Using signal detection theory comparing hits and false alarm rates (d-prime) to analyze their performance, children with ASD showed enhanced perception for pitch only compared to children with typical development. In the ASD group, high overall sensitivity were related to an overall measure of autism severity, supporting the notion that enhanced perception, particularly

pitch sensitivity, may be a phenotypic marker for ASD. This is the first study to demonstrate a relationship among perceptual sensitivity and ASD symptoms. These results have clinical significance for understanding children with ASD. For example, caregivers and teachers taking children with ASD to a noisy environment such as a gymnasium or the mall may want to provide earplugs or headphones to dampen the noise. It is possible that auditory hyper-sensitivity may underlie the development of difficulties with social-communication and may lead to repetitive behaviors in an effort to manage the environment.

LIST OF ABBREVIATIONS AND SYMBOLS

d' D prime: Measure of sensitivity based on the separation between the means of the hit rate

          and false-alarm rate in units of standard deviation

d Cohen's d: Measure of effect size for use with t-tests or ANOVA

F Fisher's F ratio: A ratio of two variances

df Degrees of freedom: Number of values free to vary after certain restrictions have been

          placed on the data

SD Standard Deviation: Measure of variation from the mean

η^2 Partial eta squared: Measure of effect size for use in ANOVA

p Probability associated with the occurrence under the null hypothesis of a value as

          extreme as or more extreme than the observed value

r Pearson product-moment correlation

t Computed value of t test

$<$ Less than

$=$ Equal to

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Introduction

A fifteen-year-old girl with Asperger's Syndrome describes her experience when she goes out in public:

> "…everything is upside down and spinning all around you. You hear all these noises coming from everywhere - you hear like everybody's conversation. It feels like lights are flashing in your head - in your eyes I mean, and your brain just goes nuts. So, what I do to try to control that is I jump up and down and flap my hands - as if that doesn't look weird. That's my coping skill for now" (Anonymous, 2009).

Her compelling description captures several diagnostic features of Autism Spectrum Disorders (ASD), including the repetitive behaviors and the social-communication difficulties that define the disorder (American Psychiatric Association, 2000). Interestingly, she links these diagnostic symptoms to sensory differences that lead to a feeling of being disoriented and overwhelmed by one's environment. These sensory differences are often reported by individuals with ASD but are not part of the diagnostic criteria in the Diagnostic and Statistical Manual of Mental Disorders, 4th edition (DSM-IV-TR). The purpose of this study was to more closely examine the sensory differences experienced by individuals with ASD.

Autism Symptomatology

According to the DSM-IV-TR, Autism Spectrum Disorders include the diagnoses of Autistic Disorder, Asperger's Syndrome, and Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS) (American Psychiatric Association, 2000). However, the proposed version of the DSM-V indicates that the diagnostic criteria for ASD will soon undergo changes

in the upcoming DSM-V. It has been proposed that the diagnosis of Asperger's Syndrome will not be included in the DSM-V because research has not supported the distinction between Asperger's and High Functioning Autism (First, 2008). In the current DSM-IV-TR, the diagnosis of Autism Spectrum Disorders is based on impairment in the three domains of social, communication, and repetitive behaviors. However, research presented at the diagnosis-related planning conference held by the American Psychiatric Association showed that the current three domains are not supported by factor, cluster, or latent class analyses, which suggests a unitary underlying factor structure (First, 2008). Therefore, it has been proposed that the social and communication domains will be combined into one domain, and the repetitive behavior domain will be simplified in the DSM-V.

Due to the heterogeneity of ASD symptoms, there is a wide variety in the presentation of social-communication symptoms. These may include impairments in using nonverbal behaviors such as facial expressions, gestures, and body postures to regulate social interactions. Social impairment may also be expressed as a lack of social or emotional reciprocity, a failure to develop appropriate peer relationships, or a lack of spontaneous seeking to share enjoyment, interests, or achievements with others. In addition, social imitative play is often impaired in young children with ASD. Severely impaired individuals with ASD may not develop spoken language at all, or language development may be limited or delayed. In individuals who develop adequate speech, they may demonstrate a marked impairment in their ability to initiate or sustain a conversation, or use repetitive language (American Psychiatric Association, 2000).

The diagnostic domain that consists of restricted, repetitive, and stereotyped patterns of behavior, interests and activities can be divided into two subtypes: lower-order and higher-order behaviors (Turner, 1999). Lower-order behaviors consist of two categories: (a) stereotyped

movements, which are seemingly purposeless movements or actions that are repeated in a similar manner; and (b) self-injurious behaviors, which are any movements or actions that have the potential to cause redness, bruising, or other injury to the body and that are repeated in a similar manner. Higher-order behaviors consist of four categories: (a) compulsions (behavior that is repeated and performed according to a rule, or involves things being done "just so"); (b) need for routines or rituals (performing activities of daily living in a similar manner); (c) insistence on sameness (resistance to change or insisting that things stay the same); and (d) restricted interests (limited range of focus, interest, or activity). Definitions for each category above are from the Repetitive Behavior Scale-Revised (Bodfish, Symons, Parker, & Lewis, 2000).

Many repetitive behaviors have a sensory aspect to them, such as finger-flicking near the eyes, listening to the same piece of music repeatedly, or rubbing a certain texture constantly. Hutt and Hutt (1968) proposed that repetitive behaviors reduce physiological arousal by providing endogenous stimulation that allows the individual to block sensory input. There has been no evidence to support the notion that the primary function of repetitive behaviors is to modulate arousal levels, although extreme arousal levels may increase rates of repetitive behavior in individuals with autism as they do in individuals with typical development and animals of other species (Turner, 1997). Dawson (1991) explored the arousal regulation theory in the context of difficulty processing unpredictable information. She suggested that if individuals have difficulties with arousal, this would negatively affect social interactions, and these difficulties may be a consequence of disruptions in early patterns of social interaction.

Although sensory symptoms are not part of the diagnostic criteria for ASD in the DSM-IV, one of the proposed revisions for the DSM-V includes adding hyper- or hypo-reactivity to sensory input or unusual interest in sensory aspects of the environment under the restricted,

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repetitive behavior category. Sensory symptoms occur very frequently in ASD. Baranek and colleagues (2006) reported that 69% of preschoolers with ASD showed sensory symptoms. In a parent-report study using the Short Sensory Profile, Rogers and colleagues (2003) found that preschoolers with ASD showed significantly higher scores than children with typical development on auditory filtering and sensitivity to taste, smell, and tactile stimuli, indicating greater sensory impairment in these areas. Studies of sensory processes in ASD have shown that individuals with ASD have both hyper- and hyposensitivity to various stimuli (Baranek, David, Poe, Stone, & Watson, 2006; Rogers, Hepburn, & Wehner, 2003). Hyper-responsiveness is an exaggerated behavioral response to sensory stimuli (e.g., aversive reaction to lights, covering ears for certain sounds, avoidance of touch). Hypo-responsiveness refers to a lack of response, or insufficient intensity of response to sensory stimuli (e.g., diminished response to pain, lack of orienting to novel sounds).

In the field of autism, reports of superior performance in auditory perception, such as cases of perfect pitch (Heaton, Davis, & Happé, 2008), and in visual perception, such as on block design tasks and embedded-figures tasks (Frith, 2003; Shah & Frith, 1983) led to the development of the theory on Enhanced Perceptual Functioning (Mottron & Burack, 2001). The Enhanced Perceptual Functioning theory is an information-processing theory that posits that individuals with ASD have enhanced auditory and visual perceptual abilities due to the over-functioning of the brain regions typically involved in primary perceptual functions (Mottron & Burack, 2006). Perception is the process of attaining awareness and understanding of sensory information, including visual, auditory, olfactory, gustatory, vestibular, and proprioceptive stimuli. The individual selectively attends to the complex stream of sensory input from the environment, then perceptual processes translate this sensory input into meaningful information,

which can then be used to guide the individual's thoughts and behaviors. Thus, perception is the intersection between selective attention and cognition. The areas of attention, cognition, and perception have been extensively studied in ASD, and some relevant research from each area will be presented here in order to give a framework for the study of perceptual abilities in children with ASD. A brief review of research on selective attention will be presented first, followed by a description of two cognitive theories that affect how information is processed meaningfully. Finally, support for the Enhanced Perceptual Functioning theory will be discussed.

Selective Attention

The role of attention in perception primarily occurs at the level of orienting, i.e., what sensory information the individual attends to. In a recent review of studies on attention in autism, Sanders et al. (2008) indicated that there have been mixed findings in the attention literature about orienting performance in individuals with ASD. The majority of the evidence suggests that attention orienting is impaired (Akshoomoff & Courchesne, 1992, 1994; Casey, Gordon, Mannheim, & Rumsey, 1993; Courchesne et al., 1994; Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Landry & Bryson, 2004; Renner, Klinger, & Klinger, 2006; Rinehart, Bradshaw, Moss, Brereton, & Tonge, 2001; Senju, Tojo, Dairoku, & Hasegawa, 2004; Townsend, Harris, et al., 1996; Wainwright & Bryson, 1996; Wainwright-Sharp & Bryson, 1993). However, other evidence suggests that orienting is intact or even enhanced (Gomot, Giard, Adrien, Barthelemy, & Bruneau, 2002; Iarocci & Burack, 2004; Leekam, López, & Moore, 2000). These discrepancies could be due to differences in automatic orienting processes based on what captures the attention of individuals with ASD. When attending to sensory input, attentional mechanisms can be automatic (i.e., bottom-up processing) or conscious (i.e., top-down processing) (Wegener, Ehn, Aurich, Galashan, & Kreiter, 2008). According to Wegener and

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colleagues, automatic mechanisms of attention are mainly driven by the perceptual saliency of a stimulus, and this is referred to as attentional capture. Conscious mechanisms of attention are mainly driven by endogenous factors based on the individual's previous experience and are modulated by cognitive processes.

Many researchers have suggested that individuals with ASD tend to rely more on automatic rather than conscious mechanisms of attention (Frith, 2003; Iarocci et al., 2006; Mottron & Burack, 2001). A metaphor that is frequently used to capture this phenomenon states that the attention of individuals with ASD is similar to a spotlight with a narrow focus, while the attention of individuals with typical development is more like a searchlight that takes in a broad range of sensory information (Bruckner & Yoder, 2007). If individuals with ASD do not automatically attend to the same sensory stimuli in the environment as individuals with typical development do, this may cause differences in their sensory perception, which could lead to changes in their cognition, and ultimately, their behavior.

Cognitive Theories of Information Processing

This bias towards an "attentional spotlight" in individuals with ASD fits well with the explanations of ASD symptomatology offered by two current cognitive theories in ASD. Weak Central Coherence (Frith, 2003) and Implicit Learning (Klinger, Klinger, & Pohlig, 2007) theories propose that individuals with ASD have difficulty integrating information into a meaningful context. The theory of Weak Central Coherence states that individuals with ASD have a cognitive style that is characterized by preferential processing of local features instead of global features of the environment, which can lead to a failure to integrate visual and perceptual details into a coherent whole (Frith & Happé, 1994). According to Frith and Happé's theory, lower-level processing is not integrated into higher, more central processes. For example,

children with ASD who are hyperlexic can read at a higher level than they understand, suggesting that the lower level phonological processing of words is independent of higher level semantic interpretations (Aram & Healy, 1988).

This theory predicts that individuals with ASD would show difficulties with tasks that require integration, but it also predicts that they would show strengths on tasks that demand attention to detail. The classic test of central coherence is the embedded-figures task, where participants are asked to detect a geometric shape among a complex background. Individuals with ASD show superior performance on the embedded-figures task, showing a strength for featural discrimination (Shah & Frith, 1983). Similarly, on the Wechsler Block Design subtest, individuals with ASD are not aided by pre-segmentation of patterns, and their errors tend to be ones of global configuration rather than local detail (Shah & Frith, 1993). Belmonte and colleagues (2004) suggest that Weak Central Coherence may form the cognitive underpinning of behavioral disturbances in autism by impairing the use of contextual information. They propose that perceptual filtering in ASD occurs in an all-or-none manner with little regard for the relevance, specificity, or sensory modality of the stimulus. This may lead to enhanced perception for some details but inefficient processing of the complex stream of sensory input.

The Implicit Learning theory suggests that the ability to automatically integrate information during learning is impaired in ASD (Klinger et al., 2007). According to Implicit Learning theory, individuals with ASD rely more on explicit learning strategies as a "bootstrapping" mechanism to compensate for difficulties with implicit learning. This impairment may lead to a rigid, narrow focus of attention that prevents individuals from perceiving the gestalt of a situation. In support of this theory, Klinger and colleagues have found impaired performance on a variety of implicit learning tasks including prototype learning and

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artificial grammar learning (Klinger and Dawson, 2001; Klinger et al., 2007). Further, Klinger and colleagues theorize that repetitive behaviors are a coping strategy to make the environment more explicit in order to handle the difficulties with implicit social interactions. They predicted that implicit learning would be strongly negatively correlated with social communication processes and modestly negatively correlated with repetitive behaviors. Using two implicit learning tasks, they found the predicted pattern in a sample of 50 children with high-functioning ASD and 50 children with typical development aged 5-17. These relationships among autism symptoms and learning style provide support for the idea that the behaviors seen in ASD are due to underlying difficulties with information processing.

Central Coherence and Implicit Learning theories are not independent of attention. Indeed, according to the Implicit Learning theory, individuals with ASD may focus on certain aspects of information in the environment to the exclusion of other important information. In an eye-tracking study examining the prototype effect using cartoon animals, children with ASD had fewer fixations within the areas of interest than children with typical development, which indicated that they were not attending to the salient information in the task and thus showed impairments in prototype learning (Klein, 2006).

This review of research on attention orienting and cognitive processing provides a necessary framework for a consideration of auditory and visual perception. When taking these areas of research into account, the emerging picture suggests that perception may be enhanced in individuals with autism due to fundamental differences in brain processes that determine what information is important to attend to and how that information is interpreted in context.

Enhanced Perception

There are two closely-related theories that address the cause of sensory differences in autism, one put forth by Plaisted, O'Riordan, and Baron-Cohen (1998), and the Enhanced Perceptual Functioning theory put forth by Mottron and Burack (2001). Plaisted's theory is limited to visual processing and will thus be subsumed under the Enhanced Perceptual Functioning theory, which encompasses both visual and auditory processing, for the purposes of this review. According to this theory, individuals with ASD show enhanced discrimination of perceptual features, and processing of these low-level features interferes with higher order processing. One example given by Mottron and Burack is that of a child who stares at a fan for hours; in this case, the lower-order perception of movement disrupts the child's ability to explore the environment.

Plaisted and colleagues (1998) propose that individuals with ASD have enhanced perception for certain perceptual features. They suggest that the features that are unique to a given stimulus are processed well by individuals with ASD, while the features held in common between stimuli are processed poorly. This enhanced perception for novel features, but not shared features, may underlie the reduced ability to generalize learned information that is seen in autism. The sequence of enhanced perception occurs when there is a deficit in a cognitive function that is followed by compensatory mechanisms (i.e., neural plasticity) and overtraining of those mechanisms due to increased demand (Mottron & Burack, 2001). While compensatory mechanisms are usually adaptive (for example, in the case of a person with visual impairments who displays increased sensitivity to sounds and odors), these mechanisms may become maladaptive if they develop beyond the optimal level. For example, increased sensitivity to

sound in an individual with ASD may lead to an inability to tolerate loud noises or particular noises such that the individual is not able to function effectively in his or her environment.

Enhanced auditory perception. Across several studies, both children and adults with ASD have been reported to show enhanced auditory perception as measured by the ability to detect differences in pitch and the direction of pitch changes (Heaton, Williams, Cummins, & Happé, 2008; Heaton, 2005). Bonnel and colleagues (2003) tested pitch sensitivity using two tasks in a sample of adolescents with high-functioning autism (n=12) compared to children with typical development (n=12) matched on chronological age and IQ. In the pitch sensitivity tasks, participants heard two tones, some of which were identical and some of which varied by 1% (hard), 2% (medium), or 3% (easy) of the first tone. In the first task, participants were asked to make same/different discriminations, and in the second task, they were asked to make high/low discriminations. Adolescents with high-functioning autism showed higher sensitivity than the comparison sample for pitch discrimination in all three conditions of the categorization task and in the easy and medium conditions of the discrimination task.

Heaton (2005) examined the ability to identify pitch direction in a musical scale (i.e., whether a short sequence of notes was ascending or descending) and the ability to identify changes in a melody in 7-14 year old children with high-functioning autism (n=15) compared to two groups of children with typical development, one group matched on verbal IQ and age and one group matched on nonverbal IQ and age (two children in the comparison sample attended specialist schools due to moderate learning difficulties and the remaining children attended mainstream schools). In the pitch direction task, the musical scales were manipulated to have small, medium, and large pitch intervals, where small pitch intervals contain notes with minute changes in pitch (1-4 semitones) and are thus more difficult to discriminate than large pitch

intervals, where the notes were further apart (9-12 semitones). On the pitch direction task, there was a significant interaction between diagnosis and interval type for small pitch intervals but not medium and large pitch intervals, indicating that children with ASD were more sensitive at detecting minute changes in pitch. In the melody processing task, participants were presented with pairs of short melodies with three conditions: same, different with a maintaining change (i.e., the new tone was consistent with the melody), or different with a violating change (i.e., the new tone was discordant with the melody). There were no significant differences between groups on this task, suggesting that superior pitch discrimination does not necessarily lead to superior musical ability.

Heaton and colleagues (2008) sought to replicate their findings in a sample of children with low- and high-functioning autism. They examined the ability to identify pitch direction and absolute pitch in 11-19 year old children with ASD (n=32; nonverbal IQs ranging from 55 to 108) compared to a sample of children with typical development (n=35) matched on chronological age and IQ (approximately half of the children in the comparison sample attended specialist schools due to moderate learning difficulties and the remaining children attended mainstream schools). Participants completed two auditory tasks that involved a visual display of a person moving up and down a set of stairs that corresponded with the presentation of the tones. For the pitch direction task, participants first completed practice trials where they were given reference points for the tones, then they heard ascending or descending pitch intervals and were asked to touch the step that corresponded to the tones they heard. Pitch memory was tested one week later to assess for absolute pitch (i.e., the ability to identify pitches without reference to a musical standard). Participants were not reminded of the reference points before being presented with six sets of tones, and they were then asked to touch the corresponding steps. Across both

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tasks, only a subset of children with ASD showed enhanced perception; 3 out of 33 children with ASD performed 4 to 5 standard deviations above the mean on both tasks. Enhanced perception was not related to IQ; low-functioning children with ASD performed as well as those without intellectual impairment. The authors suggest that this non-replication of findings may be due to increased task demands because of the combination of visual and auditory stimuli.

Enhanced visual perception. Several studies have demonstrated that individuals with ASD have enhanced visual perception as measured by the ability to discriminate changes in visual stimuli and to detect novel targets in visual arrays (Bertone, Mottron, Jelenic, & Faubert, 2005; Leader, Loughnane, McMoreland, & Reed, 2008; O'Riordan & Plaisted, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998). Bertone et al. (2005) examined perception of luminance in a sample of children and adults (aged 11-31 years) with high-functioning autism (n=13) or typical development (n=13), with groups matched on age and IQ. Luminance (which requires simple visual information-processing) and texture (which requires more complex processing) were manipulated by decreasing the contrast of a line pattern against a grey background. Participants were asked to judge the orientation of the lines (i.e., horizontal or vertical), which were more difficult to perceive in low-contrast conditions. Participants with ASD demonstrated enhanced perception for luminance-defined stimuli, but inferior perception for texture-defined stimuli, which require more complex neural networks in the visual pathway. Bertone and colleagues suggest that these findings indicate that sub-cortical perceptual processing is intact in ASD but low-level perceptual information-processing is altered due to atypical neural connectivity.

Leader and colleagues (2008) reported two experiments where they examined color discrimination in a sample of low-functioning children and adults with ASD. In the first experiment, 16 children with low-functioning autism (with a mean chronological age of 12:2

years and a mean mental age of 8:2 years) were matched on mental age with 16 children with typical development (with a mean chronological age of 7:11). The saturation of a color was manipulated to produce stimuli with lower levels of color intensity, and participants were exposed to either an equal salience condition (i.e., both stimuli had the same level of intensity) or an unequal salience condition (i.e., some stimuli had 25% lower color intensity). Participants were reinforced for choosing the "correct" stimuli (i.e., the one that matched the training card), and their most and least selected responses were analyzed to determine if their performance differed across the equal and unequal saliency conditions. The group with ASD, but not the group with typical development, showed an effect in the unequal saliency condition, indicating that the group with ASD was more sensitive to changes in color saturation than the comparison group. In the second experiment, these findings were replicated in a sample of 15 adults with low-functioning autism (with a mean chronological age of 18:6 and a mean mental age of 4:2 years), who were matched on mental age with 15 children with typical development (with a mean chronological age of 5:0 years).

Plaisted and colleagues (1998) examined featural discrimination of novel and familiar patterns of stimuli in high-functioning adults with ASD (n=8) compared to a sample of age- and IQ-matched adults with typical development (n=10). The data from the control group indicated a perceptual learning effect in that they were more accurate at discriminating familiar stimuli (i.e., stimuli that had been displayed in the pre-exposed condition) than novel stimuli. Although the ASD group did not show the perceptual learning effect as their performance was similar across both familiar and novel conditions, adults with ASD were significantly more accurate than the comparison group at detecting novel stimuli. In a later study, O'Riordan and Plaisted (2001) examined featural discrimination using a target detection task with 6-11 year old children with

ASD (n=13) compared to children with typical development (n=13) matched on age and nonverbal ability. In this study, they manipulated the similarity of the distractor stimuli to the target stimuli by changing the color or form of the distractor stimuli across four conditions (e.g., in the most difficult condition, participants searched for a red "F" target hidden among pink "F" and red "E" distractors). There was a significant interaction between group and condition, such that the superiority of the performance of the ASD group increased as target-distractor similarity increased. Thus, children and adults with ASD showed an enhanced ability to discriminate among visual features.

These studies provide some support for the Enhanced Perceptual Functioning theory. The tasks used to study visual perception involved manipulating the contrast of luminance vs. texture, examining color saturation in equal vs. unequal saliency conditions, and examining response patterns for novel vs. familiar stimuli and similar vs. dissimilar targets. The response type and task demands differed greatly among these studies, making it difficult to draw firm conclusions about the perceptual abilities of individuals with ASD. Most of the auditory perception tasks looked at discrimination of auditory stimuli along with a visual display, which could be a confound given hypothesized difficulties with multimodal processing (for a review, see Iarocci & McDonald, 2006). For example, a recent study of audiovisual integration in 7-16 year old children with high-functioning autism using the McGurk effect (where incongruent speech sounds and visual speech stimuli are presented simultaneously) found that younger children with ASD showed delayed visual accuracy and audiovisual integration compared to children with typical development (Taylor, Isaac, & Milne, 2010). Therefore, a study that examines the auditory and visual modalities in isolation from other sensory modalities and also uses simple task demands is necessary to test the Enhanced Perceptual Functioning theory. Furthermore,

there have not been any studies that examined the relationship between visual and auditory domains on comparable tasks in the same group of individuals. There have also not been any studies that looked at the relationship between enhanced perception and autism symptomatology other than IQ.

The current study sought to fill these gaps in the literature by examining the performance of children with ASD on a visual and an auditory same/different discrimination task and by correlating their perceptual abilities to autism severity. There are two hypotheses for this study: (a) individuals with ASD will show increased sensitivity on both visual and auditory perception tasks indicated by a higher d-prime (d') based on the findings of similar research, and (b) increased perceptual sensitivity will be positively correlated with autism symptomatology. This study will provide more information about perceptual processing and sensory patterns that potentially contribute to the development of autism symptoms.

Method

Participants

A total of 13 children with a previous diagnosis of ASD and 13 children with typical development participated in the study. Participants were required to meet the following inclusion criteria: 1) age 8-12 years inclusive; 2) brief Full Scale IQ greater than 70; 3) less than one year of formal musical training; 4) absence of acute medical or genetic condition (according to parent report); 5) normal hearing levels (at least 20 decibels (dB)) on a screening test, and 6) normal visual acuity (corrected to 20/20) and normal color vision on a screening test (see below for more details). In addition, participants with ASD were required to meet criteria on the Autism Diagnostic Observation Schedule (ADOS) and/or the Autism Diagnostic Interview (ADI-R). Participants with typical development were excluded based on the following criteria: 1) a score above the ASD cutoff on the Social Responsiveness Scale (SRS); 2) a history of psychiatric or developmental disorder; 3) currently taking any psychotropic medication; and 4) an immediate family member with an ASD diagnosis. In the ASD group, nine additional children were recruited and excluded. Four were excluded because they did not meet criteria for a current diagnosis on the ADOS, two were excluded because their IQ was below the cutoff, and three were excluded because they did not complete one or both perception tasks (one failed the hearing screening, one failed the vision screening, and two did not meet criteria on the visual task practice trials). In the control group, six additional children were recruited and excluded; two exceeded the cutoff score on the SRS, one child had a family member with ASD, and three did

not complete one or both perception tasks (two failed the hearing screening, one failed the vision screening, and two did not meet criteria on the visual task practice trials). Thus, the final sample was composed of 13 children with ASD and 13 children with typical development.

Participants with typical development were recruited through local elementary schools. Participants with ASD were recruited from local autism service agencies, including after school and summer programs, and the University of Alabama (UA) ASD Research Registry. The Registry consists of individuals seen in the UA ASD Clinic who indicated an interest in research and received a DSM-IV diagnosis of ASD by a licensed clinician experienced in the assessment and diagnosis of autism.

Apparatus

The tasks were administered using an Elo 12.1" touchscreen and a Dell Inspiron 6400 laptop with Windows Vista. The laptop was set to high resolution (1024 x 768 pixels) and Vista Basic 32 bit color scheme. Participants were seated in a stationary chair at a viewing distance of approximately 20 inches from the touchscreen. Sony noise-cancelling headphones (MDR-NC7) were used for the auditory task, and the volume was set to level 10 according to the laptop's sound control setting. The tasks were programmed using Inquisit version 2.0. The visual stimuli were created using Adobe Photoshop Elements version 7.0, and the auditory stimuli were created using Praat version 5.1.09 (created by Paul Boersma and David Weenink at the University of Amsterdam). Prior to beginning the study, these tasks were piloted with individuals with typical development until satisfactory task manipulations were achieved.

Stimuli

The visual stimuli consisted of geometric shapes that differed on the dimensions of luminance and hue. Three geometric shapes of a primary color were created using numerical

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red/green/blue (RGB) color values: a green circle (0.255.0), a red hexagon (255.0.0), and a blue square (0.0.255). For each dimension, the stimuli were created to produce easy, medium and hard conditions by manipulating the RGB value. The dimension of luminance was systematically manipulated by changing the RGB value for that color to differ from the first stimulus by 40 units in the easy condition, 30 units in the medium condition, and 10 units in the hard condition (either lower or higher). For example, a pair of red hexagons in the luminance-hard condition might have the RGB values of 215.0.0 and 205.0.0. To create incremental changes in hue, the RGB values for a different color were manipulated by 50 (easy), 40 (medium), and 30 (hard) units. For example, a pair of blue squares in the hue-easy condition might have the RGB values of 0.0.255 and 0.50.255 (shifting towards a green hue). Each stimulus was presented individually for 170 milliseconds (ms) with an interstimulus interval of 750 ms. The intertrial interval varied because the experimenter controlled the trial presentation (to ensure the participant was attending to the touchscreen prior to each trial). Prior to each trial, a crosshair was presented in the center of the screen. There were 24 trials for each condition (i.e., luminance-same, luminance-easy, luminance-medium, luminance-hard, hue-same, hue-easy, hue-medium, and hue-hard), with 8 trials of each shape, yielding 192 total trials. There were four experimental blocks in which luminance and color trials were intermixed, and the order of trials within each block was randomized.

The auditory stimuli consisted of pure tones that differed on the dimensions of pitch and volume. The stimuli that were manipulated consisted of 500 hertz (Hz), 750 Hz, 1000 Hz, 1250 Hz, and 1500 Hz tones. Pitch (Hz) was manipulated in increments of 3% (easy), 2% (medium), and 1% (hard) of the first stimulus presented. Volume (dB) was manipulated in increments of 40% (easy), 25% (medium), and 10% (hard) of the first stimulus. Each stimulus was presented

individually for 100 ms with an interstimulus interval of 1000 ms. There were 24 trials for each condition (i.e., pitch-same, pitch-easy, pitch-medium, pitch-hard, volume-same, volume-easy, volume-medium, and volume-hard), yielding 192 total trials.

Procedure

Potential participants completed a brief screening call based on the inclusion/ exclusion criteria. Participants and their parents were told that the purpose of the study was to evaluate the perceptual abilities of children with ASD compared to children with typical development and to see how this might relate to ASD symptoms. Participants were tested in a quiet room free from distractions. The consent and assent forms were reviewed with the participant and their parent(s), and they were given an opportunity to ask questions. The parent was asked to complete autism rating scales while the participant completed the assessments. Upon completion of the testing session, participants received $15, and parents were mailed a brief report. This study was approved by the University of Alabama Institutional Review Board.

Participants were asked to complete visual and auditory discrimination tasks to assess their perceptual sensitivity. The order of these two tasks was counterbalanced between participants. For both tasks, participants were presented with two successive stimuli and asked to indicate if they were the same or different by pressing the word on the touchscreen. Participants received the following instructions for the visual discrimination task: "You will see some shapes, and your job is to decide if the shapes are the same color or if they're different shades of a color. Some of the shapes might look the same, but they may be just a little bit different. If you think they are the same, press the 'same' button, and if you think they are different, press the 'different' button." The instructions for the auditory discrimination task were very similar: "You will hear some sounds, and your job is to decide if the two sounds are the same or different. The

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second sound may be a little higher or lower, or a little louder or softer. Some of the sounds might sound like they're the same, but they may be just a little bit different. If you think they are the same, press the 'same' button, and if you think they are different, press the 'different' button."

Participants completed two sets of practice blocks and teaching items before beginning the experimental blocks. The first practice block consisted of five trials of the same condition and five trials of the luminance-easy and hue-easy conditions. Participants repeated this practice block until they reached 70% accuracy; the task was discontinued if they did not reach this criterion after four attempts. All included participants met these criteria. Following this practice block, there were two teaching trials in which the visual stimuli were presented simultaneously for the hue-medium and luminance-hard conditions, and the participants were told that the stimuli were different. The second practice block consisted of four trials of the same condition and five trials randomly selected from the easy, medium, and hard conditions for both dimensions; there was no criterion for this practice block. The purpose of this practice block was to teach the children that some of the comparisons would be difficult and to give feedback prior to starting experimental trials. Participants did not receive feedback during the experimental trials. None of the stimuli used for the practice blocks were identical to the stimuli in the experimental blocks, although they were manipulated in the same way (e.g., the hue was shifted by the same amount but towards a different color). For the trials in which the stimuli were different, they differed only on the dimension that was being manipulated.

Similar to the visual discrimination task, participants completed two practice blocks and a set of teaching items before beginning the experimental blocks. For the auditory task, the first practice block consisted of five trials of the same condition and five trials of the pitch-easy and

volume-easy conditions. Following this practice block, there were four teaching trials in which the auditory stimuli were presented without an interstimulus interval for the medium and hard conditions for both pitch and volume, and the participants were told that the stimuli were different. The second practice block consisted of four trials of the same condition and four trials randomly selected from the easy, medium, and hard conditions for both dimensions. In all other ways, the auditory task was similar to the visual task (i.e., same criterion for the first practice block, four experimental blocks with randomized pitch and volume trials and no feedback during experimental blocks). The order of these two tasks was counterbalanced between participants.

Measures

Hearing and vision screening. Hearing and vision tests were administered to screen for impairments. Participants were required to hear at the threshold of 20 dB at the frequencies of 500, 750, 1000, and 1250 Hz using a portable audiometer (testing was conducted in a quiet but not sound-proof room). For visual testing, participants were required to read at a 20/20 level of acuity using a standard eye wall chart and to pass the Ishihara Test for Color Blindness (i.e., correctly identify the numbers in six color plates).

Cognitive testing. A brief full scale intelligence quotient (FSIQ) score was obtained using the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). The WASI has been normed for ages 4-89. The reliability coefficients for 6-16 year olds for the Verbal IQ, Performance IQ, and Full scale IQ were .93, .94, and .96, respectively. The WASI demonstrates good convergent validity with the Wechsler Intelligence Scale for Children (WISC) and the Wechsler Adult Intelligence Scale (WAIS), with *r*'s ranging from .76-.92.

Autism symptomatology. Participants with ASD were required to meet criteria on the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000) and/or the Autism Diagnostic

Interview-Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994). Participants who were recruited

from local service agencies were administered the ADOS by a trained clinician as part of the

current study. If participants had been diagnosed at the UA ASD Clinic and their parents signed

a release of information form, then their clinical records were used to confirm their diagnosis.

The ADOS and ADI-R are considered "gold standard" autism diagnostic assessment instruments.

Internal consistency for these measures was high; item-total correlations ranged from .52-.91.

Furthermore, comparisons of means indicated strong discriminant validity of ASD from non-

spectrum individuals.

The Social Responsiveness Scale (SRS; Constantino et al., 2004), a caregiver

questionnaire, was used to measure current severity of autistic symptomatology including social,

communication, and repetitive behavior symptoms. This measure has good convergent and

divergent validity; the SRS correlated highly with the ADI-R (r= .70) and was not correlated

with IQ (Constantino et al., 2003). The SRS was normed with a sample of more than 1,600

children aged 4-18 from the general population and separated by identity of rater (parent or

teacher) and gender of child (Constantino et al., 2004). Inter-rater reliability ranged from .75-.91,

and internal consistency was high for parent, teacher, and clinical ratings, ranging from .93-.97

for all groups. Test-retest reliability ranged from .77 to .85 for parent ratings. Regarding

interpretation, the SRS yields standardized scores with a cutoff score for ASD spectrum

disorders. For the SRS total, scores of 59 or below are considered in the normal range, scores of

60 to 75 are considered to be in the mild to moderate range of an ASD, and scores of 76 or

higher indicate an ASD in the severe range.

Two informant-based rating scales were used to measure repetitive behaviors. The

Repetitive Behavior Scale-Revised (RBS-R; Bodfish et al., 2000) assesses 43 discrete types of

lower-order and higher-order repetitive behavior within five categories (motor stereotypy, repetitive self-injury, compulsions, routines/sameness, and restricted interests). The RBS-R has not been normed, but it was validated with a sample of 307 individuals with pervasive developmental disorders ranging in age from 3-48 years (Lam & Aman, 2007). Internal consistency was high for all of the subscales (Cronbach's alphas ranged from .78 to .91), and interrater reliability for the subscales ranged from .57 to .73. Construct validity was evaluated using an exploratory factor analysis that produced a five-factor solution with mean factor loadings ranging from .51 to .60, and the five factors (subscales) accounted for approximately 47.5% of the variance. Mean item-total correlations for each subscale ranged from .54 to .65. Higher scores on the RBS-R indicate higher levels of repetitive behaviors.

The Childhood Routines Inventory (CRI; Evans et al., 1997) is a 19-item questionnaire that was developed to measure repetitive behaviors in preschoolers with typical development. There are two subscales that measure "just right" behaviors and repetitive behaviors (both higher-order behaviors), and these subscales were validated using a principal components analysis. The CRI showed strong internal consistency (Cronbach's alpha of .89) in a sample of 1492 parents with children with typical development aged 8-72 months. Barber and colleagues (2011) recently replicated this factor structure in older children (aged 6-17) with typical development and with ASD, indicating this measure has potential for comparing these two groups. The CRI does not have standardized scores; higher scores indicate higher levels of repetitive behaviors.

The Sensory Experiences Questionnaire version 2.1 (SEQ; Baranek et al., 2006) was used to measure sensory processing patterns. This parent questionnaire provides information on patterns of sensory hyper- and hypo-responsiveness across social and non-social contexts. The

SEQ was normed with a sample of 258 0.5-6.6 year olds and demonstrated good reliability (internal consistency of .80) and construct validity in differentiating children with autism from children with developmental delay and typical development. For the SEQ Total, scores in the range of 33 to 74 are considered typical, score in the range of 75 to 86 are considered at risk for sensory processing problems, and scores in the range of 87 to 165 indicate deficiencies in sensory processing.

In addition to these rating scales, parents were also asked to complete a form with questions gathering demographic information, including the child's age, sex, ethnicity, current interventions used (e.g., medications and/or behavioral therapy), and parental education.

Results

Participant Characteristics

Table 1

Characteristics of Included Participants

	ASD group (n=13)	Control group (n=13)	Test for group differences
Age in months			
Mean (*SD*)	126.69 (18.63)	118.38 (18.29)	*p*=.26
Range	102-153	101-151	
Brief FSIQ range	75-142	89-129	
Mean (*SD*)	104.23 (19.41)	116.38 (11.27)	*p*=.06
Verbal IQ range	72-146	102-136	
Mean (*SD*)	103.62 (23.88)	117.00 (9.95)	*p*=.08
Performance IQ range	79-129	79-131	
Mean (*SD*)	103.31 (14.15)	112.23 (14.67)	*p*=.13
Gender	10 males, 3 females	6 males, 7 females	X^2= .11
Race	10 Caucasian, 2 African American, 1 Hispanic	9 Caucasian, 2 African American, 2 more than one race	X^2= .59
Paternal Education	5 post-secondary, 7 high school or below, 1 unknown	4 post-secondary, 8 high school or below, 1 unknown	X^2= .42
Maternal Education	10 post-secondary, 2 high school or below, 1 unknown	12 post-secondary, 1 unknown	X^2= .35
SRS Total	79.33 (10.66)	42.33 (3.55)	*p*<.001**
RBS-R Total	22.00 (18.73)	0.33 (0.65)	*p*=.002**
CRI Total	42.50 (15.29)	26.83 (6.13)	*p*=.005**
SEQ Total	71.33 (12.07)	43.75 (6.15)	*p*<.001**

*Note: *p*< .05 ** *p*<.01*

Participants who met inclusion criteria were matched on chronological age. The *t*-tests revealed no significant differences between groups on age, $t=1.15$, $p=.26$, but there was a marginally significant difference on FSIQ, $t=-1.95$, $p=.06$, as well as Verbal and Performance IQs, with the control group having a higher mean FSIQ (see Table 1). Chi-square tests did not detect significant group differences on gender, race, or parental education. However, there was an unequal distribution of genders across groups, with the ASD group having more males than females compared to the control group, which had slightly more females than males. With the small sample size, the Chi-square test was not robust enough to reach significance. Given possible concerns about differences in perception across gender, gender was entered as a covariate. Thus, FSIQ and gender were entered as covariates in analyses of perceptual discrimination.

On the parent questionnaires, the ASD group showed the expected group differences with higher reported levels of symptoms than the control group. There were significant group differences on all subscales of the SRS in addition to the total score, indicating that the groups differed on autism-specific measures of social communication and autistic mannerisms (all $p<.001$). On the RBS-R and CRI, there were significant group differences on the total and all subscales (all $p<.05$). Regarding sensory behaviors, there were significant group differences on the SEQ total and all subscales (all $p<.01$).

Statistical Analysis using Signal Detection

The sensitivity index d prime (d') statistic from signal detection theory has been applied to data analysis where a stimuli is either present or absent as a means to analyze sensitivity to differences in perceptual stimuli. To analyze data using d', the trials were first sorted into hits (correct identification) and false alarms (false positive), then d' was calculated as Z(hit rate) –

Z(false alarm rate). D' is reported in standard deviation units, and provides the separation between the means of the signal and the noise distribution. Thus, a higher d' indicates greater sensitivity to differences in stimuli. Partial eta squared (η^2) was used as a measure of effect size, which can be interpreted as follows: .01 is a small effect, .06 is a medium effect, and .14 is a large effect (Pierce, Block, & Aguinis, 2004).

Group Differences on Perceptual Discrimination

Table 2

Mean d' scores for the Auditory Perception Task

	Volume Easy	Volume Medium	Volume Hard	Pitch Easy	Pitch Medium	Pitch Hard
ASD group Mean (*SD*)	1.40 (1.04)	1.27 (0.95)	1.26 (0.93)	2.05 (1.47)	1.40 (0.96)	0.66 (0.71)
Control group Mean (*SD*)	1.38 (1.07)	1.22 (0.86)	0.99 (1.04)	1.17 (1.23)	0.60 (0.95)	0.23 (0.82)

Table 3

Mean d' scores for the Visual Perception Task

	Luminance Easy	Luminance Medium	Luminance Hard	Hue Easy	Hue Medium	Hue Hard
ASD group Mean (*SD*)	2.04 (0.79)	1.47 (0.67)	0.32 (0.42)	1.13 (0.64)	0.98 (0.53)	0.74 (0.55)
Control group Mean (*SD*)	1.89 (0.62)	1.41 (0.73)	0.57 (0.35)	1.32 (0.38)	1.19 (0.49)	0.85 (0.41)

Perceptual discrimination. In order to compare performance on auditory and visual discrimination tasks, a 2 (Diagnosis: ASD, typical development) x 2 (Modality: Auditory, Visual) x 3 (Difficulty: Easy, Medium, Hard) x 4 (Dimension: Pitch, Volume, Luminance, Hue) repeated measures ANCOVA using d' was conducted with gender and FSIQ entered as covariates. See Tables 2 and 3 for d' values for each group by modality and dimension. Gender

was not a significant covariate, $F(1,22)=1.16$, $p=.29$, $\eta^2=.05$, and FSIQ was a marginally significant covariate, $F(1,22)=3.49$, $p=.08$, $\eta^2=.14$. There was a significant four-way interaction for Modality by Dimension by Difficulty by Diagnosis, $F(1,22)=11.65$, $p=.002$, $\eta^2=.35$, which suggests that diagnosis is different across all of these comparisons, however there was not a significant effect of Diagnosis, $F(1,22)=2.55$, $p=.12$, $\eta^2=.10$. As a result of this four-way interaction, it is difficult to interpret significant two-way and three-way interactions. All significant and marginally significant effects of this omnibus ANCOVA with F values greater than or equal to 2.29 and p values less than or equal to .14 are reported in Table 4. All other effects resulted in smaller F values and greater p values and are not reported. Thus, the analysis for comparing auditory and visual perception yielded a significant four-way interaction with a small to medium effect size, which suggests that there was differential performance for each diagnostic group across the auditory and visual tasks. To tease apart these significant findings, separate ANCOVAs were run for the auditory and visual discrimination data.

Table 4

Results of the Omnibus ANCOVA

	F	η^2	p
Diagnosis	2.55	.10	.12
Modality	2.37	.10	.14
Modality by Diagnosis	5.31*	.19	.03
Difficulty by FSIQ	4.70*	.18	.04
Difficulty by Diagnosis	3.38	.13	.08
Modality by Difficulty	4.12	.16	.06
Modality by Dimension by Diagnosis	5.93*	.21	.02
Modality by Difficulty by FSIQ	3.15	.13	.09
Dimension by Difficulty by Gender	3.67	.14	.07
Modality by Dimension by Difficulty by FSIQ	2.29	.09	.14
Modality by Dimension by Difficulty by Diagnosis	11.65**	.35	.002

*Note: *p< .05 ** p<.01, df (1,22) for all F values*

Auditory perception. In order to examine differences on auditory perception, a 2 (Diagnosis: ASD, typical development) x 2 (Dimension: Pitch, Volume) x 3 (Difficulty: Easy, Medium, Hard) repeated measures ANCOVA using d' was conducted with gender and FSIQ entered as covariates. Gender was not a significant covariate, $F(1,22)=1.49$, $p=.24$, $\eta^2=.06$, and FSIQ was a marginally significant covariate, $F(1,22)=3.38$, $p=.08$, $\eta^2=.13$. There was a significant main effect for Diagnosis, $F(1,22)=4.28$, $p=.05$, $\eta^2=.16$. Across all six conditions in the Auditory task, participants with ASD had a higher d' than participants with typical development. This main

effect was qualified by two significant interactions. There was a significant two-way interaction for Difficulty by FSIQ, $F(1,22)=5.93$, $p=.02$, $\eta^2=.21$, with participants across both groups with higher IQs showing higher sensitivity in easy > medium > hard conditions. There was also a significant three-way interaction for Dimension by Difficulty by Diagnosis, $F(1,22)=8.55$, $p=.008$, $\eta^2=.28$, which suggests that participants with ASD were significantly better than participants with typical development at identifying differences in pitch compared to volume, particularly for easier conditions. All significant and marginally significant effects of this ANCOVA with F values greater than or equal to 2.33 and p values less than or equal to .14 are reported in Table 5. Separate ANCOVAs for pitch and volume were run, and these follow-up analyses confirmed that there were significant effects for pitch, but not for volume. When examining sensitivity to pitch, FSIQ was a marginally significant covariate, $F(1,22)=3.98$, $p=.06$, $\eta^2=.15$. There was a significant main effect for Diagnosis, $F(1,22)=6.73$, $p=.02$, $\eta^2=.23$, as well as significant two-way interactions for Difficulty by Diagnosis, $F(1,22)=5.89$, $p=.02$, $\eta^2=.21$, and for Difficulty by FSIQ, $F(1,22)=4.83$, $p=.04$, $\eta^2=.18$, when analyzing pitch. For volume, there was a trend towards significance for the two-way interaction, Difficulty by FSIQ, $F(1,22)=2.61$, $p=.12$, $\eta^2=.11$. All other effects resulted in smaller F values and greater p values and are not reported.

Overall, analysis of the auditory discrimination task showed patterns among the data wherein individuals with ASD showed superior perception for pitch, particularly for easier conditions (i.e., in the pitch easy condition, the d' of the ASD group was nearly double the d' of the control group, 2.05 vs. 1.17, respectively). There was a small to medium effect size for this interaction. This finding is consistent with the hypothesis for pitch but not volume, indicating that individuals with ASD do not have superior perception across all domains. In order to

determine whether there were subgroups of participants who showed a pattern of hyposensitivity, Levene's test of the equality of variances was run for the four dimensions of the auditory and visual discriminations tasks. Levene's test was not significant for any of the dimensions: Volume, $F(1,12)=.04$, $p=.84$, Pitch, $F(1,12)=.02$, $p=.89$, Color, $F(1,12)=.1.95$, $p=.18$, or Luminance, $F(1,12)=.99$, $p=.33$. This indicates that there were not subgroups of participants who showed hyposensitivity on the perceptual tasks.

Table 5

Results of the Auditory ANCOVA

	F	η^2	p
Diagnosis	4.28*	.16	.05
Difficulty	2.33	.10	.14
Difficulty by FSIQ	5.93*	.21	.02
Difficulty by Diagnosis	2.49	.10	.13
Dimension by Diagnosis	2.70	.11	.11
Dimension by Difficulty by Gender	2.33	.10	.14
Dimension by Difficulty by Diagnosis	8.55**	.28	.008

*Note: *p< .05 ** p<.01, df (1,22) for all F values*

   Visual perception. A 2 (Diagnosis: ASD, typical development) x 2 (Dimension: Luminance, Hue) x 3 (Difficulty: Easy, Medium, Hard) repeated measures ANCOVA was conducted to examine differences on visual perception using d' with gender and FSIQ entered as covariates. Neither gender nor FSIQ were significant covariates (Gender: $F(1,22)=0.19$, $p=.67$, $\eta^2=.009$; FSIQ: $F(1,22)=1.63$, $p=.22$, $\eta^2=.07$). There was not a significant effect for Diagnosis,

$F(1,22)=0.02$, $p=.89$, $\eta^2=.001$. Contrary to the hypothesis, analysis of the visual discrimination task yielded only a three-way interaction for Dimension by Difficulty by Diagnosis that trended toward significance, $F(1,22)=3.05$, $p=.10$, $\eta^2=.12$. Separate ANCOVAs for luminance and hue were run, and these follow-up analyses yielded no significant main effects or interactions. All other effects resulted in p values of greater than .14 and are not reported.

Factor Analysis

An exploratory factor analysis was conducted to examine underlying patterns of performance across perceptual tasks. The 12 measures of d' were entered into the factor analysis (i.e., luminance-easy, luminance-medium, luminance-hard, hue-easy, hue-medium, hue-hard, pitch-easy, pitch-medium, pitch-hard, volume-easy, volume-medium, and volume-hard). This yielded a three-factor model; see Table 6 for the loadings from this factor analysis. As can be seen, the first factor contains high positive loadings for all variables, so this factor seems to represent overall perceptual sensitivity for auditory and visual stimuli. The second factor contains high positive loadings for visual sensitivity and negative loadings for auditory sensitivity. This second factor seems to represent modality-specific sensitivity (i.e., those who are more sensitive to discriminating either auditory or visual stimuli). The third factor contains high positive loadings for pitch and hue and negative loadings for volume and luminance. Pitch and hue are manipulated by changing the frequency of a stimulus, while volume and luminance are manipulated by changing the intensity of a stimulus. Thus, this third factor seems to represent stimulus-specific sensitivity (i.e., those who are more sensitive to discriminating either the frequency or intensity of stimuli, regardless of whether they are auditory or visual stimuli).

Table 6

Factor Scores

	Factor 1	Factor 2	Factor 3
Volume Easy	0.86	-0.12	-0.42
Volume Medium	0.87	-0.10	-0.43
Volume Hard	0.76	-0.14	-0.58
Pitch Easy	0.82	-0.44	0.06
Pitch Medium	0.78	-0.43	0.19
Pitch Hard	0.68	-0.52	0.29
Hue Easy	0.84	0.26	0.22
Hue Medium	0.80	0.05	0.38
Hue Hard	0.69	0.27	0.54
Luminance Easy	0.58	0.68	0.06
Luminance Medium	0.62	0.62	-0.16
Luminance Hard	0.16	0.80	-0.08

Based on this factor analysis, three scores were computed to create d' scores that paralleled each factor: 1) high overall sensitivity factor score (created by calculating the average of all 12 measures of d'), 2) high auditory sensitivity factor score (created by subtracting the average of the hue and luminance d' scores from the average of the volume and pitch d' scores), and 3) high frequency sensitivity factor score (created by subtracting the average of the volume and luminance d' scores from the average of the pitch and hue d' scores). Thus, a high overall sensitivity score indicates high sensitivity across auditory and visual domains, a high auditory

sensitivity score indicates higher sensitivity to auditory than visual stimuli, and a high frequency

sensitivity score indicates higher sensitivity to the frequency than the intensity of a stimulus.

These sensitivity factors were then correlated with the measures of autism symptomatology.

Relations between Perceptual Discrimination and ASD Symptoms

Although this study had a small sample size, exploratory correlations were run to

examine the relations among perception and parent-report measures of autism symptomatology.

Two-tailed Pearson partial correlations were run separately for the ASD group and the control

group with FSIQ as a covariate. According to Cohen (1988), a correlation is described as small if

$r=.1-.3$, medium if $r=.3-.5$, and large if $r=.5-1.0$. See Table 7 for correlations in the ASD group

and Table 8 for correlations in the Control group.

Table 7

Relations among Perception, Intellectual Ability, and Autism Measures in the ASD Group Controlling for FSIQ

Measure	Overall Sensitivity	High Auditory	High Frequency	SEQ Total	RBS-R Total	SRS Total
High Auditory	.56 $p=.07$	--	--	--	--	--
High Frequency	.06 $p=.85$	.26 $p=.44$	--	--	--	--
SEQ Total	.72* $p=.01$	.02 $p=.96$	-.14 $p=.67$	--	--	--
RBS-R Total	.50 $p=.12$	.01 $p=.98$	-.33 $p=.32$	.81** $p=.003$	--	--
SRS Total	.58 $p=.06$	.57 $p=.07$	.29 $p=.39$	.51 $p=.11$	.38 $p=.25$	--
SRS Motivation	.64* $p=.03$	.47 $p=.15$	.14 $p=.68$	.71* $p=.02$	.67* $p=.03$	.90** $p<.001$

*Note: *p< .05 ** p<.01*

In the ASD group, the SEQ total was significantly correlated with high overall

sensitivity, as would be expected. This finding supports the notion that parent ratings of overt

sensory behaviors are related to the child's perceptual abilities and lends validity to the SEQ for

children with ASD. Moreover, the SEQ total was significantly correlated with the RBS-R total,

supporting the overlap between sensory symptoms and repetitive behaviors. In general, high

levels of overall perceptual sensitivity were related to higher levels of autism symptomatology

on the measure of repetitive behavior (RBS-R) and the measure of overall symptomatology

(SRS). Because the SRS contains measures of both repetitive behaviors and social skills,

correlations were run with the subscales of the SRS to see whether both repetitive behaviors and

social skills were related to perceptual sensitivity. All scales yielded a positive correlation

between symptoms and perceptual sensitivity (all r's $\geq$ .33) with the only significant correlation

between overall sensitivity and the Motivation subscale.

Differential sensitivity to auditory rather than visual stimuli was less clearly related to

autism symptomatology. Differential sensitivity to auditory stimuli was not related to sensory

behavior on the SEQ or repetitive behavior on the RBS-R. However, the SRS Total and

Motivation subscale were positively related to differential auditory sensitivity with greater levels

of auditory sensitivity related to increased autism symptoms. No pattern of relations between

high frequency sensitivity and autism symptoms was found.

Table 8

Relations among Perception, Intellectual Ability, and Autism Measures in the Control Group Controlling for FSIQ

Measure	Overall Sensitivity	High Auditory	High Frequency	SEQ Total	RBS-R Total	SRS Total
High Auditory	.81** *p=.002*	--	--	--	--	--
High Frequency	.06 *p=.87*	.25 *p=.46*	--	--	--	--
SEQ Total	-.04 *p=.92*	-.19 *p=.58*	-.32 *p=.34*	--	--	--
RBS-R Total	-.50 *p=.12*	-.19 *p=.57*	-.22 *p=.52*	.37 *p=.27*	--	--
SRS Total	.14 *p=.68*	-.05 *p=.88*	-.84** *p=.001*	.25 *p=.46*	.15 *p=.65*	--
SRS Motivation	.44 *p=.18*	.11 *p=.74*	-.53 *p=.10*	.28 *p=.40*	-.21 *p=.53*	.76** *p=.007*

*Note: *$p< .05$ ** $p<.01$

In the group with typical development, autism symptoms across all measures were negatively correlated with the high frequency sensitivity score, although the only significant correlation was between the SRS total score and high frequency sensitivity (the negative correlation indicates sensitivity to intensity rather than frequency). This pattern indicates that among children with typical development, those who show higher levels of autism-like symptoms show higher sensitivity to the intensity of sensory stimuli in their environment (i.e., volume and luminance).

Discussion

Enhanced Perceptual Functioning Theory

Regarding the hypothesis that children with ASD would show enhanced perception in auditory and visual domains, the ASD group did show higher sensitivity than the control group for pitch but not for volume, hue, or luminance. Although this was a relatively small sample, there were small to medium effect sizes for the analyses, indicating that the sample size was sufficient to detect group differences. Groups were matched on chronological age, but due to slight differences between the groups on FSIQ and gender, these variables were controlled for in the analyses to make the groups more similar. The ASD group had significantly higher scores than the control group on all of the parent-report measures of autism symptomatology, as expected.

This study provides some support for the Enhanced Perceptual Functioning Theory. In addition to replicating the findings of Bonnel et al. (2003), who found enhanced discrimination for pitch in a sample of adolescents with ASD, this study demonstrated that superior pitch discrimination occurs in younger children than had previously been studied. These findings support the notion that enhanced perception for pitch may be a phenotype of ASD rather than a splinter skill demonstrated by a small subset of individuals with ASD. Although Heaton et al. (2008) only found enhanced pitch perception in a subset of their sample, there may be two reasons for these discrepant findings: 1) to assess perception of pitch direction, there was a visual display which may have involved cross-modal sensory processing, and 2) they tested for absolute

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pitch, which is an extremely rare ability that is estimated to occur in only about 0.01% of the population (Takeuchi & Hulse, 1993).

Discrimination for changes in volume had not been previously studied in ASD, and the lack of group differences on this dimension suggests that the individuals with ASD do not have broad enhanced auditory perception but that the ability to detect changes in pitch is a unique ability in individuals with ASD. This could be due to differences in the way pitch is processed in the brain due to atypical pathways in the left frontal cortex, as suggested by Gomot et al. (2002). The attention literature in ASD shows that there are differences in automatic orienting, and enhanced pitch perception may be due to hyper-sensitivity towards novel sounds. Further research on the neurobiology of pitch perception is needed to elucidate how the brain of individuals with ASD processes auditory input.

The lack of significant group differences in the visual domain suggest that the enhanced visual discrimination that has been reported previously may be due to other visual aspects than luminance or color saturation (i.e., featural discrimination of novel patterns and target detection). This non-replication of findings from previous studies may also be due to differences in methodology. Leader et al. (2008) found enhanced perception for color saturation; however, their study examined perception in the context of a learning task in a sample of low-functioning children and adults. Color saturation was consistently manipulated by 25%, which may have been easier than making same/different discriminations across three levels of difficulty. The methodology of the present study also differed from that of Bertone et al. (2005), who found enhanced perception for luminance. Their task involved asking individuals to identify the orientation of lines on a circle, and individuals may recruit different neural pathways when looking for a pattern on a stimulus as opposed to judging whether two stimuli are the same or

different. Previous research on enhanced visual perception in individuals with ASD suggests they may use a different strategy for target detection based on recruitment of different brain regions.

Relationships among Perceptual Sensitivity and Autism Symptomatology

According to the second hypothesis, perceptual sensitivity would be related to autism symptomatology. An exploratory factor analysis yielded a three-factor model. The first factor seemed to represent high overall sensitivity, the second factor seemed to represent modality-specific sensitivity, and the third factor seemed to represent stimulus-specific sensitivity. Based on these factors, d' sensitivity scores were computed and correlated with measures of autism symptomatology. This is the first study to demonstrate a relationship among perceptual sensitivity and ASD symptoms. Performance on the perceptual tasks was not correlated with all measures of autism symptomatology, and some interesting patterns emerged from these correlations.

As would be expected, there was a relationship between higher perceptual sensitivity and sensory behaviors as measured by the SEQ in the ASD group. Although not surprising, this finding indicates that children's perceptual sensitivity is expressed through overt behaviors that can be observed and reported by parents, which lends ecological validity to these findings about perceptual sensitivities in ASD. This finding also supports the validity of the SEQ as it relates to auditory and visual perception. In the ASD group, there was evidence of a relationship between overall and auditory sensitivity and autism severity as measured by the SRS, particularly difficulties with social motivation. Although the direction of the relationship cannot be inferred from these correlations, one possible explanation for this relationship may be that children with ASD who are more sensitive to visual and auditory stimuli are reluctant to approach social

situations where there may be overwhelming sights and sounds. Interestingly, a similar pattern was detected in the group with typical development. There was a relationship between higher levels of autism-like symptoms and higher sensitivity to the intensity of sensory stimuli in their environment (i.e., volume and luminance). There was a marginally significant relationship between this measure of perceptual sensitivity and difficulties with social motivation in the control group.

A longitudinal study would be necessary to tease apart the directionality of these relationships. The developmental pathway of enhanced sensitivity is not clearly delineated from this study. It may be that children with ASD maintain a higher level of sensitivity from very early childhood, or they may become more sensitive over time. Alternatively, both groups of children may have a high level of sensitivity and children with typical development may experience decreased sensitivity over their childhood. For example, research on first language acquisition (Kuhl, 2009; Werker & Fennell, 2009) shows that infants are able to distinguish among a wide variety of phonetic sounds and that there is a critical period in which they lose the ability to distinguish certain phonemes if they are not exposed to them (e.g., Japanese infants lose the ability to make the distinction between r and l). A similar developmental process may occur for pitch sensitivity wherein individuals with typical development become less able to distinguish between different pitch levels because this aspect of auditory information is not usually relevant to social interactions. In contrast, individuals with ASD may attend less to social information and maintain a high level of sensitivity to pitch differences.

There was a strong relationship between the SEQ and the RBS-R totals in the ASD group. This finding is consistent with other studies that have found relationships between sensory and repetitive behaviors (Boyd, McBee, Holtzclaw, Baranek, & Bodfish, 2009; Gabriels et al.,

2008). Gabriels and colleagues reported correlations between the RBS-R Total and sensory behaviors as measured by the Sensory Profile, and Boyd and colleagues found correlations between sensory behaviors as measured by the Sensory Questionnaire and specific repetitive behaviors as measured by the RBS-R, including Compulsions, Stereotypies, and the Total score. Further research into the relationship between sensory and repetitive behaviors will be needed to determine the direction of this relationship and the pattern of correlations among particular sensory behaviors and subtypes of repetitive behaviors in a larger sample. Future studies should examine the effect of processing unpredictable or novel information as a potential mediator of this relationship.

Overall, the findings from this study provide further support for the inclusion of sensory symptoms as a diagnostic criterion for ASD under the restricted, repetitive behavior category in the DSM-V. Even with a relatively small sample size, there was strong evidence that children with ASD demonstrated a superior ability to detect differences in pitch compared to children with typical development matched on age and controlling for FSIQ and gender, which replicated and extended previous research. The three-factor model yielded three dimensions of perception: overall sensitivity, modality-specific sensitivity, and stimulus-specific sensitivity. The pattern of correlations suggested that overall sensitivity was most related to ASD symptoms, which supports the Enhanced Perceptual Functioning theory.

Clinical Significance

These results have clinical significance for understanding children with ASD. Enhanced pitch perception may be adaptive, such as for a person with musical interests (although, as Heaton (2005) concluded, superior pitch discrimination does not necessarily lead to superior musical ability). If individuals with ASD perceive sounds in a different way, some sounds may

be experienced as pleasant. However, some sounds may be experienced as painful, such as the sound of vacuum cleaners, alarms, babies crying, and other sounds that are frequently reported in clinical accounts as being problematic for individuals with ASD. Hypersensitivity to sounds may lead to becoming easily overwhelmed in a noisy environment or having difficulty following a conversation. Given that individuals with ASD do not show overall elevations of sensory sensitivities, clinicians may need to identify specific sensitivities in a person with ASD in order to address the individual's needs. Perceptual sensitivities need to be understood better in order to adequately accommodate for them in the community as well. For example, caregivers and teachers taking children with ASD to loud public venues such as malls, movie theaters, and school gymnasiums, should be aware of the potential negative perceptions of these loud environments and may want to provide a way to dampen the sound (e.g., headphones) or intersperse loud environments with quiet rooms for "sensory breaks."

Limitations and Future Research

Two limitations for this study included the small sample size, particularly for the correlations, and the cross-sectional nature of the research. Further research studies with larger sample sizes using a longitudinal design are needed to replicate these findings and to examine the directionality of the relationship between perception and autism measures. Another limitation was that the study only included children with high-functioning autism. Enhanced perception has been tested in children with low-functioning ASD as well, so these findings should be replicated in individuals with a wider range of cognitive abilities. A developmental study that examined enhanced perception across a range of ages, including younger children, would also contribute to the literature by investigating whether perceptual abilities change over time. Studying perception

in infants who are at risk for ASD would allow researchers to determine if perceptual sensitivity is a "red flag" for ASD.

Future studies could examine other potential correlates of perception, including cognitive measures such as contextual cueing, category formation, and generalization, in order to determine if higher-level processing is affected by lower-level perceptual differences in ASD. Children who show higher perceptual sensitivity may be more aware of details in the environment, which could affect their style of cognitive processing (e.g., they may use a more explicit learning strategy for cognitive tasks like category formation because they are more likely to see stimuli as more distinct than individuals with lower perceptual sensitivity). Further research on the perceptual features that influence attention orienting is needed to elucidate the types of stimuli that capture the attention of individuals with ASD. This information may provide insight into the underlying neural processes that contribute to the ASD phenotype. Research on cross-modal processing is warranted to determine the nature of the interaction between auditory and visual perception. Examining perception in family members of individuals with ASD could potentially contribute to genetic research in ASD.

This study contributed to the literature on perceptual processing and sensory patterns that may lead to the development of cognitive and behavioral symptoms in ASD. The present study yielded novel findings about the relationship between perceptual sensitivities and ASD symptoms, suggesting that repetitive behaviors and social skill difficulties are related to increased perceptual sensitivity. Enhanced perception may be due to fundamental differences in brain processes that determine what information is important to attend to and how that information is interpreted in context. Certainly, it is likely that the ability to perceive particular stimuli differently may lead to altered patterns of behaviors and social interactions.

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