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ACOUSTIC AND SEMANTIC PROCESSING OF SPEECH AND NON-SPEECH SOUNDS

IN CHILDREN WITH AUTISM SPECTRUM DISORDERS

By

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Abstract

The processing of semantically meaningful non-speech and speech sounds requires the use of acoustic and higher-order information, such as categorical knowledge and semantic context. Individuals with an autism spectrum disorder (ASD) have been theorized to show enhanced processing of acoustic features and impaired processing of contextual information. The current study investigated how children with and without ASD use acoustic and semantic information during an auditory change detection task and semantic context during a speech-in-noise task. Furthermore, relationships among IQ, the presence of ASD symptoms and the use of acoustic and semantic information across the two tasks were examined among typically developing (TD) children. Results indicated that age-matched--but not IQ-matched--TD controls performed worse overall at the change detection task relative to the ASD group. However, all groups utilized acoustic and semantic information similarly. Results also revealed that all groups utilized semantic information to a greater degree than acoustic information and that all groups displayed an attentional bias to detecting changes that involve the human voice. For the speech-in-noise task, age-matched--but not IQ-matched--TD controls performed better than the ASD group. However, all groups utilized semantic context to the same degree. Regression analyses revealed that IQ or the presence of ASD symptoms did not predict the use of acoustic or semantic information among TD children. In conclusion, children with and without ASD utilize acoustic and semantic information when processing semantically meaningful speech and non-speech sounds during auditory change detection and speech-in-noise processing. Furthermore, a diagnosis of ASD alone does not determine lower performance on complex auditory tasks; rather, lower intellect appears to explain group differences in overall performance.

Keywords: Autism spectrum disorders, acoustic, semantic, speech, non-speech sounds

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Chapter 1: Introduction

Autism spectrum disorders (ASD) are a spectrum of neurodevelopmental disorders characterized by abnormalities in social interaction and communication, and engagement in restricted and repetitive behaviors (American Psychiatric Association, 2013). Additionally, abnormalities in the processing of low-level acoustic and higher-order semantic information during auditory and language tasks have been reported, including enhanced processing of pitch (Heaton, Hermelin & Pring, 1998; Heaton, 2005; Bonnel et al., 2003; O' Riordian & Passetti, 2006; Mayer, Hannent, & Heaton, 2016; Järvinen-Pasley & Heaton, 2007; Heaton, Hudry, Ludlow, & Hill, 2008; Järvinen-Pasley et al., 2008; Jarvinen-Pasley, Pasley, & Heaton, 2008) and impaired use of semantic context (Frith & Snowling, 1983; Happe, 1997; Jolliffe & Baron-Cohen, 1999; Lopez & Leekam, 2003; Tager-Flusberg, 1991; Eberhardt & Nadig, 2016; Norbury & Bishop, 2002).

Two main theories have been put forth to explain sensory and cognitive processing in ASD: Weak Central Coherence (WCC; Frith & Happé, 1994; Happé, 1999; updated in Happé & Frith, 2006) and Enhanced Perceptual Functioning (EPF; Mottron & Burack, 2001; Mottron et al., 2006). The WCC theory postulates individuals with ASD possess a detail-focused cognitive style that involves increased attention to low-level perceptual information accompanied by a diminished ability to integrate individual elements into a coherent whole. This processing style can lead to a reduction in sensitivity to global features and the underutilization of contextual information. WCC would predict enhanced performance on tasks that would benefit from increased attention to local perceptual information, while tasks that involve contextual integration or the use of global information would result in diminished performance relative to typically developing (TD) individuals.

Like WCC, the EPF (Mottron & Burack, 2001; Mottron et al., 2006) model also postulates enhanced processing of simple, low-level perceptual information. However, unlike WCC, this low-level enhancement is not due to an inability to integrate local elements into a coherent whole; thus, EPF does not predict an impairment in global processing. Instead, EPF attributes enhanced low-level processing to the over-functioning of low-level sensory areas. Additionally, EPF posits that relative to TD individuals, individuals with ASD have greater autonomy between perceptual and higher-order processes, especially during tasks in which it would be beneficial to focus on low-level information.

The perception of semantically meaningful speech and non-speech sounds present in our everyday environments involves complex processes that utilize higher-order information such as semantic context and prior knowledge of sound categories and schemas. For instance, typically developing (TD) listeners perceive semantically congruent sentences (e.g., The farmer harvested his *crop*) more accurately than semantically incongruent sentences (e.g., I want to know about the *crop*) (Wilson et al., 2011). Similarly, semantically meaningful non-speech sounds that are embedded in a contextually incongruent auditory scene (e.g., a rooster crowing in a hospital) are identified more readily than when embedded in a contextually congruent scene (e.g., rooster crowing in a farm) (Gygi & Shafiro, 2011; Leech, Gygi, Aydelott, & Dick, 2009). Thus, in both situations, the overall semantic context provides high-level information, based on prior knowledge about language and schemas, that enables comprehension of the sentence or auditory scene in terms of their meaning.

However, a prevalent characterization of language processing in individuals with ASD is the impaired use of semantic context. The use of semantic context during visual language processing at the sentence level has been investigated in individuals with ASD using homographs. Homographs are words that are spelled the same but have distinct semantic meanings and possibly distinct pronunciations (i.e., they are not homophones). Examples of homographs include the words tear, bow, and lead. In these tasks, participants are asked to read aloud sentences that contain a homograph. For example, "The scrap metal man first took the copper and iron and then he took the *lead"* where the last word is a homograph. To understand and correctly pronounce words such as these, it is necessary to integrate the meaning of the individual words to create a semantic context of the linguistic information. Children with ASD typically perform worse than children without ASD, providing the more frequent pronunciation of the homograph regardless of semantic context (Frith & Snowling, 1983; Happe, 1997; Jolliffe & Baron-Cohen, 1999; Lopez & Leekam, 2003). Other paradigms have used contextual information to promote memory of semantically related word lists (Tager-Flusberg, 1991), open-endedly completing ambiguous sentences (Eberhardt & Nadig, 2016), or making text-connecting or gap-filling inferences during story comprehension (Norbury & Bishop, 2002). Results have revealed impaired use of semantic context in individuals with ASD which would be predicted by WCC, but not EPF model.

Research investigating the use of semantic information during the processing of non-speech sounds in individuals with ASD is scarce. One study had participants with and without ASD complete a semantic matching task where two pictures were presented and then either a spoken word or semantically meaningful non-verbal sound was played. Participants indicated which picture matched the spoken word or non-verbal sound. There was no difference in performance among individuals with and without ASD, indicating that semantic matching of pictures to individual spoken words and non-verbal sounds is not impaired in individuals with ASD (McCleery et al., 2010). A separate study used a semantic priming word completion task with pictures and visually presented words. Participants with and without ASD were presented with either a visually presented word or picture that was congruent or incongruent with the to-be completed word. Individuals with and without ASD completed the fragmented word more quickly when the primes were congruent but individuals with ASD benefitted more when a visual picture prime was used relative to the written word. Individuals without ASD performed similarly regardless of the type of prime (Kamio & Toichi, 2000). Together, these studies suggest that the processing of individually presented, semantically meaningful stimuli (pictures, sounds, and visually or aurally presented words) is unimpaired in individuals with ASD during matching and priming tasks. These results support EPF, which does not predict a deficit in higher-order processing, whereas WCC does and therefore, these findings do not support WCC.

Acoustic information is also used during the processing of semantically meaningful speech and non-speech sounds. Spectral and temporal properties, are important for speech perception, providing information about word segmentation and identification. For example, English listeners can segment nonsense phrases into separate words based on lexical stress and rhythm (Nakatani, 1978), and mis-stressed words are harder to identify relative to words that are correctly stressed (Cutler & Clifton, 1984). Additionally, spectral and temporal information helps listeners identify semantically meaningful non-speech sounds, like a baby crying and a car starting (Gygi, Kidd & Watson, 2003).

One of the most common characterizations of auditory processing among individuals with ASD includes superior processing of pitch for simple pure tones and speech stimuli, relative to TD individuals. Pitch discrimination and categorization tasks include presenting participants with pairs of stimuli and asking them to make ‘same/different’ or ‘high/low’ judgments, respectively. Studies using pairs of pure tones, or pairs of words and short sentences, consistently reveal superior performance in individuals with ASD relative to TD individuals (Heaton, Hermelin & Pring, 1998; Heaton, 2005; Bonnel et al., 2003; O' Riordian & Passetti, 2006; Mayer, Hannent, & Heaton, 2016; Järvinen-Pasley & Heaton, 2007; Heaton, Hudry, Ludlow, & Hill, 2008; Järvinen-Pasley et al., 2008; Jarvinen-Pasley, Pasley, & Heaton, 2008). However, when the processing of other local features are investigated, like loudness (Bonnel et al., 2010; Jones et al., 2009; Khalfa et al., 2004) and timing (Falter et al., 2012; Isaksson et al., 2018), there is no evidence of enhanced processing. The findings related to pitch processing are supported by WCC and EPF models which predict enhanced processing of low-level features due to a local-oriented processing style and overspecialization of sensory areas, respectively. However, the findings related to loudness and temporal processing do not support WCC and EPF. Additionally, there is some evidence for enhanced pitch processing only being present in a subgroup of individuals with ASD that have a history of a language delay or the presence of language impairments (Heaton et al., 2008; Bonnel et al., 2010; Jones et al., 2009). Instead of the processing of local or low-level features being enhanced in individuals with ASD, this enhancement could be specific to pitch and might not be a universal characterization. Rather, it might be a characteristic of individuals with ASD who also have a history of language delay or current language impairments.

Despite individuals with ASD typically showing enhanced pitch processing, they often display difficulties perceiving speech in noisy environments (Alcantara et al., 2004; Groen et al., 2009; Bhatara et al., 2013; DePape, Hall, Tillman, & Trainor, 2012). These studies indicate that individuals with ASD require a higher signal-to-noise ratio (SNR) than TD individuals to correctly perceive the speech signal. Furthermore, several studies have investigated how acoustic properties contribute to this deficit, specifically spectral and temporal dips. Temporal dips are transient periods in which the amplitude of the background noise is sufficiently less than the speech signal, allowing clear extraction of information. Spectral dips are periods of time in which the frequency of the background noise is sufficiently distinct from the speech signal, again allowing for the clear extraction of information. Results indicate that during speech-in-noise processing individuals with ASD display greater difficulty integrating information provided by the presence of temporal dips, but not when spectral dips are present (Alcantara et al., 2004; Groen et al., 2009). Studies investigating temporal processing in individuals with ASD using gap detection tasks indicate poorer performance relative to TD individuals (Bhatara et al., 2013; Boets et al., 2015; Foss-Feig et al., 2017). In these tasks, participants are asked to indicate whether they perceived a silent gap within a presented sound stimulus or are asked to indicate which of two presented sound stimuli contained a silent gap. Individuals with ASD consistently exhibit higher gap detection thresholds, requiring longer silent durations to correctly detect the silent gap, relative to individuals without ASD. Increased gap detection thresholds in individuals with ASD indicates a difficulty in detecting rapid temporal changes in auditory stimuli which is problematic for speech perception in quiet and in noise.

Prior ASD research has focused on the processing of semantic information for visually presented language, pictures, and non-speech sounds presented in isolation. The processing of acoustic information has been investigated for sounds presented in isolation (e.g., pure tones and speech) and during a speech-in-noise task (e.g., temporal and spectral). What has yet to be investigated is the use of acoustic and semantic information during a task that includes the simultaneous presentation of multiple, semantically meaningful non-speech sounds. Furthermore, it has yet to be explored whether the use of semantic information contributes to speech-in-noise deficits in individuals with ASD.

Change deafness is an auditory phenomenon, analogous to change blindness in the visual domain, where salient auditory changes go unnoticed by listeners. Change deafness paradigms have been used to understand what information listeners use during the perception of auditory scenes comprised of multiple sound sources. Change deafness paradigms typically include the presentation of one sound scene followed by a second, wherein the second scene one of the sounds that was present in the first has now changed. Participants are asked to indicate whether the scenes are the same or different. In adults and children, changes that are acoustically similar in pitch and harmonicity are more difficult to detect than changes that are dissimilar in pitch and harmonicity (Gregg & Samuel, 2008, 2009; Vanden Bosch der Nederlanden, Snyder, & Hannon, 2016), and changes that come from the same semantic category (e.g., chihuahua bark changing to a Great Dane bark) are more difficult to detect than those that come from a different semantic category (e.g., chihuahua bark changing to a trumpet) (Gregg & Samuel, 2009; Vanden Bosch der Nederlanden, Snyder, & Hannon, 2016). However, changes that come from the same semantic category are more difficult to detect than changes that are acoustically similar, suggesting semantic information plays a more prominent role than acoustic information during change detection (Gregg & Samuel, 2009; Vanden Bosch der Nederlanden, Snyder, & Hannon, 2016). Additionally, children and adults detect changes involving the human voice better than changes that involve other semantic categories (environmental, musical, animal). This highlights the use of acoustic and semantic information, and attention to species-specific sounds during auditory scene perception and more specifically, change detection.

Speech perception is not achieved by separately processing the meaning of individual words; it requires integrating the meaning of individual words to create a semantic context, a cue that is especially useful in complex listening situations, like when having to perceive speech in the presence of background noise (Bradlow & Alexander, 2007; Wilson et al., 2011; Pichora-Fuller et al., 1995; Kalikow, Stevens, & Elliott, 1977). Speech-in-noise tasks have been used to assess the use of semantic context during speech-in-noise processing. For example, sentences with high- and low-predictability are presented in different signal-to-noise ratios (SNR) and participants are asked to repeat back the last word of each sentence. An example of a sentence with high predictability is "The candle flame melted the *wax*" where the semantic context, specifically the words "candle", "flame", and "melted" assist in predicting the last word, "wax". An example of a sentence with low predictability is "Paul can't discuss the wax". In this case, there is no semantic information that would predict the word "wax". High predictability sentences are more accurately perceived than low predictability sentences, especially at lower SNR's, displaying the benefits of semantic information during speech-in-noise processing (Bradlow & Alexander, 2007; Wilson et al., 2011; Kalikow, Stevens, & Elliott, 1977).

The current study had children with and without ASD complete a change deafness and speech-in-noise task to address the following aims: (1) Do children with ASD exhibit change deafness? (2) Do children with ASD rely on acoustic and semantic information similarly to TD children during auditory change detection? (3) Do children with ASD display an attentional bias towards human voices relative to other sound categories during auditory change detection? (4) Do children with ASD utilize semantic context similarly to TD children during a speech-in-noise task? Additionally, IQ, and the prevalence of ASD symptoms was assessed and related to the use of semantic information during perceptual tasks in TD children. The presence of ASD symptoms have been identified within TD populations (Baron-Cohen et al., 2001) and those TD individuals who present a greater amount of ASD symptoms tend to perform similarly to individuals who are formally diagnosed with ASD on auditory (Stewart, Griffiths, & Grube, 2018) and visual perception tasks (Almeida et al., 2010). Therefore, the final aim of the current study was to assess possible relationships among IQ and ASD symptoms and the use of semantic information among TD children.

Chapter 2: Methods

Participants

Twenty-nine children diagnosed with an autism spectrum disorder (ASD) (21 male; age range = 7.17 to 14.92 years, mean age = 11.18 years) and one hundred and nine typically developing (TD) children (47 male; age range = 7.0 to 14.58 years, mean age = 9.62 years) from the UNLV Ackerman Center for Autism and the Las Vegas community participated. All parents/caregivers reported the participants had normal hearing and provided written informed consent in accordance with the guidelines of the University's Office for the Protection of Research Subjects for their child to participate. The children were all fluent English speakers and provided assent prior to testing. A priori power analyses were performed using the program MorePower (Cambell & Thompson, 2012) to determine the sample size needed for each group for a medium effect size of $n_p^2 = .13$ (Cohen, 1988) with 80% power using a mixed-design analysis of variance (ANOVA) for the change deafness and speech-in-noise tasks. Results indicated that 27 participants per group would be needed to detect significant main effects of trial type (same, different) and change type (acoustic, semantic), and to detect significant trial type x group and change type x group interactions for the change deafness task. Additionally, 27 participants per group would be needed to detect a significant main effect of sentence type (HP, LP) and a significant sentence type x group interaction for the R-SPIN task. However, one-hundred and nine children without ASD participated to provide greater power for regression analyses. A total of 2 children with ASD were excluded because all experimental tasks were not completed due to child refusal (*n* = 2). Final analyses included 27 children with ASD. Children with ASD were approved to participate if they have been formally diagnosed by a clinical professional or team of clinical professionals according to the criteria of the Diagnostic and

Statistical Manual of Mental Disorders (DSM-IV). Caregivers or the UNLV Ackerman Center provided confirmation of diagnosis via medical records. A total of eight children with ASD reported comorbid diagnoses. These included: language impairment and reading disability (*n* = 1), cognitive and language impairment (*n* = 1), seizures (*n* = 1), Attention deficit hyperactivity disorder (*n* = 4), auditory processing disorder (*n* = 1). TD children had no reported personal history of neurological or developmental disorders.

Twenty-seven TD children were age- (19 male; age range = 7.58 to 14.50 years, mean age = 11.10 years, mean IQ = 104.70) and IQ-matched (19 male; age range = 7.25 to 14.58 years, mean age = 10.44 years, mean IQ = 91.15) separately to the children with ASD (19 male; age range = 8.08 to 14.92 years, mean age = 11.19 years, mean IQ = 88.85) . Both groups were additionally matched on sex resulting in 19 males and 8 females in each group. There was no significant difference in age among the ASD (M = 134.37 months, SD = 24.20) and age-matched (M = 133.22 months, SD = 23.31) groups; $t(52) = .18$, p = .860; d = .05. There was no significant difference in IQ among the ASD (M = 88.85, SD = 18.17) and IQ-matched (M = 91.15, SD = 15.92) groups; $t(52) = -.49$, p = .624; d = -.14, Participant characteristics are listed in Table 1. The criterion for the age-matched TD children was +/- 1 year and criterion for the IQ-matched TD children was +/- 12 points. All possible matches were found using these criteria. When there was more than one match between the children with and without ASD, the child without ASD was randomly chosen. All change deafness and R-SPIN analyses included separate comparisons between the ASD and age-matched groups and the ASD and IQ-matched groups.

Apparatus

All participants completed the change deafness task in a quiet room using either a MacPro4.1 running Windows7 Enterprise or a HP ProBook 645 G1 computer running Windows

Table 1
Participant Characteristics of ASD and Age- and IQ-matched Control Groups.

Group	Sex Ratio (M/F)	Chronological Age (years)	IQ	GARS
ASD (*n* = 27)	19/8	11.19 (2.02)	88.85 (18.17)	98.44 (10.34)
TD Age-matched (*n* = 27)	19/8	11.10 (1.94)	104.70 (14.59)	55.67 (10.28)
TD IQ-matched (*n* = 27)	19/8	10.44 (2.37)	91.15 (15.92)	57.70 (15.25)

Note: Means and standard deviations (in parentheses) are presented.

10, and stimuli were presented using a custom script in Presentation (Version 16.3). Sounds were presented through KidzGear headphones, Sony Professional MDR-7506 headphones, or Sennheiser HD 280 pro headphones at around 60 dB SPL. The headphones have similar frequency responses (KidzGear, Sennheiser = 20Hz – 20kHz; Sony = 10Hz – 20kHz) and sensitivity (KidzGear = 108 dB ± 3 dB; Sony = 106 dB; Sennheiser = 117 dB), so all headphones were sufficient for hearing above-threshold sounds. A green and red sticker was placed over the letters "S" and "D" on the keyboard and a custom Presentation script recorded participants' keyboard presses.

Participants completed the speech-in-noise task in either a sound-attenuated booth (Industrial Acoustics Corp., Bronx, NY) using a Pentium 4 computer with a SB X-Fi sound card (Creative Technology, Ltd.), or in a quiet room using a HP ProBook 645 G1 computer running Windows 10. Stimuli was presented using a custom script in Presentation (Version 16.3). Sounds were presented through Sennheiser HD 280 pro headphones at around 60 dB SPL. The experimenter was seated in the testing room with the participant and recorded the participants' verbal responses for later scoring.

Stimuli

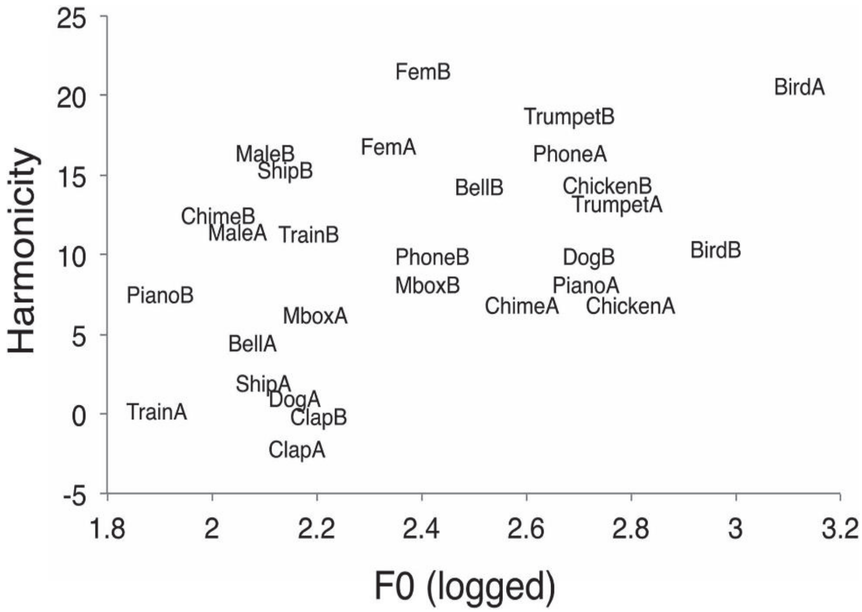
The change deafness task was originally adapted from Gregg and Samuel (2009) and used in Vanden Bosch der Nederlanden et al. (2016). Auditory stimuli consisted of 14 unique sound types with two exemplars for each sound type (e.g., dog A and dog B, trumpet A and trumpet B, etc.) resulting in a total of 28 sounds. Most of the sounds used in the current study were used with permission from Gregg and Samuel (2009). Male and female voices were included as two additional sound types to assess possible attentional biases for detecting changes that involve human voices. Five members of our lab rated 8 sounds (4 male voices and 4 female voices) based on similarity and the two sounds with the greatest dissimilarity ratings from each group (male and female) were included in the current study.

To create change trials for each change-type condition (across-category, within-category, acoustically similar, and acoustically dissimilar), sound pairs were created based on Euclidean distance and superordinate category. Euclidean distance was based on a two-dimensional (2-D) space created from each sound's mean pitch (fundamental frequency) and harmonicity (degree of periodic information relative to noise in the signal) after Gregg and Samuel (2009) (See Figure 1). Fundamental frequency was calculated using Praat's autocorrelation function (Boersma, 2001) after the floor and ceiling frequency levels were determined using the procedure and plug-in suggested by DeLooze and Hirst (2008) called Momel-Intsint (Hirst, 2005). This procedure improves the calculation of fundamental frequency and prevents octave transposition errors common to pitch measurement software. Harmonicity was calculated using the cross-correlation method in Praat, resulting in a harmonics-to-noise ratio (dB) for each stimulus.

Within- and across- category sound pairs were created by pairing sounds that come from the same (within-category) or different (across-category) superordinate categories were human

Figure 1

Acoustic Features of Sounds used in Change Deafness Task



Note. Harmonicity (measured in dB) and log of mean fundamental frequency (measured in Hz) for each sound stimulus included in the change deafness task. This two-dimensional space was used to calculate the Euclidian distance between sound pairs.

voice, musical instrument, animal, and environmental. In total, 14 across-category and 14 within-category sound pairs were created and equated for Euclidian distance to control for acoustic similarity. For example, an across-category sound pair could include "dog A" and "phone B" with a Euclidian distance of 8.83 while its within-category counterpart could include "dog A" and "dog B" with a Euclidian distance of 8.74. Acoustically similar and dissimilar sound pairs were created by pairing sounds with a Euclidian distance of 0-4 and 8-13, respectively. For example, an acoustically similar sound pair could include "Bird A" and "Female voice A" with a Euclidian distance of 2.33 and an acoustically dissimilar sound pair could include "Bird A" and

"Piano B" with a Euclidian distance of 11.87. A total of 14 acoustically similar and 14 acoustically dissimilar sound pairs were created and did not include any within-category changes. Auditory scenes were comprised of four 1s sounds with simultaneous onsets. To create the auditory scenes, three other sounds were randomly selected by a custom program in MATLAB, with the constraint that there was never two exemplars from the same sound type in any given scene. All participants were presented with the same auditory scenes.

The current study used the Revised Speech Perception in Noise Task (R-SPIN; Bilger, 1984) to assess speech-in-noise abilities. R-SPIN sentences are digital copies taken from the R-SPIN CD obtained from the University of Illinois, Department of Speech and Hearing Sciences. The CD includes four lists of 45 sentences with lists 1 and 2 being counterparts and lists 3 and 4 being counterparts such that the same target word is presented once in each list, one being presented in the high-predictability sentence and the other being presented in the low-predictability sentence. The current study used lists 1 and 2. Stimuli consisted of 90 spoken sentences in multitalker babble. The multitalker babble remained at a constant level of 65 dB SPL and the level of the sentences varied. Sentences differed in signal-to-noise ratio (SNR) ranging from -1 to 23 dB SNR in 3 dB increments resulting in 9 different SNRs. Ten sentences were presented at each SNR.

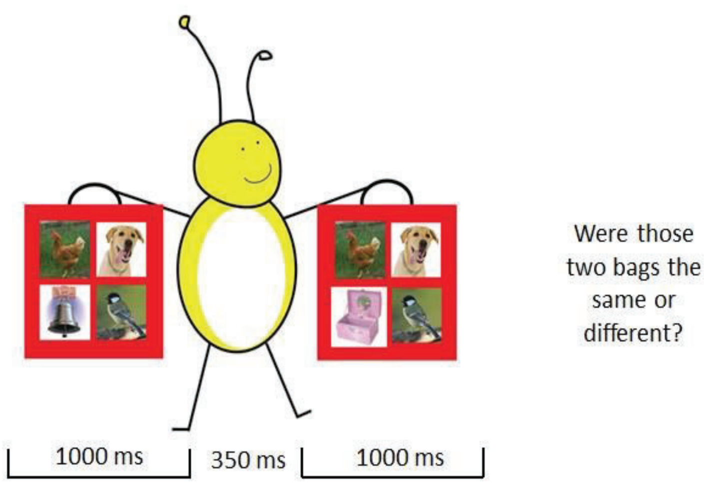
Procedure

To obtain a measurement of language ability and fluid intelligence, all participants were administered the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI; Wechsler, 2011) two-subtest IQ (Vocabulary and Matrix Reasoning subtests). Testing took place in a quiet room with the child seated across a table from the test administrator. To obtain a measurement of ASD symptom severity, all participants' caregivers completed the Gilliam Autism Rating Scale –

Third Edition (GARS-3) (Gilliam, 2014). The GARS-3 is a questionnaire that includes 58 Likert-type items about typical behaviors of the individual being rated. Items are organized into 6 sub-scales: restricted/repetitive behaviors, social interaction, social communication, emotional responses, cognitive style, and maladaptive speech. Once scored, the GARS-3 provides an autism index that ranges from 43 (unlikely probability of ASD diagnosis) to 140 (Very likely probability of ASD diagnosis). The GARS-3 is intended to be used in research settings and can be completed by caregivers who have sustained contact with the individual being rated. These measurements can be used to explore whether language ability and fluid intelligence or the degree to which individuals express autistic traits relate to change deafness or speech-in-noise processing.

Figure 2

Change Deafness Trial Example



Note. An example of a 'different' change deafness trial used in the current study. Pictures of sounds were only present during the training phase, not during the test trials.

The current study used the *one-shot paradigm* for the change deafness task. Participants were presented with a 1s auditory scene (scene 1; S1) followed by a 350 ms silent interval and then presented with a second 1s auditory scene (scene 2; S2). Participants' task was to indicate whether the two scenes sounded the same or different by pressing a green key for "same" and a red key for "different". See Figure 2 for an example of a change deafness trial. Same trials had identical sounds for both scenes whereas change trials contained one sound that had been changed from S1 to S2 while the other 3 sounds remained unchanged. Change trials were categorized into change type (within-category, across-category, acoustically similar, and acoustically dissimilar) and furthermore into superordinate category change type (human voice, musical instrument, animal, and environmental). All change trials were categorized based on the changing sound in S2. The four different change types were included to evaluate whether acoustic (i.e., pitch and harmonicity) or semantic (i.e., categorical knowledge) information takes precedence in children with and without ASD when analyzing sounds during a change deafness task. These groupings resulted in a total of 56 change trials (14 for each change type). Furthermore, these change trials were also grouped by superordinate category resulting in a total of 14 human voice, 16 musical instrument, 6 animal, and 20 environmental change trials. Grouping the change trials in this manner would reveal any automatic attentional biases for detecting changes from a particular superordinate category. Additionally, 28 same trials were included as catch trials to calculate false alarm rate. Altogether, participants completed a total of 84 trials across four blocks with 21 trials in each block. Participants were offered a break at the end of each block.

All participants first completed a training phase to familiarize them with the change deafness task. The training included an example of a same and a different trial with accompanying pictures of what sounds were in the auditory scenes. Participants then completed two training trials that contained only two sounds in each auditory scene. Next, participants completed one training trial from each change type: across-category, within-category, acoustically similar, acoustically dissimilar, and same. These trials contained four sounds in each scene and did not include accompanying pictures of the sounds. However, feedback was given during these trials.

For the R-SPIN task, participants were presented with a total of 90 spoken sentences and were asked to identify and repeat back the last word of each sentence (target word). The R-SPIN was chosen because it assesses not only general speech-in-noise perception abilities but also assesses the use of high-level linguistic cues when perceiving speech-in-noise. There was a total of 45 different monosyllabic target words and each target word was used in a high-predictability (HP) sentence and a low- predictability (LP) sentence. For HP sentences, the target word could be predicted by the semantic cues of the sentence, whereas the target word in LP sentences could not. For example, a HP sentence would be "The dog chewed on the *bone.*" And its LP counterpart would be "Miss Black would consider the *bone.*" Sentences were presented in two lists with each list containing 45 sentences resulting in 5 sentences per SNR per list. Target word pairs were randomly presented once in each list with one list containing the HP sentence and the other containing the LP sentence. All target word pairs were presented at the same signal-to-noise ratio (SNR). Sentences in lists 1 and 2 were presented in descending order beginning with 23 dB SNR. All sentences were presented to the left ear only. Participants first completed 5 practice sentences to familiarize them with the task. Next, they were presented with the 90 sentences broken up into 5 blocks of 18 sentences. Participants were offered a break at the end of each block.

To promote sustained engagement from the participants, we created a visual token system where participants earned 10 stars throughout the visit to put on their star board. Once all 10 stars were earned, participants chose a prize to take home. Participants earned one star after completion of the WASI, four stars during the change deafness task, and five stars during the R-SPIN. Additionally, we used suggested strategies from Abramov et al. (1984) when designing the experimental paradigms. For the change deafness task, participants were told a story about a yellow bug named Bugsy who was throwing a party for all his friends. He wanted to give all of his guests identical party bags (auditory scenes) that contained 4 sound-making toys in them. Bugsy had just noticed that someone had been changing the toys in the party bags so now some of them were no longer the same. The participants were asked to help figure out which party bags were the same (same trials) and which party bags were different (different trials) and ultimately solve the mystery of the toy-changing bandit. Participants earned stars along the way (one after each break) to add to their star board.

For the R-SPIN task, participants were told to imagine they were attending a field trip with their classmates and teacher, Mr. Scruffs, and they had been chosen to be the class leader during the trip. Their job was to listen carefully to Mr. Scruffs and repeat back the last word of each sentence to their classmates so everyone would know the field trip rules so the field trip won't get canceled. Participants were told that their classmates would be talking in the background (multitalker babble) at the same time as Mr. Scruffs (target sentence) so it might be hard to hear sometimes but to just do their best. Participants earned 5 stars during completion of the R-SPIN (one after each break) to add to their star board. With consent, participants were video recorded during the completion of assessments and experimental tasks to later be rated for level of attentiveness. The order in which perceptual tasks were completed were counterbalanced across participants.

Data Analyses

Change Deafness

Operationally, change deafness is traditionally measured by comparing error rates between same and different trials. If changes are undetected, there should be a greater tendency to report "same" for different trials, and thus greater error rates for different trials relative to same trials (Backer & Alain, 2012; Gregg & Samuel, 2008). To test for the presence of change deafness and any possible differences in change deafness between children with ASD and their age- and IQ-matched TD children, error rates were entered into two separate mixed model analyses of variance (ANOVAs) with trial type (same, different) as the within-subjects factor and group (ASD, TD) as the between-subjects factor. To test for differences in change detection ability between groups for semantic change types, the error rates for same and different semantic-change trials were entered into a mixed model ANOVA with semantic change type (across, within) as the within-subjects factor and group (ASD, TD) as the between-subjects factor for the age- and IQ-matched comparisons. Additionally, change detection sensitivity for semantic-change trials was evaluated by entering d' scores into a mixed model ANOVA separately for the age- and IQ-matched comparisons with semantic change type (across, within) as the within-subjects factor and group (ASD, TD) as the between-subjects factor. To test for differences in change detection ability between groups for acoustic change types, the error rates and d' scores for same and different acoustic-change trials were entered into separate mixed model ANOVAs with acoustic change type (dissimilar, similar) as the within-subjects factor and group (ASD, TD) as the between-subjects factor separately for age- and IQ-matched comparisons. To test whether acoustic or semantic information is used to a greater degree during change detection, the error rates for within semantic category and short acoustic change trials were entered into a mixed model ANOVA with change type (within, short) as the within-subjects factor and group (ASD, TD) as the between-subjects factor separately for age- and IQ-matched comparisons. Lastly, to investigate whether children with and without ASD display an attentional bias to detect changes from a particular semantic category d' was calculated for each superordinate category change type (human voices, environmental sounds, musical instruments, animal sounds). These values were entered into a mixed model ANOVA with group (ASD, TD) as the between-subjects factor and category change type (human voices, environmental sounds, musical instruments, animal sounds) as the within-subjects factor separately for age- and IQ-matched comparisons.

RSPIN

For the speech-in-noise task (RSPIN), percent correct for each speech-to-noise ratio (SNR) and for each sentence type was calculated. To test for possible differences in the use of semantic information across the 9 SNRs between the groups, these values were entered into a mixed model ANOVA, with group (ASD, TD) as the between-subjects factor and SNR (-1, 2, 5, 8, 11, 14, 17, 20, 23) and sentence type (high predictability, low predictability) as within-subjects factors separately for the age- and IQ-matched comparisons.

Relationships Among IQ, ASD symptoms, and the Use of Acoustic and Semantic Information

Originally, performing an exploratory factor analysis was proposed to investigate the possible relationships among assessments and perceptual task outcomes in terms of factors. However, after speaking with a statistical expert, the collected data was not appropriate for performing a factor analysis. The sample size of the current data was too small, and there were not at least three indicators for each factor. The low sample size combined with the variables not being designed to load on to specific factors could lead to unreliable outcomes that cannot be replicated. Therefore, to understand whether overall IQ and total GARS scores could predict the use of acoustic and semantic information in children without ASD, four regressions were performed. All regressions included IQ and GARS scores as the predictors. The dependent variables for the regressions were as follows: (1) difference in performance between within- and across-category changes (2) difference in performance between the high- and low-predictability sentences of all SNR's (3) difference in performance between the high- and low-predictability sentences for the lowest SNR's (5, 2, -1) (4) difference in performance between the long and short acoustic changes. A total of one-hundred and five children without ASD were included in these analyses (45 male; age range = 7 years 0 months to 14 years 7 months, mean age = 9 years 6 months, Mean IQ = 105, Mean GARS = 57).

Attentiveness Ratings

Recorded videos of the participants completing the WASI, change deafness, and RSPIN sessions were coded by seven raters. To evaluate inter-rater reliability, twenty videos were randomly chosen for all seven trained raters to code. The remaining videos were randomly assigned such that each rater got an equal number of videos and each video was coded twice by two separate raters. Raters assigned an attentiveness rating at one-minute intervals using the following scale, adapted from Koegel & Egel (1979):

- Tries to leave the room, resistant to verbal instructions, or refuses to perform the task. **(scored 0).**
- Remains in chair, but generally non-responsive to verbal instructions; excessive occurrence of motor movements, off-task behavior, or interference – vocalizations

unrelated to task, interrupting experimenter, vocalizing during stimulus presentation, playing with objects (e.g., hat, keyboard). **(scored 1)**

- Generally complies with instructions; definite occurrence of motor movements, off-task behavior, interference – inattentively staring or looking around, manipulating objects in room, discusses topics unrelated to task but not during stimulus presentation. (**scored 2).**
- Complies with instructions, performs task readily; seldom occurrence of motor movements or irrelevant vocalizations, frequently attends to experimenter and stays focused during tasks – quietly listens to instructions, does not manipulate objects in room, does not inattentively stare or look around. **(scored 3).**
- Performs task readily, intently attends to experimenter and task; no occurrence of interference, irrelevant motor movements, vocalizations, or off-task behaviors, may overtly express excitement towards tasks. **(scored 4)**.

To evaluate inter-rater reliability an intraclass correlation coefficient (ICC) was computed using the average attentiveness scores from the twenty videos that were coded by all raters. ICC estimates and their 95% confidence intervals were calculated using SPSS statistical package version 27 based on a mean rating (k = 7), absolute-agreement, two-way mixed model effects. Results revealed an intraclass correlation coefficient of .88 with a 95% confidence interval of .73 - .95. To test for possible differences in attentiveness between groups, the averaged attentiveness score across all tasks was computed for each participant, resulting in one attentiveness score per participant. These scores were entered into an independent sample t-test separately for each data set (ASD vs. age-matched and ASD vs. IQ-matched). Due to not all participants being video recorded, the randomly assigned age- and IQ-matched control groups resulted in a total of 14 and

18 participants being included for these analyses, respectively. A total of 21 participants from the ASD group were included.

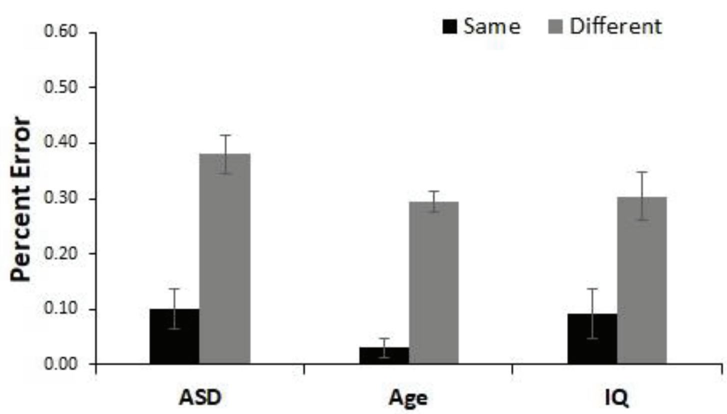
Chapter 3: Results

Change Deafness

As seen in Figure 3, all groups exhibited change deafness as revealed by a significant main effect of trial type, with higher error rates on different trials relative to same trials for age-, $F(1, 52) = 178.89$, $p < .001$, $n_p^2 = .77$, and IQ-matched comparisons, $F(1, 52) = 72.27$, $p < .001$, $n_p^2 = .58$, but trial type did not interact with group (age-matched: $F(1, 52) = 1.58$, $p = .692$, $n_p^2 = .003$, IQ-matched: $F(1, 52) = 1.31$, $p = .257$, $n_p^2 = .03$) indicating all groups exhibited change deafness to the same extent. There was a significant main effect of group for the age-matched comparison, $F(1, 52) = 10.47$, $p = .002$, $n_p^2 = .17$ but not the IQ-matched comparison, $F(1, 52) = 2.15$, $p = .148$, $n_p^2 = .04$, indicating that children with ASD had higher overall error rates regardless of trial type relative to the age-matched controls but not the IQ-matched controls.

Figure 3

Presence of Change Deafness

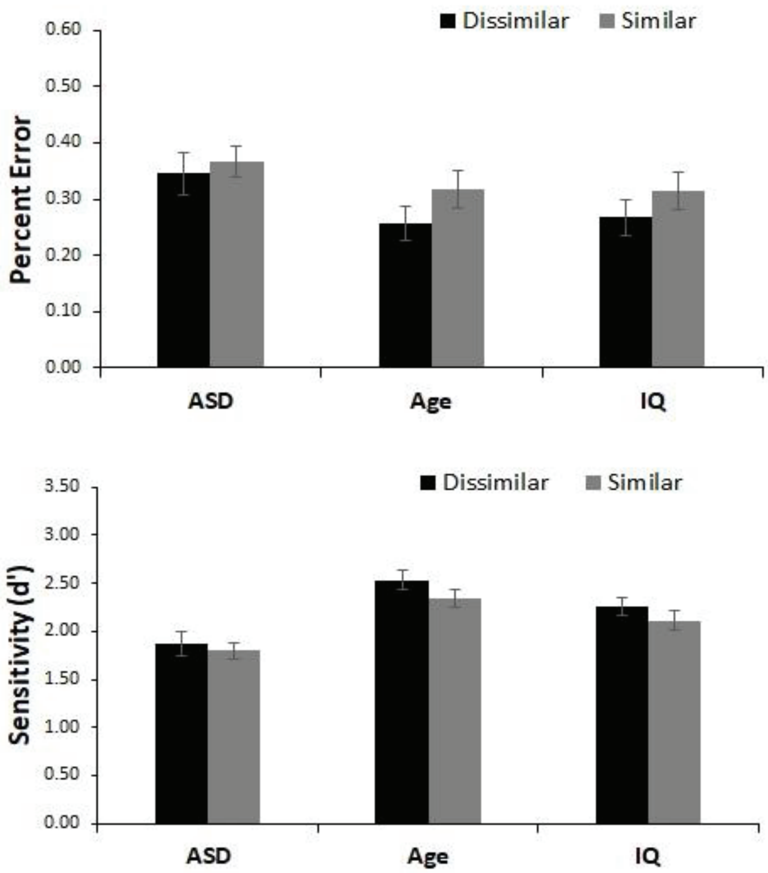


Note. Percent error for same and different trials for children with ASD, age-matched controls (age), and IQ-matched controls (IQ). Error bars represent within-subject 95% confidence intervals (Cousineau, 2005).

As depicted in Figure 4, there was a significant effect of semantic change type for age-, $F(1, 52) = 40.59$, $p < .001$, $n_p^2 = .44$, and IQ-matched, $F(1, 52) = 39.54$, $p < .001$, $n_p^2 = .43$,

Figure 4

Performance for Semantic Change Trials

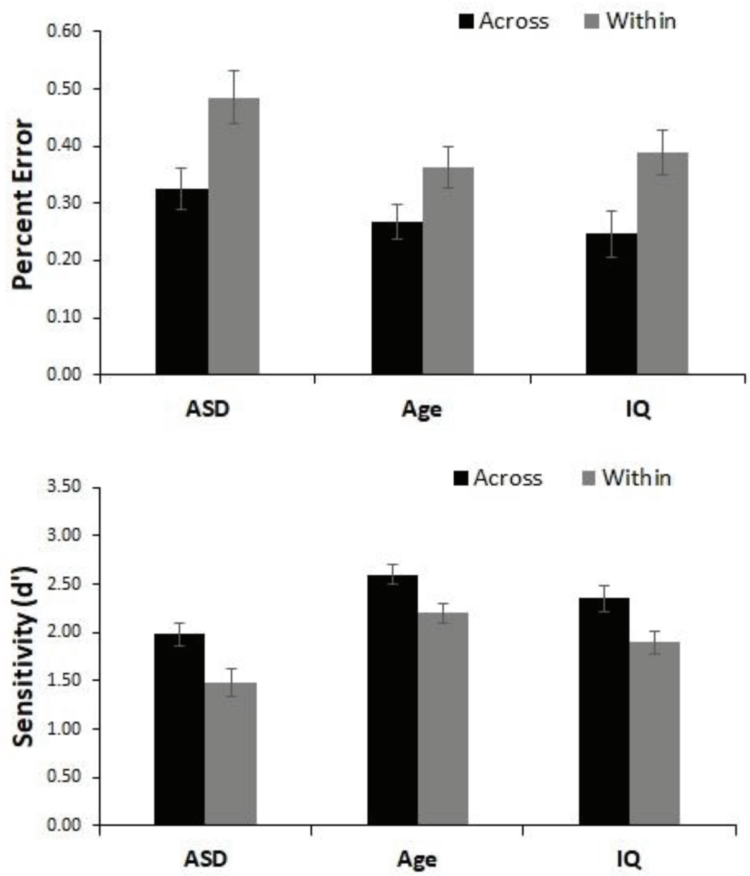


Note: Top: Percent error for acoustically similar and dissimilar changes for children with ASD, age-matched controls (age) and IQ-matched controls (IQ). Bottom: d' scores for acoustically similar and dissimilar changes for all groups. All groups utilize acoustic information such that acoustically similar changes were more difficult to detect than acoustically dissimilar changes. Error bars represent within-subject 95% confidence intervals (Cousineau, 2005).

comparisons, indicating greater error rates for within-category changes relative to across-category changes. Semantic change type did not interact with group for either comparison (age-

Figure 5

Performance for Acoustic Change Trials



Note. Top: Percent error for across- and within-category changes for children with ASD, age-matched controls (age) and IQ-matched controls (IQ). Bottom: d' scores for across- and within-category changes for all groups. All groups utilize semantic information such that within-category changes were more difficult to detect than across-category changes. Error bars represent within-subject 95% confidence intervals (Cousineau, 2005).

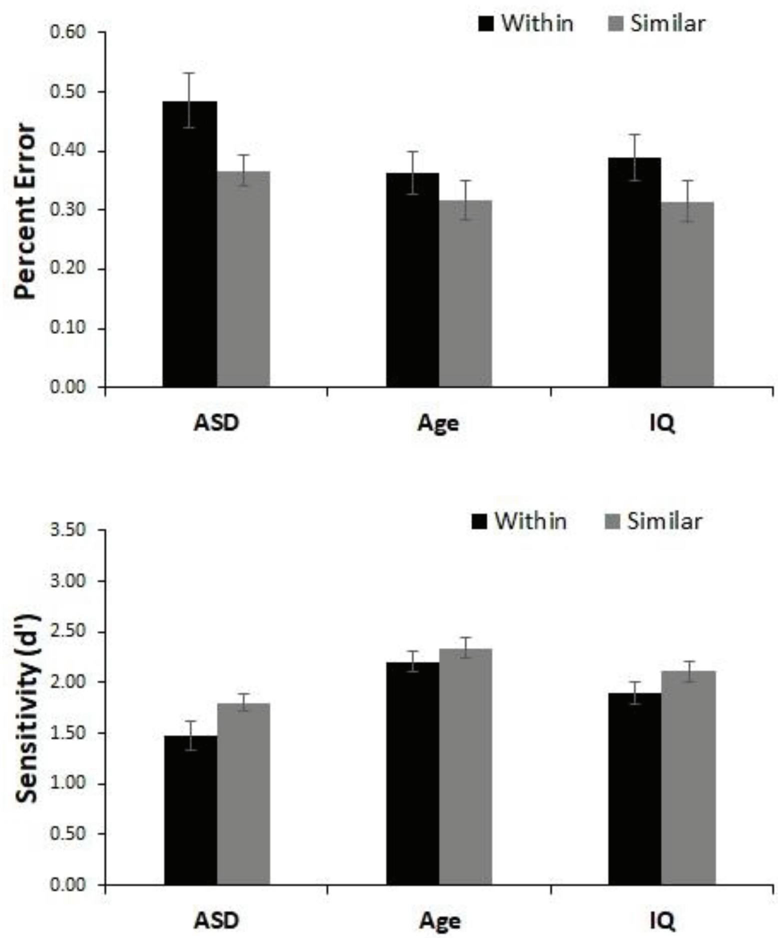
matched: $F(1, 52) = .583$, $p = .449$, $n_p^2 = .01$, IQ-matched: $F(1, 52) = .13$, $p = .721$, $n_p^2 = .002$). Thus, all groups utilized semantic information similarly during the change detection task. There was a significant main effect of group for the age-matched, $F(1, 52) = 6.74$, $p = .012$, $n_p^2 = .12$ and IQ-matched comparisons, $F(1, 52) = 4.08$, $p = .049$, $n_p^2 = .07$, because children with ASD displayed significantly greater error rates for semantic changes relative to the age- and IQ-matched controls. However, the p-value for the IQ-matched comparison was $p = .049$ with a $n_p^2 = .07$. This barely significant result could be a consequence of the small sample size. A Similar pattern of results occurred when d' scores were evaluated, except there was no significant group difference among the IQ-matched comparison: significant effects of semantic change type for age-, $F(1, 52) = 41.57$, $p < .001$, $n_p^2 = .44$, and IQ-matched, $F(1, 52) = 38.41$, $p < .001$, $n_p^2 = .43$, comparisons, no interaction between semantic change type and group for either comparison (age-matched: $F(1, 52) = .621$, $p = .434$, $n_p^2 = .01$, IQ-matched: $F(1, 52) = .11$, $p = .745$, $n_p^2 = .002$), and a significant effect of group for the age-matched comparison, $F(1, 52) = 12.73$, $p <.001$, $n_p^2 = .20$, but not the IQ-matched comparison, $F(1, 52) = 3.02$, $p = .088$, $n_p^2 = .06$.

As seen in Figure 5, there was a significant effect of acoustic change type for age-, $F(1, 52) = 40.59$, $p < .001$, $n_p^2 = .44$, and IQ-matched, $F(1, 52) = 4.77$, $p = .034$, $n_p^2 = .08$, comparisons, indicating greater error rates for similar acoustic changes relative to dissimilar acoustic changes. Acoustic change type did not interact with group for either comparison (age-matched: $F(1, 52) = .58$, $p = .449$, $n_p^2 = .01$, IQ-matched: $F(1, 52) = .58$, $p = .449$, $n_p^2 = .01$). This indicates all groups utilized acoustic information similarly during the change detection task. There was a significant effect of group for the age-matched comparison, $F(1, 52) = 6.74$, $p = .012$, $n_p^2 = .12$, but not the IQ-matched comparison, $F(1, 52) = 2.21$, $p = .143$, $n_p^2 = .04$, suggesting that children with ASD display greater error rates for acoustic change types relative to age-matched but not IQ-matched controls. These same pattern of results were found when d' scores were evaluated: significant effects of acoustic change type for age-, $F(1, 52) = 5.68$, $p = .021$, $n_p^2 = .10$, and IQ-matched, $F(1, 52) = 4.21$, $p = .045$, $n_p^2 = .08$, comparisons, no interaction between acoustic change type and group for either comparison (age-matched: $F(1, 52) = 1.24$, $p = .270$, $n_p^2 = .02$, IQ-matched: $F(1, 52) = .48$, $p = .490$, $n_p^2 = .01$), and a significant effect of group for the age-matched comparison, $F(1, 52) = 9.22$, $p = .004$, $n_p^2 = .15$, but not the IQ-matched comparison, $F(1, 52) = 2.25$, $p = .140$, $n_p^2 = .04$.

If semantic information is used to a greater degree than acoustic information, then there should be greater error rates for the within semantic category change types that are more acoustically different than the acoustically similar change trials. The opposite would be true if acoustic information is used to a greater degree. As seen in Figure 6, results revealed a significant effect of change type for age-, $F(1, 52) = 14.40$, $p < .001$, $n_p^2 = .22$, and IQ-matched, $F(1, 52) = 17.64$, $p < .001$, $n_p^2 = .25$, comparisons, indicating greater error rates for within semantic category changes relative to short acoustic changes. Thus, for all groups, semantic information was used to a greater degree relative to acoustic information. Change type did not interact with group for either comparison (age-matched: $F(1, 52) = 2.77$, p .10, $n_p^2 = .05$, IQ-matched: $F(1, 52) = .86$, $p = .359$, $n_p^2 = .02$). There was a significant effect of group for the age-matched comparison, $F(1, 52) = 6.40$, $p = .014$, $n_p^2 = .11$, but not the IQ-matched comparison, $F(1, 52) = 3.98$, $p = .061$, $n_p^2 = .06$, indicating that children with ASD display greater error rates regardless of change type relative to age-matched but not IQ-matched controls. These same pattern of results were found when d' scores were entered into the mixed model ANOVA:

Figure 6

Magnitude of the use of Semantic vs. Acoustic Information



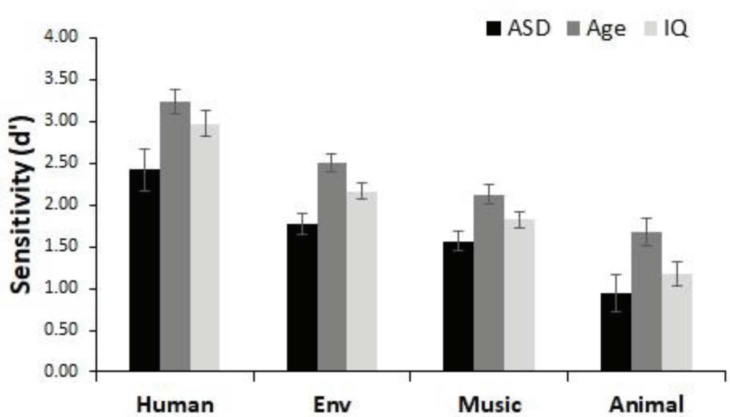
Note. Top: Percent error for within-category changes and acoustically similar changes for children with ASD, age-matched controls (age) and IQ-matched controls (IQ). Bottom: d' scores for within-category and acoustically similar changes for all groups. All groups utilize semantic information to a greater degree than acoustic information such that within-category changes were more difficult to detect than acoustically similar changes. Error bars represent within-subject 95% confidence intervals (Cousineau, 2005).

significant effects of change type for age-, $F(1, 52) = 13.85$, $p < .001$, $n_p^2 = .21$, and IQ-matched, $F(1, 52) = 16.62$, $p < .001$, $n_p^2 = .24$, comparisons, no interaction between change type and group for either comparison (age-matched: $F(1, 52) = 2.23$, $p = .141$, $n_p^2 = .04$, IQ-matched: $F(1, 52) = .66$, $p = .421$, $n_p^2 = .01$), and a significant effect of group for the age-matched comparison, $F(1, 52) = 14.82$, $p < .001$, $n_p^2 = .22$, but not the IQ-matched comparison, $F(1, 52) = 3.45$, $p = .069$, $n_p^2 = .06$.

Results comparing change detection sensitivity across the 4 different semantic categories revealed a significant effect of category change type for age-, $F(3, 156) = 85.00$, $p < .001$, $n_p^2 = .62$, and IQ-matched, $F(3, 156) = 101.69$, $p < .001$, $n_p^2 = .66$ comparisons, as depicted in Figure 7. Post-hoc tests revealed that all categories were significantly different from one another for

Figure 7

Performance for Semantic Categories



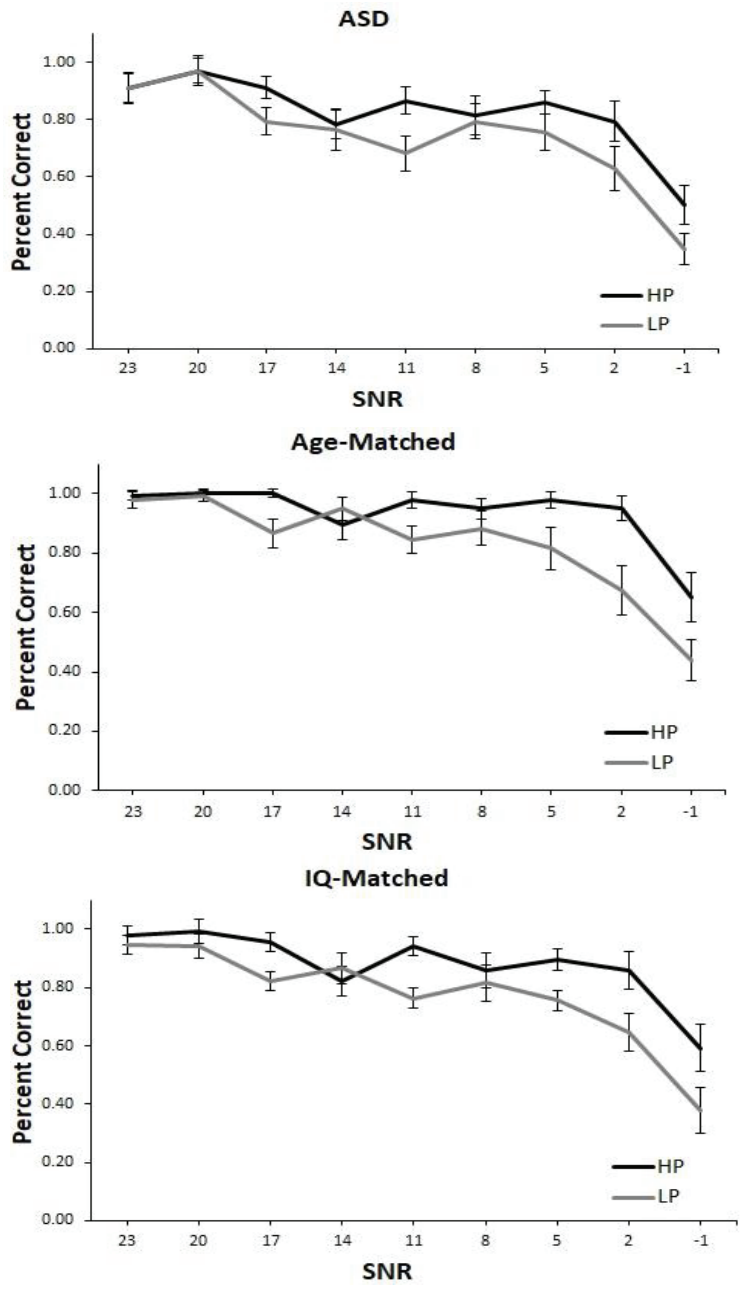
Note. Sensitivity (d') for each semantic category change type for all groups. All groups displayed the greatest sensitivity to detect changes that involve the human voice, followed by environmental sounds, then musical instruments, then animal sounds. Error bars represent within-subject 95% confidence intervals (Cousineau, 2005) both age- and IQ-matched comparisons (*p*'s <.001) such that change detection was most accurate for changes involving the human voice (age-matched = 2.82, IQ-matched = 2.69) followed by environmental sounds (age-matched = 2.13, IQ-matched = 1.96), musical instruments (age-matched = 1.84, IQ-matched = 2.69), and animal sounds (age-matched = 1.31, IQ-matched = .1.06). Thus, all groups displayed an attentional bias towards detecting changes that involve the human voice. There was no significant interaction between group and category change type for the age-, $F(1, 52) = .64$, $p = .593$, $n_p^2 = .01$, or IQ-matched comparisons, $F(3, 156) = 1.19$, $p = .315$, $n_p^2 = .02$. There was an effect of group for the age-matched comparison, $F(1, 52) = 15.76$, $p < .001$, $n_p^2 = .23$, but not the IQ-matched comparison, $F(1, 52) = 2.30$, $p = .135$, $n_p^2 = .04$, showing that children with ASD display greater error rates overall relative to age-matched but not IQ-matched controls.

RSPIN

Figure 8 depicts the results for the RSPIN task. Results revealed significant effects of SNR for both age-, $F(8, 416) = 108.06$, $p < .001$, $n_p^2 = .68$, and IQ-matched, $F(8, 416) = 98.65$, $p < .001$, $n_p^2 = .65$ comparisons, with participants performing better on higher SNR's. SNR did not interact with group for the age-, $F(8, 416) = 1.74$, $p = .087$, $n_p^2 = .03$, or IQ-matched, $F(8, 416) = .73$, $p = .666$, $n_p^2 = .01$, comparisons. Both comparisons also revealed a significant effect of sentence type with participants performing better on the high-predictability sentences relative to low-predictability sentences (age-matched: $F(1, 52) = 88.60$, $p < .001$, $n_p^2 = .63$, IQ-matched: $F(1, 52) = 77.15$, $p < .001$, $n_p^2 = .60$). However, sentence type did not interact with group for age-, $F(1, 52) = 1.02$, $p = .317$, $n_p^2 = .02$, or IQ-matched, $F(1, 52) = .95$, $p = .334$, $n_p^2 = .02$ comparisons. For both comparisons, sentence type did interact with SNR indicating greater use

Figure 8

Performance for RSPIN Task



Note. Percent correct for high-predictability (HP) and low-predictability (LP) sentences for each signal-to-noise ratio (SNR) for the (A) ASD, (B) age-matched, and (C) IQ-matched groups. The ASD group performed worse overall relative to age- and IQ-matched controls. All groups utilized semantic context such that performance was higher for HP relative to LP sentences.

of semantic context for lower SNR's (age-matched: $F(8, 416) = 9.94$, $p < .001$, $n_p^2 = .16$, IQ-matched: $F(8, 416) = 8.12$, $p < .001$, $n_p^2 = .14$). Neither age-, $F(8, 416) = 1.07$, $p = .380$, $n_p^2 = .02$, or IQ-matched, $F(8, 416) = .48$, $p = .872$, $n_p^2 = .01$, comparisons revealed a significant three-way interaction with SNR, sentence type, and group. Lastly, there was a main effect of group for the age-matched comparison, $F(1, 52) = 3527.50$, $p < .001$, $n_p^2 = .98$, but not the IQ-matched, $F(1, 52) = 1.54$, $p = .220$, $n_p^2 = .03$, comparison indicating children with ASD performed worse than age-matched but not IQ-matched controls regardless of SNR or sentence type.

Relationships Among IQ, ASD symptoms, and the Use of Acoustic and Semantic Information

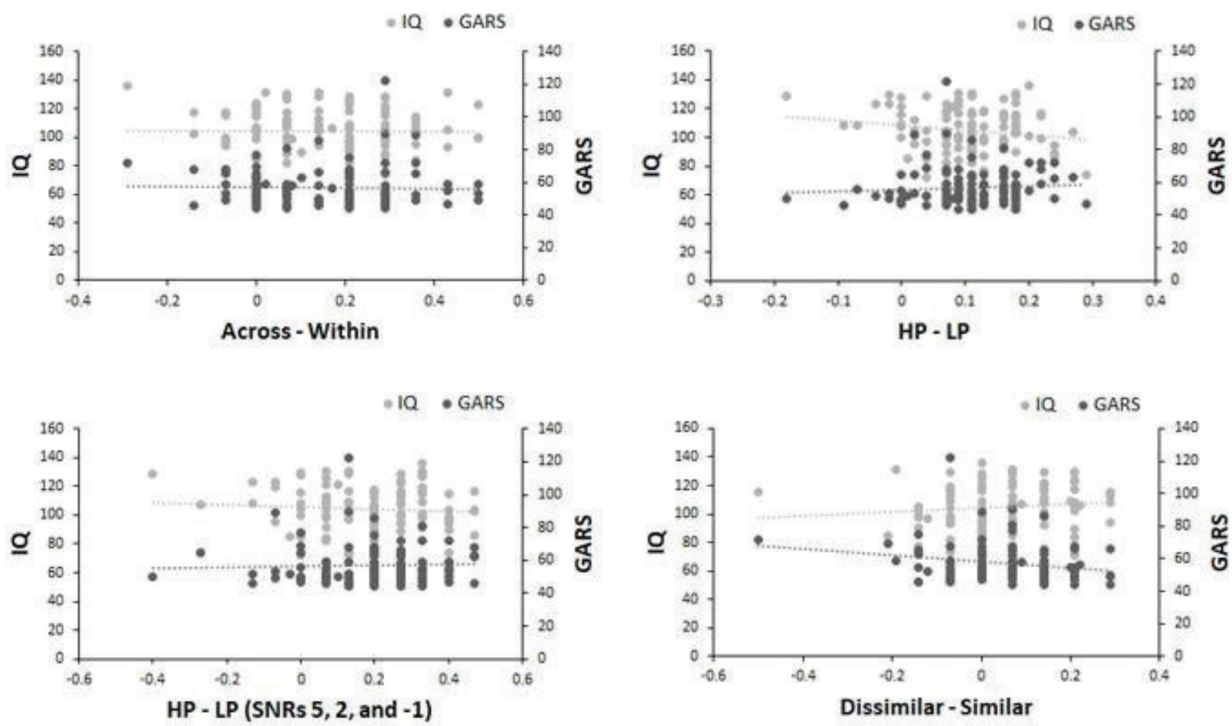
The results of all four regressions revealed that IQ and GARS scores do not predict the use of acoustic, $R^2 = -.033$, F(2, 104) = 2.80, $p = .065$, or semantic, $R^2 = -.019$, F(2, 104) = .04, $p = .959$, information during auditory change detection, or the use of semantic information during speech-in-noise perception (All SNR's: $R^2 = .009$, F(2,104) = 1.47, $p = .236$; Low SNR's: $R^2 = -.014$, F(2, 104) = .294, $p = .746$). Scatterplots are presented in Figure 9.

Attentiveness Ratings

Results revealed no significant difference in attentiveness scores between the ASD (M = 3.18, SD = .52) and age-matched (M = 3.36, SD = .49) groups; $t(33) = -1.05$, p = .302; d = .5, and the ASD (M = 3.18, SD = .52) and IQ-matched (M = 3.42, SD = .39) groups; $t(37) = -1.56$, p = .127; d = .5.

Figure 9

GARS, IQ, and Perceptual Performance in TD Children



Note. Scatterplots that show the relationship between IQ, GARS and across category – within category changes for the change deafness task (across – within), high-predictability – low predictability sentences for all SNR's for the speech-in-noise task (HP – LP), high-predictability – low-predictability sentences for SNR's 5, 2, and -1 for the speech-in-noise task (HP – LP (SNRs 5, 2, -1)), and acoustically dissimilar – acoustically similar changes for the change deafness task (dissimilar – similar). These data only include TD children.

Chapter 4: Discussion

This study provides the first evidence of the presence of change deafness in children diagnosed with ASD, and the extent to which change deafness occurs does not differ among children with and without ASD. Moreover, children with ASD use semantic and acoustic information similarly to children without ASD such that within-category changes are more difficult to detect than across-category changes and changes that are acoustically similar are more difficult to detect than changes that are acoustically dissimilar. However, it is worth noting that the difference in performance between the acoustically similar and dissimilar changes for the ASD group are extremely small, with acoustically similar error rates being 37% and acoustically dissimilar error rates being 35%. It is possible that with more power, and thus, a larger sample size the interaction among group and trial type could be significant indicating that children with ASD utilize acoustic information differently than TD children when detecting auditory changes. Additionally, children with and without ASD rely more on semantic rather than acoustic information when asked to detect changes between two auditory scenes and display an attentional bias to detect changes that involve the human voice. These results replicate previous findings within typically developing adults (Gregg & Samuel, 2008, 2009; Vanden Bosch der Nederlanden, Snyder, & Hannon, 2016) and children (Vanden Bosch der Nederlanded, Snyder, & Hannon, 2016) and extend these findings to children with ASD.

Prior behavioral research has shown unimpaired processing of semantic information in individuals with ASD during matching (Mcleery et al., 2010) and priming tasks (Kamio & Toichi, 2000) that involve individually presented pictures, spoken words, and semantically meaningful non-speech sounds. The results of this study show that semantic processing of auditory scenes that contain multiple sounds presented simultaneously are also unimpaired in children with ASD during an auditory change detection task. Furthermore, children with and without ASD had greater difficulty detecting within-category changes relative to similar acoustic changes, despite the within-category changes being more acoustically different. This indicates that not only do children with ASD use semantic information during auditory change detection, they do so to a greater degree than acoustic information, similar to children without ASD. Thus, children with and without ASD encode sounds based on categorical knowledge and can use this information more readily than acoustic information to detect auditory changes. This suggests that the developmental processes that lead to the ability to form meaningful taxonomies of everyday sounds and organize them based on this knowledge is unaltered in children with ASD.

The current results suggest that behaviorally, semantic processing of non-speech sounds is unimpaired in children with ASD. It would be interesting for future research to examine whether children with and without ASD employ the same neural processes when utilizing semantic information. For example, the N400 is an event-related potential (ERP) that is elicited by semantic information; however, its amplitude increases when a stimulus does not meet semantic expectations. In typically developing children, the N400 has been elicited to within- and across-category violations during the presentation of pairs of pictures and sounds (Hendrickson et al., 2019). Investigating the possible effects of the N400 during a change detection task between children with and without ASD could provide insight into the neural processing of semantic information of non-speech sounds.

Although semantic information is used to a greater degree, children with and without ASD also encode the physical attributes of auditory scenes and utilize this information to detect changes. In this study, there was no evidence of enhanced processing of pitch and harmonicity in children with ASD. Although prior research has shown enhanced processing of pitch for individually presented pure tones (Heaton, Hermelin & Pring, 1998; Heaton, 2005; Bonnel et al., 2003; O' Riordian & Passetti, 2006; Mayer, Hannent, & Heaton, 2016) and speech stimuli (Järvinen-Pasley & Heaton, 2007; Heaton, Hudry, Ludlow, & Hill, 2008; Järvinen-Pasley et al., 2008; Jarvinen-Pasley, Pasley, & Heaton, 2008) in children with ASD, this does not appear to be present during the processing of semantically meaningful non-speech sounds. The current study is the first to assess the processing of acoustic information of complex auditory scenes that include the simultaneous presentation of multiple sound sources in children with ASD. It is possible that the increased complexity of the stimuli used in this study does not lead to enhanced processing of low-level features. Prior research showing enhanced processing of pitch in individuals with ASD have typically used simple tasks that require the comparison of two individual sounds presented in isolation and therefore do not require the organization of multiple sound sources or represent complex scene perception.

Gregg and Samuel (2008) had typically developing participants complete a change deafness task, followed by an object-encoding task. The object-encoding task included presenting participants with two individual sounds and asking the participants which sound was present in one of the two scenes. They found that although acoustic information was utilized during change detection, the acoustic manipulations did not affect object-encoding. This may suggest that when participants are completing the change detection task, the auditory system is not encoding the physical features of each individual sound, instead it is the difference in the global acoustic representation between the two scenes that is being utilized. If this is also the case for the children with ASD, then perhaps the processing of global acoustic information is not enhanced.

Another interesting finding was that children with ASD, like TD children, displayed an attentional bias to detect changes that involve the human voice. Children with ASD have been shown to orient less to social stimuli, such as hands clapping or their name being called, (Dawson et al., 1998) and prefer orienting to speech-derived noise relative to their mother's, (Klin, 1991) or child-directed speech (Kuhl et al., 2005). These studies are auditory preference studies typically using a head-turn preference procedure and use semantically meaningful speech stimuli. Here, the human voice stimuli used did not include semantically meaningful speech, instead it was male and female individuals repeating a phrase, replacing the individual words with the syllable "ma" to not access verbal memory or semantic representations. The lack of semantic information, along with participants being asked to complete a change detection task, could have played a role in the presence of an attentional preference to detect changes involving the human voice in the current study. The ability to detect changes to social stimuli during visual change detection tasks have been investigated in individuals with ASD. Smith & Milne (2009) found that children with ASD detected social changes that occurred to people just as well as changes involving inanimate objects, similarly to TD children. Kikuchi et al. (2009) found that children without ASD were faster at detecting changes to human faces relative to non-social changes while children with ASD detected the social and non-social changes equally fast. The current study did not measure reaction time but this would be an interesting approach for future studies to better ascertain whether this attentional bias in children with ASD remains comparable to TD children.

Children with ASD displayed the same pattern of results as children without ASD such that semantic and acoustic information were used similarly during change detection and that changes involving the human voice were better detected relative to other semantic categories.

However, children with ASD consistently performed worse overall as evidenced by greater error rates and decreased sensitivity relative to age-matched but not IQ-matched controls. When children with ASD were matched to TD children for IQ, performance was indistinguishable. Group differences emerged when children with ASD were compared to age-matched controls. These findings indicate that a diagnosis of ASD alone does not guarantee overall poorer performance during a change detection task. Rather the results suggest that overall lower intellect results in poorer task performance, regardless of ASD diagnosis. Furthermore, the overall poorer performance in the change detection task in the children with ASD relative to the age-matched controls could be attributed to factors that have been found to be related to change deafness, such as the capacity to process multiple objects (i.e., scene size; Gregg, Irsik, & Snyder, 2017), attention (Irsik, Vanden Bosch der Nederlanden, & Snyder, 2016), or auditory short-term memory (Vanden Bosch der Nederlanden et al., 2020). Investigating these processes and how they relate to change deafness in children with and without ASD will help to shed light on the nature of the group differences found here.

To our knowledge, this study was the first to investigate the use of semantic information during speech-in-noise perception in children with and without ASD. Children with ASD had greater difficulty perceiving speech in the presence of background noise relative to age-, but not IQ-matched controls; however, all groups similarly utilized semantic context. Previous research has shown impaired speech perception in noise in individuals with ASD (Alcantara et al., 2004; Groen et al., 2009). Here, we only show overall poorer performance in children with ASD when compared to age-matched controls. The overall poorer performance in the speech-in-noise task seen in the children with ASD relative to the age-matched controls could be attributed to individual differences in the processing of acoustic information or more general cognitive abilities, like working memory. For example, the overall poorer performance could be attributed to deficits in temporal processing. Poor temporal processing has been reported in individuals with ASD (Bhatara et al., 2013; Boets et al., 2015; Foss-Feig et al., 2017) and has been positively correlated to speech-in-noise perception abilities (Bhatara et al., 2013). Speech-in-noise perception has also been related to working memory capabilities for phonological sounds (Akeroyd, 2008) and frequency information (Lad, Holmes, Chu & Griffiths, 2020). Including additional assessments of acoustic processing and cognitive abilities in future studies could further elucidate the speech-in-noise processing difficulties seen in the current study.

Prior research has shown impaired use of semantic context during visual language tasks that require participants to read aloud sentences that contain a homograph (Frith & Snowling, 1983; Happe, 1997; Jolliffe & Baron-Cohen, 1999; Lopez & Leekam, 2003), memory tasks that ask participants to memorize lists of words that are semantically related or unrelated (Tager-Flusberg, 1991), or make contextual inferences during reading comprehension (Norbury & Bishop, 2002). However, there is also evidence of unimpaired use of semantic information during the identification of homonyms in children with ASD who have typical receptive and expressive language abilities (Eberhardt & Nadig, 2016). Although we did not specifically assess language abilities, our results are in line with the finding that impaired use of semantic information is not universal in individuals with ASD.

The findings of the current study provide mixed support for the EPF model and provide no support for the WCC model of sensory and cognitive processing in individuals with ASD. Here, children with ASD did not display enhanced processing of low-level acoustic information, as indicated by no significant interactions among group and acoustic change types that reveal better performance in the ASD group, a finding that would be expected according to WCC and

EPF theories. Furthermore, children with ASD utilized semantic information similarly to TD children during a change detection and a speech-in-noise task. This finding supports EPF which does not predict a deficit in contextual processing in individuals with ASD but does not support the predictions of WCC. The current results suggest that impaired use of high-level information or context is not a ubiquitous characterization of ASD, as suggested by WCC. Furthermore, enhanced processing of low-level sensory features is also not a ubiquitous characterization of ASD, as suggested by WCC and EPF. It will be important for future research to identify what factors may lead to enhanced sensory processing and impaired use of contextual information, considering different aspects of language abilities, the complexity of the stimuli, and nature of that task being completed. This information can then be used to inform and update current theories of sensory and cognitive processing in ASD.

Lastly, IQ and the presence of ASD symptoms amongst TD children were not able to predict the use of acoustic or semantic information during auditory change detection or the use of semantic information during a speech-in-noise task. Eberhardt & Nadig (2016) found that structural language ability, not nonverbal IQ or ASD diagnosis, was a significant predictor of the use of semantic context during tasks requiring the identification of homonyms and the completion of ambiguous sentences. Here, overall IQ and overall GARS scores were used as predictors in the current study. It is possible that separating IQ into verbal and nonverbal abilities or using a more sensitive measure of specific language skills could predict the use of acoustic or semantic information during change detection or speech-in-noise perception.

In summary, this study used a change deafness and speech-in-noise task to investigate the use of semantic and acoustic information in children with and without ASD. The findings provide evidence that children with ASD do exhibit change deafness to the same extent as TD controls. For the change deafness and speech-in-noise task, performance was indistinguishable between children with ASD and IQ-matched controls whereas children with ASD performed worse overall relative to age-matched controls. This indicates that a diagnosis of ASD alone does not predict poor change detection abilities or deficits in speech-in-noise processing. However, results also indicate that all groups do utilize acoustic and semantic information when asked to detect changes between two complex auditory scenes and do utilize semantic context when perceiving speech in the presence of background noise. The lack of evidence for enhanced pitch processing, and the use of semantic information for speech and non-speech sounds across two separate tasks contradicts current theories of ASD. Current theories of sensory and cognitive processing in ASD appear to be incomplete and can be strengthened by further investigating the influence of different phenotypes, like language abilities, on the use of acoustic and semantic information across a variety of tasks that range in task demands and stimulus complexity.

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Vanden Bosch der Nederlanden, C. M., Zaragoza, C., Rubio-Garcia, A., Clarkson, E., & Snyder, J. (2020). Change detection in complex auditory scenes is predicted by auditory memory, pitch perception, and years of musical training. *Psychological Research, 84,* 585-601. doi:10.1007/s00426-018-1072-x

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Curriculum Vitae

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EDUCATION

Present — University of Nevada, Las Vegas
Experimental Psychology, Ph.D Program
Anticipated completion: February 2021
Advisor: Dr. Joel Snyder

May 2016 — University of Nevada, Las Vegas
Master of Arts in Psychology
Thesis: *Neural Processes Underlying Auditory Context Effects*
Advisor: Dr. Joel Snyder

May 2012 — University of Nevada, Las Vegas
Bachelor of Arts in Psychology

RESEARCH EXPERIENCE AND INTERESTS

Fall 2011-Present **Auditory Cognitive Neuroscience Lab**

- Auditory Processing Abilities in Children with and without Autism Spectrum Disorder – Bottom-up and Top-down Influences
    - Successfully recruiting participants from special populations
    - Collaborating with internal and external agencies to recruit and collect data
    - Administering Wechsler Abbreviated Scale of Intelligence – 2nd Edition (WASI-II) and Gilliam Autism Rating Scale – 3rd Edition (GARS-III)
    - Created two kid-friendly experimental paradigms
    - Training and managing research assistants to effectively collect and analyze data

- Bottom-up and Top-down Mechanisms of Auditory Scene Analysis – Electroencephalography (EEG)
    - Collected EEG data with a 72 active-electrode system (Biosemi ActiveTwo system)
    - Analyzed EEG data using Brain Electrical Source Analysis (BESA) software
    - Acoustically analyzed sound stimuli using Adobe Audition
    - Completed time-frequency analysis
    - Completed global field power and global map dissimilarity analyses
    - Trained and managed research assistants to collect and analyze EEG data

- Experience with programming in Neurobehavioral Systems Presentation (Presentation), Microsoft Excel, SPSS, and MATLAB.

PEER-REVIEWED PUBLICATIONS

Higgins, N. C., Little, D. F., **Yerkes, B. D.,** Nave, K. M., Kuruvilla-Mathew, A., Elhilali, M., & Snyder, J. S. (2020). Neural correlates of perceptual switching while listening to bistable auditory streaming stimuli. *Neuroimage, 204,* 116220.

Yerkes, B. D., Weintraub, D. M., & Snyder, J. S. (2019). Stimulus-based and task-based attention modulate auditory stream segregation context effects. *Journal of Experimental Psychology: Human Perception and Performance, 45*(1), 53-66.

Snyder, J. S., **Yerkes, B. D.**, Irsik, V. C., & Vanden Bosch der Nederlanden, C. (2016). Varieties of

attention affect auditory perception of scenes. *The Journal of the Acoustical Society of America, 140*(4), 3208.

Snyder, J. S., **Yerkes, B. D.**, & Pitts, M. (2015). Testing domain-general theories of perceptual awareness with auditory brain responses. *Trends in Cognitive Science, 19*(6), 295-297.

Ramage, E., Klimas, N., Vogel, S., **Yerkes, B. D.**, Flores, A., Sutton, G…Snyder, J.S. (2015). Concurrent sound segregation impairments in schizophrenia: The contribution of auditory-specific and general cognitive factors. *Schizophrenia Research*, *170*(1), 95-101.

TEACHING EXPERIENCE

2016-2017 — **Foundations of Perception**
Four sections — University of Nevada, Las Vegas
An introduction to the study of psychophysics, sensory systems, and perceptual phenomena and theories.

2015-2016 — **General Psychology**
Two sections — University of Nevada, Las Vegas
Introduction to psychology including introductory treatment of sensation-perception-cognition, physiological psychology, learning, personality, development, social psychology, assessment, and history.

SERVICE

March 2019 — **UNLV Rebel STEM Academy Presenter**
Presented research from the Auditory Cognitive Neuroscience Laboratory and demonstrated transcranial magnetic stimulation (TMS) to Las Vegas high schoolers. This program provides academic enrichment opportunities to underrepresented students from diverse backgrounds.

March 2019 **Dawson College Bound Program Presenter**
Presented research from the Auditory Cognitive Neuroscience Laboratory and demonstrated transcranial magnetic stimulation (TMS) to Las Vegas high schoolers. This program provides academic enrichment opportunities to underrepresented students from diverse backgrounds.

March 2019 **Beal Bank USA Southern Nevada Regional Science & Engineering Fair**
Evaluated and scored high-school students scientific research.

May 2018 **Dawson College Bound Program Presenter**
Presented research from the Auditory Cognitive Neuroscience Laboratory and demonstrated transcranial magnetic stimulation (TMS) to Las Vegas high schoolers. This program provides academic enrichment opportunities to underrepresented students from diverse backgrounds.

April 2018 **UNLV Ackerman Center for Autism Volunteer**
Disseminated diagnostic, treatment, and services information to families and healthcare providers at the Autism Walk.

March 2018 **Beal Bank USA Southern Nevada Regional Science & Engineering Fair**
Evaluated and scored high-school students scientific research.

March 2017 **Beal Bank USA Southern Nevada Regional Science & Engineering Fair**
Evaluated and scored high-school students scientific research.

March 2016 **APSSC Student Reviewer**
Evaluated the merit of research proposals for the APSSC student grant competition.

2015-Present **Outreach Undergraduate Mentoring Program**
Advised and supported underrepresented students preparing to apply to graduate programs.

PROFESSIONAL EXPERIENCE

Summer 2018 Multiple Approaches to the Study of Speech Perception Summer School - Groningen, Netherlands

- Attended talks from an array of disciplines related to the perception of speech
- Participated in workshops and trainings including statistical analyses and neurophysiological research techniques

Summer 2015 Army Research Laboratory – Aberdeen, Maryland

- Trained Army researchers to operate Biosemi ActiveTwo EEG system
- Set up and collected data for an EEG experiment
- Researched change detection abilities in Army soldiers and implemented training to improve change detection abilities

Summer 2014 The Dynamics of Music and Language Summer School, University of California, Merced, Merced, CA.

- Attended talks and engaged in critical discussions related to current issues in music, language, and related topics in neuroscience
- Participated in EEG analysis workshops using EEGLab
- Received programming training in MATLAB

ACADEMIC APPOINTMENTS

2013-2015 Graduate Teaching Assistant for Dr. Joel Snyder
Auditory Cognitive Neuroscience
University of Nevada, Las Vegas

2014-2015 Graduate Teaching Assistant for Dr. Diane Villa
Cognitive Psychology
University of Nevada, Las Vegas

2013-2014 Graduate Research Assistant
Auditory Cognitive Neuroscience Lab
Funded through an NSF grant awarded to Dr. Joel Snyder
University of Nevada, Las Vegas

PROFESSIONAL ORAL PRESENTATIONS

Yerkes, B. D., (2019, March). *Assessing Auditory Processing Biases in Children with and without Autism* Given at the UNLV Graduate and Professional Student Association Research Forum

Yerkes, B. D., (2016, November). *Organizing sound: Influences of the past and present.* Given at the UNLV 3 Minute Thesis Competition in Las Vegas, Nevada – Semi-finalist.

Yerkes, B. D., (2016, March). *Assessing the influences of low- and high-level factors during auditory processing in individuals with autism.* Given to the UNLV Psychology Department in Las Vegas, Nevada.

Yerkes, B. D., (2015, November). *Auditory processing in children with autism.* Given at the UNLV 3 Minute Thesis Competition in Las Vegas, Nevada – Semi-finalist.

Yerkes, B. D., (2015, January). *Neural mechanisms underlying auditory context effects.* Given to the UNLV Psychology Department in Las Vegas, Nevada.

Yerkes, B. D., (2014, November). *Neural mechanisms of auditory context effects.* Given at the UNLV 3 Minute Thesis Competition in Las Vegas, Nevada – Semi-finalist.

Yerkes, B. D., (2014, February). *Attention modulates auditory stream segregation context effects.* Given to the UNLV Psychology Department in Las Vegas, Nevada.

PROFESSIONAL POSTER PRESENTATIONS

Higgins, N. C., Little, D. F., Kuruvilla-Mathew, A., **Yerkes, B. D.,** Nave, K. M., Elhilali, M., & Snyder, J. S. (2018, February). *Neural Correlates of Perceptual Switching During Auditory Streaming of Bistable Stimuli.* Presented at the Association for Research in Otolaryngology Conference in San Diego, California.

Yerkes, B. D., Weintraub, D., Snyder, J. S., (2016, June). *Stimulus-based attention and task-based attention modulate different auditory context effects.* Presented at the Association for the Scientific Study of Consciousness Research Conference in Buenos Aires, Argentina.

Yerkes, B. D., Weintraub, D., Snyder, J. S., (2016, February). *Auditory context effects during processing of mistuned harmonic tones: Behavioral and electrophysiological evidence.* Presented at the Association for Research in Otolaryngology Conference in San Diego, California.

Yerkes, B. D., Weintraub, D., Snyder, J. S., (2013, July). *Attention modulates auditory stream segregation context effects.* Presented at the Association for the Scientific Study of Consciousness Research Conference in San Diego, California

COMPETITIVE HONORS AND AWARDS

May 2019	University of Nevada, Las Vegas Summer Doctoral Fellowship
May 2018	University of Nevada, Las Vegas Patricia Sastaunik Scholarship
April 2018	University of Nevada, Las Vegas Student Summer Research Award
March 2018	Nominated by Psychology Department for Outstanding Graduate Student Teaching Award
Summer 2017	Invitation to Graduate Writing Boot Camp, University of Nevada, Las Vegas

May 2017	University of Nevada, Las Vegas Summer Doctoral Fellowship
May 2017	University of Nevada, Las Vegas Patricia Sastaunik Scholarship
August 2016	University of Nevada, Las Vegas Graduate Access Grant
August 2016	University of Nevada, Las Vegas Summer Scholarship
August 2015	University of Nevada, Las Vegas Student Summer Faculty Research Grant
August 2015	University of Nevada, Las Vegas Graduate Access Grant

PROFESSIONAL MEMBERSHIPS

- Association for Research in Otolaryngology
- Association for Psychological Science
- Association for the Scientific Study of Consciousness
- The Society for the Teaching of Psychology