Running Head: PROSODY PROCESSING IN AUTISM

The use of prosody during syntactic processing in children and adolescents with autism spectrum disorders

Joshua John Diehl[1]

Carlyn Friedberg[2]

Rhea Paul[3]

Jesse Snedeker[2]

[1]Center for Children and Families, Dept. of Psychology, University of Notre Dame, IN

[2]Department of Psychology, Harvard University, Cambridge, MA

[3]Yale Child Study Center, Yale University School of Medicine, New Haven, CT

Correspondence concerning this article should be addressed to: Joshua John Diehl, Ph.D. Department of Psychology, 118 Haggar Hall, University of Notre Dame, Notre Dame, IN 46556. Phone: (574) 631-1371. Email: joshua.diehl@nd.edu. Fax: (574) 631-8883

Abstract

In this study, we employed an eye-gaze paradigm to explore whether children (8-12) and adolescents (12-18) with autism spectrum disorders (ASD) are able to use prosodic cues to disambiguate syntactic structure of an utterance. Persons with ASD were compared to typically-developing peers matched on chronological age, IQ, gender, and receptive language abilities. We found that the ASD and TD groups were equally sensitive to prosodic cues when they were first presented to them (block 1), suggesting an intact representation of prosodic structure and its relationship to syntax. However, in block two, when the prosodic cue shifted to favor a different syntactic analysis, the younger ASD group often interpreted the sentences incorrectly. Analyses of the children's eye-movements in the second block reveal that both the younger TD and younger ASD groups experienced interference from the first block, but TD children were able to overcome it and interpret the utterance correctly.

KEYWORDS: Autism, prosody, intonation, syntax, language comprehension, communication

The use of prosody during syntactic processing in children with autism spectrum disorders

Autism is a neurodevelopmental disorder characterized by deficits in social relations and communication, along with a propensity to engage in repetitive behaviors or have restricted interests (APA, 2000). The severity of these deficits and the ways in which they are expressed vary considerably. One reflection of this is the term Autism Spectrum Disorders (ASD) which captures the notion of gradients of impairment along multiple dimensions and is used to refer to a set of diagnoses, including autism and Asperger syndrome, which share the core characteristics described above (Volkmar, Lord, Bailey, Schultz, & Klin, 2004). Until recently, most children who were diagnosed with autism had severe language impairments or delays, and researchers estimated that as many as half of all people with autism were non-verbal (Bryson, Clark & Smith, 1988; Lord & Rutter, 1994; Lord & Paul, 1997). However, as diagnostic and treatment practices have changed, the composition of this population has shifted (Gernsbacher, Dawson & Goldsmith, 2005; Diehl, Tang, & Thomas, in press), leading to a revision in these estimates (Lord, Risi, & Pickles, 2004). A substantial proportion of the school-aged children currently diagnosed with ASD do not appear to have deficits in vocabulary, articulation or syntax (Kjelgaard & Tager-Flusberg, 2001; Joseph, Tager-Flusberg & Lord, 2002).

But curiously, there are two domains of language which seem to be impaired even in highly-verbal children with ASD. First, almost by definition, persons with ASD have impairments in pragmatics—the skills that allow us to use language as a social tool by going beyond the literal meaning of an utterance to understand the role that it plays in a particular interaction (Kelley, Paul, Fein & Naigles, 2006; Tager-Flusberg, Paul, & Lord, 2005; Young, Diehl, Morris, Hyman, & Bennetto, 2005). In highly-verbal persons with autism, these deficits are manifest in a reduced ability to: maintain a topic, take turns in conversation, correct communicative breakdowns, determine the amount or kind of information to provide in a conversation, or infer information that is missing from the discourse (Landa, 2000; Surian, Baron-Cohen & van der Lely, 1996; Adams, Green, Gilchrist & Cox, 2002; Joliffe & Baron-Cohen, 1999; Paul, Orlovksi, Chuba, Marcinko & Volkmar, 2009).

Second, the use of prosody is often atypical in ASD, even in persons with no frank structural language impairments (see Tager-Flusberg, et al., 2005 for review). The term *prosody* refers to the suprasegmental characteristics of speech including pitch, duration and intensity. Descriptions of prosody in ASD have varied from flat and monotonous to variable, sing-song, or pedantic (Amoroso, 1992; Goldfarb, Braunstein, & Lorge, 1956; Kanne, 1943; Lord & Paul, 1997; Provonost, Wakstein, & Wakstein, 1966). Recent work suggests that this variable impression is the result of more extreme pitch variation used to produce simpler pitch contours which are used more repetitively (Diehl et al., 2009; Edelson et al., 2007; Green & Tobin, 2009; Nadig & Shaw, 2011). Atypical prosodic production has been documented using diverse methods at all levels of ability within the autism spectrum (e.g., Baltaxe, 1984; Diehl, Watson, Bennetto, McDonough, & Gunlogson, 2009; Diehl & Paul, 2011; Diehl & Paul, in press; Grossman, Bemis, Plesa Skwerer, & Tager-Flusberg, 2010; Nadig & Shaw, 2011; Paul, Augustyn, Klin, & Volkmar, 2005; Peppé, McCann, Gibbon, O'Hare, & Rutherford, 2007; Shriberg, Paul, Black, & van Santen, 2011). These prosodic differences are clinically significant: they are correlated with ratings of social and communicative functioning in ASD (Paul et al., 2005), they often persist even when other areas of language improve, and they can be a barrier to social acceptance (Shriberg et al., 2001).

There is a smaller but growing body of evidence demonstrating that people with ASD also have deficits in the use of prosody during *language comprehension* (see Diehl & Paul, 2009; McCann & Peppé, 2003 for reviews). Much of this work has focused on prosodic cues to a speaker's emotional state and pragmatic intentions (see e.g., Chevalier, Noveck, Happe & Wilson, 2011; Golan, Baron-Cohen, Hill & Rutherford, 2007; Kleinman, Marciano, & Ault, 2001; Rutherford, Baron-Cohen & Wheelwright, 2002; Wang, Lee, Sigman & Dapretto, 2006), However, prosody also plays a role in structural language processes such as lexical segmentation, lexical identification, and syntactic parsing (Wagner & Watson, 2010; Cutler, Dahan & vanDonselaar, 1997). Research on these non-pragmatic functions of prosody in ASD is critical for determining whether there are prosodic deficits that are separate from the general pragmatic deficit noted earlier. While work in this area has begun, the findings so far leave many questions unanswered (Chevalier, Noveck, Happe & Wilson, 2009; Diehl, Bennetto, Watson, Gunlogson, & McDonough, 2008; Grossman et al., 2010; Paul et al., 2005; Peppe et al., 2007).

The present study explores how children and adolescents with ASD use prosodic cues to disambiguate the syntactic structure of an utterance. In our paradigm, participants follow simple instructions with syntactic ambiguities which are resolved by the placement of prosodic boundaries, while their eye-movements are recorded. This allows us to measure how prosody influences comprehension over time, in a task which does not explicitly focus attention on prosody or require overt metalinguistic judgments. In the remainder of the introduction, we discuss: the prior evidence for deficits in the perception and comprehension of prosody in ASD, with a focus on syntactic parsing; recent work on prosody and syntactic parsing in typically-developing preschoolers; and the hypotheses that motivate the present experiment.

The perception and comprehension of prosody in ASD

Linguistic theories describe prosody as a structure which organizes the phonetic form of an utterance into larger units (e.g., prosodic words and intonational phrases) and assigns prominence to units within this structure (e.g., accents or tones, see e.g., Selkirk, 1986 or Beckman, 1996; for a tutorial, see Shattuck-Huffnagel & Turk, 1996). This prosodic structure is marked by changes in the acoustic properties of speech such as fundamental frequency, duration, pausing, and intensity. The prosodic form that a speaker uses for an utterance is shaped by its lexical content, its syntactic structure, the role of the utterance in the discourse, the speaker's emotional state and speech rate, and the intended audience (Shattuck-Huffnagel & Turk, 1996; Wagner & Watson, 2010 for reviews). Thus prosodic form contains valid cues to the syntactic, semantic, and pragmatic interpretation of an utterance. These cues are rapidly exploited by listeners during language comprehension (Snedeker & Trueswell, 2003; Ito & Speer, 2008, see Wagner & Watson, 2010 for review).

Research on the comprehension of prosody in autism has focused primarily on information at the pragmatic level. Several studies have found that even very high-functioning persons with ASD have deficits in using vocal cues to identify the speaker's emotion (Chevalier et al., 2011; Golan, et al., 2007; Kleinman et al., 2001; Peppe et al., 2007; Rutherford et al., 2002). These behavioral differences depend on the nature of the task (Chevalier, et al., 2011) and are often absent in categorization studies involving a small number of basic emotions (see e.g., Paul et al., 2005; Grossman et al., 2010; Hobson, Ouston & Lee, 1988). However, electrophysiological studies suggest that, even for these simple contrasts, vocal emotion processing is atypical in high-functioning adults and children (Korpilahti et al., 2007; Kujala et al., 2005). A smaller number of studies have explored prosodic cues to irony, the differentiation of question and statements, and the use of contrastive stress as a cue to discourse structure (Paul et al., 2005; Peppe et al., 2007; Wang et al., 2006; Chevalier et al., 2009).

However, there are good reasons for suspecting that the prosodic comprehension deficit in ASD extends beyond the use of prosody as a pragmatic cue. Electrophysio-logical studies suggest that neural processing of the acoustic correlates of prosodic structure (such as frequency and intensity) is atypical in autism (Bonnel et al., 2003; Gomot et al., 2006; Lepistö, Silokallio, Nieminen-von Wendt, Alku, Näätänen, & Kujala, 2006; Kujala et al., 2007; Kujala et al., 2010; Russo et al., 2008). For example, Russo and colleagues (2008) recorded the evoked brainstem response to syllables with rising and falling intonational contours using a passive listening task. In typical children, this response tightly tracked the changing pitch of the stimulus. In children with high-functioning ASD, this signal was noisier, suggesting that the neural encoding of pitch was less accurate. Because frequency is critical for determining the prosodic structure of an utterance, such deficits should affect both the pragmatic and non-pragmatic functions of prosody. Further support for this hypothesis comes from behavioral studies demonstrating that children with autism are less accurate in discriminating between prosodic contours (Peppe et al., 2007; Jarvin-Pasely et al., 2008).

Thus, it is somewhat surprising that the existing studies on prosodic comprehension provide only weak evidence for deficits in non-pragmatic tasks. The three studies which have explored the use of prosodic stress for lexical identification (e.g., reCORD vs REcord) have found no differences between persons with ASD and well-matched controls (Chevalier et al, 2009; Grossman et al., 2010; Paul et al., 2005). Nevertheless, there is a consistent decrement in performance across the three studies (3-6%) which fails to reach significance, raising the possibility that there are group differences but the existing studies lack the power to find them.

The role of prosody in syntactic parsing has been explored in five experiments, with a mixed pattern of findings. Four of these experiments used standard judgment tasks, in which participants heard an utterance with a grouping ambiguity (e.g., chocolate biscuits and jam vs. chocolate, biscuits and jam) and then either selected a picture or gloss that matched the utterance (Peppé et al., 2007; Jarvin-Pasley et al. 2008; Paul et al., 2005) or judged whether a picture matched the utterance (Chevalier et al., 2009). Three of these studies found no difference between persons with ASD and typically-developing controls (Paul et al., 2005; Chevalier et al., 2009; Peppé et al., 2007), while one found that persons with ASD performed reliably worse than age and language matched controls (Jarvin-Pasley et al., 2008).

While these differences are open to many interpretations, they suggest that age and developmental level may play a critical role in performance. The participants in the Jarvin-Pasley study were younger and less verbally proficient than those in the Paul and Chevalier studies, suggesting that deficits in the use of prosody for syntax may be limited to children with structural language impairments or resolve over development. In contrast, the children in the Peppé study also had moderate verbal impairments but were even younger (M = 9;10 years vs. M = 12;7 years). In this case, the performance for the control group was quite low suggesting that the task may have been too difficult for these younger language-matched children (M=6;10 years, for discussion see Peppé, McCann, Gibbon, O'Hare, & Rutherford, 2006).

This explanation, however, cannot readily account for the findings of the fifth study. Diehl and colleagues (2008) adapted a psycholinguistic paradigm al., 2008) to examine prosodic comprehension in adolescents with high-functioning ASD in comparison to a typically developing control group matched on age, IQ, and receptive language abilities. Participants were presented with syntactically ambiguous sentences, like (1) and (2), in which they needed to use prosody to determine the correct action.

1. Put the dog…in the box on the star (Put the dog into the box that's on a star).
2. Put the dog in the box…on the star (Put a dog that's in a box onto a star).

Overall, the group with ASD was less likely than their typically developing peers to act in concordance with the prosodic cue. Diehl's participants were similar in age, IQ and language level to those in the Chevalier and Paul studies. Thus, the difference in performance presumably reflects the differences in the tasks that were used.[1]

One possibility is that the overt judgment tasks used by Chevalier and Paul may have drawn participants' attention on the ambiguity and the contrast between the two prosodic forms

[1] The differences between these studies could also result from sampling error. The critical group differences in the Diehl and Jarvin-Pasley studies are statistically reliable but small ($.02 > p > .05$) raising the possibility of a type 1 error. Alternately, the other studies may lack sufficient power to detect real, but small, effects.

allowing them to adopt an explicit strategy incorporating these cues (Klin, Jones, Schultz & Volkmar, 2003; Paul et al., 2005), while the participants in the Diehl task may have simply responded to commands without becoming aware of the ambiguity or the different prosodic forms. If this were true, we would expect that participants with ASD would take longer to make these overt judgments than controls who presumably do not need to devise task specific strategies. However, Chevalier and colleagues found no difference in reaction times between the two groups.

A second possibility is that ASD group had difficulties with the Diehl task that were not attributable to the perception or comprehension of prosodic cues. Diehl and colleagues (2008) used ambiguous sentences with the verb *put* (e.g., 'Put the dog in the box on the star'). *Put* requires two post-verbal arguments: an object to be moved and a location to which it should be moved. This creates a strong bias to initially interpret the first prepositional phrase (in the box) as a destination, resulting in verb phrase (VP) attachment (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Critically, in the Diehl study, the ASD group only had difficulty with stimuli in which the prosodic cue was in conflict with this initial lexical bias; otherwise they performed identically to their typically-developing peers. In typical adults, this initial bias can be revised when subsequent information in the sentence suggests that this interpretation is incorrect (e.g., the second prepositional phrase or a subsequent prosodic break), but young children fail to revise these initial commitments (Trueswell, Sekerina, Hill, & Logrip, 1999). This ability emerges gradually between five and eleven year of age (Weighall, 2008) and has been argued to reflect the development of an aspect of executive function known as cognitive control—the ability to detect and resolve conflicts between conflicting representations (Novick, Trueswell & Thompson-Schill, 2005).

Persons with autism have been found to have executive function deficits (Pennigton & Ozonoff, 1996; see Hill, 2004 for review) including deficits in cognitive control (Solomon, Ozonoff, Cummings & Carter, 2008) that persist across the development (Luna, Doll, Hegedus, Minshew & Sweeney, 2007) and are present even in high-functioning, highly-verbal populations (Verte, Guerts, Roeyers, Ooosterlaan, & Sergeant, 2006). Taken together, this raises the possibility the performance of the ASD group in the Diehl study is not the result of a deficit in the use of prosody, but instead reflects an inability to revise misinterpreted sentences, due to immature executive functions.

The use of prosody for syntactic analysis in typically developing children

Curiously, when younger typically-developing children (3-7 years) are tested on prosodic comprehension using choice tasks like those above, they also perform quite poorly (Vogel & Raimy, 2002; Choi & Mazuka, 2003; Mazuka, Jinko & Oishi, 2009). These failures are unlikely to result from a basic deficit in prosodic perception. Prosody plays a central role in early speech perception: newborns prefer languages that are prosodically similar to their own (Mehler, Jusczyk, Lambertz, Halsted, Bertoncini, & Amiel-Tison, 1988), older infants use prosodic structure to find words in the speech stream (Johnson & Jusczyk. 2001; Morgan, 1996) and prosodic information may even be used during the acquisition of syntax (Christophe, Millotte, Bernal & Lidz, 2008). Critically, young children are able to use these same prosodic boundary cues to find the ends of words (Choi & Mazuka, 2003) and even to group words together in more scaffolded training tasks (Beach, Katz & Skowronski, 1996).

Snedeker and Yuan (2008; S&Y hereafter) suggested that young children's failure in prosody for parsing tasks was due to the design of these experiments, coupled with their executive function limitations (see also Mazuka et al., 2009). Specifically, like the ASD studies, these experiments used within-subject designs which required children to shift between two response types across trials. Thus, to succeed in these tasks, children must override the interpretation that they got on the previous trial to arrive at the correct interpretation on the next. S&Y tested this hypothesis using a blocked design. In the first half of the study, prosodic form was manipulated between participants: half the children received utterances like (3) and half received utterances like (4).

3. You can pinch the bear…… with the barrette. (Use the barrette to pinch)
4. You can pinch…..the bear with the barrette. (Pinch the one that has a barrette)

Then in the second half, the conditions flipped and participants were given new sentences with the other prosody. Critically, these sentences contain only a single ambiguous prepositional phrase, thus there is no need for participants to revise their analysis of this phrase based on subsequent words. The utterances were instructions involving toys on a tabletop and performance was measured by the action that the child carried out. Four and five year old children performed as well as adults in the first half, indicating that they were sensitive to these prosodic cues and able to use them for syntactic parsing. However, in the second half the children tended to perseverate, particularly in the initial trials, resulting in chance level performance.

S&Y used an additional measure: as participants listened to the instructions their eye movements were recorded, providing information about how their interpretation of the utterance changed over time (see Tannenhaus et al., 1995). They found that, during the first block, children began using prosodic information within 500 milliseconds after the onset of the critical word ("barrette" in 3 & 4), just a few hundred milliseconds after the adults. Thus they concluded that young children rapidly and spontaneously use prosodic information to resolve syntactic ambiguities, but these abilities are can be masked by perseveration across trial in within-subject designs.

Purpose of this Study

In the present study, we use the S&Y task to explore prosodic comprehension in high-functioning children with ASD and typically-developing children matched for age, language ability and IQ. This will allow us to address four open questions.

1) Are children with ASD less likely to use prosodic information during syntactic parsing than their typically-developing peers? As noted above, the findings of the prior experiments are mixed and their interpretation is uncertain. If there *is* a prosodic comprehension deficit in autism, which disappears in explicit judgment tasks which focus attention on prosodic cues, then this deficit should be visible in the open-ended act out task, particularly in the first block when participants have heard only one form of the utterance. However, if the differences between groups in the previous studies are due solely to difficulties with syntactic revision or perseveration, then the ASD group should perform as well as controls in the first block where there is no need to revise or resist prior interpretations.
2) Do children with ASD make use of prosodic cues to syntax as rapidly as typically-developing children do? If prosodic comprehension in autism is the result of slow strategic processes, we should expect to see little or no influence of prosody on the early eye-

movements in this group. In contrast, if children with autism are processing this information in the same way as controls, then we should expect the effects of prosody to emerge at the same time for both groups.

3) How are prosodic comprehension abilities in both populations influenced by interference from prior utterances? While we know that typical adults flexibly shift between interpretations in this task, and preschoolers do not, we do not know how this interference affects older children and adolescents. Given the executive function impairments in ASD we might expect that the ability to resist interference would be impaired in this population, resulting in poorer performance on the second block of trials.
4) How does this profile of abilities change from middle childhood into adolescence? The prior studies using explicit judgment tasks tentatively suggest that performance in typical children improves rapidly around six to nine years of age (Vogel & Raimy, 2002) but this improvement is delayed by a few years in children with ASD, resulting in group differences during later part of middle childhood (Jarvin-Pasley et al., 2008) which resolve by adolescence (Chevalier et al., 2009; Paul et al., 2005). To explore these developmental changes we tested two age groups: children (8-12 years) and adolescents (13-18 years).

Methods

Participants

Autism spectrum disorders group. Participants in this group were 48 individuals with high-functioning ASD between the ages of 7 and 17 (see Table 1 for descriptive characteristics). Participants were recruited from a database of children who had expressed interest in participating in research at the University of Notre Dame, or had participated in either clinical or research activities at the Yale Child Study Center in the five years prior to data collection. During an initial prescreening interview over the phone, parents were asked about the results of previously administered standardized tests. Families were invited to participate in the study if the prescreening interview lead us to believe that they would meeting the inclusion criteria (see below).

Each participant was independently evaluated by our research team for diagnostic confirmation, and met DSM-IV-TR (APA, 2000) criteria for one of the three ASD diagnoses

(Autistic Disorder, Asperger's Disorder, or Pervasive Developmental Disorder, Not Otherwise Specified). Diagnostic confirmation included the Autism Diagnostic Interview-Revised (ADI-R; Rutter, Le Couteur, & Lord, 2003) and the Social Communication Questionnaire - Lifetime Form (SCQ; Rutter, Bailey, Berument, Lord, & Pickles, 2003), and the judgment of an experienced clinician. IQ was measured using either the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) or the Differential Ability Scales (Elliott, 1990). Participants also completed the age appropriate subtests in the Clinical Evaluation of Language Fundamentals – Fourth Edition (CELF-4; Semel, Wiig, & Secord, 2003) necessary for a Receptive Language Index score. Participants were excluded from this study: if they had a Full Scale IQ (FSIQ), Verbal IQ (VIQ), or CELF-4 Receptive Language Index score below 80; if English was not their first language and the primary language spoken at home; or if they had any uncorrected sensory disorders (vision or hearing) that would have interfered with study administration.

Typically developing comparison group. Participants included a final sample of 48 individuals between the ages of 7 and 17 (see Table 1 for descriptive characteristics). Typically developing (TD) participants were recruited from the community and from one of three participant databases (Notre Dame, Harvard, Yale) that consisted of families who had previously participated in a study and indicated a willingness to be contacted for future studies. All participants in this group had typical development as reported by their parents, had no first degree relatives with an ASD, no previous history of clinical diagnosis or special educational services, and were reported to be in the appropriate grade for their age in school. Participants were additionally screened for an ASD diagnosis using the same procedures as the participants with ASD (ADOS, SCQ and clinical judgment), and all had FSIQ, VIQ, and CELF-4 Receptive Language Index standard scores above 80.

Matching procedures. In order to examine potential age differences and facilitate comparison with prior research, participants in each group were divided into two groups based on an age cutoff (12.5 years), creating four comparison groups: (a) participants with ASD younger than the cutoff (ASD child), (b) participants with ASD older than the cutoff (ASD teen), (c) typically developing peers below the cutoff (TD child), and (d) typically developing peers above the cutoff (TD teen). The child groups were similar in age to the participants in the Peppé study (2007), while the teen groups were similar in age to the participants in the Chevalier (2009) and Paul (2005) studies. The TD and ASD children in each age group were matched on chronological age and all four groups were matched on gender, FSIQ, VIQ, and CELF-4 Receptive Language Index (see Table 1). Note that while Table 1 only reports statistical comparisons between ASD and TD groups within each age range, these same comparisons were made between all of the groups on measures of FSIQ, VIQ, and CELF-4 Receptive Language Index scores, and none of these comparisons had $p<.3$ or an $\eta^2_{partial}>.02$.

Procedure

Participants were tested individually in a quiet room in our laboratories at Notre Dame, Harvard, and Yale, or in the participant's home (N=2). The standardized tests were administered according to the published instructions. The procedure for the experimental task was based closely on that used by S&Y. Participants were told that they would be playing a game about following instructions. They were seated in front of an inclined podium which had four shelves for toys, one in each quadrant, and a camera in the middle which was focused on the participant's face allowing us to code fixations after the experiment was completed (see Figure 1). A second camera, placed behind the participant and to the side, recorded their actions.

At the beginning of each trial, the experimenter laid out the props and labeled each one twice. The experimenter then played prerecorded sound files through external computer speakers. On each trial, the participant initially heard an instruction to look at a fixation point at the center of a display. Next, they heard a command to act on the toys. After they completed this action, they heard a second command, which they also completed, before moving on to the next trial. The experimenter moved out of the child's view before the first sentence began and remained there until the action was completed. Children were praised for all responses.

Stimuli.

The sound files and the toy sets that were used in the present study were the same as those used in S&Y and are described in greater detail in that paper. A single set of materials was used across the three sites. On the critical trials, the commands were syntactically ambiguous as in (5).

(5) You can feel the frog with the feather.

Specifically, each critical instruction contained a prepositional phrase headed by *with* that could be syntactically parsed as a part of the noun phrase (NP-attachment) or as a part of the verb phrase (VP-attachment). NP-attachment results in phrase being semantically interpreted as a modifier (*the frog that has the feather*) while VP-attachment results in it being interpreted as an instrument (*use the feather to feel the frog*). These sentences were constructed to ensure that the verb and prepositional object were not biased toward either a modifier or instrument reading (see Snedeker & Trueswell, 2004).

Prosody was manipulated by placing an intonational phrase break before the first noun phrase (You can feel…the frog with the feather) to indicate a modifier reading or before the prepositional phrase (You can feel the frog …with the feather) to indicate an instrument reading. This manipulation of prosody was based on the production patterns observed in child-directed speech (Snedeker & Yuan, 2008) and adult-directed speech (Snedeker & Trueswell, 2003). The set of toys that accompanied each critical trial consisted of: (a) a target instrument, a full scale object which could be used to carry out the action (e.g., a feather), (b) a target animal, a stuffed animal holding a small replica of the target instrument (e.g., a frog with a feather), (c) a distractor instrument (e.g., a candle), and (d) a distractor animal holding a small replica of the distractor instrument (e.g., a giraffe holding a candle).

Thus we would expect that participants who heard instrument prosody would arrive at a syntactic analysis where the prepositional phrase was VP-attached and semantically interpreted as an instrument. This should result in more looks to the target instrument after the onset of the critical word ("feather") and use of the target instrument to act upon the target animal. In contrast participants who heard modifier prosody should interpret the prepositional phrase as an NP-attached modifier indicating (redundantly) the animal that they should act upon. This should result if very few looks to the target instrument and action upon the target animal without the use of any instrument. Prior studies have documented this pattern in both adults and preschool-aged children (Snedeker & Trueswell, 2003; Snedeker & Trueswell, 2004; Snedeker & Yuan, 2008).

Design

We used a blocked design: Prosody was manipulated within subject but the instrument and modifier prosody trials were not intermixed. Instead participants were given all the trials of prosody type before hearing any trails of the other type. Prosody was counter-balanced across lists such that: every sentence occurred with both modifier and instrument prosody across participants and each participant heard just one version of each sentence. Trial order was also counterbalanced. As a result half the participants in every group heard the instrument prosody first and half heard the modifier prosody first. The critical trials were interspersed with filler trials using instructions that were globally unambiguous. The experiment began with two practice trials, followed by 19 trials (8 critical trials and 11 unambiguous fillers). Each trial included two commands. On the critical trials, the first command was always the critical command. The second instruction was an unambiguous filler. Thus, participants heard a total of 38 commands (not including practice trials), 8 of which were critical ambiguous commands.

Coding.

Trained coders who were naive to group membership and study goals watched the videos to determine the action of the participants. Coders classified actions in one of four categories: (a) instrument responses (i.e., the target instrument was used to execute the act on the target animal), (b) mini-instrument responses (i.e., the participant used the small version of the instrument that was attached to the target animal to execute the action), (c) modifier responses (i.e., the participant executed the action on the target animal themselves, without the instrument), and (d) other responses (i.e., the participant performed a different action than was specified in the command, or acted on one of the distractor objects). Mini-instrument responses were treated as instrument responses in the data analysis, following S&Y. Reliability between coders, which was performed on 20% of the participants, was very high (k=.96, range=.77-1.00), and disagreements in coding were resolved by consensus between coders.

Eye movements were coded from the videotape of the participant's face, using a Sony DV deck with frame-by-frame viewing. One coder recorded the onset of the sentence and the beginning of the action, with the audio on. A second coder was provided with this information and coded the onset of each change in gaze and the direction of each subsequent fixation, with the audio off. This coder was blind to the prosodic form of the utterance and to the location of each toy (because the toys were not visible in the eye video). This second coder identified the participant's direction of fixation as being in one of the four quadrants of the podium, the center hole (at the camera), or away from the display. Any frames in which the participants' eyes were closed (blinks) or not visible were excluded from the analyses. Twenty-three percent of participants were coded by an additional coder, who achieved high reliability on direction of gaze (90%). Disagreements were resolved by a third person.

Results

The results are divided into two sections below. First, we present the participants' actions in response to the target instructions, analyzing whether the target instrument was used to complete the action. This measure reflects participants' final interpretation of the ambiguous phrase. Second, we analyze the participants' fixations as the utterance unfolds over time to explore the process of moment-to-moment language comprehension. For each variable, we conducted an analysis of variance (ANOVA) on the participant means. Because of the prior evidence for perseveration in this task in younger children, a separate analysis was conducted for each block of trials. Thus, for each ANOVA, there were three between-participant factors (Age, Diagnosis, and Prosody). Parallel ANOVAs were conducted on the item means with List as a between-item factor and Age, Diagnosis, and Prosody as within-item factors. Effect sizes were calculated as partial eta squared (η_p^2) (Cohen, 1973).

Actions

Figure 2 plots the proportion of trials in the first block on which participants performed instrument actions, thus revealing that they had interpreted the ambiguous prepositional phrase as a VP-attached argument or adjunct. Figure 3 plots the proportion of instrument actions during the second block of trials. Table 2 lists the results of the ANOVAs for both Blocks.

On Block 1, all four groups were strongly influenced by prosody and appeared to use it to roughly the same degree resulting a strong effect of Prosody, no effect of Age or Diagnosis, and no interactions between these variables and Prosody. In addition, separate one-way ANOVAs were conducted for each of the four subgroups, which confirmed that the effect of Prosody was reliable in all of them (all F's>13, all p's <.005, all η_p^2's>.3).

The pattern in Block 2 was somewhat different. Again there was a reliable main effect of Prosody in the ANOVA. However, there were also marginal interactions between Prosody and Age; Prosody and Group; and Prosody, Group and Age, suggesting that the effects of prosody varied across participants. Based on our a priori hypothesis, that persons with ASD might show delayed development of the ability to shift their interpretation of the ambiguous sentence, we conducted separate one-way ANOVAs on each of the four subgroups (with Prosody as a between-participant variable). The effect of Prosody was reliable in both groups of typically developing children and in the ASD teen group (all F's>11, all p's <.01, all η_p^2>.3). For the ASD child participants, however, there was no effect of prosody in the second block ($F_1(1,22)=.025$, $p>.8$, $\eta_p^2=.001$; $F_2(1,7)= .027$, $p>.8$, $\eta_p^2=.004$). Thus although all participants were able to use prosody to guide their final interpretation of utterances in the first block of trials, the children in the ASD child group were at chance in the second block, suggesting that they had difficulty shifting their interpretation of the ambiguous utterance when the prosodic cues changed.

Temporal Analysis of Eye Movements

To explore how participants' interpretation of the utterance changed over time, we analyzed the proportion of looking time to the target instrument for both Block 1 (Figures 4 a & b) and Block 2 (Figures 5a & b). The first three data points in each panel represent the proportion of time that participants were looking at the target instrument during each critical time window, while the last data point in each figure shows the proportion of instrument actions. The critical time windows are synchronized to the onset of the object in the prepositional phrase (e.g. "stick" in "You can turn over the bear with the stick"). The standard practice in psycholinguistics is to begin analysis windows 200ms after the onset of the critical linguistic information, to account for the time that it takes to program and launch an eye movement (Allopena, Magnuson, & Tanenhaus, 1998). Thus, our initial time window (0-200ms) is called the *with*-window because it should include gaze shifts that occurred in response to the initial part of the prepositional phrase (*with the)* but no fixations programmed in response to the critical noun *(stick)*. In contrast, our early-prepositional phrase (PP) window (233ms-700ms) includes some fixations initiated after the onset of the critical word (*stick)* and our late-PP window (733-1200ms) includes some fixations initiated after the utterance ended. Tables 3 and 4 list the results of the ANOVAs for the critical variables for Block 1 and Block 2, respectively.

On Block 1 prosody had a reliable effect on the participants' eye movements starting at the early-PP window and continuing into the late-PP window (Figures 4a & b). Participants looked at the target instrument more often when they heard instrument prosody. To explore the effects of Prosody in more detail, additional one-way ANOVAs on each of the four subgroups were performed. In the early-PP window, Prosody had a reliable effect on the teen participants and the TD child group (all F's>8, all p's<.05, all η_p^2's>.2). During this time window the effect failed to reach significance in the ASD child group ($F_1(1,22)=2.03$, $p>.1$, $\eta_p^2=.08$). However, in the omnibus ANOVA for this time window (Table 2), we saw no evidence that Group (ASD or TD) interacted with Prosody or any other variables. Thus we cannot conclude that early processing of prosody differs between the two groups. Critically, in the late-PP window, the effect of prosody was reliable in all four groups of participants (all F's>5, all p's<.05, η_p^2's>.2). Thus all participants were able to use prosodic cues to guide their unfolding interpretations of the utterances during the first block of trials.

In the omnibus analysis, there was no main effect of Prosody during the *with*-window. This suggests that most children were not shifting their attention to the potential instrument (e.g., the big stick) until the relevant word ("stick") began. But curiously, there was an interaction between Prosody and Diagnosis in the *with*-window which was significant in the items analysis and marginal in the subjects analysis (p = .054). This interaction reflected a difference in the earliest responses to Prosody in the two groups. Even before the target instrument was named, children with ASD tended to look at it more in the instrument prosody condition than in the modifier prosody condition, presumably because they were predicting that the with-phrase would introduce an instrument of some kind. The TD groups did not show this pattern. This raises the possibility that the participants with ASD show more predictive processing than typical controls. However, the difference between the two groups was small and the difference between the two prosody conditions was not reliable in the ASD group (or the TD group). Finally, during the early-PP window, there was also a marginal effect of Age and an interaction between Prosody and Age that was reliable only in the items analysis. As the figures suggest, these last two trends reflect a weak tendency for teens to show more target instrument looks in the instrument prosody condition than the child groups.

The eye movements in Block 2 (Figures 5a & b) showed a somewhat different pattern. Once again there was a reliable effect of Prosody in the ANOVA for the early and late-PP windows.

As in Block 1, participants who heard the utterances with instrument prosody were more likely to look at the target instrument than participants who heard modifier prosody. Furthermore, there were no effects of Diagnosis and no interaction between Prosody and Diagnosis, suggesting that children and teens with ASD used these cues during online processing to the same degree as typically developing controls.

However the effects of the Prosody manipulation differed in subtle ways between the two age groups, resulting in reliable interactions between Prosody and Age in the *with*-window and early-PP window. In both groups of teens, there were no reliable effects of Prosody in the *with*-window but robust effects of Prosody in the early-PP and late-PP window (F's>6, p<.05, η_p^2's>.2). This effect is in the same direction as the effect observed in Block 1: participants looked more at the target instrument in the instrument prosody condition than in the modifier prosody condition.

In contrast, the two child groups show a reliable effect of Prosody during the with-window. It was significant in the subjects analysis for both groups (F's>5, p's<.05, η_p^2's>.2). In the items analysis, the effect was significant for the ASD group ($F_2(1,14)=6.77$, $p<.05$, $\eta_p^2=.33$) and marginal in the TD group ($F_2(1.14)=4.05$, p=.064, $\eta_p^2=.22$). This effect, however, was in the opposite direction of the effects described above: Participants who heard sentences with modifier prosody looked at the target instrument more than those who heard instrument prosody. Thus it is likely that these effects are not a result of the prosodic manipulation itself but a result of interference from the participants' interpretation of the earlier utterances. The children who had heard instrument prosody in Block 1 continued looking at the target instrument in Block 2, even though they were now hearing modifier prosody. Similarly, the children who had heard modifier prosody in Block 1 continued ignoring the target instrument in Block 2. This suggests that the child participants were predicting the meaning of the utterance on the basis of their initial experiences in the study, and were (at first) failing to notice the prosodic cues that signaled a shift in interpretation.

This "reverse" prosody effect disappears in the early-PP window and the expected pattern begins emerging in the final time window. As a result, there is no effect of Prosody for either the child ASD or child TD group during the early-PP window (F's<1, p>.3, η_p^2's<.05) or the late-PP window in the subjects analysis (F's>0, p's > .1, η_p^2's<.13). In the items analysis, the effect of prosody is significant in the child TD group in the late-PP window (F>5, p<.05, $\eta_p^{2>}$.2) but not significant in the child ASD group (F<1, p>.9, η_p^2<1). However, in this window the effect of Prosody is marginal when the two groups are collapsed in the subjects analysis (F_1(1,43)=3.8, p=.058, η_p^2=.081) and significant in the items analysis (F_2(1,30)=7.1, p=.012, η_p^2=.19) suggesting that some of the children may be beginning to revise their misanalysis during this time window.

Discussion

The results of this experiment answer the questions that we posed in the introduction.

We found that children with ASD are as likely as typically-developing children to use prosodic information to resolve syntactic ambiguity, provided that there is no need to revise their interpretation of the utterance or override perseveration. On the initial block of trials, both groups responded correctly about 80% of the time.

Furthermore, the ASD groups are able to use prosodic cues to syntax as rapidly as typically-developing children, suggesting that similar comprehension mechanisms were used by both populations. Specifically, prosody robustly influenced interpretation of the ambiguous phrase shortly after the onset of the critical word, and it did so to roughly the same extent for all groups (Block 1, early-PP window). These effects persisted thorough out the trial (Block 1, late PP-window). There was only one measure in the first block that suggested that the two groups might be different (the marginal interaction between diagnosis and prosody in the Block 1 *with*-window) and this effect indicated that persons with ASD were, if anything, faster in their use of prosodic information. Thus, the present findings suggest that this ability is not the result of slow, effortful, compensatory strategy but instead reflects intact prosodic processing.

Finally, the interpretation of previously encountered utterances leads both of the child groups to make erroneous predictions as the utterance unfolds (Block 2, *with*-window). The TD children are able to overcome this initial interference and correctly interpret the prosodic cues, while the ASD children are not (Block 2, actions). In contrast, the teens show no evidence of interference in Block 2 in either their eye movements or their actions.

In the remainder of this paper we explore: what we learned about ASD by measuring the moment-to-moment process of language comprehension; how to account for the perseveratory errors in the child ASD group; what these results tell us about typical development; how they can be reconciled with prior studies of prosody and parsing in ASD; and how they constrain our understanding of the broader prosodic impairment in ASD. We end by discussing the limitations and clinical implications of these results.

Measures of online processing provide insights that measures of outcome cannot

To date only one published study has use the visual-world paradigm to explore moment-to-moment language comprehension in ASD (Brock, Norbury, Einav & Nation, 2008). The visual world paradigm has clear advantages for people working with special populations. Many of the methods that provide temporally sensitive measures of language comprehension involve the simultaneous performance of two tasks (e.g., cross-model priming, self-paced reading) which places a burden on executive function. This limits the range of populations that can be studied and complicates the interpretation of data patterns in populations with impaired executive function. Other paradigms require participants who are fluent readers (eye-tracking while reading). Visual world paradigm provides rich information about how interpretation involves overtime based on a measure which requires little or no training.

The present experiment demonstrates the utility of this paradigm for understanding into the processes that underlie language comprehension in developmental disorders. By using a temporally-sensitive measure we were able to gain insights into prosodic processing in autism that could not have been gleaned from the participants' final responses.

Specifically, the eye-movement data from the first block demonstrates that children with ASD not only use prosody to resolve ambiguity, they do so using a mechanism that has the same temporal profile as the mechanism used by typical children. If they were using a less efficient and more strategic process, we would expect that that the effects of prosody would be delayed. The rapid use of prosody in the ASD groups strongly suggests that they use the same mechanism as typical children. This contrasts sharply with theory of mind tasks, where people with high-functioning ASD also succeed but appear to do so by virtue of a different mechanism than that employed by typical children (Senju, Southgate, White & Frith, 2009).

Second, the eye data in the second block reveals an unexpected similarity between the Child ASD and Child TD groups. While children with ASD fail to use prosody to guide their actions in the second block, TD children succeed in doing this. Without the eye-tracking data we might infer that children with ASD experience interference while TD children do not. The eye-movement data clarifies the nature of the difference between the groups: both groups develop expectations about the utterances on the basis of their experience, but while typical children are able to overcome this initial misanalysis, those with ASD do not.

Finally, the eye data clarifies the nature of the developmental changes that occur between childhood and adolescence. If we had only the actions, we might have thought that adolescents with ASD perform better than children with ASD because they are able to resolve interference like typical children. Our data suggests that adolescents, in both groups, appear to avoid interference altogether.

Why do children with ASD have difficulty overcoming interference?

The one difference that we observed between the ASD and TD groups was the poorer performance on the child ASD group on the second block, which appears to reflect the inability to override interference from the earlier trials. This inability is not absolute. If the children were completely immune to the change in prosody, we would expect them to continue as they did in the first block, resulting in a reliable reverse prosody effect in their actions. The pattern of performance across trials suggests that the children with ASD gradually adjust their interpretation to match the new prosodic form: children get 78% of the actions right on block 1 with little difference across trials, on the first trial after the switch performance is below chance (27% correct), for the next two trials it hovers around chance (60% and 53%) and then in the final trial performance returns to roughly the level that it was in the first block (73%). In contrast, for the other three groups performance is above chance on the first switch trial (67% for ASD teen, 67% for TD child, and 60% for TD teen) and there is no clear trend toward improved performance after that time (means for trials 5-8: 69% for ASD teen, 69% for TD child, and 75% for TD teen).

Thus between the ages of eight and twelve children with ASD are able to form strong expectations about syntax on the basis of prosodic information, but they have difficulty overriding these expectations when prosody changes. However, they do appear to detect the change in prosody and over the course of a few trials they gradually shift their response pattern. We suspect that this pattern reflects deficits in executive function in the ASD group.

Children with ASD perform more poorly than controls on a wide range of executive function measures (for reviews see Hill, 2004; Russo, Flanagan, Iarocci, Berringer, Zelazo & Burack, 2007). The deficit that is most consistently found is a difficulty switching between different rules across trials on the Wisconsin Card Sorting Task and similar paradigms; persons with ASD tend to perseverate, producing responses that are consistent with the rule that they had learned earlier (see Russo et al., 2007 for discussion) much like they did in our prosody task. These deficits are present even in highly-verbal persons with autism and even when participants are matched on the basis of their verbal abilities (Ambery, Russell, Perry, Morris & Murphy, 2006; Ozonoff, Rogers & Pennington, 1991; Ozonoff 2004; Verte, Guerts, Roeyers, Ooosterlaan, & Sergeant, 2006). Thus, while we did not collect any information about executive function abilities in our sample, it very likely that the ASD and TD groups differed in this respect.

It is unclear how to conceptualize this executive function deficit. Overriding one interpretation of a stimulus in order to carry out a second plan requires inhibition (of the first rule), working memory (to hold the second in mind), and set shifting (to move from the first rule to the second). Russo and colleagues (2007) have argued that the executive function deficit in ASD is most parsimoniously described as a deficit in set shifting, since persons with ASD are often unimpaired in tasks that involve only inhibition or working memory. Our data are consistent with this claim but they point to a limitation of this conceptualization. Set shifting is defined largely in terms of the result or function of the process (the ability to switch between goals or construals of a stimulus), but a cognitive theory of set shifting will ultimately require that we break this complex cognitive function down into simpler operations. Presumably, one of those operations will involve abandoning the prior construal of the stimulus, a process that might require active inhibition or disengagement. In other words, there may be inhibition without set shifting but it is not clear that there can be set shifting without some form of inhibition or disengagement. Our eye-tracking data suggest that disengagement is the locus of the difference between TD and ASD child groups. Both groups of children continue to show activation of the incorrect interpretation of the sentence during the second block of trials (reverse prosody effects on early eye-movements). The TD children abandon this construal as the sentence unfolds, the ASD children do not.

In contrast, the difference between the child groups and the teen groups is most readily conceived of as a difference in establishing and holding onto the new goal: the adolescents do not show continued looks that are consistent with the old goal and instead show predictive looking consistent with the new stimulus. The fact that no differences were found between ASD and TD teens suggests that the executive function requirements of this task are simple enough that both groups have mastered them at this age, which is to be expected given the continued growth of executive functions throughout childhood and adolescence in both populations (O'Hearn, Asato, Ordaz, & Luna, 2008).

What these findings tell us about typical development

While primary goal of the present study was to understand prosodic parsing in autism, this research also provides much needed information about the development of this ability in typical children.

First, we found that initial sensitivity to prosody does not change between the ages of four and twelve: on the first block of trials, both the 4-5 year olds in S&Y and the 8-12 year olds in the present study acted in accordance with prosody 75% of the time. This is remarkable given the dramatic changes in attention, motivation, and education across this age range. It also suggests that the present task has few extraneous demands. However, a comparison of the eye-movement data from the first block of trials indicates that school-aged children are faster to use prosody than preschoolers. S&Y found that preschoolers showed no effect of prosody on eye-movements until the late-PP window (500-1000 ms after the critical word), while adults showed effects in the early-PP window (0 – 500 ms). This delay could not be attributed to slower overall language processing since verb information was used equally quickly in both groups. The school-aged children and adolescents in the present study performed similarly to the adults, suggesting that ability to use prosody speeds up between six and eight years of age.

Critically we found that the tendency to perseverate across trials, which is robustly present in 4-5 year olds, has disappeared by about 8 years of age. This is not because school-age children do not experience interference across blocks—their early eye-movements suggest that they do—

instead it reflects an improved ability to overcome interference and respond in accordance with the prosodic cues. This pattern is reminiscent of the change that occurs in children's ability to revise garden path sentences. Young children, like adults, use the information that they encounter early in a sentence to determine how to interpret syntactic ambiguities. Adults will revise these commitments on the basis of cues that occur later in the sentence but children will not (Trueswell et al. 1999). The ability to correctly interpret these garden-path sentences appears to develop rapidly at around the age of eight (Trueswell et al., 1999; Weighall, 2008), though no eye-movement data has been published for these older groups to confirm that revision is involved. To the best of our knowledge, this data set is the first that documents the present evidence of misanalysis of a structural ambiguity in school aged children (with window block 2) which is later correctly revised (late-PP window and actions block 2). Thus our findings, in concert with S&Y, confirm that the ability of revise misanalyzed sentences shows substantial development at around 8 years of age. The development of syntactic revision has been argued to reflect the development of domain general executive functions (specifically cognitive control see Novick et al., 2005), and the failure to revise in the ASD children, who would be expected to have executive function impairments, is consistent with this hypothesis.

Finally, we found that adolescents differed from the school-aged children in one critical respect: their eye movements suggested that they did not experience prolonged interference when they shifted from one interpretation to another. It is unlikely that the adolescents in our sample simply failed to make any predictions about the ambiguity on the basis of the earlier trials. Studies of structural priming using this same paradigm suggest that such effects are robustly present in adults as well as children (Thothathiri & Snedeker, 2008a/2008b). One possibility is that adolescents did make predictions, which created some interference on the first trial after the switch, but they were able to override this expectation on the subsequent trials and thus it is not visible in the present data. The ability to quickly shift perspectives could be due to an awareness of the ambiguity of the sentence, and the subsequent expectation that both interpretations will be present in the study. In prior studies using similar materials, adults were typically aware of syntactic ambiguities when unbiased verbs are used and the context supports both interpretations of the ambiguous phrase (Snedeker & Trueswell, 2003; Snedeker & Trueswell, 2004).

Reconciling the findings on prosody and parsing in autism

The results of this study are consistent with the prior literature on prosody and parsing in autism and provide insight into findings that had seemed incompatible. As we noted in the introduction, four of the five prior studies used judgment tasks in which participants had to shift between two different syntactic structures, creating the potential for interference across trials (Mazuka et al., 2009). This study, in concert with S&Y, demonstrates that the ability to override this interference develops between the ages of 6 and 8 in typically developing children and is delayed in children with ASD, emerging when they reach a verbal age of about 12. This suggests that children with ASD will diverge from language-matched controls on these tasks when they have verbal mental ages between 8 to 12 years but otherwise perform similarly. This prediction is confirmed; studies in which the average verbal age is below 8 (Peppé et al., 2007) or over 13 (Paul et al., 2005; Chevalier et al., 2009) have found no differences between groups, while the one study with sizeable portion of children in this critical developmental window found did find a difference between children with ASD and language children with developmental delays (Järvinen-Pasley et al., 2008a).[2]

The Diehl study does not conform to this pattern (Diehl et al., 2008). Although the participants were primarily over 12 (11-19 years, M=15;3) and the selection criteria were similar to those employed in the present study, there was a reliable difference in performance between the ASD and TD groups. We believe that this is because the stimuli used in that study place additional demands on executive functions. Specifically, they require the participants detect a syntactic misanalysis, inhibit this misinterpretation, and construct the correct one, skills which appear to draw heavily on domain-general executive functions such as cognitive control and working memory (see Novick et al., 2005). On the critical trials, participants first heard an unambiguous command like ("Put the dog in the basket") which was followed by a critical command with ambiguity that was prosodically disambiguated as either a VP-attachment ("Put the dog… in the basket on the star") or as an NP-attachment ("Put the dog in the basket… on the star").

---

[2] The Järvinen-Pasley sample spans the age range of both our child and teen groups (7-16 years; M=12;7) but the participants were less verbally proficient than those in the present study (mean standard score for vocabulary was 84). Thus the ability level of the sample appears to be close to that of our child groups.

ASD and TD teens performed equally well with VP-attached utterances (> 90%). But both groups had more difficulty with the NP-attached utterances, and the ASD teens performed worse than their peers (50% vs. 70%). Several factors should lead participants to initially interpret the first prepositional phrase (*in the basket*) as a VP-attachment destination. The verb (*put*) typically occurs with destination phrase which creates a bias to assign this role to the prepositional phrase as soon as it is encountered (Tanenhaus et al., 1995). Furthermore, in the sentence immediately preceding the critical command the same prepositional phrase was used as a destination, priming this interpretation. In the VP-attached condition, the prosodic information merely reinforces this interpretation. However, in NP-attached condition, participants have to revise their syntactic analysis of the sentence on the basis of the prosody. The critical information for detecting this misanalysis is the prosodic break between the first and second prepositional phrase which occurs only after participants have committed to the incorrect analysis (prior to that point the utterance has no strong breaks, and thus the prosody is ambiguous between the two interpretations, see Snedeker & Trueswell, 2003). We know from previous research that syntactic revision is difficult for young children (Trueswell et al., 1999) and that revision in adults appears to be associated with executive functions, particularly cognitive control and working memory. Thus it seems plausible that the deficits that were observed in the Diehl study are due to deficits in executive functions that affect syntactic revision, rather than impairments in the comprehension of prosodic cues to syntactic structure. In contrast, in the present study the critical prosodic cues always occur before the child encounters the ambiguous phrase, thus reanalysis of prior material is never required.

Critically, our results rule out an alternate interpretation of the prior literature. The discrepancy between the Diehl data and the explicit judgment studies cannot be attributed to differences between action based tasks and reflective tasks (that might give rise to strategizing); we also employed an act-out paradigm with similar task demands but found no deficits in prosodic processing for adolescents with ASD.

Characterizing the prosodic deficit in ASD

The present results also constrain our characterization of the broader prosodic deficit in autism. If children with ASD do not have a specific deficit in the use of prosody to determine the syntactic structure of an utterance, it suggests that their other prosodic difficulties are not due to a global inability to perceive or represent prosodic structure, but instead reflect a more circumscribed deficit. The broader literature suggests three possibilities.

A. *The perception and representation of prosodic structure is intact in ASD and deficits in using prosody appear only when prosodic information is interacting with another process (like pragmatics) which is itself impaired.*

On this hypothesis, we would expect that persons with ASD would typically have deficits in using prosody for pragmatic functions because they have impairments in pragmatics independent of prosody. But the ability to use prosody as a cue to syntactic or lexical processing would depend upon the person's broader lexical and syntactic abilities. When those skills were intact, we would expect the use of prosody for these purposes to be intact as well. Because most studies of prosody compare persons with ASD to language-matched peers, this should result in no difference between diagnostic groups, unless the task itself draws heavily on other abilities which are impaired (e.g., executive function demands in the present task).

This hypothesis is consistent with the findings of most of the prior research. First, there is very little evidence that persons with ASD have deficits in using prosody for non-pragmatic functions. As we noted earlier, the majority of studies find that people with ASD perform as well as language-matched controls in tasks tapping syntactic comprehension (Chevalier et al., 2009; Paul et al., 2005; Peppé et al., 2007; and the present study), and the exceptions in this domain (Diehl et al., 2008; Järvinen-Pasley et al., 2008a) appear to reflect the inhibitory demands of the tasks that were used and thus may be better understood as a deficit in executive function. In addition, all the existing data suggests that syntactic production (Paul et al., 2005; Peppé et al., 2007) and lexical comprehension (Chevalier et al, 2009; Grossman et al., 2010; Paul et al., 2005) are also commensurate with structural language abilities. The findings, however, are less clear for the production of stress to disambiguate lexical items (reCORD vs. REcord). One of two studies of this phenomenon, found less accurate production in persons with ASD (Paul et al., 2005), while the other found that speakers with ASD were equally accurate but produced words with a longer duration (Grossman et al., 2010).

We suspect that the group differences in both studies reflect the demands that the experimental tasks make on pragmatic processing and executive function. For example, the reading task used by Paul and colleagues is similar to the task used to study the disambiguation of homographs ("She will wind up the string" vs. "The cold wind will below"). Adults and children with ASD consistently perform more poorly in homograph reading tasks than language and reading matched controls (Frith & Snowling, 1983; Happé, 1997; Jolliffe & Baron-Cohen, 1999; Lopez & Leekam, 2003), which cannot be attributed to prosodic deficits since the alternate forms of the homographs differ phonemically but not prosodically. Instead this deficit appears to reflect difficulties in using context to identify the correct meaning (Happé, 1997) or in inhibiting one pronunciation of an orthographic string shortly after using another (Hala, Pexman & Glenwright, 2007). Similarly, Grossman and colleagues used a cloze procedure to elicit the critical words ("Kate calls Tom on his cell phone. When Tom doesn't answer, Kate wishes he would…."). This task requires participants to make inferences about how the discourse will continue based on the meaning of the sentence and world knowledge. Given their pragmatic difficulties, children with ASD may be less confident that they have made the correct inference, resulting in slower, more tentative speech. Given the absence of any deficit in perceiving lexical stress (Chevalier et al., 2009; Grossman et al., 2010; Paul et al., 2005), it seems most parsimonious to assume that the deficits in the production studies reflect these extraneous task demands.

Second, there is substantial evidence for a deficit in using prosody for pragmatic purposes. For example, deficits in using vocal cues to identify the speaker's emotional state have been observed in categorization tasks with children, adolescents and adults (Golan, et al., 2007; Järvinen-Pasley et al., 2008a; Kleinman et al., 2001; Peppé et al., 2007; Rutherford et al., 2002), as well as production tasks (Peppé et al., 2007). While some studies find no differences in categorization accuracy, particularly with high-functioning populations (Chevalier et al., 2011; Paul et al., 2005; Grossman et al., 2010), differences in processing can still be detected in electrophysiological studies and dual task paradigms (Chevalier et al., 2011; Korpilahti et al., 2007; Kujala et al., 2005). Similarly, there is robust evidence for a deficit in the production of pitch accents or prosodic stress (Baltaxe & Guthrie 1987; DePape, Chen, Hall & Trainor, 2012;

McCaleb and Prizant, 1985; Paul et al., 2005; Peppé et al., 2007), which provides information about the pragmatic function of a word in the discourse ("an orange plate and RED plate" vs. "a red cup and a red PLATE").

Nevertheless, many studies have failed to find deficits in the use of prosody for pragmatic purposes. Some of these null findings may be attributable to ceiling effects, floor effects, or the use of small and heterogenous samples. For example, performance on the contrastive stress comprehension task used by Peppé and colleagues (2007) appears to be at or near chance for many of the children in both groups, raising the possibility that the task is too hard for this age group (see also Järvinen-Pasley et al., 2008a; Peppé et al., 2006). But some null findings are more problematic. For example, across a wide range of age and ability levels, persons with ASD perform as well as controls at using prosodic cues to distinguish questions from statements both in comprehension and in production (Chevalier et al., 2009; Erwin et al., 1991; Järvinen-Pasley et al., 2008a; Peppé et al., 2007; Paul et al., 2005). One possible explanation is that the pragmatic process involved in distinguishing questions from statements is one that is not impaired in high-functioning autism, and thus the use of prosody for this purpose is also unimpaired. This inference could be spared because it is relatively simple, requires very little mental state modeling, or is grammatical rather than pragmatic (see Paul et al., 2005 and Chevalier et al., 2009). This would be consistent with recent studies on scalar implicature, a pragmatic process with a similar profile, which have also found no impairments in high functioning ASD (Pijnacker, Geurts, Van Lambalgen, Kan, Buitelaar & Hagoort, 2009; Chevalier, Wilson, Happé & Noveck, 2010).

There is however, one substantial problem with the hypothesis that prosodic deficits are merely pragmatic deficits that happen to involve prosody: it is inconsistent with the sizeable literature documenting deficits in the perception and imitation of prosody in ASD (Bonnel et al., 2003; Gomot et al., 2006; Lepistö et al., 2006; Jarvin-Pasely et al., 2008; Kujala et al., 2007; Kujala et al., 2010; Peppé et al., 2007; Russo et al., 2008). While this might seem like sufficient reason for rejecting this hypothesis, the correct interpretation of these findings, and their relevance for understanding prosodic processes, is unclear. Take, for example, the finding that the encoding of pitch in the brainstem is less accurate in children with ASD (Russo et al., 2008).

This would seem to suggest that the prosodic deficit in autism stems from a pure sensory deficit, but a perceptual deficit of this kind would be difficult to reconcile with evidence that pitch discrimination is actually often enhanced in high-functioning autism (Bonnel et al., 2003; Bonnel et al., 2010). In fact, much of the electrophysiological evidence for abnormal sensory processing in ASD comes from studies showing enhanced (earlier or larger) responses to auditory stimuli (see Marco, Hinkley, Hill & Nagarajan, 2011 for review). This may not be a concern: both enhanced and attenuated responses are plausibly interpreted as causally linked to prosodic deficits on the basis of reasonable hypotheses about the effects of hypo- or hyper-sensitivity over the course of development. However, the pattern of findings is often inconsistent across studies which appear to test the same underlying process. For example, in some experiments the mismatch negativity in response to changes in the fundamental frequency of speech stimuli is attenuated in ASD (Kujala et al., 2005; 2010), while in other experiments it is enhanced (Lepisto, 2006; Lepistö, Nieminen-von Wendt, von Wendt, Näätänen, & Kujala, 2007) or similar to typically-developing controls (Ceponiene et al., 2003). The behavioral findings are equally opaque: while children with ASD are impaired in prosodic imitation tasks and discrimination tasks using larygograph recordings (Järvinen-Pasley et al., 2008a; Peppé et al., 2007; Peppé et al., 2011), they are actually more adept than typical children at matching utterances to visual depictions of their prosodic contour (Järvinen-Pasley, Wallace, Ramus, Happé & Heaton, 2008b). Given these discrepancies, it would be premature to draw strong conclusions about the perception of prosody in autism on the basis of the existing data.

B. While the perception of prosody is impaired in ASD, the use of prosody for parsing is not because it relies on prosodic features that are spared

The label *prosody* is applied to a wide range of perceptual properties which appear to play different roles in the linguistic system. Theories of prosody generally assume or propose a two-way distinction between prosodic structure and paralinguistic prosody. Prosodic structure is a characterization of prosodic changes within an utterance that is both systematic and amendable to formal linguistic analysis. In contrast, paralinguistic prosody typically describes global properties of an utterance (speed, mean pitch, tone of voice) that provide information about the physiological/emotional state or communicative intentions of the speaker. Prosodic structure has two partially independent dimensions: the placement of prosodic boundaries (intonational phrasing) determines how the words in an utterance are grouped together into prosodic units, while the placement of pitch accents which indicates the prominence of units within this structure (Wagner & Watson, 2010; Speer & Ito, 2009). Syntactic structure is systematically linked to intonational phrasing but not to pitch prominence (Lee & Watson, 2011) or paralinguistic prosody. In contrast, accent placement provides information about what information in an utterance is new and how the utterance relates to the prior discourse. Thus one interpretation of the existing literature is that the use of intonational phrasing is unimpaired in ASD while the use of pitch accents and paralinguistic prosody is impaired.

Thus a theory which posited that perception and production of pitch accents is specifically impaired in ASD, while the use of intonational phrasing is intact, would correctly predict that children with ASD would perform poorly on tasks involving contrastive stress but well on tasks in which prosodic boundaries provide syntactic information. This hypothesis is also consistent with the naturalistic production studies which suggest that prosody in autism is characterized by the use of repetitive and simple pitch contours which are produced with more extreme pitch variation (Diehl et al., 2009; Edelson et al., 2007; Green & Tobin, 2009; Nadig & Shaw, 2011). However, these three phenomena are also compatible with the pragmatic hypothesis, since the placement of pitch accents in English largely depends on the pragmatic function of the utterance.

This proposal, however, does make some unique predictions. First, if we assume that lexical stress depends on the same perceptual and prosodic features as the detection of pitch accents, then there should deficits in the use of stress for lexical disambiguation. As we noted earlier, the empirical picture here is murky. Second, if there were pragmatic inferences that depended primarily on the placement of prosodic boundaries, they should not be impaired. However, to the best of our knowledge, there are no inferences of this type. Finally, unlike the pragmatic hypothesis it suggests that pragmatic inferences that depend on paralinguistic prosody (e.g., judgments of emotion, anxiety, and intended audience) may show different patterns of impairment across population and tasks than those that depend on pitch prominence. This could explain why the findings on emotion tasks are more variable (see above).

Much of the appeal of this hypothesis comes from its potential to connect the deficits in these linguistic tasks to deficits in perception. For instance, if pitch prominence was primarily signaled by one acoustic parameter (e.g., fundamental frequency) and boundary strength was conveyed by a different parameter (e.g., duration or pausing), then a specific deficit in processing pitch accents could arise from atypical sensory processes. This hypothesis would be broadly consistent with the literature on auditory perception which suggests that atypical processing of frequency is more common than atypical processing of duration and intensity (Jones et al., 2009; O'Connor, 2012; Marco et al., 2011). However, the mapping between acoustic variables and prosodic structure is more complex than this account would suggest. Both pitch accents and boundary locations are associated with an increase in duration and a change in fundamental frequency (see Wagner & Watson, 2010 for review). In fact, in English, pitch accents are more reliably associated with intensity than with either the mean or maximum fundamental frequency (Breen, Federenko, Wagner & Gibson, 2010; Kochanski, Grabe, Coleman, and Rosner, 2005). But critically, a listeners' interpretation of a pitch accent appears to depend on the shape of the fundamental frequency curve (Issacs & Watson, 2010; Chen, den Os & de Ruiter, 2007) suggesting that frequency may play a privileged role in pitch accent perception.

C. True prosodic deficits in ASD occur but only in persons who also have language delays. Those without language delays perform poorly on prosody tasks only when the task requires pragmatic skills or makes heavy demands on executive functions.

Three lines of reasoning suggest that the nature of the prosodic deficit in autism might vary with a person's overall level of linguistic functioning. First, because prosody plays a central role in language acquisition and comprehension, it seems unlikely that a child with a broad prosodic deficit would acquire language on the typical developmental timetable. For example, both infants and adults use prosody during speech perception to figure out where where words begin and end (lexical segmentation, see Cutler et al., 1997; Johnson & Jusczyk. 2001). Consequently, someone who was prosodically insensitive would be expected to have delays in vocabulary acquisition (because they have difficulty learning word forms) and spoken language comprehension (because lexical access would be slower). Likewise, to the degree that prosody is implicated in syntactic parsing and the acquisition of syntax (Christophe et al., 2008, Morgan, 1996), then we should expect that prosodic deficits in infancy will result in syntactic deficits in childhood.

Second, there is some experimental evidence that the scope of prosodic deficits in ASD varies depending on whether the participants have a history of language delays. Specifically, Peppé and colleagues (2011) compared children with high-functioning autism who had a history of preschool language delay (HFA) with children who did not (AS for Asperger's syndrome). They found that the HFA group performed worse than language-matched controls on most of their measures of expressive prosody, while the AS group performed similarly to controls on every measure but one (imitation). The possibility that prosodic deficits are linked to language delay, and not just language age, is also consistent with the broader literature. Studies in which the ASD sample has language abilities at or above age level often find that performance on prosodic comprehension tasks is similar language-matched controls (Chevalier et al., 2009; Chevalier et al., 2011; Grossman et al., 2010; Paul et al., 2005; but see Diehl et al., 2008), while studies in which the participants have mild to moderate language delays often do not (Peppé et al., 2007; Järvinen-Pasley et al., 2008a). The two prosodic deficits that are well established in highly-verbal ASD are arguably linked to pragmatics: 1) atypical prosodic production, which could reflect difficulty in using phrase accents to mark discourse structure (Paul et al., 2005; Nadig & Shaw, 2011, and 2) the comprehension of prosodic cues to complex emotional states (Jones et al., 209; Golan et al., 2007).

Finally, atypical acoustic perception is present in only a subset of persons with ASD. For example, Russo (2008) found that only 20% of her ASD sample had an abnormal brainstem response to pitch.. Similarly, only a small subgroup of persons with ASD show superior frequency discrimination and this group appears to be characterized by language delays in childhood (Bonnel et al., 2010) and a combination of low language scores and relatively high performance IQ in adulthood (Jones et al., 2011). Thus it is possible that ASD with language delay is characterized by broad prosodic deficits, while the prosodic deficits in persons without language delays are manifestations of a pragmatic deficit.

Limitations and Clinical Implications

The present study has several limitations which should be considered in assessing its clinical relevance. First, we focused solely on children with strong basic language skills, thus the results may not generalize to the broader population of children with ASD. However, as we noted above, an increasing proportion of children with the ASD diagnoses have language abilities within the normal range. This population may be of particular relevance to those working with ASD children in mainstream educational settings. Second, we did not test children under eight years and thus we cannot assess whether the early development of prosodic parsing in ASD deviates from that of TD children. Finally, we tested only one of the possible manipulations of prosody, and thus we cannot know whether other aspects of the syntax-prosody interface develop more slowly in ASD, perhaps because they are more subtle or complex. This reflects our limited knowledge of prosody and parsing in typical children.

Nevertheless, this study is of relevance to clinicians, keeping these limitations in mind. The strong performance of the children in the first block, in concert with the prior literature, suggests that the use of prosody for parsing is not an area of particular vulnerability in autism. Consequently, it should be a target of intervention only when there is clear evidence that a child has a deficit in this area. More generally, clinicians should be aware that prosodic abilities do not appear to be unitary and some children may have prosodic deficits that are primarily linked to the pragmatic or social functions of prosody.

The perseveratory errors in the child ASD group demonstrate how executive function impairments can impact language comprehension. This finding suggests that interventions that address flexibility and set switching, particularly in the context of language interpretation, may be effective in improving language processing, as well as other aspects of cognitive and social function. Activities such as matching sentences of different form with the same meaning (*He ate breakfast before he brushed his teeth*; *He brushed his teeth after he ate breakfast*), using word cards to create different sentences made up of the same words by rearranging their order (*The boy chases the dog*; *The dog chases the boy*), and generating paraphrases for sentences may help to establish greater adaptability in language processing. Providing guided practice in set shifting specifically around prosodic cues, such as placing pauses at different junctures in sentences and demonstrating and discussing changes in interpretation may be helpful not only in advancing interpretation of prosodic information but in enhancing flexibility overall. These activities might be combined with non-linguistic contexts for set-shifting, such as categorization.

Finally, the disappearance of these errors in the adolescents is a critical reminder that ASD is a developmental disorder, and we should expect and promote continued progress through adolescence and beyond.

Acknowledgements

We would like to thank the children and families who made this work possible. We are grateful to Heidi Miller, the Sonya Ansari Center for Autism at Logan, Lauren Berkovits, Daria Diakonova, Amanda Worek, Debra Loprete, and Karen Tang for their contributions to this project, which included participant recruitment, data collection, and data management. This paper was supported in part by the NIDCD Grant # K24 HD045576 awarded to Rhea Paul, NICHD Grant # P01-HD03008 (Project 3).

	ASD-Child M (SD) [range]	*TD-Child M (SD) [range]*	*F*	*p*	*ASD-Teen M (SD) [range]*	*TD-Teen M (SD) [range]*	*F*	*p*
N	24	24			24	24		
Gender (M:F)	21:3	19:5			19:5	20:4		
Chron. Age	10.0 (1.1) [7-12]	10.3 (1.6) [7-12]	.75	.39	15.3 (1.4) [12-17]	15.1 (1.5) [12-17]	.21	.65
Full Scale IQ	113.3 (16.5) [88-148]	113.8 (13.6) [88-136]	.02	.90	111.3 (13.7) [83-141]	110.0 (11.7) [91-135]	.13	.72
Verbal IQ	113.7 (16.5) [85-151]	113.5 (13.6) [89-136]	.01	.98	112.8 (16.4) [85-143]	109.9 (12.0) [82-135]	.47	.50
CELF-IV Receptive Language	104.5 (18.0) [81-140]	107.5 (13.1) [85-128]	.42	.52	105.5 (12.2) [82-125]	108.3 (11.0) [88-130]	.67	.41

Table 1. Descriptive characteristics of the sample by diagnostic group. Participants younger than 12.5 were included in the child groups, and those above 12.5 were included in the teen groups. IQ was measured using either the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999) or the Differential Ability Scales (Elliott, 1990). CELF-IV=Clinical Evaluation of Language Fundamentals, 4th edition (Semel et al., 2003). ASD = autism spectrum disorder. TD = typically developing comparison group.

	Block 1	Block 2
Prosody	F_1(1,88)= 95.89, p <.001**, η_p^2= .50 F_2(1,7)= 96.83, p <.001**, η_p^2= .93	F_1 (1,88)=33.75, p <.001**, η_p^2=.23 F_2(1,7)= 50.27, p <.001**, η_p^2= .88
Age (Child or Teen)	F_1 (1,88)<1, p>.7, η_p^2<.005 F_2 (1,7)<1, p>.9, η_p^2<.005	F_1 (1,88)<1, p>.5, η_p^2<.005 F_2 (1,7)<1, p>.6, η_p^2<.05
Diagnosis (ASD or TD)	F_1 (1,88)<1, p>.5, η_p^2<.005 F_2 (1,7)<1, p>.7, η_p^2<.05	F_1 (1,88)<1, p>.8 η_p^2<.001 F_2 (1,7)<1, p>.8, η_p^2<.005
Prosody * Age	F_1 (1,88)<1, p>.2, η_p^2<.05 F_2 (1,7)=1.50, p>.2, η_p^2=.18	F_1 (1,88)= 3.17, p=.07, η_p^2<.05 F_2 (1,7)=3.41, p=.11, η_p^2=.33
Prosody * Diagnosis	F_1 (1,88)<1, p>.8, η_p^2<.001 F_2 (1,7)<1, p>.5, η_p^2=.05	F_1 (1,88)= 3.68, p=.06, η_p^2<.05 F_2 (1,7)=3.63, p=.10, η_p^2=.34
Age * Diagnosis	F_1 (1,88)= .13, p>.7, η_p^2<.005 F_2 (1,7)<1, p>.7, η_p^2<.05	F_1 (1,88)<1, p>.5, η_p^2<.005 F_2 (1,7)=1.59, p>.2, η_p^2=.19
Prosody * Diagnosis * Age	F_1 (1,88)<1, p>.4, η_p^2<.01 F_2 (1,7)=1.21, p>.3, η_p^2=.15	F_1 (1,88)= 3.09, p=.08 η_p^2<.05 F_2 (1,7)=5.99, p = .044*, η_p^2=.46

Table 2. Analysis of actions on objects carried out by participants by block of presentation. The dependent variable is the proportion of instrument actions. ASD=autism spectrum disorder. TD=typically developing comparison group.

	With-window	Early-PP window	Late-PP window
Prosody	$F_1(1,87)<1, p>.5\ \eta_p^2<.005$	$F_1\ (1,87)=35.5, p<.001^{**}, \eta_p^2=.29$	$F_1\ (1,86)=68.5, p<.001^{**}, \eta_p^2=.44$
	$F_2(1,56)<1, p>.4, \eta_p^2<.05$	$F_2\ (1,56)=67.0, p<.001^{*}, \eta_p^2=.55$	$F_2\ (1,56)=61.7, p<.001^{*}, \eta_p^2=.52$
Age (Child or Teen)	$F_1\ (1,87)<1, p>.4, \eta_p^2<.01$	$F_1\ (1,87)=3.2, p=.078, \eta_p^2<.05$	$F_1\ (1,86)=1.7, p>.2, \eta_p^2<.05$
	$F_2\ (1,56)<1, p>.4, \eta_p^2<.05$	$F_2\ (1,56)<1=5.2, p<.05^{*}, \eta_p^2=.09$	$F_2\ (1,56)=2.2, p>.1, \eta_p^2<.05$
Diagnosis (ASD or TD)	$F_1\ (1,87)<1, p>.4, \eta_p^2<.01$	$F_1\ (1,87)<1, p>.8, \eta_p^2<.005$	$F_1\ (1,86)<1, p>.8, \eta_p^2<.005$
	$F_2\ (1,56)<1, p>.6, \eta_p^2<.005$	$F_2\ (1,56)<1, p>.9, \eta_p^2<.001$	$F_2\ (1,56)<1, p>.3, \eta_p^2<.05$
Prosody * Age	$F_1(1,87)<1, p>.5, \eta_p^2<.005$	$F_1\ (1,87)=2.5, p>.1, \eta_p^2<.05$	$F_1\ (1,86)<1, p>.9, \eta_p^2<.001$
	$F_2\ (1,56)<1, p>.4, \eta_p^2<.01$	$F_2\ (1,56)=4.6, p<.04^{*}, \eta_p^2=.08$	$F_2\ (1,56)<1, p>.8, \eta_p^2<.001$
Prosody * Diagnosis	$F_1\ (1,87)=3.8, p=.054, \eta_p^2<.05$	$F_1\ (1,87)=1.3, p>.2, \eta_p^2<.05$	$F_1\ (1,86)=2.7, p>.1, \eta_p^2<.05$
	$F_2\ (1,56)=4.8, p<.04^{*}, \eta_p^2=.08$	$F_2\ (1,56)=1.6, p>.2, \eta_p^2<.05$	$F_2\ (1,56)=1.37, p>.2, \eta_p^2<.05$
Age * Diagnosis	$F_1\ (1,87)<1, p>.3, \eta_p^2<.05$	$F_1\ (1,87)<1, p>.9, \eta_p^2<.001$	$F_1\ (1,86)<1, p>.3, \eta_p^2<.05$
	$F_2\ (1,56)=1.02, p>.3\ \eta_p^2<.05$	$F_2\ (1,56)<1, p>.8, \eta_p^2<.001$	$F_2\ (1,56)<1, p>.5, \eta_p^2<.01$
Prosody * Diagnosis * Age	$F_1\ (1,87)>1, p>.6, \eta_p^2<.005$	$F_1\ (1,87)<1, p>.6, \eta_p^2<.005$	$F_1\ (1,86)<1, p>.3, \eta_p^2<.01$
	$F_2\ (1,56)<1, p>.6, \eta_p^2<.005$	$F_2\ (1,56)<1, p>.4, \eta_p^2<.01$	$F_2\ (1,56)<1, p>.4, \eta_p^2<.05$

Table 3. Temporal analyses of gaze fixations for Block 1. The dependent variable is the proportion of looking time to the target instrument. ASD=autism spectrum disorder. TD=typically developing comparison group. PP=prepositional phrase.

	With-window	Early-PP window	Late-PP window
Prosody	F_1 (1,87)>1, p>.3, η_p^2<.05	F_1 (1,87)=15.3, p<.001**, η_p^2=.15	F_1 (1,81)=20.3, p<.001**, η_p^2=.2
	F_2 (1,56)=1.0, p>.3, η_p^2<.05	F_2 (1,56)=19.6, p<.001*, η_p^2=.26	F_2 (1,56)=27.9, p<.001*, η_p^2=.33
Age (Child or Teen)	F_1 (1,87)>1, p>.3, η_p^2<.05	F_1 (1,87)=5.73, p<.02*, η_p^2=.062	F_1 (1,81)<1, p>.7, η_p^2<.005
	F_2 (1,56)<1, p>.4, η_p^2<.05	F_2 (1,56)=8.71, p<.01* η_p^2=.14	F_2 (1,56)<1, p>.9, η_p^2<.001
Diagnosis (ASD or TD)	F_1 (1,87)>1, p>.7, η_p^2<.05	F_1 (1,87)<1, p>.5, η_p^2<.005	F_1 (1,81)<1, p>.3, η_p^2<.05
	F_2 (1,56)<1, p>.7, η_p^2<.005	F_2 (1,56)<1, p>.6, η_p^2<.005	F_2 (1,56)<1, p>.4, η_p^2<.05
Prosody * Age	F_1 (1,87)=10.4, p<.005*, η_p^2=.11	F_1 (1,87)=8.6, p<.005* η_p^2=.09	F_1 (1,81)=2.5, p>.1, η_p^2<.05
	F_2 (1,56)=8.4, p<.01*, η_p^2=.13	F_2 (1,56)=13.0, p<.005*, η_p^2=.19	F_2 (1,56)<1, p>.4, η_p^2<.05
Prosody * Diagnosis	F_1 (1,87)>1, p>.6, η_p^2<.005	F_1 (1,87)=1.5, p>.2, η_p^2<.05	F_1 (1,81)<1, p>.7, η_p^2<.05
	F_2 (1,56)<1, p>.7 η_p^2<.005	F_2 (1,56)=1.6, p>.2, η_p^2<.05	F_2 (1,56)<1, p>.8, η_p^2<.005
Age * Diagnosis	F_1 (1,87)>1, p>.5, η_p^2<.005	F_1 (1,87)<1, p>.6, η_p^2<.005	F_1 (1,81)<1, p>.5, η_p^2<.005
	F_2 (1,56)<1, p>.7, η_p^2<.005	F_2 (1,56)<1, p>.8, η_p^2<.005	F_2 (1,56)<1, p>.5, η_p^2<.01
Prosody * Diagnosis * Age	F_1 (1,87)>1, p>.5, η_p^2<.01	F_1 (1,87)<1, p>.5, η_p^2<.005	F_1 (1,81)<1, p>.7, η_p^2<.005
	F_2 (1,56)<1, p>.5, η_p^2<.05	F_2 (1,56)<1, p>.7, η_p^2<.005	F_2 (1,56)<1, p>.7, η_p^2<.005

Table 4. Temporal analysis of fixations for Block 2. The dependent variable is the proportion of looking time to the target instrument. ASD=autism spectrum disorder. TD=typically developing comparison group. PP=prepositional phrase.

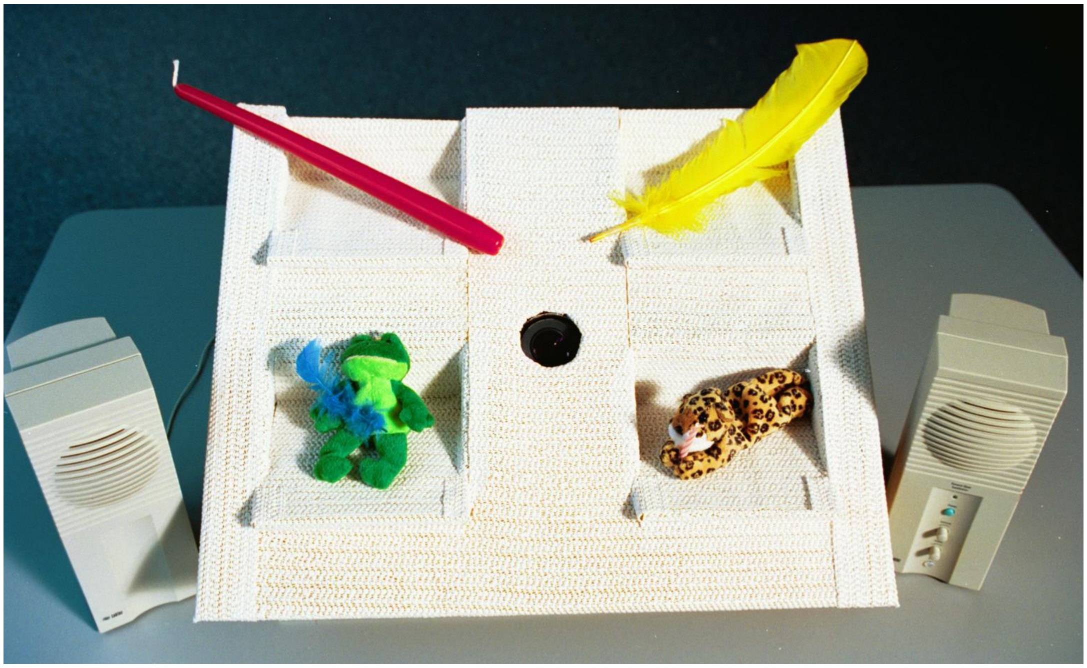

Figure 1. Sample trial in experimental setup. The setup would be accompanied by the utterance "You can feel the frog with the feather." The feather represents the target instrument, the frog (holding a feather) is the target animal, the feather that the frog is holding is the mini-instrument, and the candle and the leopard (holding a candle) are the distracter instrument and the distracter animal, respectively.

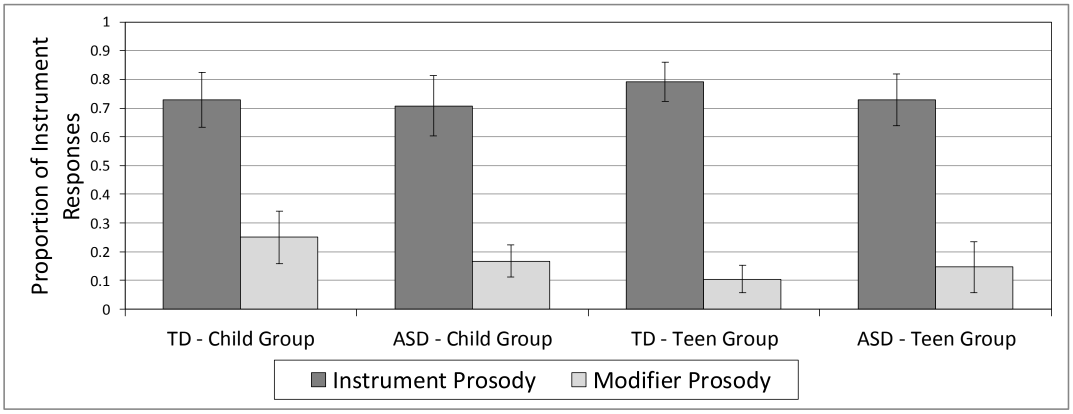

Figure 2. Actions in Block 1. The proportion of instrument responses in Block 1, by group. We would expect that instrument prosody would elicit a large number of instrument responses, whereas the modifier prosody would elicit few instrument responses. ASD=autism spectrum disorder. TD=typically developing comparison group.

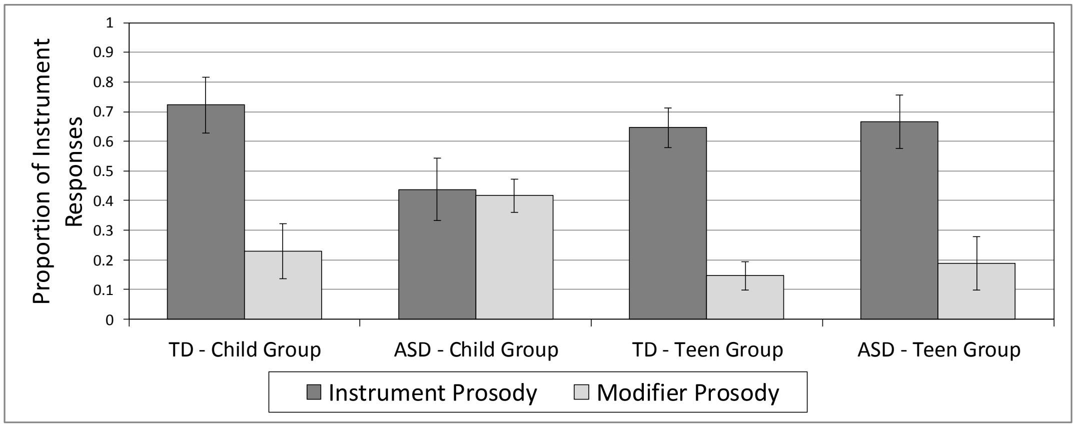

Figure 3. Actions in Block 2. The proportion of instrument responses in Block 2, by group. We would expect that instrument prosody would elicit a large number of instrument responses, whereas the modifier prosody would elicit few instrument responses. ASD=autism spectrum disorder. TD=typically developing comparison group.

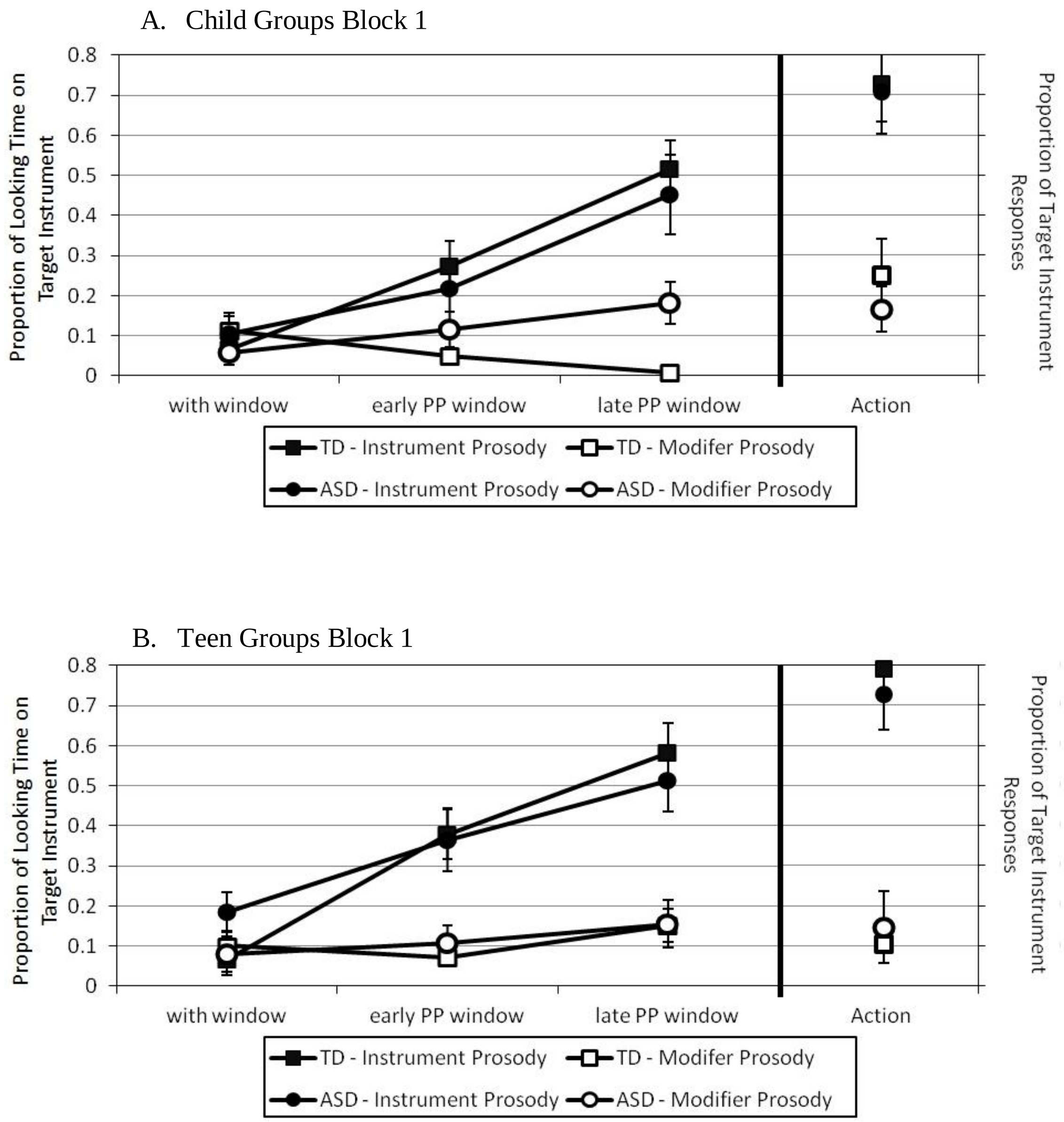

Figure 4. Target instrument looking time relative to the ambiguous prepositional phrase in Block 1. (a) represents the responses of the child groups (8-12.5 yrs), and (b) represents the responses of the teen groups (12.5-17 yrs). Action responses are included in the right window for comparison. ASD=autism spectrum disorder. TD=typically developing comparison group. PP=prepositional phrase.

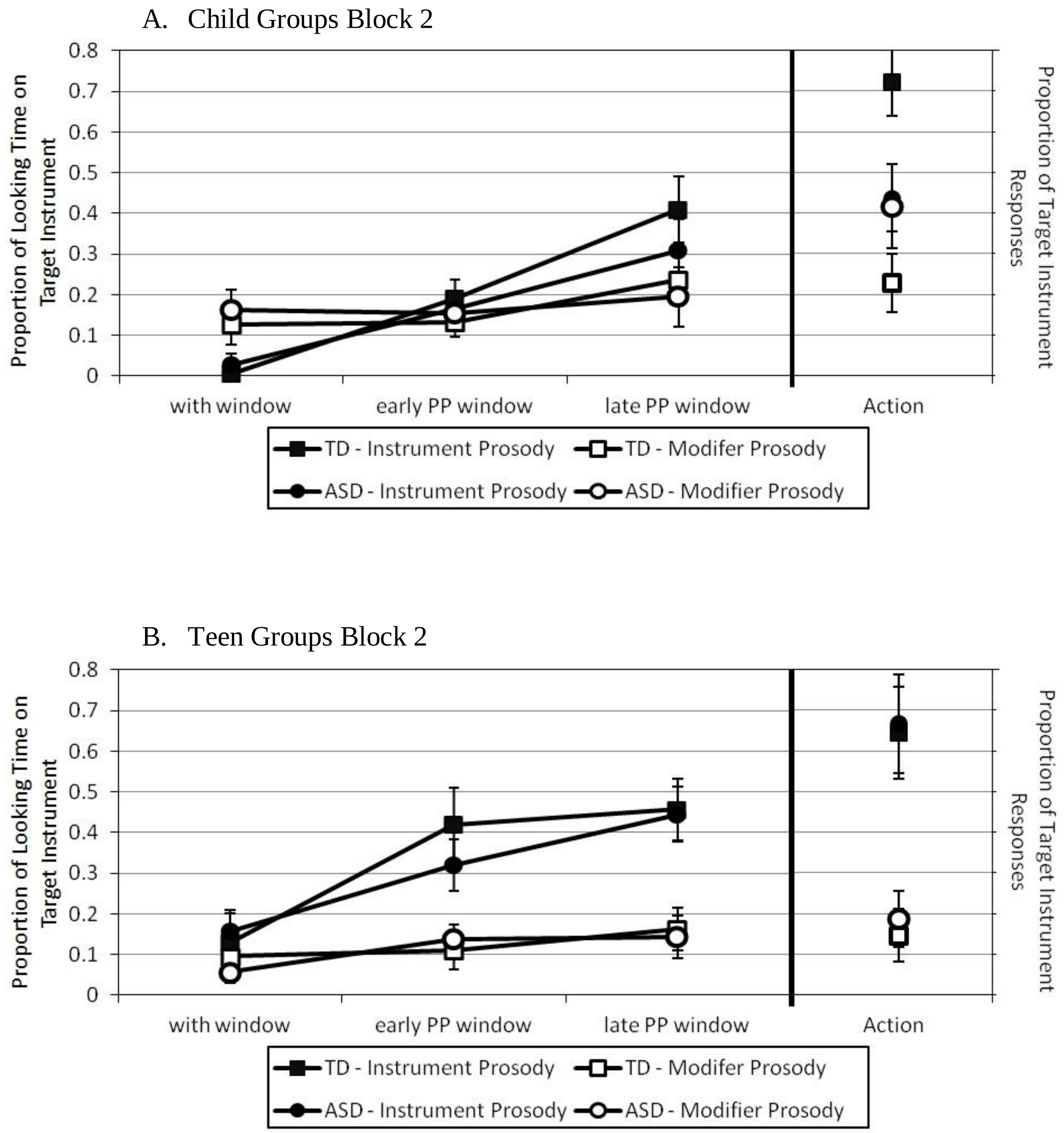

Figure 5. Target instrument looking time relative to the ambiguous prepositional phrase in Block 2. (a) represents the performance of the child groups (8-12.5 yrs), and (b) represents the performance of the teen groups (12.5-17 yrs). Action responses are included in the right panel for comparison. ASD=autism spectrum disorder. TD=typically developing comparison group. PP=prepositional phrase.

References

Adams, C., Green, J., Gilchrist, A., & Cox, A. (2002). Conversational behaviour of children with Asperger syndrome and conduct disorder. *Journal of Child Psychology and Psychiatry, 43,* 679–690.

Allopena, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language, 38,* 419-439. doi:doi:10.1006/jmla.1997.2558

Ambery, F., Russell, A., Perry, K., Morris, R., & Murphy, D. (2006). Neuropsychological functioning in adults with Asperger syndrome. *Autism, 10,* 551–564.

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders, text revision* (4th ed.). Washington, D.C.: American Psychiatric Association.

Amoroso, H. (1992). Disorders of vocal signaling in children. In H. Papousek, U. Jurgens, & M. Papousek (Ed.), *Nonverbal vocal communication: Comparative and developmental approaches* (pp. 192-204). Cambridge: Cambridge University Press.

Baltaxe, C. A. M. (1984). Use of contrastive stress in normal, aphasic, and autistic children. *Journal of Speech and Hearing Research, 27*(1), 97-105.

Baltaxe, C, & Guthrie, D. (1987). The use of primary sentence stress by normal, aphasic, and autistic children. *Journal of Autism and Developmental Disorders. 1987*, 255–271.

Beach, C., Katz, W., & Skowronski, A. (1996). Children's processing of prosodic cues for phrasal interpretation. *Journal of the Acoustical Society of America, 99,* 1148-1160.

Beckman, M. E. (1996). The parsing of prosody. *Language and Cognitive Processes, 11,* 17-67.

Bonnel, A., McAdams, S., Smith, B., Berthiaume, C., Bertone, A., Ciocca, V., Burack, J.A., & Mottron, L. (2010) Enhanced pure-tone pitch discrimination among persons with autism but not Asperger syndrome. *Neuropsychologia, 48,* 2465–2475.

Bonnel, A., Mottron, L., Peretz, I., Trudel, M., Gallun, E., & Bonnel, A. (2003). Enhanced pitch sensitivity in individuals with autism: A signal detection analysis. *Journal of Cognitive Neuroscience, 15*(2), 226-235. doi:10.1162/089892903321208169

Breen, M., Fedorenko, E., Wagner, M., & Gibson, E. (2010). Acoustic correlates of information structure. *Language and Cognitive Processes, 25,* 1044-1098.

Brock, J., Norbury, C.F., Einav, S., & Nation, K. (2008). Do individuals with autism process words in context? Evidence from language-mediated eye-movements. *Cognition, 108,* 896-904.

Bryson, S. E., Clark, B. S., & Smith, T. M. (1988). First report of a Canadian epidemiological study of autistic syndromes. *Journal of Child Psychology and Psychiatry, 29,* 433–445.

Ceponiene, R., Lepisto, T., Shestakova, A., Vanhala, R., Alku, P., Näätänen, R., & Yaguchi, K. (2003). Speech-sound-selective auditory impairment in children with autism: they can perceive but do not attend. *Proceedings of the National Academy of Sciences, 100,* 5567–5572.

Chapman, R. (2000). Children's language learning: An interactionist perspective. *Journal of Child Psychology and Psychiatry, 41*, 33-54.

Chen, A., den Os, E., & de Ruiter, J. P. 2007. Pitch accent type matters for online processing of information status: Evidence from natural and synthetic speech. *The Linguistic Review, 24,* 317-344.

Chevallier, C., Noveck, I., Happé, F., & Wilson, D. (2011). What's in a voice? Prosody as a test case for the Theory of Mind account of autism. *Neuropsychologia, 49*(3), 507-517.

Chevallier, C., Noveck, I., Happé, F., & Wilson, D. (2009). From acoustics to grammar: Perceiving and interpreting grammatical prosody in adolescents with asperger syndrome. *Research in Autism Spectrum Disorders, 3*, 502-516. doi:10.1016/j.rasd.2008.10.004

Chevallier, C., Wilson, D., Happé, F. & Noveck, I. (2010) Scalar inferences in Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders, 40*(9), 1104-1117.

Choi, Y., & Mazuka, R. (2003). Young children’s use of prosody in sentence parsing. *Journal of Psycholinguistic Research, 32,* 197–217.

Christophe, A., Millotte, S., Bernal, S. & Lidz, J. (2008). Bootstrapping lexical and syntactic acquisition. *Language and Speech, 51,* 61-75.

Cohen, J. (1973). Eta-squared and partial eta-squared in fixed factor ANOVA designs. *Educational and Psychological Measurement, 33,* 107-112.

Cooper, R. P., & Aslin, R. N. (1994). Developmental differences in infant attention to the spectral properties of infant-directed speech. *Child Development, 65*, 1663-1677. doi:10.1111/j.1467-8624.1994.tb00841.x

Cutler, A. D., Dahan, D., & van Donselaar, W. (1997). Prosody in the comprehension of spoken language: A literature review. *Language and Speech, 40*, 141–201.

DePape, A., Chen, A., Hall, G., & Trainor, L. (2012). Use of prosody and information structure in high functioning adults with Autism in relation to language ability. *Frontiers in Psychology, 3*(72), 1-13.

Diehl, J. J., Bennetto, L., Watson, D., Gunlogson, C., & McDonough, J. (2008). Resolving ambiguity: A psycholinguistic approach to understanding prosody processing in high-functioning autism. *Brain and Language, 106*(2), 144-152. doi:10.1016/j.bandl.2008.04.002

Diehl, J. J., & Berkovits, L. (2010). Is prosody a diagnostic and cognitive bellwether of autism spectrum disorders? In A. Harrison (Ed.), *Speech disorders: Causes, treatments, and social effects* (pp. 159-176). New York: Nova Science Publishers.

Diehl, J. J., & Paul, R. (2009). The assessment of prosodic disorders and neurological theories of prosody. *International Journal of Speech-Language Pathology, 11*, 287-292. doi:10.1080/17549500902971887

Diehl, J. J., & Paul, R. (2011). Acoustic differences in the imitation of prosidic patterns in children with autism spectrum disorders. *Research in Autism Spectrum Disorders, online first* doi:doi:10.1016/j.rasd.2011.03.012.

Diehl, J. J., & Paul, R. (in press). Acoustic and perceptual measurements of prosody production on the PEPS-C by children with autism spectrum disorders. *Applied Psycholinguistics.*

Diehl, J. J., Tang, K., & Thomas, B. (in press). High-functioning autism (HFA). In F. Volkmar (Ed.), *Encyclopedia of autism spectrum disorders*. New York: Springer.

Diehl, J. J., Watson, D. G., Bennetto, L., McDonough, J., & Gunlogson, C. (2009). An acoustic analysis of prosody in high-functioning autism. *Applied Psycholinguistics, 30*(3), 385-404. doi:10.1017/S0142716409090201

Edelson, L., Grossman, R., & Tager-Flusberg, H. (2007). Emotional prosody in children and adolescents with autism. Poster *presentation at the 6th International Meeting for Autism Research*, Seattle, WA.

Erwin, R.., Van Lancker, D., Guthrie, D., Schwafel, J., Tanguay, P., & Buchwald, J. S. (1991). P3 responses to prosodic stimuli in adult autistic subjects. *Electroencephalography and Clinical Neurophysiology, 80,* 561–571.

Elliott, C. D. (1990). *Differential ability scales*. San Diego: Harcourt Brace Jovanovich.

Erwin, R., Van Lancker, D., Guthrie, D., Schwafel, J., Tanguay, P., & Buchwald, J. S. (1991). P3 responses to prosodic stimuli in adult autistic subjects. *Electroencephalogr and Clinical Neurophysiol.*, *80*(6), 561-71.

Fernald, A. (1983). The perceptual and affective salience of mothers' speech to infants. In L. Feagans (Ed.), *The origins and growth of communication.* (pp. 5-29). New Brunswick, N.J.: Ablex Publishing Corporation.

Frith, U., & Snowling, M. (1983). Reading for meaning and reading for sound in autistic and dyslexic children. *Journal of Developmental Psychology, 1,* 329–342.

Gernsbacher, M. A., Dawson, M., & Goldsmith, H. H. (2005). Three reasons not to believe in an autism epidemic. *Current Directions in Psychological Science, 14,* 55-58.

Golan, O., Baron-Cohen, S., Hill, J. J., & Rutherford, M. D. (2007). The Reading the Mind in the Voice Test—Revised: A study of complex emotion recognition in adults with and without autism spectrum conditions. *Journal of Autism and Developmental Disorders, 37,* 1096–1106.

Goldfarb, W., Braunstein, P., & Lorge, I. (1956). A study of speech patterns in a group of schizophrenic children. *American Journal of Orthopsychiatry, 26*, 544-555.

Gomot, M., Bernard, F. A., Davis, M. H., Belmonte, M. K., Ashwin, C., Bullmore, E. T., et al. (2006). Change detection in children with autism: an auditory event-related fMRI study. Neuroimage, 29. 475-84.

Green, H. & Tobin, Y. (2009). Prosodic analysis is difficult – but worth it: A study in High Functioning Autism. *International Journal of Speech-Language Pathology, 11*(4), 308-315.

Grossman, R. B., Bemis, R. H., Plesa Skwerer, D., & Tager-Flusberg, H. (2010). Lexical and affective prosody in children with high-functioning autism. *Journal of Speech, Language, and Hearing Research, 53,* 778-793. doi:10.1044/1092-4388(2009/08-0127)

Hala, S., Pexman, P.M., & Glenwright, M. (2007). Priming the meaning of homographs in typically developing children and children with autism. *Journal of Autism and Developmental Disorders, 37,* 329–340.

Happé, F. (1997). Central coherence and theory of mind in autism: Reading homographs in context. *British Journal of Developmental Psychology, 15,* 1–12.

Hill, E. (2004). Executive Dysfunctions in Autism. *Trends in Cognitive Sciences, 8*(1), 26-32.

Hirsh-Pasek, K., & Golinkoff, R. M. (1996). *The origins of grammar*. Cambridge, MA: MIT Press.

Hobson, R., Ouston, J., & Lee, A. (1988). Emotion recognition in autism: Coordinating faces and voices. *Psychological Medicine, 18*(4), 911–923.

Isaacs, A., & Watson, D. G. (2010). Accent detection is a slippery slope: Direction and rate of F0 change drives listeners' comprehension. *Language and Cognitive Processes, 25,* 1178–1200.

Ito, K. & Speer, S. R. (2008). Anticipatory effect of intonation: Eye movements during instructed visual search. *Journal of Memory and Language, 58,* 541-573.

Järvinen-Pasley, A. M., Peppé, S., King-Smith, G., & Heaton, P. (2008a). The relationship between form and function level receptive prosodic abilities in autism. *Journal of Autism and Developmental Disorders, 38*(7), 1328–1340.

Järvinen-Pasley, A. M., Wallace, G. L., Ramus, F., Happé, F., & Heaton, P. (2008). Enhanced perceptual processing of speech in autism. *Developmental Science, 11,* 109–121.

Johnson, E. K. & Jusczyk, P. W. (2001). Word segmentation by 8-month-olds: When speech cues count more than statistics. *Journal of Memory and Language, 44,* 548-567.

Jolliffe, T.-D., & Baron-Cohen, S. (1999). Linguistic processing in high-functioning adults with autism or Asperger syndrome: Is local coherence impaired? *Cognition, 71,* 149-185.

Jones, C. R., Happé, F., Baird, G., Simonoff, E., Marsden, A. J., Tregay, J. et al. (2009). Auditory discrimination and auditory sensory behaviours in autism spectrum disorders. Neuropsychologia, 47(13), 2850-2858.

Jones, C. R. G., Pickles, A., Falcaro, M., Marsden, A. J. S., Happé, F., Scott, S. K., Sauter, D., Tregay, J., Phillips, R. J., Baird, G., Simonoff, E., & Charman, T. (2011). A Multimodal Approach to Emotion Recognition Ability in Autism Spectrum Disorders. *Journal of Child Psychology and Psychiatry, 52*, 275-285.

Joseph, R. M., Tager-Flusberg, H., & Lord, C. (2002). Cognitive profiles and social-communicative functioning in children with autism spectrum disorder. *Journal of Child Psychology and Psychiatry, 43*, 807–821.

Jusczyk, P. W. (1993). Syntactic units, prosody, and psychological reality during infancy. In J. L. Morgan, & K. Demuth (Eds.), *Signal to syntax: Bootstrapping from speech to grammar in early acquisition.* (). Hillsdale, N.J.: Erlbaum.

Jusczyk, P. W. (2003). The role of speech perception capacities in early language acquisition. In M. B. M. Mack (Ed.), *Language: Multidisciplinary perspectives* (pp. 61-83). Mahwah, N. J.: Lawrence Erlbaum Associates.

Jusczyk, P. W., Houston, D. M., & Newsome, M. (1999). The beginnings of word segmentation in english-learning infants. *Cognitive Psychology, 39*, 159-207. doi:10.1006/cogp.1999.0716

Kanner, L. (1943). Autistic disturbances of affective contact. *The Nervous Child, 2,* 217–250.

Kelley, E., Paul, J., Fein, D., & Naigles, L. (2006). Residual language deficits in children with a history of autism. *Journal of Autism and Developmental Disorders, 36,* 807-828.

Kjelgaard, M. M. & Tager-Flusberg, H. (2001). An investigation of language impairment in autism: Implications for genetic subgroups. *Language and Cognitive Processes, 16(2-3),* 287-308.

Kleinman, J., Marciano, P. L., & Ault, R. L. (2001). Advanced theory of mind in high-functioning adults with autism. *Journal of Autism & Developmental Disorders, 31*(1), 29-36. doi:10.1023/A:1005657512379

Klin, A., Jones, W., Schultz, R., & Volkmar, F. (2003). The enactive mind, or from actions to cognition: lessons from autism. *Philosophical Transactions of the Royal Society B: Biological Science, 358,* 345–360.

Kochanski, G., Grabe, E., Coleman, J., & Rosner, B. (2005). Loudness predicts prominence: Fundamental frequency lends little. *The Journal of the Acoustical Society of America, 118,* 1038-1054 .

Korpilahti, P., Jansson-Verkasalo, E., Mattila, M.-L., Kuusikko, S., Suominen, K., Rytky, S., et al. (2007). Processing of affective speech prosody is impaired in Asperger syndrome. *Journal of Autism and Developmental Disorders, 37,* 1539–1549.

Kujala, T., Lepistö, T., Nieminen-von Wendt, T., Näätänen, P., & Näätänen, R. (2005). Neurophysiological evidence for cortical discrimination impairment of prosody in Asperger syndrome. *Neuroscience Letters, 383,* 260–265.

Kujala, T., Aho, E., Lepistö, T., Jansson-Verkasalo, E., Nieminen-von Wendt, T., von Wendt, L., & Näätänen, R. (2007). Atypical pattern of discriminating sound features in adults with Asperger syndrome as reflected by the mismatch negativity. *Biological Psychology, 75,* 109-114.

Kujala, T., Kuuluvainen, S., Saalasti, S., Jansson-Verkasalo, E., von Wendt, L. & Lepistö, T. (2010). Speech-feature discrimination in children with Asperger syndrome as determined with the multi-feature mismatch negativity paradigm. *Clinical Neurophysiology, 121*, 1410-1419.

Landa, R. (2000). Social language use in Asperger syndrome and high-functioning autism. In A. Klin, F. Volkmar, & S. Sparrow (Eds.), *Asperger syndrome* (pp. 125–155). New York: Guilford Press.

Lee, E.-K.. & Watson, D. G. (2011). Effects of pitch accents in attachment ambiguity resolution. *Language and Cognitive Processes, 26,* 262-297.

Lepistö, T., Nieminen-von Wendt, T., von Wendt, L., Näätänen, R., & Kujala, T. (2007). Auditory cortical change detection in adults with Asperger syndrome. *Neuroscience Letters, 414*(2), 136-40.

Lepistö, T., Silokallio, S., Nieminen-von Wendt, T. Alku, P., Näätänen, R., & Kujala, T. (2006). Auditory perception and attention as reflected by the brain event-related potentials in children with Asperger syndrome. *Clinical Neurophysiology, 117,* 2161-2171.

Lopez, B., & Leekam, S. R. (2003). Do children with autism fail to process information in context? *Journal of Child Psychology & Psychiatry, 44*, 285–300.

Lord, C., & Paul, R. (1997). Language and communication in autism. In D. Cohen & F. Volkmar (Eds.), *Handbook of autism and pervasive developmental disorders* (pp. 195-225). New York: Wiley.

Lord, C., Risi, S., & Pickles, A. (2004). Trajectory of language development in autism spectrum disorders. In M. L. Rice, & S. F. Warren (Eds.), *Developmental language disorders* (pp. 7-30). Mahwah, N.J.: Lawrence Erlbaum Associates.

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview -- Revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism & Developmental Disorder, 24*(5), 659–685.

Luna, B., Doll, S. K., Hegedus, S. J., Minshew, N. J., Sweeney, J. A. (2007). Maturation of executive function in autism. *Biological Psychiatry, 61*(4), 474–481.

Marco, E. J., Hinkley, L. B., Hill, S. S. & Nagarajan, S. S. (2011). Sensory processing in autism: A review of neurophysiologic findings. *Pediatric Research, 69,* 48R–54R.

Mazuka, R., Jincho, N., & Oishi, H. (2009). Development of executive control and language processing. *Language and Linguistic Compass, 3*(1), 59-89.

McCaleb, P., & Prizant, B. (1985). Encoding of new versus old information by autistic children. *Journal of Speech and Hearing Disorders, 50,* 226–230.

McCann, J., & Peppé, S. (2003). Prosody in autism spectrum disorders: A critical review. *International Journal of Language & Communication Disorders, 38*(4), 325-350. doi:10.1080/1368282031000154204

McCann, J., Peppé, S., Gibbon, F. E., O'Hare, A., & Rutherford, M. (2007). Prosody and its relationship to language in school-aged children with high-functioning autism. International Journal of Language and Communication Disorders, 42, 682–702.

Mehler, J., Jusczyk, P. W., Lambertz, G., Halsted, N., Bertoncini, J., & Amiel-Tison, C. (1988). A precursor of language acquisition in young infants. *Cognition, 29*, 143-178.

Moon, C., Cooper, R. P., & Fifer, W. P. (1993). Two-day olds prefer their native language. *Infant Behavior and Development, 16*, 495-500. doi:10.1016/0163-6383(93)80007-U

Morgan, J. L. (1996). Prosody and the roots of parsing. In P. Warren (Ed.), *Prosody and parsing.* (pp. 69-106). United Kingdom: Psychology Press.

Nadig, A., & Shaw, H. (2011). Acoustic and perceptual measurement of expressive prosody in high-functioning autism: Increased pitch range and what it means to listeners. *Journal of Autism and Developmental Disorders, online first* doi:10.1007/s10803-011-1264-3

Novick, J. M., Trueswell, J. C., & Thompson-Schill, S. L. (2005). Cognitive control and parsing: Re-examining the role of Broca's area in sentence comprehension. *Journal of Cognitive, Affective, and Behavioral Neuroscience, 5*(3), 263-281.

O'Connor, K. (2012). Auditory processing in autism spectrum disorder: A review. *Neuroscience and Biobehavioral Reviews, 36*(2), 836-854.

O'Hearn, K., Asato, M., Ordaz, S., & Luna, B. (2008). Neurodevelopment and executive function in autism. *Developmental Psychopathology, 20*(4), 1103-32.

Oller, D. K., Niyogi, P., Gray, S., Richards, J. A., Gilkerson, J., Xu, D., . . . Warren, S. F. (2010). Automated vocal analysis of naturalistic recordings from children with autism, language delay, and typical development. *Proceedings of the National Academies for the Sciences, 107*(30), 13354-13359. doi:10.1073/pnas.1003882107

Ozonoff, S., Cook, I., Coon, H., Dawson, G., Joseph, R. M., Klin, A., . . . Wrathall, D. (2004). Performance on Cambridge neuropsychological test automated battery subtests sensitive to frontal lobe function in people with autistic disorder: Evidence from the collaborative programs of excellence in autism network. *Journal of Autism & Developmental Disorders, 34*(2), 139-150.

Ozonoff, S., Goodlin-Jones, B. L., & Solomon, M. (2005). Evidence-based assessment of autism spectrum disorders in children and adolescents. *Journal of Clinical Child and Adolescent Psychology, 34*(3), 523-540.

Ozonoff, S., & Jensen, J. (1999). Brief report: Specific executive function profiles in three neurodevelopmental disorders. *Journal of Autism & Developmental Disorders, 29*(2), 171-177.

Ozonoff, S., Pennington, B., & Rogers, S. (1991). Executive function deficits in high-functioning autistic individuals: Relationship to theory of mind. *Journal of Child Psychology and Psychiatry, 32,* 1081–1105.

Paul, R., Augustyn, A., Klin, A., & Volkmar, F. (2005). Perception and production of prosody by speakers with autism spectrum disorders. *Journal of Autism & Developmental Disorders, 35*(2), 205-220. doi:10.1007/s10803-004-1999-1

Paul, R., Fuerst, Y., Ramsay, G., Chawarska, K., & Klin, A. (2011). Out of the mouths of babes: Vocal production in infant siblings of children with ASD. *Journal of Child Psychology and Psychiatry, 52*(5), 588-598. doi:10.1111/j.1469-7610.2010.02332.x

Paul R., Orlovski S., Marchinko H., & Volkmar F. (2009). Conversational behaviors in youth with high-functioning autism and Asperger syndrome. *Journal of Autism and Developmental Disorders, 39,* 115–125. doi: 10.1007/s10803-009-0739-y.

Paul, R., Shriberg, L. D., McSweeny, J., Cicchetti, D., Klin, A., & Volkmar, F. (2005). Brief report: Relations between prosodic performance and communication and socialization ratings in high functioning speakers with autism spectrum disorders. *Journal of Autism & Developmental Disorders, 35*(6), 861-869. doi:10.1007/s10803-005-0031-8

Pennington, B. F. & Ozonoff, S.J. (1996). Annual Research Review: Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 37*(1), 51–87.

Peppé, S. (2009). Why is prosody in speech-language pathology so difficult? *International Journal of Speech-Language Pathology, 11*(4), 258-271. doi:10.1080/17549500902906339

Peppé, S. J. E., Cleland, J., Gibbon, F. E., O'Hare, A. E., & Martínez-Castilla, P. (2011). Expressive prosody in children with autism spectrum conditions. *Journal of Neurolinguistics, 24,* 41–53.

Peppé, S., McCann, J., Gibbon, F., O'Hare, A., & Rutherford, M. (2007). Receptive and expressive prosodic ability in children with high-functioning autism. *Journal of Speech, Language & Hearing Research, 50*(4), 1015-1028. doi:10.1044/1092-4388(2007/071)

Peppé, S., McCann, J., Gibbon, F., O'Hare, A., & Rutherford, M. (2006). Assessing prosodic and pragmatic ability in children with high-functioning autism. *Journal of Pragmatics, 38*(10), 1776-1791. doi:10.1016/j.pragma.2005.07.004

Pijnacker, J., Geurts, B., Van Lambalgen, M., Kan, C. C., Buitelaar, J. K., & Hagoort, P. (2009). Defeasible reasoning in high-functioning adults with autism: Evidence for impaired exception-handling. *Neuropsychologia, 47,* 644-651.

Provonost, W., Wakstein, M., & Wakstein, D. (1966). A longitudinal study of speech behaviors and language comprehension in fourteen children diagnosed as atypical or autistic. *Exceptional Children, 33,* 19-26.

Russo, N., Flanagan, T., Iarocci, G., Berringer, D., Zelazo, P.D., & Burack, J.A. (2007). Deconstructing executive deficits among persons with autism: Implications for cognitive neuroscience. *Brain and Cognition, 65*, 77-86.

Russo, N. M., Skoe, E., Trommer, B., Nicol, T., Zecker, S., Bradlow, A., et al. (2008). Deficient brainstem encoding of pitch in children with autism spectrum disorders. *Clinical Neurophysiology, 119,* 1720-31.

Rutherford, M. D., Baron-Cohen, S., & Wheelwright, S. (2002). Reading the mind in the voice: A study with normal adults and adults with asperger syndrome and high functioning autism. *Journal of Autism & Developmental Disorders, 32*(3), 189-194. doi:10.1023/A:1015497629971

Rutter, M., Bailey, A., Berument, S. K., Lord, C., & Pickles, A. (2003). *Social communication questionnaire (SCQ)*. Los Angeles: Western Psychological Services.

Rutter, M., Le Couteur, A., & Lord, C. (2003). *Autism diagnostic interview-revised*. Los Angeles: Western Psychological Services.

Schoen, E., Paul, R., & Chawarska, K. (2011). Phonology and vocal behavior in toddlers with autism spectrum disorders. *Autism Research, online first* doi:10.1002/aur.183

Selkirk, E. O. (1986) On derived domains in sentence phonology. *Phonology, 3,* 371-405.

Semel, E., Wiig, E. H., & Secord, W. A. (2003). *Clinical Evaluation of Language Fundamentals (CELF-4).* San Antonio, TX: The Psychological Corporation.

Senju, A., Southgate, V., White, S., & Frith, U. (2009). Mindblind eyes: An absence of spontaneous theory of mind in Asperger syndrome. *Science, 325,* 883-885.

Shattuck-Hufnagel, S. & Turk, A. (1996). A prosody tutorial for investigators of auditory sentence processing. *Journal of Psycholinguistic Research, 25,* 193–247.

Shriberg, L. D., Paul, R., Black, L. M., & van Santen, J. P. H. (2011). The hypothesis of apraxia of speech in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, online first* doi:10.1007/s10803-010-1117-5

Shriberg, L. D., Paul, R., McSweeny, J. L., Klin, A., Cohen, D. J., & Volkmar, F. R. (2001). Speech and prosody characteristics of adolescents and adults with high-functioning autism and asperger syndrome. *Journal of Speech, Language & Hearing Research, 44*(5), 1097-1115. doi:10.1044/1092-4388(2001/087)

Snedeker, J. & Trueswell, J. (2003). Using Prosody to Avoid Ambiguity: Effects of Speaker Awareness and Referential Context. *Journal of Memory and Language, 48,* 103-130.

Snedeker, J. & Trueswell, J. (2004). The developing constraints on parsing decisions: The role of lexical-biases and referential scenes in child and adult sentence processing. *Cognitive Psychology, 49*(3), 238-299.

Snedeker, J., & Yuan, S. (2008). Effects of prosodic and lexical constraints on parsing in young children (and adults). *Journal of Memory and Language, 58*(2), 574-608. doi:DOI: 10.1016/j.jml.2007.08.001

Solomon, M., Ozonoff, S. J., Cummings, N., & Carter, C. S. (2008). Cognitive control in autism spectrum disorders. *International Journal of Developmental Neuroscience, 26,* 239-247.

Speer, S. R. & Ito, K. (2009). Prosody in first language acquisition - Acquiring intonation as a tool to organize information in conversation. *Language and Linguistics Compass, 3*(1), 90-110.

Surian, L., Baron-Cohen, S., & Van der Lely, H. (1996). Are children with autism deaf to Gricean maxims? *Cognitive Neuropsychiatry, 1,* 55–72.

Tager-Flusberg, H. (2005). What neurodevelopmental disorders can reveal about cognitive architecture: the example of theory of mind. In *The Structure of the Innate Mind* (pp. 3–24). Oxford: Oxford University Press.

Tager-Flusberg, H., Paul, R., & Lord, C. (2005). Language and communication in autism. In F. R. Volkmar, R. Paul, A. Klin & D. J. Cohen (Eds.), *Handbook of autism and pervasive developmental disorders: Diagnosis, development, neurobiology, and behavior* (Third ed., pp. 335-364). Hoboken, New Jersey: John Wiley & Sons, Inc.

Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M., & Sedivy, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science, 268*(5217), 1632-1634.

Thothathiri, M., & Snedeker, J. (2008a). Syntactic priming during language comprehension in three- and four-year-old children. *Journal of Memory and Language, 58,* 188-213.

Thothathiri, M., & Snedeker, J. (2008b). Give and take: Syntactic priming during spoken language comprehension. *Cognition, 108*(1), 51-68.

Trueswell, J. C., Sekerina, I., Hill, N. M., & Logrip, M. L. (1999). The kindergarten-path effect: Studying on-line sentence processing in young children. *Cognition, 73*(2), 89-134. doi:DOI: 10.1016/S0010-0277(99)00032-3

Verte, S., Guerts, H., Roeyers, H., Ooosterlaan, J., & Sergeant, J. (2006). Executive functioning in children with an autism spectrum disorder: Can we differentiate within the spectrum? *Journal of Autism and Developmental Disorders, 36*, 351–372.

Volkmar, F. R., Lord, C., Bailey, A., Schultz, R. T., & Klin, A. (2004). Autism and pervasive developmental disorders. *Journal of Child Psychology and Psychiatry, 45*, 135-170. doi:10.1046/j.0021-9630.2003.00317.x

Wagner, M., & Watson, D. Experimental and theoretical advances in prosody: A review. *Introduction to Special Issue of Language and Cognitive Processes, 25*(7), 905–945.

Wang, A. T., Lee, S. S., Sigman, M., & Dapretto, M. (2006). Neural basis of irony comprehension in children with autism: the role of prosody and context. *Brain, 129*(4), 932.

Wechsler, D. (1999). *Wechsler abbreviated scale of intelligence*. San Antonio: Pearson.

Weighall, A. (2008). On still being led down the kindergarten path: Children's processing of structural ambiguities. *Journal of Experimental Child Psychology, 99,* 75–95.

Young, E. C., Diehl, J. J., Morris, D., Hyman, S. L., & Bennetto, L. (2005). The use of two language tests to identify pragmatic language problems in children with autism spectrum disorders. *Language, Speech, and Hearing Services in Schools, 36*(1), 62-72. doi:10.1044/0161-1461(2005/006)