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Is Prosody to Blame? High-Functioning Autistic Children Parse Syntactically Ambiguous Utterances with Prosodic Cues.

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Senior Honors Thesis Spring 2012

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ACKNOWLEDGEMENTS AND DEDICATION

All research was funded by the Simons Foundation. This research project was conducted by Dr. Jesse Snedeker and Dr. Noemi Hahn at The Lab for Developmental Studies, Department of Psychology, Harvard University, Cambridge, MA.

I dedicate this work to my brother, Adam, whose diagnosis of autism has inspired me to do all that I can in the field of autism research.

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Abstract

Prosody, the melody and rhythm of language, is widely reported as abnormal in those diagnosed with autism spectrum disorder (ASD) (McCann & Peppé, 2003). Previously published studies report that typically developing adults, children, and even infants rely on prosody to provide additionally relevant information that is not evident from language structures (i.e. words, grammar, etc.) alone (Speer & Ito, 1999). The intonational phrase boundary (primarily pause) is a prosodic cue that helps to delineate boundaries between words or phrases in stream of a fluent speech (Wilkinson, 1998). Based on previous finding that the lexical and syntactic elements of language are not impaired in individuals with high-functioning autism (HFA) (Thurber & Tager-Flusberg, 1993), it is hypothesized that these same individuals have no impairment in their ability to detect and process pause as a prosodic cue. The present study tests whether children, ages 6-9, with HFA (*N=27*) can effectively process an intonational phrase boundary to resolve ambiguous syntactic phrasing. It also compares the trajectory of on-line processing by HFA children with typically developing, same-aged peers (*N=29*), and peers of a slightly younger age (ages 4-5; *N=16*). Both TD and HFA children, ages 6-9, effectively use an intonational phrase boundary to signal the early syntactic closure of a phrase, but it takes children with HFA approximately 100 ms longer to process this cue. By contrast, young TD children do not appear to be able to use prosodic cue at any point during the two-clause presentation. These observations support the hypothesis that, by ages 6-9, HFA children are developmentally on-track with typically developing children of the same age, who use prosody for syntactic phrasing. However, their need for slightly more time suggests that the children with HFA may not be using the entire prosodic cue as efficiently as TD peers.

Is Prosody to Blame? High-Functioning Autistic Children Parse Syntactically Ambiguous Utterances with Prosodic Cue.

Individuals with autism are often characterized as having a “disordered prosody,” but neither the cause of this impairment nor the extent of its involvement in the communication deficits associated with ASD is well understood (Kanner, 1943; Rutter, LeCouteur & Lord, 2003b; Wilkinson, 1998). The present study is designed to examine a particular form of prosody, used to delineate boundaries between words and phrases, known as an intonational phrase boundary (IPh) (Speer & Ito, 1999). Investigators want to know how diagnosis of autism and developmental age may affect the process of chunking phrases that are syntactically ambiguous without the additional information that an IPh provides. Because prosody is considered one of the earliest precursors of social understanding, it is of crucial interest to researchers investigating the primary characteristics that underlie autism spectrum disorder (Garvais et al., 2004).

1.1 Introduction to Autism

Autism Spectrum Disorder (ASD) is a developmental disorder, classified under the *DSM-IV-TR*’s Pervasive Developmental Disorder. The disorder is characterized by communicative, social, and pragmatic deficits, along with stereotyped behaviors and restricted interests (American Psychiatric Association, 2000). As the name “spectrum disorder” suggests, the extremity to which the disorder’s characteristics affect each individual can vary. For instance, if a child, teenager, or adult has an average IQ and lacks significant speech delays, but still displays social and pragmatic deficits that significantly interfere with his or her daily life, that individual may have received a diagnosis of Asperger's syndrome. The difference between Asperger's syndrome and high-functioning autism (HFA) is currently not standardized in diagnostic practices, and can be considered interchangeable for means of this paper (McCann & Peppé, 2003).

Scientists are currently working to discover which systems of human development dictate pragmatic and social functioning, both generally and as they pertain to ASD (Wilkinson, 1998). Because prosody is essential to the processing of pragmatic inferences, a key attribute of social understanding (Baron-Cohen, 1995), the melody and rhythm of language has become a key target of interest to researchers in the field of autism research.

1.2 Introduction to Pragmatics

Pragmatics is a higher-order level of processing that takes into account inexplicit cues and situational context for purposes of interpreting language input in social settings (Jarvinen-Pasley, Peppé, King-Smith, Heaton, 2008). As highly communicative beings, humans rely on pragmatic processing of language on a day-to-day basis. The system of pragmatics within language augments linguistic structures (i.e., words, grammar, etc.) in support of social interaction (Wilkinson, 1998). Pragmatics also encompasses a type of conversational implicature, involving the deciphering and inferring of affect, irony, and general intent of the speaker (Grice, 1975). Grice's Cooperative Principle, which is made up of the maxims of Quantity, Quality, Relation, and Manner, guides successful communicative discourse between humans partaking in conversation, as one individual is expected to adapt his or her speech context based on knowledge of the other party and that other party's feedback (Grice, 1975). While this ability to gauge and adapt conversations based on the verbal and nonverbal responses of a listener is a pragmatic task that even young children can do, it appears to be impaired in the ASD population (Baron-Cohen, 1988). Persons with ASD have been observed to violate Grice's maxims of conversation by perseverating on a preferred topic, veering off the mutually determined topic of conversation, and failing to modulate appropriate turn taking (i.e., interrupting) (Fay & Schuler, 1980; Surian, Baron-Cohen, & van der Lely, 1996). In each instance, the person with ASD fails to appropriately detect feedback cues from the other party to the conversation (Baron-Cohen, 1988). These violations do not appear to be related to a reduced linguistic intelligence, but rather to a failure to consider the mental state of the other party that is engaging in conversation (Surian et al., 1996).

1.3 Theory of Mind

The inability to infer the mental states of others has been coined "Theory of Mind" (Premack & Woodruff, 1978). When an individual has an impaired Theory of Mind (ToM), he or she lacks the ability to appropriately infer the content of other people's mental states, which are often signaled with nonexplicit cues and contextual information. Because individuals with autism often fail to regulate their participation in conversations by taking into account the perceptive of the other party, it has been hypothesized that they lack ToM (Baron-Cohen, Leslie, & Frith, 1985).

However, this paper challenges the assumption that an impaired ToM (a skill which usually begins to present itself around the age of fourteen months and is not fully formed until 4 to 5 years of age) (Malle, 2002; Buresh & Woodward, 2006; Moll, Carpenter, & Tomasello, 2007; Peterson, Wellman, & Slaughter, 2012) is at the core of the pragmatic deficits in the ASD population. Rather, this paper hypothesizes that one element that serves pragmatics – prosody – which is detected before ToM, is a precursor to the development of ToM and is a significant contributor to the development of pragmatic and social skills relevant in ASD (Sakkalou & Gattis, 2012; DeCasper & Fifer, 1980).

1.4 Introduction to Prosody

Prosodic intonation, through means of rhythm, stress, duration, pause, and pitch contours are readily available markers inserted into language to make it more comprehensive (McCann & Peppé, 2003). Prosody serves pragmatics by highlighting "important temporal locations in the speech stream, such as the location of words that convey central aspects of an utterance's message, and the locations where critical information about the phonological, syntactic, and semantic content are aligned in time" (Speer & Ito, 2008, p. 90). Infants learning any language are sensitive to prosodic contours of speech signal, relying on them in order to learn phonemes, lexicons, syntax, and semantics (Kjelgaard & Speer, 1999). According to Mehler & Christophe (1994), a young child "needs to represent the speech signal, segment the relevant words, identify the prosodic phrases, and categorize the acoustic-phonetic segments" before he or she can develop a competency for lexical, syntactic, and semantic information (p. 13). This claim is supported by the prosodic bootstrapping hypothesis (Gleitman & Wanner, 1982) which explains that infants may be sensitive to prosodic patterns in order to advance their development of linguistic structures (Peppé, McCann, Gibbon, O'Hare, & Rutherford, 2006; Soderstrom, Seidl, Nelson, & Jusczyk, 2003).

Moreover, after the acquisition of language, prosodic structure continues to be an important contributor to syntactic and semantic structures during the analysis of sentence comprehension (Kjelgaard & Speer, 1999). Affective intonation, turn-end/intonation, stress/focus, and chunking/phrasing are all elements of prosody that enhance language. Affective intonation, as will be discussed in more detail later, refers to tonal cues that cue the listener to perceive language as holding an emotion (e.g., happy, sad, excited, or bored. Turn-end/intonation is the form of prosody that provides the cue that an utterance is either a question or, alternatively, a declarative statement. The contrastive stress pattern within a phrase, used to highly that one word is particularly important, is referred to as stress/focus. Chunking/phrasing involves the prosodic use of intonational phrase boundaries to aid semantic and syntactic disambiguation. All of these prosodic patterns are mostly noted in spoken language, but can also be expressed in written language through the use of marks such as commas, periods, and question marks. For example, the ability to comprehend ordered lists relies on the boundaries of phrases, spaced with intonational phrase boundaries; a phrase like "chocolate cake and buns" will be analyzed from a syntactic perspective as completely different from the phrase, "chocolate, cake, and buns" (McCann & Peppé, 2003). It is important to note that standard intonational phrase boundaries (IPh) combine the pause with intonational contours (Speer & Ito, 1999). With these intonational contours, the final segment of a phrase is distinguished with a lengthening and a fall or fall-rise tone, while the beginning of the subsequent phrase is marked with an initial strengthening or resetting of pitch range (Speer & Ito, 1999).

In addition to its role in the interpretation of syntactic and semantic information, prosody functions as a tool in the pragmatic level of language processing, which conveys cues and context for purposes of interpreting language input in social settings. Prosodic cues are often noted for the ability to convey contextual cues surrounding emotion (i.e., affect). For instance, the affect of someone's language is interpreted as negative rather than positive if it has a wider and higher pitch range (Couper-Kuhlen, 1986), and as intense if it has a fast speech frequency (Nadig & Shaw, 2011). Understanding whether a speaker is intending to ask a question or make an assertive statement is also of concern to pragmatic inferences. Prosodic cues address this ambiguity by pairing a rising, rather than falling, intonation at the end of a sentence to distinguish it as a Yes-No question (McCann & Peppé, 2003). While all typically developing children develop a system for perceiving systematic prosodic cues – a skill that will ultimately allow them not only to develop their functional receptive language skills, but also to produce the same systematic clues in their own expressive language – it is still unclear exactly how this skill develops and thus what occurs differently when it fails to develop typically.

1.5 Innate Sensitivity to Prosody

From their earliest development, humans are tuning into the tones and rhythmic patterns of speech (Sakkalou & Gattis, 2012; DeCasper & Fifer, 1980). This keen sense of prosodic patterns is perhaps first exemplified as infants recognize and track their mother's voice when they are only a few days old (DeCasper & Fifer, 1980). Even more impressive is that newborns have been found to differentiate rhythmic patterns of their own native language from other languages (Mehler, Jusczyk, Lambertz, Halstead, Bertoncini, & Amiel-Tison, 1988), and, moreover, to favor the sounds present in their native language over others (Speer & Ito, 1999; Christophe, Gout, Peperkamp, & Morgan, 2003). By five months, infants are reacting with positive affect (i.e. smile) in response to an approving prosodic pitch, indicated by a rise-fall countour, and with negative affect to disapproving-toned contours (Sakkalou & Gattis, 2012). By six months, infants attend to prosodic boundaries in order to segment strings of words into lexical items (Jusczyk, Culter, & Redanz, 1993; Johnson & Jusczyk, 2001). At this same age, infants also prefer speech with pauses that coincide correctly with the separation, rather than interruption, of clauses (Jusczyk, Hirsh-Pasek, Nelson, & Kennedy, Woodward, & Piwoz, 1992; Jusczyk, Hohne, & Mandel, 1996).

It is also around this same age (5-7 months) that brain studies have noted a development in how young children process speech vocalizations. By the time infants are 7 months old (but not at 4 months), several channels within the upper bank of the left and right superior temporal sulcus are able to distinguish speech vocalizations from other, general acoustic stimuli (Grossman, Oberecker, Koch, & Friederici, 2010); these results are functionally similar to patterns of brain activation in adults when discriminating such stimuli, functioning similar in STS response (Belin, Zatorre, Lafaille, Ahad, & Pike, 2000). Upon further investigation of affective prosody, which is predominantly processed by the right hemisphere (Baum & Pell, 1999), Grossman et al. (2010) found that select voice-processing channels in the right posterior temporal cortex react with similar increases in oxygenated hemoglobin concentration to affective prosody (i.e., happy and angry affect, compared to neutral conditions). Evidence from brain studies that show intact prosodic processing provide an effective baseline against which abnormal processing activity can be compared.

1.6 Inferences about Intent from Infant-Directed Speech

There have also been studies of prosody that have focused particularly on infant-directed speech (the simple but highly inflected speech commonly referred to as "baby talk"). As previously mentioned, a listener can use prosodic cues to obtain contextual information about the meaning and intent of an utterance. It has been shown that infants as young as 12-months-old exhibit the ability to infer some sort of communicative intent from prosodic cues in infant-directed speech (IDS) (Vaish & Striano, 2004; Sakkalou & Gattis, 2012). Sakkalou & Gattis (2012) in particular found that 14-to-18-month-old infants were able to use rising and falling pitch, regardless of the language it was vocalized in, as a means of distinguishing intent (e.g., a parent expressing an action as accidental rather than purposeful). A previous study by Carpenter, Akhtar, & Tomasello (1998) found that infants imitate another person's intentional behaviors more often than their accidental behaviors. Thus, Sakkalou & Gattis (2012) designed their methods to match behaviors with coinciding prosody – a pattern of falling pitch for intentional behavior and a pattern of rising pitch for accidental behavior. The fact that infants imitated behaviors that were matched with the intentional, falling pitched, prosody, suggests that they were able, to some extent, to understand how prosody signals the difference between intentional and accidental behavior (Sakkalou & Gattis, 2012). Interestingly, both Sakkalou & Gattis (2012) and Vaish & Striano (2004) manipulated their experiments so that voicing was the only cue provided to the infants; by controlling for facial cues (i.e., cues that have previously been found to guide infants in intentionality-reading), they demonstrated the possibility that prosodic cues can be sufficient as the sole indicator of intent (Vaish & Striano, 2004).

Moreover, according to the Sakkalou & Gattis (2012), a rising contour is a feature of IDS that mothers use to encourage the infant to engage in joint attention towards an object. This fact is critical, because previous studies have pinpointed poor joint attention as one of the earliest signs of ASD (Sakkalou & Gattis, 2012; Baron-Cohen, 1995). Similar to current measures of joint attention via eye tracking of infants who are at high risk for ASD, assessment of response to prosodic contours in infants and young children may be an effective early marker of future diagnosis.

2. Introduction to Prosody in Autism

Individuals with ASD have been characterized as displaying atypical patterns of prosody ever since Kanner's original description of autism in 1943. Various research has continued to reinforce Kanner's initial observation (Baltaxe & Simmons, 1985, 1992; Fay & Schuler, 1980; Tager-Flusberg, 1981, 1995; Klin & Volkmar, 1995), and current diagnostic tools continue to list disordered expressive prosody as a feature of the disorder (ADOS; Lord, Rutter, & DiLavore, 1999). However, the experiments to date that identify and analyze disordered prosody in individuals with autism deal almost exclusively with expressive language and rarely address the receptive processing of prosody (Diehl, Friedberg, Paul, & Snedeker, in prep). In addition, a fair amount of studies described in the existing literature on this topic are based on small sample sizes or have compared groups of children that were not matched for verbal or nonverbal IQ (raising the possibility of confounding factors). These and other methodological limitations in these studies – along with widely conflicting results – have made it difficult to draw definitive and specific conclusions about how prosody in ASD may be impaired (Eigsti, Schuh, Mencl, Schultz, & Paul, 2011).

In addition to these behavioral and clinical reports, TD children (i.e., average listeners who are untrained in the recognition of speech abnormalities) can notice the irregular intonational speech patterns of their ASD-diagnosed peers (Lord & Paul, 1997). In particular, when TD peers judged the communication competence of ASD individuals based on their language production, various elements of prosodic performance, including problems of resonance (i.e., nasality) and stress (i.e., syllabic intensity, pitch, and duration) were considered signs of oddness (Paul, Shriberg, McSweeny, Cicchetti, Klin, & Volkmar, 2005b; Mesibov, 1992).

Despite these commonly observed patterns, there is still extreme heterogeneity among the population. Within the segment of the ASD population with disordered expressive prosody, the specific atypical characteristics in intonational and stress patterns vary widely, from monotone or wooden to exaggerated (Wilkinson, 1998; Peppé et al., 2006; Diehl, Friedberg, Paul, & Snedeker, in prep). For those who produce atypical prosody, differences are noted from an early age and persist despite progress in other realms of language development (Diehl et al., in prep). Furthermore, there is a broad range of basic language abilities within the ASD population. There also appears to be a link between basic language ability and prosodic ability in children with ASD that is not detected in children with a diagnosis of Specific Language Impairment (SLI) (McCann, Peppé, Gibbon, O'Hare, & Rutherford, 2006). Marshall, Harcourt-Brown, Ramus, & van der Lely (2009) reported similar results, finding that prosody was not impaired in children with SLI or dyslexia. Together, these findings suggests that prosodic impairment is not simply a result of language impairment, but also a manifestation of underlying deficits across autism, present in even children with ASD who do not have language impairments. These children were also matched with controls based on receptive language measures, suggesting that their prosodic deficit is impaired independently of language acquisition (Peppé, Cleland, Gibbon, O'Hare, & Martinez Castilla, 2011).

The one aspect of prosody that appears to be intact throughout the ASD population is the "form" of prosody, which involves the articulation and recognition of phonemes (Jarvinen-Pasley et al., 2008; Thurber & Tager-Flusberg, 1993; Wilkinson, 1998). In fact, canonical babbling, which is related to fine motor control of speech and the phonetic ability to articulate language, appears to be intact in preverbal children with ASD (Sheinkopf, Mundy, Oller, & Steffens, 2000). The reasons for the unaffected auditory-perceptual form-level prosodic ability are unclear (Jarvinen-Pasley et al., 2008). One possibility is that echolalia – the repetition of words and phrases – gives children with ASD the opportunity to practice language at the phonemic and lexical level (Prizant & Rydell, 1993). Prizant & Rydell (1993) speculate that echolalia may be utilized by children to memorize speech phrases and analyze them for purposes of linguistic learning at a later point. On the other hand, it is also not unusual for children with ASD to never develop functional language, which may suggest a problem with parsing lexicons from a string of auditory input. Because prosodic ability at the form-level is considered to be a "prerequisite of function-level cognitive prosodic abilities" (Jarvinen-Pasley et al., 2008,

p. 1329), further research is needed to explain why prosodic abilities at the functional level appear to be consistently impaired in ASD, while abilities at the form-level frequently remain undisturbed.

2.1 Innate Prosodic Differences in Autism

Suprasegmental aspects of speech (i.e., prosody) are among the first atypical behaviors to be detected in infants later diagnosed with ASD (Oller, Niyogi, Gray, Richards, Gilkerson, Xu, Yapenel, & Warren, 2010; Paul, Fuerst, Ramsay, Chawarska, & Klin, 2011). In particular, infants who had an older sibling with ASD and were thus considered at higher risk for autism produced fewer canonical syllables, fewer consonant types, and fewer speech vocalizations than infants who were at low risk (Paul et al., 2011). In addition, atypical vocal quality, consisting of non-reflexive syllables made up of atypical phonation (e.g., squeals), was found to be more frequently produced in preverbal children (ages 25-53 months) with ASD than in preverbal children with another form of developmental delay (Sheinkopf, et al., 2000). Patterns of atypical phonation may prove to be an important early sign of longer-term atypical expressive prosody (i.e., exaggerated or sing-song).

Similarly, Oller et al. (2010) compared infants (ages 10-48 months) who either had ASD, another language delay, or were TD, and found that children with ASD "organize acoustic infrastructure for vocalization differently" than the other two groups, especially in terms of their control of rhythm and syllabicity (p. 13356-13358). Their method, which they deemed very successful, involved attaching an audio recorder to each child's shirt, so that the child's vocalizations could be recorded in a natural setting over a long time span. Using signal processing software, researchers were able to examine twelve infrastructural acoustic features of prosody, including rhythm/syllabicity (Oller et al., 2010).

Based on strong recent findings of prosodic differences in the babbling patterns of infants with ASD, it would be beneficial for future studies to continue examining these babbling patterns, replicating methods, such as the one used by Oller et al. (2010), that use natural recordings and automated vocal analysis to detect atypical prosody in very young children who are at higher risk for ASD.

2.2 Brain Studies Reveal ASD Abnormalities

Researchers have also been able to confirm, through brain imaging analysis, that differences in processing of prosody in speech are occurring in not only young children but also full-grown adults with ASD. As previously mentioned, the upper bank of the superior temporal cortices specializes in processing human vocalizations but not general nonvocal or general acoustic stimuli (Grossman et al., 2010). However, in ASD adults, this voice-sensitive region of the superior temporal sulcus is significantly less activated than it is in TD adults (Gervais et al., 2004). Gervais et al. (2004) also found that when participants were asked to recall the sounds they had heard, the adults with ASD recalled significantly fewer vocal sounds than general acoustics.

The left supra marginal gyrus, a neural network mechanism involved in receptive prosody, also seems to be abnormally activated in adults with HFA (Hesling, Dilharreguy, Peppé, Amirault, Bouvard, and Allard, 2010). Hesling et al. (2010) used fMRI during the receptive processing of different prosodic elements, including the assessment of prosodic input used for chunking, focus/stress, and affect. The left supra marginal gyrus is linked with the working memory loop for phonological processes; moreover, prosody at the phonemic level (tonal contrasts) and lexical level (stress) originates in the left hemisphere (Baum & Pell, 1999). Hesling et al. (2010) speculate that the left SMG is more highly activated because HFA children are inappropriately relying on it for phonemic discrimination and articulatory representations, while their TD peers effectively focus on prosodic features. Brain studies such as these are helping to pinpoint the developmental basis for the odd qualities of prosody in ASD that both researchers and casual observers have been noticing for a long time.

2.3 Components of Prosodic Use

Although the heterogeneity of characteristics across ASD creates a challenge for empirical research, studies are attempting to identify specific elements of impaired prosody that are widely shared by individuals with ASD. In order to assess each of the components of prosodic development, researchers have examined how prosody is utilized for affective intonation, turn-end/intonation, stress/focus, and chunking/phrasing.

The most conclusive results have come from the examination of prosody as a means of conveying affect, a component of pragmatic language. The literature on this topic is extensive, and for purposes of this paper, it will not be discussed in depth. The consensus, however, is that even individuals with HFA have difficulty assessing a speaker's affective state from prosodic cues (Korpilahti, Jansson-Verkasalo, Mattila, Kuusikko, Suominen, Rytky, Pauls, & Moilanen, 2006; Peppé, McCann, Gibbon, O'Hare, & Rutherford, 2007; Jarvinen-Pasley et al., 2008). As Rutherford, Baron-Cohen,

& Wheelwright (2002) put it, these individuals lack the ability to "read the mind in the voice" (Korpilahti et al., 2006). If individuals with HFA have a diminished ability to process another person's affective prosody, this could result in their having insufficient information with which to develop their comprehension of the other person's mental states and emotions. However, while a correlation between prosodic and affective deficits has been observed, the causality has not been determined. In other words, it is unclear whether atypical comprehension of prosodic cues results in an impaired understanding of affect that is conveyed through language, or whether, alternatively, there is a broader inability to understand socio-emotional states that manifests itself, in part, in the form of impaired reception of affective prosodic cues.

Turn-end prosody and stress are both cues that aid the semantic level of language. According to Jarvinen-Pasley et al. (2008) and Peppé et al. (2007), individuals with HFA frequently fail to deduce from a rising intonation that the utterance being heard is a question, and are more likely to interpret utterances of being declarative, regardless of the inflection. Studies have found mixed results with respect to the ability of individuals with HFA to rely on stress as a cue for distinguishing key information from the other words in the phrase. Stress/focus is important during the interpretation of a phrase like, "I want the YELLOW hat," which puts an emphasis on the color, yellow (Peppé et al., 2007). Peppé et al. (2007) found both productive and receptive language deficits in HFA children's ability to place accents and interpret stress cues appropriately, and Baltaxe (1984) found that children with ASD could not use stress cues effectively for semantic understanding. In contrast, Paul, Augustyn, Klin, & Volkmar (2005a) and Jarvinen-Pasley et al. (2008) found that HFA and TD participants produced similar patterns of stress/focus perception. In each of these studies, HFA and TD participants were matched with respect to verbal age and nonverbal IQ (Jarvinen-Pasley et al., 2008; Paul et al., 2005a; Peppé et al., 2007).

Several other studies have operationalized grammatical prosody in terms of the participants' ability to express chunking/phrasing. Again, the results for how individuals with ASD chunk/phrase with prosody are mixed and inconclusive. Thurber & Tager-Flusberg (1993) carried out one of the earlier studies to test individuals with autism and found that they do not exhibit impaired grammatical prosody, as they in fact produce less nongrammatical pausing than their peers with learning disabilities. In contrast, Fosnot & Jun (1999) found that individuals, ages 7 to 14, with autism produce more non-grammatical pausing than their TD peers. However, in both cases, the results were based on relatively few participants with ASD, ten and four respectively. In a more comprehensive study by Shriberg, Paul, McSweeny, Klin, Cohen, & Volkmar (2001), forty percent of the adults with HFA produced "inappropriate and disfluent phrasing on more than twenty percent of their utterances" (Peppé et al., 2006, p. 4). These results certainly would initially suggest that individuals with HFA have more trouble with their prosodic phrasing than TD peers. However, while the authors describe the utterances in their study as "disfluent phrasing," what they are actually analyzing is speech characterized by repetitions and revisions (similar to stuttering and tripping over words), which is different from difficulty with phrasing used for syntactic/semantic purposes (McCann & Peppé, 2003). Finally, in a recent study by Peppé et al. (2011) studying the expressive prosodic abilities in HFA children, it was found that chunking/phrasing tasks, in comparison to turn-end, affect, and stress tasks, is the only area of performance that is not significantly different between HFA and TD children. While these studies on expressive language are helpful, it has been speculated that the increase of speech errors when a child with HFA is engaging in language performance for an extended period of time may be attributed to confounding factors like anxiety (Fosnot & Jun, 1999; Shriberg et al., 2001).

Moreover, while the studies to date primarily deal with the role of expressive prosodic language in ASD, it has become clear that receptive language in individuals with autism also holds clues relevant to our understanding of the disorder. Peppé et al. (2007), Paul et al. (2005b), and Jarvinen-Pasley et al. (2008) are among the few who have tested recessive language (i.e., processing) in this population. When assessing receptive language, they all found that children with autism had only a mild significant difference in functioning (compared to TD peers) with respect to their ability to appropriately process chunking or grammatical pausing through prosodic cues.

In order to understand the expression of prosody, we must examine receptive language processing, which theoretically is the foundation of expressive prosody. Basic processing of prosodic cues in receptive language may help researchers gain better insight into how prosodic deficits in expressive language originate.

2.4 Grammatical Prosody in Individuals with HFA

Some researchers have attempted to explain the components of prosody in terms of the linguistic levels it serves: phonology, semantics, and pragmatics. Such hypotheses have led to various conclusions about which level or levels of prosodic function fail to develop typically in individuals with autism. Tager-Flusberg (1981) speculated early on that children with autism develop phonological and syntactic language, but may have developmental delays in their acquisition of these skills; thus, she pinpointed pragmatics and semantics as the main areas of concern. Kjelgaard and Tager-Flusberg (2001) agree that notwithstanding the wide range of abilities among the ASD population with respect to basic language skills, the observed problems generally relate to deficits in semantics and pragmatics, rather than to problems with phonology, lexical knowledge, and syntax. From their observation that individuals with HFA have intact syntax yet display atypical pragmatic and social-emotional development, Shriberg et al. (2001) hypothesize that "the prosodic deficits so frequently attributed to people with autistic syndromes reside primarily in the pragmatic and affective aspects of prosody, with grammatical aspects relatively spared" (p. 1099). If individuals with HFA have intact grammatical prosody, we should not expect them to make errors using prosody – whether productively or receptively – for the systematic function of chunking/phrasing. As previously mentioned, however, the literature contains mixed results.

3. Understanding the Methods: Prosodic Parsing of Early and Late Closure Syntax

For purposes of understanding how prosodic cues functions at the syntactic level, it is important to comprehend the linguistic architecture of phrasing/chunking clauses. In English, a full clause is made up of a noun phrase and a verb phrase. This verb phrase is often further made up of a verb, a noun phrase (including a determiner, adjective, and direct object), and also possibly a prepositional phrase. During a typical two-clause sentence, the listener expects the most common construction of a verb phrase – a direct object (DO) following the verb. In this construction, the late closure heuristic predicts that a noun phrase following a verb phrase belongs to that clause, thus serving as a DO. For example, when hearing the phrase "While Gort the robot walked the nice....," the listener will expect the verb "to walk" to take a direct object (e.g., "the nice dog"). The late closure structure is almost assumed by parsing, and thus an intonational phrase boundary (prosodic cues) after the DO should not make much of a difference.

While less frequent, verb phrases can also be composed of a verb without a DO, in which case the first clause is considered to have early closure. In the phrase, "While Gort the robot walked, the nice..."), the verb "to walk" would not take a DO, and a new noun phrase would start, such that "the nice" would take an animate object that is not walked (e.g., "the nice man"). In English, such cases usually include an intonational phrase boundary to cue the listener that the first clause is ending and a new one is starting. When a new clause within a sentence is starting, grammar mandates that it start with a noun phrase, again. The prosodic cues that occur after the first clause's verb will thus signal the listener that the first clause has ended and that he should next expect a noun phrase; this phrase closure right after the verb is referred to as an early closure condition. However, if the speaker states an early closure condition but does not include prosodic boundary cues, the listener is likely to follow the late closure heuristic, such that he or she will expect a DO rather than a noun phrase. As a result, the listener will produce what is known as a "garden path effect." During grammatically correct sentences, "garden path" effects can arise if the initial processing of the beginning of a sentence leads the parser to expect an alternate, incorrect ending to the sentence.

In on-line sentence-processing studies, researchers can operationally measure garden path effects as a means of tracking how participants predict the end of a clause based on their cues provided earlier in that clause. In addition, these measures of garden path effects can be utilized to evaluate how participants misinterpret a clause's larger semantic meaning (Kjelgaard & Speer, 1999). Kjelgaard & Speer (1999) found that when prosodic boundaries coincided with the boundaries in early closure syntactic phrases, typically developing adult participants did not produce garden path effects; however, when those prosodic boundaries were absent, garden path effects arose. "Lack of such [a garden path] effect in the cooperative condition indicates that prosody is used to prevent syntactic misanalysis (or perhaps to reanalyze them quickly)" (Kjelgaard & Speer, 1999, p. 170).

3.1 Methodology of Relevant Literature

Intonational phrase boundaries are, in the majority of structural contrasts, reliable cues for expressing and comprehending clause boundaries (Price, Ostendorf, Shattuck-Hufnagel, & Fong, 1991). For example, Snedeker & Yuan (2008) found that when adults were asked to read clauses with ambiguous prepositional phrases, they systematically and reliably used the same prosodic phrasing patterns to disambiguate the phrases for their listeners. As previously mentioned, these boundaries are marked by a lengthening of the final word, a pause, and end/start boundary tones and pitch resetting (Speer & Ito, 1999; Price et al., 1991). In particular, functional prosody has been found to serve as a powerful factor in the comprehension of a phrase that is syntactically ambiguous (Speer & Ito, 1999). Kjelgaard & Speer (1999), Snedeker & Trueswell (2003), and Snedeker & Yuan (2008) have all concluded that the performance of TD adults is affected by prosody when the presented phrase is ambiguous, but not bolstered or hindered when the phrase is unambiguous. Moreover, numerous studies have shown the robust effect of prosodic cues during on-line sentence processing, in adults (Weber, Grice, & Crocker, 2006; Trueswell, Sekerina, Hill, & Logrip, 1999; Snedeker & Trueswell, 2003). Such studies support the hypothesis that prosodic boundaries are used to inform the listener about how the utterance should be parsed in an on-line fashion, i.e., as it is received (Kjelgaard & Speer, 1999). In addition, such evidence about on-line parsing validates the present study's use of on-line eye gaze tracking, which aims to follow processing of syntax and prosody for means of language comprehension in real time (Spivey, Tanenhaus, Eberhard, & Sedivy, 2002).

After the publication of these results on adult subjects, additional studies were undertaken to determine the age at which prosodic cues become an effective tool for deriving intent and meaning from syntax, affect, and overarching pragmatics (Trueswell et al., 1999; Snedeker & Yuan, 2008). Hahn & Snedeker (2011) expanded upon the research of Kjelgaard & Speer (1999), Snedeker & Trueswell (2003), and Snedeker & Yuan (2008) by measuring the on-line sentence processing of children ages six through nine as they parsed temporarily ambiguous syntactic phrases. Hahn & Snedeker (2011) found that these children effectively use prosodic cues to disambiguate phrasing at the same point of on-line processing as adults, right after the occurrence of the intonational phrase boundary. The present study continues to expand on this research in prosodic parsing of syntactically ambiguous, on-line phrases. In particular, it uses the same procedural methods as Hahn & Snedeker (2011) in order to compare HFA children with their already established subject pool of TD children.

3.2 Methodological Approaches to the Examination of Syntactic Prosody

The syntactic structure with coinciding prosodic cues on which subjects were tested in the present study is very similar to the format used by Kjelgaard & Speer (1999), which tested adults on temporarily ambiguous phrases with cooperating, baseline, and conflicting prosodic conditions. Sentences were either late closure (with a direct object proceeding the first verb) or early closure (with no direct object proceeding the first verb). A sample sentence of late closure is: “When Roger leaves the house, it’s dark.” In contrast, an example of that same phrase, but as an early closure in Kjelgaard & Speer’s stimuli, would read: “When Roger leaves, the house is dark.” While the commas are apparent here, under baseline prosodic conditions the sentences would be read as if the comma were not present. The first two experiments by Kjelgaard & Speer (1999) relied on participants’ end-of-sentence comprehension, whereas the third experiment used a cross-modal naming procedure for a better gauge of on-line processing. In all three experiments, instances of cooperative prosody resulted in the fastest and most accurate language processing (Kjelgaard & Speer, 1999). In addition, participants attended more closely to prosodic cues during conditions of early closure versus utterances of late closure (Kjelgaard & Speer, 1999).

Snedeker & Trueswell (2004) conducted a similar study on adults and five-year-old children, using globally ambiguous phrases in varying referential contexts. Each phrase had a prepositional phrase (PP) whose attachment was ambiguous (e.g., “Feel the frog with the feather”). Each sentence was globally, rather than temporarily, ambiguous because it was never definitively determined whether ‘with the feather’ should be attached to the verb, ‘feel’, or the noun, ‘the frog’ (Snedeker & Trueswell, 2004).

Requests were made either in a one- or in a two-referent context: in a one-referent context, a target animal (e.g., a frog holding a feather), a distracter animal (e.g., an elephant holding a pen), a target instrument (e.g., a feather), and a distracter instrument (e.g., a pen) were displayed; in a two-referent context, the exhibit had the target and distracter animals be of the same kind (e.g., both would be frogs), while retaining the differentiated target and distracter instruments. For adults, modifier bias (i.e., preference towards the feather being a property of the frog) was partially increased in a two-referent context (Snedeker & Trueswell, 2004). This minor difference may result from an assumption (by the listener) that the presence of two or more items requires there to be a distinguishing property between the two, which is supplied by the prepositional phrase attachment (Snedeker & Trueswell, 2004). However, for children, referential context had no effect on their interpretation of the globally ambiguous phrases. Such findings suggest that five-year-old children may rely on statistical and lexical biases to inform their parsing decisions (Snedeker & Trueswell, 2004).

Snedeker & Yuan (2008) continued to build on this line of research, using a very similar paradigm to Snedeker & Trueswell (2004). Stimuli again consisted of globally ambiguous prepositional phrase-attachment utterances that instructed the participant to carry out commands (e.g., "You can tickle the pig with the fan"). However, this time, only one-referent contexts were presented, and instead, prosodic cues were manipulated. The study applied a between-subjects, or two block, design in which participants were exposed first either to instrumental prosody or to modifier prosody, and then subsequently exposed to the other. Instrumental task conditions were reliably presented with a prosodic phrase boundary between the words 'frog' and 'with', whereas modifier task conditions were expressed with a prosodic phrase boundary between the words 'feel' and 'the'. Snedeker & Yuan (2008) tracked the direction of the subject's eye gaze during the presentation of a visual world paradigm, which displayed four items (e.g., a frog holding a feather, a feather, a distracter animal holding a distracter instrument, and a distracter instrument). Snedeker & Yuan (2008) observed that in the first block of testing, adults looked significantly more towards the target instrument or target object, based on prosodic cue to "feel the frog [with the feather]", approximately 200 ms after the onset of the prepositional object (i.e., 'feather'). In comparison, TD four to six-year-old children began to use these cues 500 ms after the onset of the PP-object, but perseverated across trials on the second testing block. Moreover, instrumental bias (assuming that the verb took a direct object) led to participants responding by using the instrument to perform their action, regardless of whether they were being presented with an instrumental or modifier prosodic cue. This confounding factor in Snedeker & Yuan's methodology is one reason why the present experiment and that of Hahn & Snedeker (2011) chose to eliminate the use of such instrumental tasks.

Finally, Diehl, Friedberg, Paul, and Snedeker (in prep) conducted a follow-up study to that of Snedeker & Yuan (2008). Diehl et al. (in prep) uses the same methodology, but works with four distinct groups of children: children, ages 7 to 12.5, with and without HFA, and children, 12.5 to 17, with and without HFA. Of the four groups, only the younger set of children with HFA were unable to use prosodic cues in the second, between-subjects, block (Diehl et al., in prep). This study is highly significant to the present study, but it leaves unanswered the question of how children with HFA, ages 7 to 12.5, compare to younger typically developing children. The present study will continue to investigate how high-functioning children with autism compare to typically developing controls, using a very similar procedure that monitors eye movements throughout presentation of on-line syntactically ambiguous phrases with coinciding prosodic cues.

4. Methods and Objectives

This study investigates whether individuals with HFA (with average verbal and nonverbal IQs) correctly parse a syntactically ambiguous phrase by attending to and processing the meaning of an intonational phrase boundary. To this end, the following experiment is designed to provide evidence on whether the processing of prosodic cues for syntactic purposes by individuals with HFA is intact (comparable to TD peers), entirely absent, or slightly delayed. Because individuals with HFA are noted as having relatively intact syntax, and prosody assists with parsing syntax, we hypothesize that they will succeed at resolving the appropriate syntactic closure of an ambiguous phrase, using the information provided by the prosodic cues at the point of ambiguity. However, if the subject is obtaining some but perhaps not all of the information provided by the prosodic cues (IPh, comprised of both pause and inflection), the processing may occur less efficiently than for TD peers. The results of this study may also shed light on the hypothesis that all elements of receptive prosody are not uniformly disordered in individuals with HFA, but rather that these individuals process particular prosodic cues (such as pause) in a manner similar to their TD peers.

4.1 Subjects

Twenty-seven children (M_{age}= 7;7 years (SD = 10 months); 4 female, 23 males) diagnosed with autism spectrum disorder, ages six to nine, were compensated for their participation in this study. The children were matched in age, nonverbal IQ, and basic language IQ with previously studied, typically developing, children (Hahn & Snedeker, 2011). Age, gender, nonverbal intelligence, and language intelligence for these two participant groups are displayed in **Table 1**.

Another, younger set of TD children, ages 4-5 (N= 16; M_{age} = 5.0 years (SD = 2.7 months); 9 females, 7 males), was subsequently tested using the same methodology; however, matching procedures were not administered for these children.

Table 1 Characteristics of matched 6-to-9-year-old participants. Age, Gender, KBIT Nonverbal IQ, CELF Language IQ.

	HFA (*n* = 27)		TD (*n* = 29)		p value
	Mean (SD)	Range	Mean (SD)	Range	
Age (in months)	91.5 (10.6)		87.8(10.4)		*p*=0.1
Gender	4 females, 23 males		9 females, 20 males		*p*=0.08
KBIT NVIQ	116.4 (14.6)	[91,139]	115.9 (15.7)	[83,149]	*p*=0.9
CELF Language	111.5 (13.1)	[84,150]	114.7 (12.0)	[85,138]	*p*=0.3

4.2 Matching Procedures

For the six-to-nine-year-old children (TD and HFA), a matching procedure was implemented. After the experimental task was completed, a researcher administered two standardized tests on each child: the *Clinical Evaluation of Language Fundamentals, Edition 4* (*CELF-4;* Semel, Wiig, & Secord, 2003) basic language test and the *Kaufman Brief Intelligence Test*, *Second Edition* (*KBIT-2*; Kaufman & Kaufman, 2004) *Matrices* subtest. Participants were selected for data analysis if their score fell within the average range for their age on both tests.

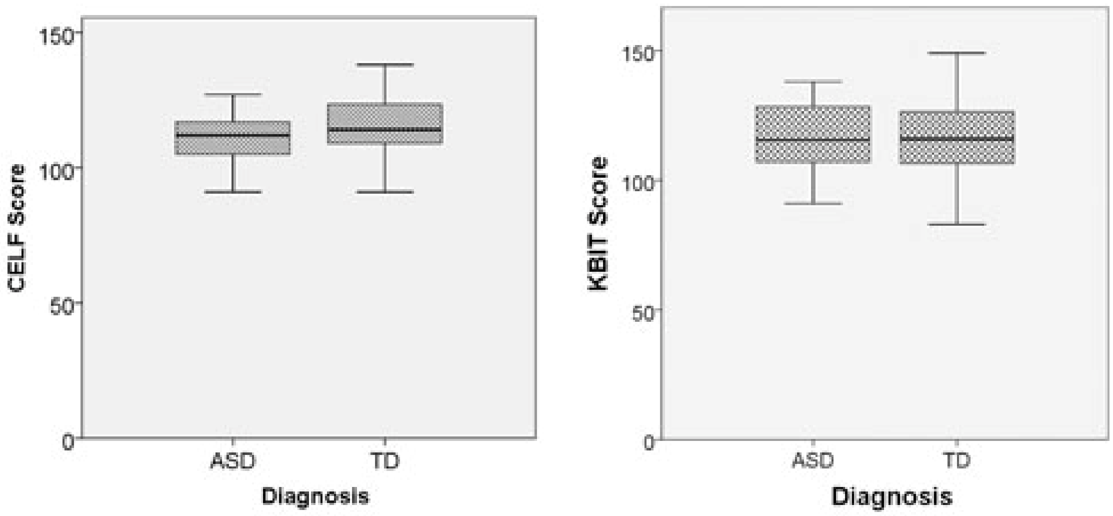
The CELF basic language score consists of several subtests: Concepts & Following Directions (assessing syntax/metalinguistics), Word Structure (assessing morphology), Recalling Sentences (assessing syntax/metalinguistics), and Formulated Sentences (assessing syntax/semantics). KBIT was used as a measure of nonverbal IQ. The KBIT *Matrices* subtest specifically assesses the ability to solve analogies; these analogies are completely made of images and geometric patterns. By controlling results based on standardized scores in language and nonverbal IQ, the study accounts for confounds, such as the inability to comprehend the sentence cues, presented in the following study. By controlling for results based on standardized scores in language and nonverbal IQ, the study accounts for confounds, such as the inability to comprehend the language presented in each sentence. The average score for both KBIT and CELF IQ among the general child population is standardized to be 100 (*SD* = 15).

Slightly higher than the standardized average, the average score of the 29 typically developing, child participants in this study is M =114 (*SD* = 12). The average score of the 27 children with HFA is 116 (SD: 14). Furthermore, the average CELF score for the 29 TD participants was 115 (*SD* = 15), while the twenty-seven children with HFA in our study was 111 (*SD* = 13). As **Figure 1** shows, neither the CELF scores nor the KBIT scores are significantly different between populations (both with $p>0.1$).

A parent of each child participant was also asked to complete a *Social Communication Questionnaire* - Lifetime form (SCQ; Rutter, Bailey, Berument, Lord, & Pickles, 2003a) describing his or her child, to ensure that the TD controls were accurately classified.

Figure 1. No significant differences in Nonverbal IQ (KBIT) or Language IQ (CELF) between the

children, 6-9, diagnosed with HFA and TD controls.



4.3 Assessment Procedure and Stimuli

Participants are seated in front of a ToBI eye-tracker and overlapping touch-screen. They are told that this game is called "The Robot Game." A series of trials are then presented to the participant. Each trial has three items on the touch screen. A robot subject, an animate object, and an inanimate object. The robot is always placed as the first noun for the initial clause. The animate object serves as a possible noun for a second clause, while the inanimate object serves as a possible direct object (DO) for the first verb of the first clause.

For each trial, a pre-recorded, narrative sentence is orally presented to the participant over speakers. This oral narrative is a recording of a real person's voice. Each utterance always has two clauses; the first clause of every utterance ends in either an early closure structure or a late closure structure. There are 16 possible conditions administered, using a composite of 36 sentence utterances [**Appendix A**]. Each condition had two within-subjects factors: prosodic cues (presence or absence of a IPh at the syntactic boundary) and syntactic closure (determined by whether the verb has a DO

– referred to as late closure – or no DO – referred to as early closure). Conditions of this 2x2 factorial are listed as cooperative early (CE), neutral early (NE), cooperative early (CE), and cooperative late (CL). Each of the selected verbs was capable of taking a DO or of functioning independently (e.g., the verb "to read," which can stand in isolation or take a DO like "the book"). The robot is always the first subject in the first clause of the sentence. The animate object acts as a potential subject for the beginning of the second clause, and the inanimate object serves as a potential DO for the first clause.

An intonational phrase boundary (IPh) serves as a prosodic cue during the phrase's ambiguous window, which occurs between the onset of the determiner and the offset of the adjective (-400 to 0 ms). A professional with training in phonology and phonetics determined the appropriate prosodic cues (boundary tone and pause) for the acoustic stimuli. The first syntactic clause boundary is marked with a low phrase accent, a low boundary tone, and a level break. In addition, because of the silence, the first clause's final syllable is lengthened. The syntactic boundary is marked by an IPh in cooperative prosodic conditions, but not in baseline conditions. Refer to **Appendix B** for a chart of these duration differences.

The ToBI eye-tracker records eye movements on average every 16 milliseconds. The dependent variable – participants' eye gaze towards the image that corresponded to the direct object – was conducted throughout the auditory presentation of a narrative sentence. Eye gaze is analyzed as a proportion of looks to the direct object relative to a summation of the looks to the direct object and the subject noun. This measure is taken to reflect participants' processing of input in an on-line, real-timed, manner. In particular, it was of interest what target the participant's gaze was fixating on during each trial utterance's ambiguous window, occurring between the onset of the determiner and the offset of the adjective, both of which immediately follow the first verb (occurring between -400 ms and 0 ms). The ambiguous window is the time frame in which adults use prosodic cues to disambiguate syntax. A measure of gaze fixations was also of interest during the delayed time window, immediately following the ambiguous window. This window is timed between 0 ms and 100 ms, between the onset and offset of the direct object or second-clause noun.

Once the sentence is read to the participant, a machine-generated robot voice asks a "who" or "what" question related to that previous narrative. These questions have no direct relevance to the study's objectives and simply work to motivate the children to listen carefully to the on-line sentences. The participant selects an answer from three choices presented on an on-screen display (the images previously displayed during the prompt – i.e., the robot, the animate object, and the inanimate object), and then he or she is given feedback for each trial about whether his or her selection is correct or incorrect.

4.4 Analysis

Consistent with the standard practice in psycholinguistics, the analysis window is defined to begin 200 ms 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). A total of 36 trials per participant were analyzed. Paired-samples t-tests were conducted to compare the means of each condition (CE, NE, CL, NL). In addition, we conducted an analysis of variance (ANOVA) on the participant means, for each variable. Between-subjects analysis of variance was conducted using either group age or group diagnosis. The significance threshold was based on a 95% confidence interval, with $p<0.05$. If over 50 percent of the data was not available from eye gaze, then the participant's data was not counted. Outlier data was also omitted.

5. Results

While the discussion here primarily pertains to the results with respect to HFA children, the results also cover previously tested TD adults and TD children, ages 6-9. The discussion here also includes preliminary findings based on data collected from TD children, ages 4-5. The results of each population discussed can be seen in **Table 1** and **Figure 2**.

5.1 Results of Children, 6-9, with High-functioning Autism

During the ambiguous processing window, children with HFA showed no signs of using cooperative prosodic cues for syntactic disambiguation ($F(1,26)=0.033$, $p>0.05$). Based on previous results of this paradigm on TD adults (Hahn & Snedeker, 2011), it was expected that prosodic cues would lead participants to look less frequently at the direct object during the CE (cooperative prosody x early closure) condition than in any of the other conditions. However, the results did not quite bear this out. When participants with HFA heard the CE condition, they looked at the direct object (DO) 54% of the time (i.e., performing insignificantly different from chance, $t(1,27)=-0.913$, $p=0.37$) during the ambiguous window, when the CE cues should have signaled them instead to direct their attention to a new subject. The participants also showed no significant tendency to look towards the DO during the cooperative late condition (47%), when a correct processing of prosodic cues would have led the listener to assume a late-closure heuristic. Similarly, subjects looked the same amount at the DO and the subject during the NE and NL conditions (*M* = 51% and *M* = 50%, respectively). Thus, no main effects of prosody were found (F(1,26)=0.423, p>0.05), and an interaction between prosody and closure failed to reach significance (F(1,26)=0.033, p>0.05).

However, after completing an analysis of variance during the delayed window, children with HFA did show signs of processing prosody for syntactic parsing (F(1,26)=7.973, p<0.01). During this window (100 ms after prosodic cues appear to be processed in TD controls), HFA participants looked significantly less often at the direct object in the early closure cooperative condition than in the other three conditions (p<0.001). Children with HFA only looked at the direct object 29% of the time during the EC condition that signals the ending of the first clause; in contrast, they looked at the direct object in the cooperative late, neutral early, and neutral late conditions, respectively: 61%, 43%, and 57%. A paired samples t-test on prosody in early closure syntax reveals that there is a significant difference between the cooperative early condition and every other conditions (p<0.001). Of special interest is the significant difference between CE and NE (t(1,26)=-3.277, p=0.003).

5.2 Between-subjects comparisons of TD and HFA children, ages 6-9

As reported in Hahn & Snedeker (2011), during the ambiguous processing window, typically developing children (i.e., controls for HFA subjects in this experiment), ages 6-9, looked at the probable direct object less often in the early closure/cooperative prosody condition than in the other three conditions (p<0.001); this resulted in a significant prosody by closure interaction ($F(1,28) = 4.174$, p=0.05, η_p^2 =

0.130). In particular, the CE condition was significantly different from the NE condition (t(1,28=-3.42, p=0.002), meaning that cooperative IPh effectively cued the listener to parse the phrase as early closure. However, these interaction effects disappear by the noun window, $F(1,28)=1.433$, $p>0.1$, $\eta_p^2 = 0.024$. Adults show signs of parsing early closure syntax with prosody in the same manner as TD 6-to-9-year-olds during the ambiguous window – looking at the DO less during the EC condition than in any other condition (Hahn & Snedeker, 2011). However, the adults continue to use prosody in the noun window as well, suggesting that perhaps because they have more experience with prosody, they have learned to trust it more for linguistic cues. In all groups, no significant differences were found between conditions of varying prosodic cue at the phrase boundary of late closure sentences, suggesting that individuals are very likely to assume a clause will follow the late closure heuristic; thus, late closure prosodic cue cannot be reliably compared between groups. These significant results on control data (for both TD 6-to-9-year-old children and TD adults) are consistent with Kjelgaard & Speer's (1999) findings of garden path effects in typically developing young adults.

The significant difference between HFA children and TD children during their processing of prosodic cues during the ambiguous window is displayed in **Figure 3a**. There was a significant effect of diagnosis during this block, due to the HFA group's atypical proportion of fixations to the DO during the cooperative early (CE) condition ($F(1,54)=9.921$, $p=0.003$). While the children with HFA do not appear to use prosody effectively as a cue in syntactic disambiguation during the ambiguous phrase, they produce similar results to the processing of TD children during the ambiguous processing window. Both populations look significantly less at the direct object during the cooperative prosody x early closure condition. **Figure 3b** depicts the pattern that both populations display, similarly and effectively using prosody for means of disambiguating syntactic closure.

Table 2

	Ambiguous Window	Delayed Window
Adult		
Prosody	F(1,23)=10.872, p=.003*	F(1,23)=2.126, p>0.05
Closure	F(1,23)=5.099, p<0.05*	F(1,23)=2.864, p>0.05
Prosody * Closure	F(1,23)=5.756, p<0.05*	F(1,23)=4.899, p<0.05*
Children (TD)		
Prosody	F(1,28)=8.579, p=0.007*	F(1,28)=0.557, p>0.05
Closure	F(1,28)=18.855, p<0.001**	F(1,28)=34.416, p<0.001
Prosody * Closure	F(1,28)=4.174, p=0.5*	F(1,28)=1.433, p>0.05
Children (HFA)		
Prosody	F(1,26)=0.423, p>0.05	F(1,26)=3.116, p>0.01
Closure	F(1,26)=0.724, p>0.05	F(1,26)=0.000, p>0.01,
Prosody * Closure	F(1,26)=0.033, p>0.05	F(1,26)=7.973, p<0.01*
Younger Children		
Prosody	F(1,15)=1.902, p>0.05	F(1,15)=0.146, p>0.05
Closure	F(1,15)=0.027, p>0.05	F(1,15)=29.198, p<0.001
Prosody * Closure	F(1,15)=0.267, p>0.05	F(1,15)=1.606, p>0.05

The dependant variable is the proportion of trials with looks to the direct object.

Figure 2. Analysis of fixations. Dependent variable (y-axis) depicts participants' looks to the direct object (DO) as proportion of the total sum of looks to the DO and subject noun. Conditions of cooperative and neutral prosody x early closure are referred to as cooperative early (CE) and neutral early (NE). Adults and TD children significantly show an interaction between prosody and closure during the ambiguous window (-400 ms to 0ms). HFA children show this same pattern of interaction, but during the noun processing window (0ms to 100 ms). Younger TD children do not show this pattern at all.

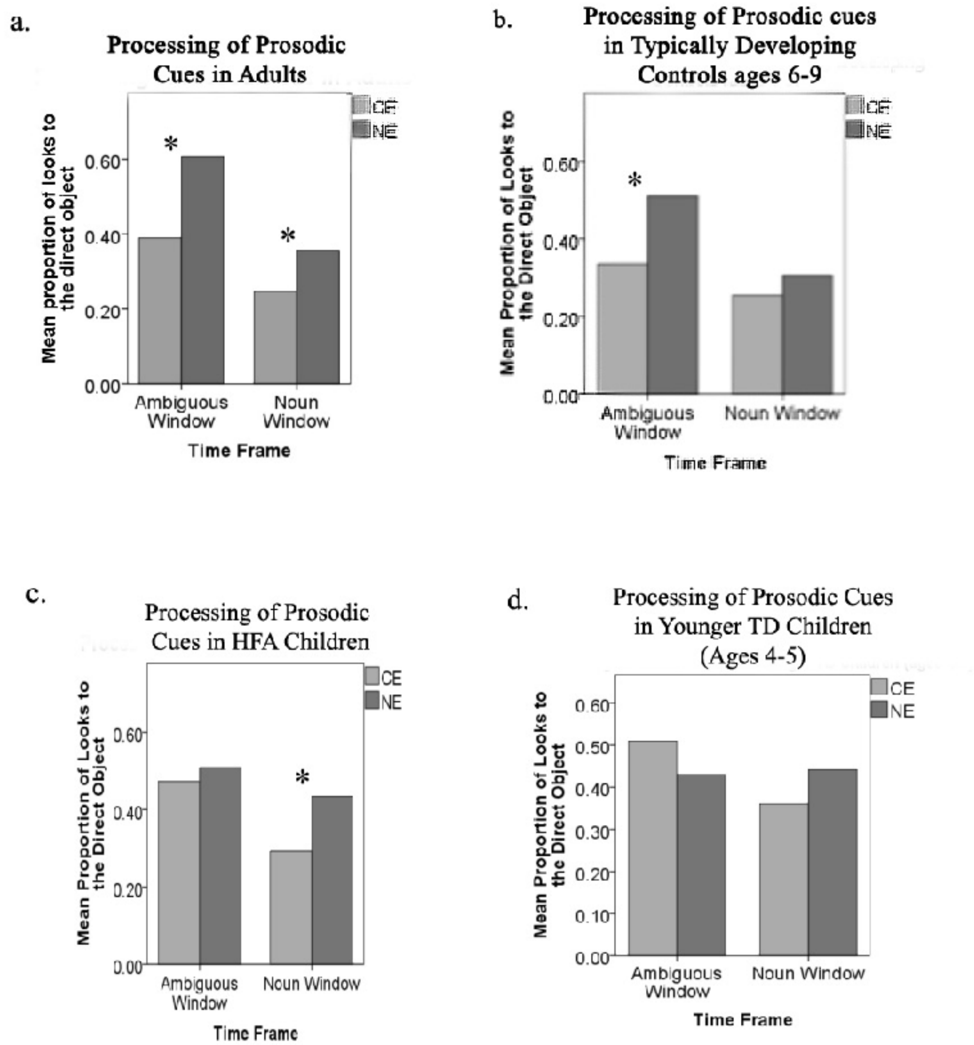
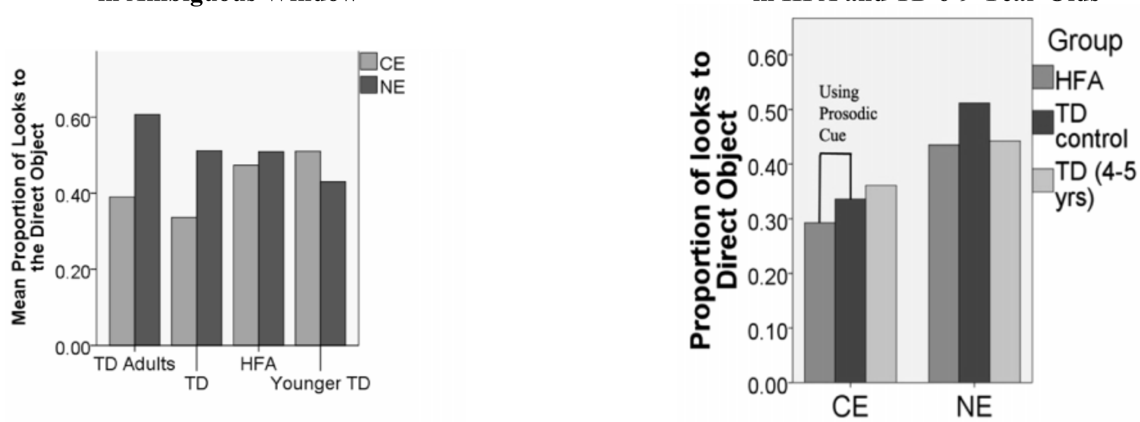


Figure 3. Comparison of fixations.
a. Participants' looks to the direct object (DO) as proportion of the total sum of looks to the direct object and subject noun during auditory input between -400 and 0 ms, otherwise referred to as the syntactically "ambiguous" window. A significant difference between the CE condition and its neutral prosody counterpart (NE) is evident for TD subjects (6-9-year-old children and adults) but not HFA subjects nor younger children.
b. This figure displays the effective processing of cooperative prosodic cues to signal early closure in both HFA and TD groups, but at different time intervals. HFA participants' looks to the direct object as proportion of the total sum of looks to the direct object and subject noun during auditory input between 0 and 100 ms (i.e., the noun window), compared to similar fixations of TD participants during the auditory input between -400 and 0 ms (i.e., the ambiguous window).

a. Processing of Prosodic cues in Ambiguous Window

b. Appropriate use of Prosody in HFA and TD 6-9-Year-Olds



5.3 Younger typically developing children (4-5)

The results for the younger group showed that, at an earlier age, even TD children had not developed the ability to use the prosodic cues for syntactic disambiguation. At no point during the on-line processing of the test phrase did these younger children react as though they were responding to the prosodic cues (**Figure 2d**). In neither the ambiguous window nor the noun window was there any main effect of prosody or closure; moreover, as expected from this, no interaction between prosody and closure was found ($F(1,15)=0.267$, $p=0.613$, $\eta_p^2=0.007$ and $F(1,15)=1.606$, $p>0.05$, $\eta_p^2= 0.221$, respectively). As a result of the difference between 4-5- and 6-9-year-old TD children to use prosody for syntactic disambiguation, there was a significant effect of age in the CE condition (ANOVA: $F(1,43)=12.583$, $p=0.001$). In the noun-processing window, the results are similar. The interaction between prosody and closure is $F(1,15)=1.606$, $p=0.224$, $\eta_p^2= 0.062$.

Although this section of the study has interesting implications with regard to the absence of prosodic cue processing in TD children under the age of 6, these non-significant results are based on only 16 participants, lack statistical power, and should be considered preliminary findings for future studies to replicate. It is also important to note that these findings partially contrast with research on 72 TD children, ages 4-6.5 (Snedeker & Yuan, 2008), which found that children can resolve syntactic ambiguity using prosodic cues during the first block of a non-mixed stimuli experiment. Snedeker & Yuan's study indicates that children of this age use some level of prosodic processing, but not enough to gauge it correctly in a non-blocked, or mixed, situation (2008).

6. Discussion

The present study was designed to address the question of whether children with autism have the receptive pragmatic capacity to use prosody to disambiguate syntactic phrasing. While 6-to-9-year-old children with HFA process prosodic cues more slowly than their typically aged peers, they nonetheless do parse it in order to resolve syntactic ambiguity. Moreover, children with HFA are developmentally in sync with their same-aged, TD peers, as they competently use the prosodic cues in intonational phrase boundaries. The results indicate that children, ages 6-9, in both the HFA and TD diagnostic groups, are developmentally more capable to process prosodic cues for means of syntactic disambiguation than younger TD children, ages 4-5, who cannot use this cue effectively at any point in their on-line processing. This study provides evidence against the generalization that individuals with ASD do not process prosody in any form. Rather, it supports the conclusion that children with ASD who have normal-range language intelligence are sensitive to intonational phrase boundaries, even though they cannot use IPh for parsing language as effectively as TD children of the same age.

Researchers have studied prosody for its ability to enhance the communicative functionality of language (McCann & Peppé, 2003). Failure to effectively use prosody may result in atypical development in the social and pragmatic skills that normally benefit from the presence of this additional information (Baltaxe & Simmons, 1985; McCann & Peppé, 2003; Paul et al., 2005a; Paul et al., 2005b; Jarvinen-Pasley et al., 2008; Grossman et al., 2010; Peppé et al., 2011; Diehl et al., in prep; and others). As such, impairments in prosody may be a root cause for the failure of individuals with ASD to develop theory of mind and an understanding of others' intentions. The study's results have interesting implications for our understanding of the developmental trajectory of individuals with autism spectrum disorder.

6.1 Explanations for Previous and Current Results

The results of this study demonstrate that persons with HFA do, in fact, process prosodic cues at the higher-order syntactic level, but with a notable time delay. The present study's finding that individuals with HFA effectively use prosody to serve the grammatical function of phrasing is consistent with previous findings by Peppé et al. (2007; 2011). However, the apparent processing delay implies that this system may not be functioning as well as Peppé et al. (2007)'s results suggest. Conversational discourse presents itself at a fairly rapid pace, and speakers and listeners alike are required to follow the conversation in order to continue providing appropriate and relevant contributions (Grice, 1975).

One possibility is that children, ages 6-9, can process the pause cue of an intonational phrase boundary, but not the tonal contours surrounding the boundary, allowing them to parse syntax using IPh with diminished efficiency. This hypothesis stems from the previous findings that indicate that children with HFA have a harder time with intonational prosodic cues (turn-end, affect) than they do with rhythmic prosodic cues (stress/focus, chunking) (Korpilahti et al., 2006; Jarvinen-Pasley et al., 2008; Paul et al., 2005a; Peppé et al., 2011). A relative strength of their ability to process the rhythmic element in IPh (as opposed to the subsidiary tonal changes) would be consistent with the finding that children with HFA exhibit intact lexical and syntactic acquisition, which rely primarily on the pause cue within the IPh, and impaired pragmatic skills, which rely more on intonational cues. Using the cue provided by pause alone, the children with HFA may have adequate information to correctly parse the syntactic meaning of a sentence, but an impaired ability to process supplemental tonal information might introduce inefficiency into the global processing of the IPh cues (i.e., leading to a 100 ms delay). However, further research is needed to confirm or refute this hypothesis.

While the present study's results on receptive language skills do not directly translate to expressive language skills, there may be a relationship between receptive processing delay and the production of expressive prosodic cues for syntactic disambiguation. Children with ASD have been noted to have a larger expressive than receptive deficit, although the reasons for this are not known (McCann et al., 2006). One possible explanation is that children have learned to process elements of prosody, but due to a lack of Theory of Mind, do not express those same cues for the benefit of others' understanding. Assuming that receptive prosody is a precursor to the development of expressive prosody, as speculated by Jarvinen-Pasley et al. (2008), the more general findings of appropriate receptive processing in the present study suggest that expressive prosody, for means of syntactic phrasing, is likely to be fairly unimpaired, as well. If possible, this study should be modified so that it can also be used to test productive prosody for means of syntactic disambiguation.

6.2 Analysis of the Selective Demographic of Participants

Another important element of this study is that its participants were a group of high-functioning individuals, whose standard language IQ was similar, on average, to that of their typically developing peers. However, this demographic only represents a small portion of the broader spectrum of individuals diagnosed with ASD. Twenty-five to fifty percent of the diagnosed population has fairly little functional communication or is mute (Jarvinen-Pasley et al., 2008). Because language abilities vary widely across the autism spectrum, it is not clear how these results may pertain to ASD children with less-intact language skills (Kjelgaard & Tager-Flusberg, 2001). However, there is some evidence that prosodic impairments, especially in terms of those involving receptive language, are greater for those with lower language scores, thus suggesting some level of correlation between prosody and language ability (McCann et al., 2006; Peppé et al., 2011). The present study did not test children with below-average language IQ in order to avoid language-related confounding variables and to isolate prosodic as the only (potentially) differentiating mean of processing ambiguous syntactic stimuli. However, considering that the majority of the ASD population does have a broader language deficit, further studies should inquire into ways of investigating how HFA individuals with a lower-than-average language IQ use prosodic cues at the syntactic level.

One indicator that lower functioning individuals with ASD are indeed sensitive to prosody is the fact that, in producing echolalia, these individuals frequently reproduce highly accurate, inflected vocalizations of the speeches they are repeated – i.e., not simply the lexical/syntactic aspect of the phrases but also the contours and tones. For instance, children with ASD often "adopt the accent and speech mannerisms of characters in videos with great accuracy" (Peppé et al., 2011, p. 50). Thus, while these children cannot necessarily apply the rules of prosody when they produce original utterances, they reproduce it accurately in echolalia. This suggests that lower-functioning children with ASD have some sensitivity to prosody, despite impairments in the ability to process or express prosody in a fully functional manner.

6.3 Clinical Importance

The investigation of prosodic processing in individuals with ASD is clinically important for understanding the communication deficits that are evident across the affected population. Poor interpersonal competence in ASD children has been specifically attributed to their inappropriate production of prosody (Paul et al., 2005b), and further knowledge about this inappropriate prosody may advance our understanding of what drives abnormal social competence in the ASD population at large. While the present study did not find that the ability to process pause cue for phrasing is completely lacking in those with ASD, it did detect differences in prosodic processing (slower response time) that would clearly affect their social interactions. In particular, some individuals with high-functioning autism are noted to interrupt when engaging in conversational discourse (Fay & Schuler, 1980). This deficit may be explained by receptive processing delays of prosodic IPh cues, which might make it difficult for HFA individuals to efficiently decide whether or not a speaker has finished speaking (McCann & Peppé, 2003). Moreover, a component of ToM may be essential for the comprehension of appropriate social discourse rules, which dictate that the speaker should pause to allow a response from the listener (Wilkinson, 1998). Clinical interventions should stress the overarching importance of prosody to enhance pragmatic skills. In particular, clinical interventions could focus on prosodic cues, either by over-emphasis of acoustic variations or by explicitly drawing attention to how acoustic and linguistic content coincide, as a means of helping HFA individuals to increase the speed and efficiency with which they process prosody in their daily lives.

4.5 *Further Research*

Perceptual processing of voices is a key attribute of processing socially relevant information (Gervais et al., 2011). This prosodic processing begins to form at an early age of development and is likely to be a bootstrapping device for pragmatic, linguistic, and social development. As previously mentioned, a few studies have examined the prosodic differences in canonical babbling, as an indicator of future language production (Sheinkopf et al., 2000). Only a few studies have also noted that joint attention with infants may be facilitated by prosodic melodies (Sakkalou & Gattis, 2012). It would be worthwhile for future studies to analyze the babbling of infants who are at high risk for autism (i.e., they have an older sibling with autism) for prosodic atypicalities. An established measure of prosodic differences in the population could provide a critical benchmark for diagnosing children at an early age.

Additional research is also needed to refine the current understanding of prosody in autism, going beyond the general observations concerning disordered prosody to identify the particular aspect or aspects of prosody that are impaired throughout the ASD population. Despite observations that suggest that high numbers of HFA children use inappropriate stress patterns and inappropriate prosodic resonance, studies of this population acknowledge that the nature and extent of these deficits vary across participants (Paul et al., 2005a). Participants who score low in one realm of prosody may display typical expressive and/or receptive prosody in another realm; thus, like many attributes of persons with ASD, their capabilities and impairments with respect to prosody form a wide spectrum. Yet, even within this wide variation, there are likely to be common, fundamental deficits in how individuals use prosody (both receptively and expressively). More studies are needed to distinguish specific patterns of impairment in the prosodic facilitation of syntactic, semantic, and pragmatic language that occur consistently among individuals with ASD.

Appendix A
All Experiment Stimuli Sentences.

Iph format[1], to be applied to all the following sentences:
1. When Crystal the robot dressed, the nice cookies baked.
CE: When Crystal the robot dressed**H*L—L%** the nice cookies baked.
When Crystal the robot dressed the nice cookies baked.
NE: When Crystal the robot**L+H*** dressedL—the cookies **H*L**—baked.
When Crystal the robot dressed the nice girl, the cookies baked.
CL: When Crystal the robot dressed the nice girl**H*L—L%** the cookies baked
When Crystal the robot dressed the nice girl the cookies baked
NL: When Crystal the robot**L+H*** baked**L**—the nice cookies**H*L**—the cookies baked.

1. When Crystal the robot dressed, the nice cookies baked.
When Crystal the robot dressed the nice girl, the cookies baked.

2. While GI the robot won, the big girl ran away.
While the GI the robot won the big prize, the girl ran away.

3. Because Zet the robot lost, the pretty lady comforted him.
Because Zet the robot lost the pretty bag, the lady comforted him.

4. While the Gnut the robot read, the old man fell asleep.
While the Gnut the robot read the old book, the man fell asleep.

5. When Bors the robot ate, the nice boy opened his presents.
When Bors the robot ate the nice cake, the boy opened his presents.

6. When Trurl the robot swallowed, the nice man got hungry.
When Trurl the robot swallowed the nice chocolate, the man got hungry.

7. While the Aniel the robot kicked, the nice coach looked at his watch.
While the Aniel the robot kicked the nice ball, the coach looked at his watch.

8. While the Tidy the robot packed, his favorite dog barked.
While the Tidy the robot packed his favorite suitcase, his dog barked.

9. When the Fagor the robot hunted, the big stone rolled away.
When the Fagor the robot hunted the big moose, the stone rolled away.

10. When Solo the robot shot, the little phone rang.
When Solo the robot shot the little bird, the phone rang.

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[1] Intonational Phrases (Iph) are defined by: high, low pitch accents (H*, L*); High, low phrase accents (H-, L-); high, low boundary tone (H%, L%).

11. Because Elio the robot scratched, the big nurse told him to stop.
Because Elio the robot scratched the big dog, the nurse told him to stop.

12. While Dub the robot wrote, a short boy called her.
While Dub the robot wrote a short essay, a boy called her

13. While Dee the robot typed, the important boss waited patiently.
While Dee the robot typed the important article, the boss waited patiently.

14. While Dorfl the robot drove, his pretty wife was on the phone.
While Dorfl the robot drove his pretty car, his wife was on the phone.

15. When Nimu the robot studied, the old teacher came to sit beside her.
When Nimu the robot studied the old textbooks, the teacher came to sit beside her.

16. Because Freya the robot hid the big cannon, the man got scared.
Because Freya the robot hid, the big man got scared.

17. While Gort the robot walked, the nice neighbor mowed the lawn.
While Gort the robot walked the nice dog, the neighbor mowed the lawn.

18. Because Torg the robot vacuumed, the dirty cat got scared.
Because Torg the robot vacuumed the dirty carpet, the cat got scared.

19. While Chani the robot paddled, the big dog went swimming.
While Chani the robot paddled the big boat, the dog went swimming.

20. While Garth the robot rode, his nice daughter gave him ice cream.
While Garth the robot rode his nice boat, his daughter gave him ice cream.

21. While Necron the robot grilled, the big man ate tomatoes.
While Necron the robot grilled the big steak, the big man ate tomatoes.

22. When Pris the robot drew, the nice policeman complimented.
When Pris the robot drew the nice picture, the policeman complimented.

23. While Vahki the robot stirred, the nice boy sang.
While Vahki the robot stirred the nice soup, the boy sang.

24. While Gerty the robot drank, the nice fireman ate a cookie.
While Gerty the robot drank his nice juice, the fireman ate a cookie.

25. When Dor the robot attacked, the new sword was shining.
When Dor the robot attacked the new spaceship, the sword was shining.

26. When Morg the robot counted, his small son came to help.

When Morg the robot counted the small coins, his son came to help.

27. While Verda the robot raced, the new computer turned off.
While Verda the robot raced the new boy, his computer turned off.

28. While Quark the robot played, the fun doctor smiled.
While Quark the robot played the fun game, the fun doctor smiled.

29. While Reddion the robot painted, his nice daughter cleaned the house.
While Reddion the robot painted his nice picture, his daughter cleaned the house.

30. While Atoz the robot parked, the big baby took a nap.
While Atoz the robot parked the big car, the baby took a nap.

31. Because Voc the robot cleaned, the pretty girl gave him a smile.
Because Voc the robot cleaned the pretty kitchen, the girl gave him a smile.

32. When Zed the robot wrestled, the nice soup got cold.
When Zed the robot wrestled the nice dog, his soup got cold.

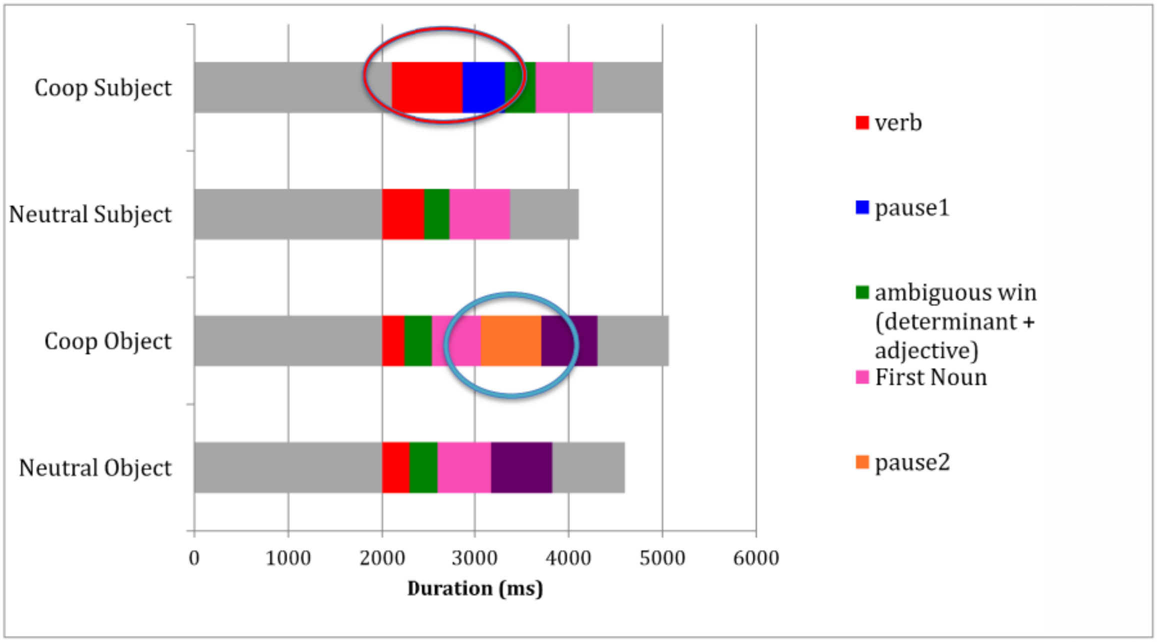
33. While Kraal the robot chewed, the lovely lady took a picture.
While Kraal the robot chewed the lovely chicken, the lady took a picture.

34. When Dum the robot sniffed, the pretty woman gave her a tissue.
When Dum the robot sniffed the pretty flower, the woman gave her a tissue.

35.While Zarl the robot baked, the big postman delivered the mail.
While Zarl the robot baked the big muffins, the postman delivered the mail.

36. Because Ark the robot bathed, the nice carpet got soaked.
Because Ark the robot bathed the nice baby, the carpet got soaked.

Appendix B
Time-scale of phrases



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