Statistical Word Learning in Children with Language Disorders

By
Eileen Haebig

A dissertation submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
(Communication Sciences and Disorders)

at the
University of Wisconsin-Madison
2015

Date of final oral examination: May 13, 2015

This dissertation is approved by the following members of the Final Oral Committee:
Susan Ellis Weismer, Professor, Communication Sciences and Disorders
Jan Edwards, Professor, Communication Sciences and Disorders
Margarita Kaushanskaya, Associate Professor, Communication Sciences and Disorders
Audra Sterling, Assistant Professor, Communication Sciences and Disorders
Jenny Saffran, Professor, Psychology

Table of Contents

Dedication

This dissertation is dedicated to families who have children with neurodevelopmental disorders, to researchers, and to clinicians who will hopefully benefit from this work.

Acknowledgments

This work was supported by the following NIH grants: F31 DC013485 (Haebig), R01 DC011750 (Ellis Weismer & Kaushanskaya), T32 DC005359 (Susan Ellis Weismer), R37 HD037466 (Saffran), and P30 HD003352 (Mailick). Additional support was provided by the Wisconsin Speech-Language Pathology and Audiology Association Foundation through the Vicki Lord Larson and James R. Larson Research Grant and the Emma Allen Fellowship Award through the University of Wisconsin – Madison Department of Communication Sciences and Disorders.

I would like to thank my advisor, Dr. Susan Ellis Weismer, and my dissertation committee: Dr. Jan Edwards, Dr. Rita Kaushanskaya, Dr., Audra Sterling, and Dr. Jenny Saffran for their support and encouragement. In addition, I would like to thank the members of the Language Processes Lab and the Language and Attention Project, with particular thanks to Courtney Venker, Meghan Davidson, Heidi Sindberg, Corey Ray-Subramanian, Megan Gross, Milijana Buac, Ishanti Gangopadhyay, Anthony Goodwin, and Sara Kover. Furthermore, I am grateful for the help given to me by Kaitlin Meyer, Lizzy Elkin, Andrea Solochek, Madeleine Swenson, Anna Dorrance Bina, Tayrn Stricker, and Liz Premo. I would also like to thank the members of the Infant Learning Lab, the Little Listeners Project, and the Growth Curve Modeling group, especially Erica Wojcik, Chris Potter, Brianna McMillan, Ron Pomper, Martin Zettersten, Lyn Perry, Viridiana Benite, Tristan Mahr, and last but definitely not least Matt Winn.

Additionally, I would like to thank the children and families who participated in this study.

Lastly I would like to thank my family and friends, whose support means so much to me. In particular I thank Chris Cox, who provided astute scientific and statistical guidance and loving encouragement every step of the way.

Abstract

Word learning abilities are important for academic and social development. As such, it is necessary to understand the mechanistic underpinnings of word learning in children with typical and atypical development. This study examined word learning mechanisms in children with typical development, autism spectrum disorder (ASD), and specific language impairment (SLI) who were matched on chronological age and nonverbal cognition. Specifically, abilities in statistical learning and fast mapping were examined. This study was the first to examine whether the output of statistical learning enhanced word learning abilities in school age children with typical and atypical language development. It was found that children with SLI have deficits in statistical learning and fast mapping abilities, relative to children with ASD and typical development. In addition, exploratory analyses revealed that statistical learning and fast mapping abilities in children with ASD who have concomitant language impairments are relatively intact, but slightly depressed. Lastly, when examining the role of statistical learning in word learning, it was found that exposure to an artificial language that contains some of the words presented in a subsequent word learning task enhanced learning in children with SLI. However, the word learning appeared to have been facilitated by the exposure to the sounds in the artificial language instead of the statistical structure. Implications to theory are discussed.

Chapter 1: Introduction

School-age children with typical development learn as many as 12 words per day (Bloom, 2000); however, children with language impairments show persistent deficits in word learning. Children with autism spectrum disorders (ASD) and children with specific language impairment (SLI) demonstrate word learning difficulties that are noticeable early in development and extend into the school-age years (Baron-Cohen, Baldwin, & Crowson, 1997; Gray, 2004; Luyster, Lopez, & Lord, 2007; Oetting, Rice, & Swank, 1995). Word knowledge is pivotal to language development (e.g., grammatical and morphological development) and greatly impacts academic learning (Durkin, Conti-Ramsden, & Simkin, 2012) and social development (Bashir & Scavuzzo, 1992). Academic achievement is heavily influenced by reading abilities, and importantly, word knowledge is associated with reading. In fact, both breadth and depth of word knowledge relate to phonemic awareness, decoding, and reading comprehension skills, which are pivotal skills for successful reading (Ouellette, 2006; Tannenbaum, Torgesen, & Wagner, 2006; Walley, Metsala, & Victoria, 2003). Accordingly, reading interventions have integrated word-learning activities in oral language interventions and have found improvements in reading abilities (Clarke, Snowling, Truelove, & Hulme, 2010). Clearly, word learning is a pivotal skill that has broad implications for performance in other domains, even beyond the preschool years. As such, word learning mechanisms need to be better understood in children with language impairments, such as children with ASD and SLI. Researchers have worked towards studying the mechanisms of word learning by first assessing how children track information about the sounds in their native language.

Statistical Learning

Children are exposed to an extraordinarily vast amount of input through multiple senses every day. In order for the input to be informative, children must be able to extract trends or patterns, and make connections to prior knowledge. Some of the information they learn is made explicit to them, and they experience episodic learning. Other information, however, is learned by implicitly processing complex information without conscious awareness of the information being learned. Statistical learning is a type of domain-general implicit learning mechanism whereby individuals exploit the statistical structure of the input to facilitate learning (Reber, 1967; Saffran, Aslin, & Newport, 1996; Saffran, Newport, Aslin, Tunick, & Barrueco, 1997). Importantly, research has found that humans have an attention bias to regularities in the environment regardless of task relevance or intrinsic salience, which facilitates implicit learning (Zhao, Al-Aidroos, & Turk-Browne, 2013). Although implicit learning seems to depend on attentional and working memory mechanisms, it is thought that minimal attention is required for implicit learning to occur (Seger, 1994).

In typically developing populations, statistical learning serves as a language learning mechanism for phonetic discrimination (Maye, Werker, & Gerken, 2002), word learning (Smith & Yu, 2008), and syntactic learning (Amato & MacDonald, 2010; Gomez & Gerken, 1999). Infants as young as 8 months of age evidence this powerful learning mechanism that enables them to learn the types of structures that exist in language systems (Saffran et al., 1996). Before infants learn their first words, they must first learn how to segment the sounds that comprise meaningful words. Acoustic cues often cannot reliably be used to identify word boundaries; therefore, infants must learn patterns in their native language(s) to identify statistical regularities

in order to segment words. Once words are isolated, their meanings can be learned. But how do infants learn to segment speech?

One method of studying statistical learning is through a segmenting task. Segmenting tasks use various types of stimuli and testing paradigms. For example, Saffran and colleagues (1996) identified statistical learning skills in 8-month-old infants by measuring looking times during a segmenting task. Infants listened to an artificial language that contained no prosodic or timing cues to facilitate segmentation of words. Words could only be segmented by implicitly picking up on statistical patterns in the speech signal. Segmenting tasks have been widely used to demonstrate the ability to track co-occurrence frequencies between syllables and learn transitional probabilities between syllables. Transitional probability (TP) is the likelihood of stimulus Y given stimulus X, as a function of the frequency of the co-occurrence of XY (i.e., frequency of XY| frequency of X; [Saffran et al., 1996]). For example, the likelihood of "bay" being followed by "bee" (baby) is extremely high and therefore a word with very high internal predictability, or transitional probability between the two syllables. Conversely, the transitional probability of the syllables "leebay" (e.g., silly baby) is very low in English, which would make it unlikely that the two syllables would be segmented together. Multiple types of statistics can be tracked in statistical learning. The previous example demonstrated forward transitional probability. In addition, individuals can track and learn backward transitional probability (Pelucchi, Hay, & Saffran, 2009a; Perruchet & Desaulty, 2008). Backward transitional probability is the probability of X preceding Y (i.e., frequency of XY | frequency of Y).

Artificial languages contain many features found in real languages, but still allow researchers to control certain features, such as the amount of exposure and the type of exposure individuals receive in learning tasks. Although artificial languages contain many characteristics

of language, they are less complex than natural languages. Artificial languages contain a limited number of phonemes, syllable combinations, and words. Furthermore, most artificial languages remove rhythmic patterning, pitch variation, and other acoustic variation typically present in natural languages. Given this, learning challenges differ between artificial and natural languages that are syntactically correct and semantically meaningful. To address this concern, Pelucchi and colleagues created Italian corpora that maintained complexities found in natural language, but contained syllables with differing strengths in internal transitional probabilities (Pelucchi et al., 2009a, 2009b). Particular words and word orders were chosen so that the internal transitional probabilities between syllable sequences were controlled, allowing specific target words to have internal transitional probabilities that were very high (e.g., HTP = 1.0) and other words to have low transitional probabilities (e.g., LTP = 0.33). Pelucchi and colleagues tested infant statistical learning after hearing 3 minutes of a natural Italian language sample through a preferential looking head turn methodology (Saffran et al., 1996). Pelucchi and colleagues demonstrated that infants can, in fact, learn forward and backward transitional probabilities in unknown natural languages. Thus, statistical learning is a learning mechanism that is robust enough to allow for learning in unfamiliar natural languages, which contain added syntactic, semantic, and phonologic complexities. Of note though, the reinforcing redundancies of the natural language patterns may also strengthen learning, rather than distract.

Sound to Meaning

Word learning requires a sequence of cognitive processes. To learn a word, one must process phonological information in new words, attend to relevant linguistic and nonlinguistic contextual cues, map meaning onto the phonological form of the word, relate the new meaning with previous conceptual knowledge, retain the form-meaning association in one's memory, and

be able to recall and use the word appropriately (Alt, Plante, & Creusere, 2004; Alt & Plante, 2006; Ellis Weismer & Evans, 2002; Kan & Windsor, 2010; Nation, 2014). Therefore, segmenting sounds into chunks with high transitional probabilities is not sufficient for lexical development. To better establish statistical learning as a language-learning mechanism, Graf Estes and colleagues studied how infants apply knowledge of sounds of their language to establish a connection between sounds and meanings (Graf Estes, Evans, Alibali, & Saffran, 2007). More specifically, Graf Estes and colleagues studied the output of statistical learning by testing whether newly segmented sound sequences serve as good candidate words to which novel meanings will be mapped.

In the study by Graf Estes et al. (2007), 17-month-old infants were familiarized with an artificial language for a short period of time. The artificial language contained disyllabic words that could only reliably be segmented from the continuous speech stream by the distributional information in the artificial language (i.e., transitional probability). Directly after the familiarization phase, children were taught object-label associations using either words from the artificial language (TP = 1.0), part-words (TP = 0.5; syllable sequences that were presented sequentially but crossed word boundaries in the artificial language), or nonwords (TP = 0.0; syllable sequences that did not appear sequentially in the artificial language). A modified Switch paradigm was used to test learning (Werker, Cohen, Lloyd, & Casasola, 1998). Half of the test trials were Same trials, in which the object and label pairings were the same as the object-label pairs that were taught in the teaching phase. The other half of the test trials were Switch trials, in which the object and label pairings were switched from teaching (e.g., label A was paired with object B). Longer looking time to the Switch trials indicated a novelty preference, suggesting that infants had learned the object-label association during the teaching phase. Graf Estes and

colleagues found that only the infants who were taught the object-label associations with the words (TP = 1.0) as labels displayed a novelty preference during the Switch trials. The children who had been taught object-label associations with part-words (TP = 0.5) or nonwords (TP = 0.0) did not demonstrate novelty preferences. Thus, newly segmented sound sequences with high transitional probability seem to function as good candidate words. Graf Estes et al. (2007) demonstrated that the output of statistical learning can support object-label association learning in infants.

To explore statistical learning further, Hay and colleagues (2011) built upon the work completed by Graf Estes and colleagues (2007) and examined whether infants treat newly segmented words with high transitional probabilities, derived from exposure to an unknown natural language, as candidate words to improve subsequent word learning opportunities. Hay and colleagues used the same study design as Graf Estes et al. (2007); however, instead of using an artificial language, they used a natural language (i.e., Italian; Pelucchi et al., 2009a, 2009b), that was grammatically and semantically correct and used trochaic stress patterns. Infants were able to track both the backward and forward transitional probabilities in the natural input and these statistical cues facilitated learning over and above the trochaic stress cues that were present in both high and low transitional probability words. Words with high transitional probabilities (forward or backward) served as better candidate labels for objects than words with low transitional probabilities.

In the current study, the concept of mapping meaning to sounds or words refers to learning object categories, or learning to use a label to refer to a specific referent or members of that group (e.g., “That’s a modi.”). This description of “meaningful label” is commonly referred to as count noun (Hall, Williams, & Bélanger, 2010; Smith, Jones, & Landau, 1992). Admittedly,

this definition is simplistic, for the demands of the semantic system are rather low (Nation, 2014). Individuals learn much more information about words during word learning experiences (e.g., phonological form, word class, semantic information, facts associated with labels, relationships with other previously learned concepts).

Experience with Phonological Forms and the Link to Lexical Development

Infants' exposure to words and sounds shape the way they process acoustic information. It is well known that the language parents provide their children improves child language learning and language outcomes (e.g., Hart & Risley, 1992; Landry, Smith, Miller-Loncar, & Swank, 1997; Tomasello & Todd, 1983). In fact, maternal linguistic input has been found to improve lexical development and lexical processing (Hurtado, Marchman, & Fernald, 2008). Lexically supported learning is a learning strategy where one uses known words to learn new words (Gathercole, 2006). Lexical learning also can support grammatical learning and the development of general construction types (i.e., lexical bootstrapping; Wilson, 2003). For example, performance on nonword repetition tasks relates to language knowledge; there is an association between word knowledge and performance on nonword repetition (Edwards, Beckman, & Munson, 2004). In addition, individuals are more accurate at repeating novel words that have high wordlikeness than words that do not have high wordlikeness (Gathercole, 1995).

The capacity to hold phonological information in working memory has been shown to be associated with vocabulary development and language development (e.g., Gathercole & Baddeley, 1990). According to Baddeley and colleagues' model, when learning a word, the phonological information is temporarily stored in the phonological loop (Baddeley, Gathercole, & Papagno, 1998; Baddeley & Hitch, 1974). As discussed above, meaning is mapped onto the sounds that are being temporarily stored in the phonological loop during word learning. As such,

individuals also can use storage-mediated learning to facilitate word learning by relying on the ability to temporarily store phonological information during a word learning experience instead of using the lexically supported learning strategy. Indeed, increased ability to temporarily store phonological information, as demonstrated in nonword repetition tasks, is believed to have a reciprocal developmental relationship with lexical knowledge (Gathercole, 1995), in that lexical knowledge facilitates nonword repetition abilities, and nonword repetition facilitates word learning.

Phonological storage is influenced by several factors. It can be affected by learning experiences and the initial construction of the phonological representations. In addition, abilities in phonological storage can be influenced by characteristics of the individual and how those characteristics affect the quality and the strength of the phonological representations that are formed (Gathercole, 2006). Children with SLI are believed to have deficits in phonological storage and processing skills (Edwards & Lahey, 2008; Gathercole, 2006; Lahey, Edwards, & Munson, 2001). Researchers have devoted a great deal of attention to phonological processing and phonological storage capacity in individuals with SLI. Although individuals with SLI are sometimes characterized as having primarily grammatical deficits, additional research has identified other deficits in this population. In fact, some theories have proposed that language impairments seen in SLI occur because of deficits in phonological working memory (Ellis Weismer, 1996; Gathercole & Baddeley, 1990; Leonard et al., 2007) or phonological processing (Joanisse & Seidenberg, 2003; Tallal, Miller, & Fitch, 1993), among other theories of SLI.

Although statistical learning has been found to be a robust learning mechanism across several domains, more work is needed to help explain how the output of statistical learning contributes to the process of linking knowledge of sound patterns to meaning. Even more

research is needed to understand this process in children with atypical language development (Nation, 2014). In the following sections, two populations will be discussed, both of which have language deficits: children with specific language impairment (SLI) and children with autism spectrum disorder (ASD). A great deal of research on language acquisition in SLI has been completed, which will provide possible theories of atypical language development that could potentially be applied to the explanation of language difficulties in children with ASD.

Specific Language Impairment

Some views of SLI primarily portray deficits in a domain-specific skill, the grammatical domain of language (Rice & Wexler, 1996; Rice, Wexler, & Cleave, 1995; van der Lely, 2005; van der Lely & Ullman, 2001). The presence or role of other cognitive deficits is not considered to play a causal role in domain-specific deficits of linguistic skills. For example, the Extended Optional Infinitive (EOI) theory posits that children with SLI experience an extended period of grammatical development that is seen in younger typically developing children (Rice, Tomblin, Hoffman, Richman, & Marquis, 2004; Rice et al., 1995; Rice, Wexler, & Redmond, 1999; Rice & Wexler, 1996). Rice and colleagues based the EOI theory on Wexler's (1994) Optional Infinitive theory, which characterizes language development in children with typical development. Wexler (1994) noted that typically developing children go through a phase in which they correctly mark finite markers (e.g., regular past tense –ed, third-person singular –s), but do so inconsistently. Instances when finiteness markers are not marked correctly typically result in omission errors (e.g., walk/walked, walk/walks). It is reasoned that children only obtain partial understanding of the linguistic rule of finiteness marking and hold the misconception that finiteness markers can be marked optionally without impacting meaning. Rice and colleagues found that children with SLI mirrored this phase in later years, resulting in inconsistently marked

finite markers at ages that were well beyond expectations for typical language development; thus, an extended optional infinitive theory was presented. Rice and colleagues also argue that these linguistic errors are specific to finite markers (Rice & Wexler, 1996) and cannot be explained by general impairments like low cognition (Rice et al., 2004).

Another perspective has discussed SLI in terms of the link between language and the procedural and declarative memory systems. Ullman presented the declarative/procedural model in a domain-specific framework (Ullman & Pierpont, 2005; Ullman, 2001). In this theory, two domains of language, grammar and vocabulary are described as structurally distinct, much like Chomsky (1959) and Pinker's (1994) description of language. This perspective assumes that procedural learning and memory facilitate the learning of grammatical information. Procedural learning and memory are thought to be supported by brain structures such as frontal/basal ganglia circuits. Procedural learning is a type of implicit learning. In contrast to grammatical knowledge, vocabulary is stored in one's mental lexicon and words are learned by the declarative memory system. In the Procedural Deficit Hypothesis, Ullman suggests that children with SLI have a procedural learning deficit as evidenced by their impaired grammatical performance. Ullman and Pierpont (2005) suggest that abilities in declarative memory are a relative strength and may be used to compensate for procedural deficits in word learning tasks. The reduced ability to use phonological computational/statistical implicit information during word learning may be overridden by other strengths in in declarative memory skills during word learning.

Ullman's procedural/declarative model fails to acknowledge that words are not taught in isolation. Infants learn about the sound system to which they are exposed and discover words in continuous speech. As previously discussed, one method that infants use to segment sounds that

cohere into words is through statistical learning. Although performance in grammar is particularly poor in children with SLI, other abilities also can be impaired (Leonard, 2014).

Other competing theories of SLI take a broader, less modular, approach to explaining language impairments in individuals with SLI. For example, Leonard proposed the Surface Account (Leonard, 1989, 2014; Leonard et al., 1992; Leonard, Eyer, Bedore, & Grela, 1997). Leonard suggested that children with SLI have difficulties in processing certain morphemes. More salient morphemes that have syllabic status (e.g., -ing; high phonetic-substance morphemes) are more clearly perceived and learned earlier. However, non-syllabic morphemes (e.g., plural –s, third-person singular –s; low phonetic-substance morphemes) are more difficult to process, making learning of the morphosyntactic role the morpheme plays a more difficult task. In fact, Leonard (1998) examined finite and nonfinite markers to test Rice and Wexler's (1996) extended optional infinitive theory and Ullman and Gopnik's (1999) implicit rule learning impairment theory. Leonard found that, although children with SLI performed poorly on finiteness markers, they also produced errors (dropped markers) on nonfinite forms such as plural –s, albeit to a smaller degree. Leonard did not rule out Rice and Wexler's extended optional infinitive theory but suggested that underlying processing deficits could help explain language errors seen in children with SLI (e.g., Leonard, 1989).

Although there are several models, many that have not been discussed here, that attempt to describe causal sources of language impairments, a consensus has not been reached. In fact, some propose that there is no single cause of language impairment and that there are different cognitive factors that may interact in a probabilistic manner (Bishop, 2006; Nation, 2014). This seems particularly likely to be the case given that children with SLI form a rather heterogeneous group.

Word learning and word knowledge in children with SLI. Although the vast majority of research on children with SLI has focused on grammar, some research has assessed other linguistic skills, such as lexical knowledge. Many children with SLI, but not all, have lexical deficits. Lexical deficits are often seen early in development during the toddler years (Haynes & Naidoo, 1991) and frequently persist through adolescence, and likely beyond, (Rice, 2004; Stothard, Snowling, Bishop, Chipchase, & Kaplan, 1998). These deficits exist in both breadth and depth of word knowledge (Leonard, Nippold, Kail, & Hale, 1983; McGregor, Rost, Guo, & Sheng, 2010; Sheng & McGregor, 2010).

Despite this, word learning studies in children with SLI have provided mixed findings (Ellis Weismer & Hesketh, 1996; Ellis Weismer, 1996; Gray, 2004, 2006; Rice, Buhr, & Nemeth, 1990). One meta-analysis on word learning in children with SLI assessed 28 word learning studies (Kan & Windsor, 2010). Group and moderator effects were evaluated. Group analyses compared children with SLI with chronological age-matched typically developing children and younger language-matched children with typical development. Language-matched groups were created differently for studies in the meta-analysis; typically children were matched or receptive vocabulary or expressive language (e.g., MLU). Kan and Windsor found that children with language impairments performed significantly worse on word learning studies than chronological age-matched children with typical development; however, children with language impairment did not statistically differ in accuracy from language-matched children with typical development on comprehension assessments within word learning tasks.

Beyond these group findings, Kan and Windsor (2010) found moderator affects that influenced word learning performance across the studies. Participant characteristics influenced word learning performance, such that the following variables positively relate to word learning:

chronological age, receptive language, and cognitive abilities. For example, older children were more successful in word learning studies. Also, children with less severe language impairments performed better in word learning tasks.

Task characteristics also influenced performance. For instance, more frequent exposures to novel words facilitated learning. Rice and colleagues described this as a "minimal input constraint" that affects learning (Rice, Oetting, Marquis, Bode, & Pae, 1994; p. 119). Learning is facilitated by extended exposure in both typically developing children and children with language impairment. In addition, children with SLI benefit from added stress or more explicit teaching about words (Ellis Weismer & Hesketh, 1993, 1996; Gray, 2005). Furthermore, larger group differences are seen on tasks that assess word learning through comprehension or recognition tasks than production tasks. Both children with typical development and language impairment required additional learning opportunities to be able to accurately produce learned words in the test phase of the experiment but children with language impairment seem to demonstrate greater difficulties in producing newly learned words (e.g., Dollaghan, 1987). Lastly, nouns appear to be easier to learn than verbs for children with SLI and typical development, but children with language impairment had greater difficulty learning verbs compared to their typically developing chronologically age-matched peers (e.g., Windfuhr, Faragher, & Conti-Ramsden, 2002).

Research has gone beyond word learning studies and evaluated the words that children with SLI know. It has been suggested that children with SLI, especially those with expressive and receptive language difficulties, have weak lexical representations (Lahey & Edwards, 1999; Sheng & McGregor, 2010). Difficulties in learning phonological representations for new words have been well documented in nonword repetition tasks (e.g., Archibald & Gathercole, 2006;

Edwards & Lahey, 1996; Ellis Weismer et al., 2000; Gathercole & Baddeley, 1990). In addition, children with SLI have naming deficits and are more vulnerable to lexical access interference on words with frequent phonotactic patterns or high phonological neighborhood density (Coady, 2013). It has been suggested that children with SLI have phonological representations that have been less securely learned or maintained compared to typically developing peers due to impaired phonological perception and processing (Joanisse & Seidenberg, 1998, 2003). Joanisse and Seidenberg suggested that such phonological processing deficits could lead to difficulties in learning word meanings and also lead to syntactic impairments.

Building on Lahey and Edward's (1999) theory of weak semantic-lexical representations in children with SLI, McGregor et al. (2012) found that children with SLI have superficial vocabulary knowledge. A limited amount of work has been done to characterize the relationship between phonological and semantic information and the ways in which children with SLI learn both pieces of information. However, recently Mainela-Arnold and Evans (2014) studied whether skills in statistical learning relate to lexical knowledge. They found that statistical learning skills, measured through a segmenting task, only related to lexical-phonological aspects of word knowledge but not knowledge about words' semantic meanings.

Cognitive deficits in children with SLI. Beyond the linguistic domain, researchers have studied a range of nonlinguistic skills in individuals with SLI. Deficits in nonlinguistic domains have been identified. For example, Kail proposed the general slowing hypothesis, suggesting that children with SLI are slow processors, or have a limited processing capacity (Kail & Salthouse, 1994; Kail, 1994). Others have suggested that deficits in working memory significantly contribute to language impairments in children with SLI (Ellis Weismer, Evans, & Hesketh, 1999; Ellis Weismer, 1996; Montgomery & Evans, 2009). Specifically, some suggest that

deficits in verbal working memory cause language impairments (Gathercole & Baddeley, 1990; Montgomery, 1999).

Both behavioral and neural studies have identified abnormalities in adolescents with SLI during verbal working memory tasks (Ellis Weismer, Plante, Jones, & Tomblin, 2005). Children with SLI have been found to have less accurate performance on verbal working memory tasks and slower reaction times on more complex verbal working memory tasks, indicating that global processing deficits (e.g., general slowing hypothesis) may not most accurately describe abilities in SLI. Furthermore, fMRI data has identified atypical coordination of activation across regions of the brain during verbal working memory, indicating an overreliance on a less functional network during task performance (Ellis Weismer et al., 2005). Many of these findings indicate that constraints in nonlinguistic systems contribute to difficulties observed in individuals with SLI. Although researchers are now identifying weaknesses in domains other than language, we do not fully understand the mechanisms that contribute to children's language impairment.

Deficits in implicit learning may be another example of nonlinguistic constraints in individuals with SLI. Tomblin and colleagues have used a serial reaction time (SRT) task to assess procedural learning (Tomblin, Mainela-Arnold, & Zhang, 2007). Of note, the SRT task uses visual, nonlinguistic stimuli that requires children to press a button that corresponds to an animated figure appearing in one of four squares depicted on a computer screen. Thus, the SRT task represents visual-motor procedural learning abilities. Tomblin and colleagues found a relationship between visual-motor procedural learning and long-term histories of poor language learning in individuals identified as having SLI in kindergarten (Tomblin et al., 1997). Adolescents diagnosed with SLI in kindergarten, with a persistent history of language impairment, had slower learning rates and different learning patterns compared to a control

group with normal language even after controlling for baseline random pattern performance improvement. Importantly, the procedural learning task was visual and motor, not auditory or linguistic, yet performance on the visual-motor procedural learning task was associated with linguistic abilities, suggesting that nonlinguistic abilities relate to linguistic abilities in individuals with SLI.

Interestingly, Tomblin and colleagues conducted additional analyses to assess Ullman's (2001) claim that grammatical and semantic abilities are supported by two distinct systems. Tomblin et al. (2007) combined the typically developing and SLI groups and then created a grammatical impairment group and a normal grammar group, using the adolescents' kindergarten grammar scores, and tested whether group membership affected performance on the visual-motor procedural learning task. Group differences on grammatical abilities were almost identical to the SLI versus the normal language group comparisons. Adolescents with grammatical impairments were slower to learn in the visual-motor procedural learning task. Conversely, when the sample was divided according to vocabulary size (also measured in kindergarten), no group differences were found on the visual-motor procedural learning task. The divide between syntactic and vocabulary knowledge in the linguistic system mirrored findings by Mainela-Arnold and Evans (2014) and speaks to the larger debate of unified learning mechanisms versus modular learning mechanisms.

Weak implicit learning in individuals with SLI also has been found on artificial grammar learning tasks. Plante and colleagues compared young adults with language/learning disabilities to young adults with typical development and no history or familial history of language/learning disabilities on an artificial grammar task (Plante, Gomez, & Gerken, 2002). The participants listened to grammatical strings from an artificial language for about five minutes (10 different

strings that each repeated 8 times in a pseudorandom order). After listening to the artificial grammar strings, Plante and colleagues tested whether the participants were able to generalize learning of the artificial grammar to novel stimuli. Participants judged whether strings with novel words that did not occur in the artificial language during the exposure phase followed the grammatical structure of the artificial language. Half of the test strings followed the finite-state grammar rules in the artificial language, and the other half of the test strings violated the finite-state grammar. Individuals with language/learning disabilities performed significantly worse on the test items, demonstrating deficits in the ability to implicitly learn a novel grammar from exposure to exemplars from the artificial grammar. Deficits in procedural learning have also been identified in individuals with language impairments when tested on artificial grammars with non-adjacent dependencies (Hsu, Tomblin, & Christiansen, 2014). Additional work in artificial grammar learning in individuals with language/learning disabilities has found that they can learn artificial grammars, but they are less efficient than typically developing adults (von Koss Torkildsen, Dailey, Aguilar, Gomez, & Plante, 2013).

As can be expected, statistical learning also has been found to be an area of weakness in children with SLI. Evans and colleagues tested statistical learning through a segmenting task in children with SLI (Evans, Saffran, & Robe-Torres, 2009). Children listened to an artificial language (Saffran et al., 1997) for 21 minutes while coloring on a computer software program. Following exposure, children's segmenting abilities were tested through a two-alternative forced-choice paradigm, where children listened to two items and were asked to pick the item that sounded like the sounds they heard when they were listening and drawing. The items in the forced-choice task consisted of word-nonword pairs, with words appearing in the artificial language with high transitional probability. Nonwords, however, had a transitional probability of

0 because the syllables within the nonwords never appeared next to each other in the artificial language. Children with SLI were at chance on the two alternative forced-choice task (52% accuracy) whereas children with typical development were above chance (58% accuracy). Even after controlling for age and nonverbal intelligence, the children with typical development performed significantly better than the children with SLI.

In a follow-up experiment that occurred six months later, fifteen of the children with SLI and 15 of the typically developing from experiment 1 returned and listened to the same artificial language, but for 42 continuous minutes. After the extended exposure period, the children performed the same two-alternative forced-choice task. This time, children with SLI performed above chance (56.2%), as did the children with typical development (64.4%). However, children with SLI demonstrated weak learning in that accurate forced-choice performance did not occur when target words were paired with highly phonologically similar foil words. Interestingly, the children with SLI demonstrated links between segmenting skills and language knowledge. Receptive vocabulary was correlated with forced-choice performance. Although previous work has demonstrated associations between lexical knowledge and statistical word learning tasks (Evans et al., 2009), additional work is required to explicitly study whether the output of statistical learning in children with SLI directly relates to word-learning (i.e., whether newly segmented words serve as good candidate words to which meaning will be mapped; Graf Estes et al., 2007).

As is evident by this review, a great deal of research has been devoted to individuals with SLI. However, the language impairments seen in individuals with SLI are not unique to SLI. For example, similar language deficits are seen in some children with autism spectrum disorder (ASD; Kjelgaard & Tager-Flusberg, 2001; Roberts, Rice, & Tager-Flusberg, 2004). In fact,

Tomblin (2011) suggested that children with SLI do not represent a unique type of language learner. Other work within the literature demonstrates that children with other disorders have been found to have overlapping linguistic phenotypes with children with SLI (Caselli, Monaco, Trasciani, & Vicari, 2008; Estigarribia, Roberts, Sideris, & Price, 2011; Sterling, Rice, & Warren, 2012; Williams, Botting, & Boucher, 2008). As such, it is important to develop a clearer understanding of the overlapping linguistic phenotype in children across different diagnostic groups (Ellis Weismer, 2013). The focus of this paper will now turn to individuals with autism spectrum disorder (ASD) and present theoretical links from SLI to the explanation of language impairment in individuals with ASD.

Autism Spectrum Disorder

Autism spectrum disorder is a neurodevelopmental disorder that is characterized as having core deficits in social communication and displaying restricted interests and repetitive behaviors (American Psychiatric Association, 2013; Filipek et al., 1999; Liss et al., 2001). Language development is usually delayed in young children with ASD (Charman et al., 2003; Ellis Weismer, Lord, & Esler, 2010). In fact, parents' first concerns about ASD are most often in response to delayed language milestones (De Giacomo & Fombonne, 1998). Although language abilities greatly vary, it is estimated that about one-third of children with ASD do not have functional speech (Bryson, 1996; Helen Tager-Flusberg & Kasari, 2013).

The role of nonverbal IQ in language is unclear. For example, some studies report that there is no significant relationship between nonverbal IQ and spoken language abilities in children with ASD (Charman et al., 2003b; Mundy, Sigman, & Kasari, 1990; Siller & Sigman, 2002). However, other studies have found that nonverbal cognition serves as a strong predictor of receptive and expressive language (Charman et al., 2005; Ellis Weismer & Kover, 2015; Ellis

Weismer et al., 2010). As such, some researchers have concentrated on characterizing the cognitive-linguistic phenotype in children with ASD (Joseph, McGrath, & Tager-Flusberg, 2005; Kjelgaard & Tager-Flusberg, 2001).

Pragmatic deficits are a defining feature of ASD; however, some children also have structural language deficits (Brock, Norbury, Einav, & Nation, 2008; McGregor et al., 2012). It has been found that, when compared to nonverbal mental age-matched children with developmental delays, preschool children with ASD display more severe language comprehension and production deficits (Lord & Pickles, 1996). Young children with ASD have difficulties developing lexical knowledge and combining words (Charman et al., 2003; Ellis Weismer et al., 2010). Also, some children with ASD display a receptive-expressive language profile that counters typical development with smaller receptive language advantages (Barrett, Harris, & Chasin, 1991; Charman et al., 2003; Haebig, Matthews, Venker, & Ellis Weismer, 2012; Hudry et al., 2010; Kover, McDuffie, Hagerman, & Abbeduto, 2013; Luyster et al., 2007; Maljaars, Noens, Scholte, & van Berckelaer-Onnes, 2012). However, linguistic profiles seem to change over time (Bennett et al., 2008; Kjelgaard & Tager-Flusberg, 2001; Rapin, Dunn, Allen, Stevens, & Fein, 2009; cf Kwok, Brown, Smyth, & Oram Cardy, 2015).

Within the syntactic domain of language, deficits are seen in some children with ASD relative to their chronological age. The extent of syntactic deficits is debated in the literature, however. Some believe that early syntax, although delayed at first, is on par with mental age or vocabulary abilities. For instance, Tager-Flusberg and colleagues assessed the development of lexical and grammatical skills in six children with ASD for 12 to 26 months and compared their development to children with Down syndrome, who were matched on MLU at the beginning of the study (H Tager-Flusberg et al., 1990). It was reported that most of the young children with

ASD demonstrated comparable development of lexical and grammatical skills to the children with Down syndrome. Although this study provided helpful and detailed information about the development of early language, the sample size was small. Furthermore, the children with ASD were compared to children with Down syndrome who are known for having relative weaknesses in grammatical skills (Rice, Warren, & Betz, 2005). Other studies have used experimental tasks to examine syntactic comprehension skills in children with ASD. These studies have demonstrated that children with ASD are able use syntactic cues such as word order to facilitate language comprehension (Naigles, Kelty, Jaffery, & Fein, 2011; Paul, Fischer, & Cohen, 1988; Swensen, Kelley, Fein, & Naigles, 2007).

Although studies demonstrated that children with ASD utilize word order as a language strategy (e.g., Paul et al., 1988; Tager-Flusberg, 1981), other weaknesses have been identified. Children with ASD have difficulties understanding more syntactically complex sentence forms, such as nonreversible (Prior & Hall, 1979) and passive sentence structures, compared to typically developing children matched on receptive vocabulary (Paul et al., 1988; Tager-Flusberg, 1981; but see Swensen et al., 2007 for contrary findings, indexed via eye gaze methodology). In addition, Eigsti, Bennetto, and Dadlani (2007) identified early syntactic deficits in young children with ASD, compared to children with developmental delays without ASD and children with typical development, matched on receptive vocabulary. Eigsti and colleagues found that children with ASD had significantly lower MLUs than children with developmental delays but no ASD, and lower MLUs than younger, typically developing control children that approached, bud did not reach, statistical significance. Furthermore, the children with ASD scored significantly lower on the IPSyn, an assessment that measures grammatical skills from a language sample, than both the children with developmental delays and typical development.

These studies suggest that although children with ASD demonstrate syntactic knowledge, syntactic development is nonetheless delayed. However, social communication deficits and social anxiety may influence linguistic performance during conversational or play-based language sampling tasks (Tager–Flusberg, 2000).

In a study with older children, Eigsti and Bennetto (2009) found that children with ASD performed significantly worse than typically developing children matched on chronological age and IQ on a grammatical judgment task. Specifically, children with ASD performed worse than the typically developing control children on the following finite markers: third-person singular, past tense, and present progressive. Similarly, Roberts, Rice, and Tager–Flusberg (2004) found that a subgroup of children with ASD who had receptive vocabulary deficits also had impairments in nonword repetition tasks and tasks that required production of the third-person singular and past tense. Additional studies have identified phenotypic overlap with SLI and ASD by documenting instances where subgroups of children with ASD have language impairments that resemble language difficulties seen in children with SLI (e.g., Bennett et al., 2008; Kjelgaard & Tager-Flusberg, 2001; Roberts et al., 2004). These cases call into question whether language impairment seen in populations with other concomitant disorders have the same type of language impairment seen in SLI. Traditionally, SLI has diagnostic criteria that exclude individuals with other known disorders, such as ASD, from receiving a diagnosis of SLI. This criterion is being called into question (e.g., Riches, Loucas, Baird, Charman, & Simonoff, 2010; Tomblin, 2011).

Poor nonword repetition is a clinical marker of SLI (Dollaghan & Campbell, 1998). As such, some studies have used nonword repetition tasks to compare performance between children with ASD and children with SLI. In a simple comparison, children with SLI and children with ASD and language impairment perform similarly on a nonword repetition task, with both groups

committing more errors than children with ASD and normal language abilities (Lindgren, Folstein, Tomblin, & Tager-Flusberg, 2009). However, in other nonword repetition studies, researchers have assessed errors committed in nonword repetition tasks in children with ASD and SLI and found some differences (Riches, Loucas, Baird, Charman, & Simonoff, 2011; Williams, Payne, & Marshall, 2012). Williams et al. (2012) found that school age children with ASD and language impairment performed more similarly to language-matched children with typical development on a nonword repetition task. The children with SLI, however, demonstrated some different error patterns compared to the other two groups, such as cluster creation and increased difficulties reproducing consonant clusters in the medial position. Riches et al. (2011) found that adolescents with SLI produced more phoneme errors than adolescents with ASD and language impairment (Riches et al., 2011). In addition, adolescents with SLI were more affected by increasing syllable length, evidenced by more errors, suggesting short term memory limitations. Although both groups committed phonological structure errors that suggested difficulties with auditory-perceptual encoding, the two clinical groups produced some different types of errors. Riches and colleagues cautiously concluded that there were not clear group differences that would suggest different mechanisms of language impairment between the SLI and ASD.

Though some nonword repetition tasks have noted potential difficulties with auditory-perceptual encoding in children with ASD, such difficulties do not seem to be as severe as in those with SLI. Interestingly, individuals with ASD have been described to have a bias to low-level sensory information, or a detail-focused processing style, according to the weak central coherence theory (Happé & Frith, 2006; Happé & Booth, 2008). According to this model, individuals with ASD also may struggle to extract global meaning from input, potentially at the

word or sentence level. Indeed, previous studies have found that adults with typical development demonstrate preference to attending to semantic details relative to phonological details in lexical tasks, whereas adults with ASD recall both types of information (Toichi & Kamio, 2002, 2003). Toichi and Kamio suggest that it maybe that the relationship between semantic memory and episodic memory may be atypical in individuals with ASD, rather than having specific deficits in semantic memory itself. Additional work has found that children with ASD may have an attentional bias to the sound structure of language, which may lead to stronger learning of phonological features of words and relatively weaker learning of semantic features (Norbury, Griffiths, & Nation, 2010). Such processing may reflect a featural/surface-biased information-processing style that may enhance processing of a single stimulus cue instead of focusing on multiple stimulus cues (Järvinen-Pasley, Wallace, Ramus, Happé, & Heaton, 2008). The impact of these attentional biases on learning has only begun to be explored.

Word learning and lexical knowledge in children with ASD. As noted previously, most children with ASD have delayed vocabulary skills. Later in development, though, lexical/semantic deficits seem to persist for some children with ASD. For example, some, but not all children have reduced breadth of word knowledge, with smaller vocabulary sizes compared to typically developing peers (Kjelgaard & Tager-Flusberg, 2001; Kover et al., 2013; Roberts et al., 2004). Additionally, many children with ASD have limited depth of word knowledge that is characterized by weaker word definitions, limited knowledge of multiple word meanings, and poor word-to-word relationship knowledge (i.e., partial word knowledge; Boucher, Bigham, Mayes, & Muskett, 2008; McGregor et al., 2012; Norbury, 2005).

In a word learning study, Norbury and colleagues compared fast mapping and slow mapping (retention and consolidation of taught information) in children with high functioning

autism and children with typical development (Norbury et al., 2010). The groups were matched on chronological age, mental age, and receptive vocabulary, but differed on performance on a word definition task, with the children with ASD performing worse than the children with typical development. Norbury and colleagues examined children's ability to learn both phonological and semantic information. Children were taught labels through a simple video-recorded social learning experience played on a computer. Recognition of newly-taught objects was tested immediately after teaching and then again, four weeks later to test slow mapping abilities. Both groups were able to use social cues to learn object labels immediately after teaching, with the children with ASD showing a slight advantage immediately after teaching. Children with ASD performed significantly better on a naming identification task by producing a higher proportion of phonemes correct when labeling a novel object. This advantage was larger immediately after teaching and decreased over time.

Conversely, when asked to describe the novel objects, as a measure of semantic learning, children with ASD produced significantly fewer descriptions than the children with typical development. An even greater difference between the two groups existed four weeks later, with typically developing children providing even more object descriptions than in the first test phase. Children with typical development demonstrated off-line consolidation of learning, whereas children with ASD did not and instead performed worse on tasks in the second testing phase. Norbury and colleagues suggested that initially, children with ASD may have allotted more attention to learning phonological information. However, the phonological information initially learned did not improve and was not consolidated with other semantic information after initial learning opportunities. In contrast, the children with typical development may have invested more attention to learning semantic features during learning opportunities and consolidated

phonological representations of the newly taught words with the semantic information during off-line processing. Although children with high functioning autism and well-matched typically developing children demonstrated word learning abilities, there were differences in the type of information that was learned. Attention to the sound structure, or phonological information, and the failure to integrate semantic information to support language development aligns with attentional biases predicted by the weak central coherence theory.

Additional studies that assess word-learning mechanisms in children with ASD are limited in number. The extant studies have indicated strengths and weaknesses, along with areas of ambiguity in word learning in this population. Like Norbury and colleagues (2010), other studies have found that toddlers and children with ASD were able to use social cues to learn new words (Luyster & Lord, 2009; McGregor, Rost, Arenas, Farris-Trimble, & Stiles, 2013). Despite these findings, social learning, such as use of eye gaze, has been identified to be a deficit in children with ASD that negatively impacts word learning in other studies (Baron-Cohen et al., 1997; Preissler & Carey, 2005). Moreover, children with ASD have demonstrated use of shape bias to facilitate word learning, a strategy that typically developing children also show (Tek, Jaffery, Fein, & Naigles, 2008). Also mirroring typical development, toddlers with ASD demonstrate a noun bias and word order strategy in word learning experiences (Swensen et al., 2007). In addition, children with ASD demonstrate mutual exclusivity in word learning tasks (de Marchena, Eigsti, Worek, Ono, & Snedeker, 2011; Preissler & Carey, 2005). Finally, children with ASD also demonstrate cross-situational word learning abilities, which serves as a type of statistical word learning (McGregor, Rost, et al., 2013; Venker, 2013).

Although children with ASD demonstrate use of learning mechanisms in word learning tasks, they still demonstrate delayed word learning and language development. In a study by

McDuffie and colleagues, children with ASD demonstrated word learning, but children with typical development performed significantly better, even when nonverbal cognition was controlled (McDuffie, Kover, Hagerman, & Abbeduto, 2013). In addition, toddlers at risk of ASD display mutual exclusivity in word learning tasks, but fail to benefit from feedback, which negatively impacts long-term retention of word-object mappings (Bedford et al., 2013).

Because of the range of language performance and profiles seen, conflicting theories of language development in ASD have been proposed. For instance, Boucher, Mayes, and Bigham (2008) suggest that children with ASD have deficits in declarative memory that lead to language impairment. Earlier work has shown that children with ASD often fail to use semantic information to facilitate sentence or phrase comprehension (Prior & Hall, 1979; Tager-Flusberg, 1981; but see Brock, Norbury, Einav, & Nation, 2008; Hahn, Snedeker, & Rabagliati, 2015). Although the research in word learning in children with ASD is limited, initial studies have demonstrated above chance associative word learning performance. Associative learning is supported by the declarative memory system. Walenski, Tager–Flusberg, and Ullman (2006) proposed that children with ASD have a relative strength in declarative memory and reduced procedural memory skills. Despite these conflicting theories, deficits in both semantic and syntactic language have been found and often co-occur in children with ASD (e.g., Boucher, 2012; Eigsti et al., 2007; Roberts et al., 2004). Additional research is warranted to improve our understanding of the mechanisms that underlie language impairment in this population.

Cognitive learning mechanisms in children with ASD. Implicit learning abilities in children with ASD are not well understood. Some believe implicit learning is intact (Barnes et al., 2008; Brown, Aczel, Jiménez, Kaufman, & Grant, 2010; Müller, Cauich, Rubio, Mizuno, & Courchesne, 2004). Many of these studies have been conducted with children with high

functioning autism, which may not accurately portray abilities in the broader phenotype. Branching from a larger study, Brown and colleagues (2010) analyzed performance on implicit learning tasks collected from children with ASD with lower nonverbal cognitive skills and found that performance on implicit learning tasks did not differ from chronological age matched peers with typical development despite group-wise differences in IQ. In contrast to these findings, others have identified deficits in implicit learning (Gidley Larson & Mostofsky, 2008; Motofsky, Goldberg, Landa, & Denckla, 2000). Also, in a neuroimaging study, Müller and colleagues found neural abnormalities during the late stages of a visuomotor learning task despite behavioral evidence of learning in adolescents and adults with high functioning autism (Müller et al., 2004). Lastly, Gordon and Stark (2007) assessed procedural learning through a sequential reaction time (SRT) task in low functioning children with autism. They found that the children were able to learn sequential tasks implicitly when provided with additional learning time. Taken together, children with ASD represent a very heterogeneous group that appear to broadly have implicit learning abilities, but differences may be evident depending on certain child characteristics or task assessment method.

Segmenting tasks also have been used to assess statistical learning in individuals with ASD. As in the broader literature on implicit learning, conflicting findings exist. Scott-Van Zeeland and colleagues used fMRI to assess neural evidence of learning in an online segmenting task in children with high functioning autism and chronological age and IQ-matched children with typical development (Scott-Van Zeeland et al., 2010). The children listened to two artificial languages; one language contained random syllable sequences and the other artificial language either contained statistical cues or statistical cues plus prosodic cues to word boundaries. The children with autism failed to show a facilitory effect when exposed to the artificial language

with cues to word boundaries, indicating that the children with autism have deficits in statistical learning.

In conflict with Scott-Van Zeeland's (2010) finding, Mayo and Eigsti (2012) found that children with high functioning autism are able to demonstrate intact statistical learning skills. Mayo and Eigsti compared behavioral performance on a segmenting task in children with high functioning autism and children with typical development, matched on chronological age and IQ. They followed Evans and colleagues' (2009) experiment 1 design and exposed children to an artificial language (Saffran et al., 1997) for 21 minutes. Immediately after exposure, children were given a two-alternative forced-choice test to examine segmenting skills. Both groups of children learned transitional probabilities from the artificial language. Children with typical development learned words with higher transitional probabilities better than words with lower transitional probabilities, but children with high functioning autism had less differentiation in learning words with differing transitional probability strength. In contrast with Evans and colleagues' (2009) findings, segmenting performance was not significantly associated with current language abilities in the two groups. However, the children included in Mayo and Eigsti's (2012) had a history of language delays, but did not have concurrent language impairments.

Current Study

Additional work is needed to better understand statistical learning abilities in children with ASD. Furthermore, a systematic comparison of statistical learning between children with ASD and children with SLI is warranted in order to improve our understanding of the mechanisms that drive language impairment and to determine whether overlapping deficits in statistical learning contribute to the language impairments seen in both populations.

Though researchers have begun to assess statistical learning in children with ASD and SLI, separately, no single study has evaluated the output of statistical learning in both of these populations. Given deficits in consolidation of linguistic information in children with ASD and weak phonological representations or phonological working memory in children with SLI, it is unclear whether children are able to map meaning onto newly segmented words. Specifically, no study has assessed whether school-age children treat segmented sounds as candidate words to which meaning will be mapped.

Information from this study contributes to the understanding of language learning mechanisms in children with atypical development. This work stems from theoretical accounts of normal language acquisition and attempts to bridge theoretical accounts across the literature from the disordered and non-disordered literature. Abilities in key components of word learning are assessed and compared across three populations to identify potential differences. Furthermore, sensitive quantitative analysis methods were applied to the data from this study. The specific research questions were:

1) Do children with ASD and/or SLI have deficits in statistical learning, compared to typically developing children matched on nonverbal cognition and chronological age?
2) Do children with ASD and/or SLI have difficulties in word learning, compared to typically developing children?
3) Are children with ASD and/or SLI able to map meaning onto newly segmented words? How does performance compare to typically developing children?
4) Is there a relationship between concurrent abilities of these populations on online experimental measures of language and learning and abilities measured by standard assessments?

Chapter 2: Methodology

Participants

A total of 84 children with typical development, ASD, and SLI participated in the current study. Participants were recruited through a parent grant, examining the concurrent and longitudinal relationship between language and executive functions in these populations. Parents and children were informed about the current study and asked if they were interested in participating in the extra tasks while they were present for the parent grant visits. If they agreed, parents provided informed written consent and children provided verbal assent. This study was approved by the University of Wisconsin-Madison's Institutional Review Board. The parent grant recruited participants locally through educational, clinical, community and website postings. Additionally, children with ASD were recruited using a research participant registry that was developed from a previous longitudinal study examining language development in toddlers with ASD (Ellis Weismer & Kover, 2015; Ellis Weismer et al., 2011).

To meet inclusionary criteria, typically developing children: obtained language scores that were no lower than 1 standard deviation below the mean on the *Clinical Evaluations of Language Fundamentals – 4th edition* (CELF-4; Semel & Wiig, 2003) core language standard scores, had no history of special education services, and were monolingual English speakers. Children with SLI scored 1.25 standard deviations below the mean on one or more of the composite measures of language on the CELF-4 (i.e., Core Language, Receptive Language, or Expressive Language) or demonstrated at least a 14 point gap between one of the CELF-4 composite measures and the nonverbal cognitive measure and had a history of, or were currently receiving language intervention services. In addition, children with SLI had nonverbal cognitive standard scores of 84 or higher. Children in the ASD group had a documented community

diagnosis of an autism spectrum disorder, met additional confirmatory criteria for the diagnosis (described below), and had no other reported genetic disorders (e.g., Down syndrome, fragile X syndrome). All children passed a hearing screening of 1000 Hz, 2000 Hz, and 4000 Hz at 20dB (ASHA, 1997) in at least one ear, except one child with typical development and one child with SLI. The parents of both children reported no concerns of hearing loss and the child with typical development passed the hearing screening during the previous visit for the larger study. As such, both children were retained in the study. An additional inclusionary criterion was that children had to contribute data for at least two of the three experimental tasks in the current study.

A total of 121 children participated in the study (50 children with typical development, 36 children with ASD, and 35 children with SLI). The published studies assessing segmenting abilities in children with ASD and SLI have matched children on nonverbal cognition and age (Evans et al., 2009; Mayo & Eigsti, 2012; Scott-Van Zeeland et al., 2010). Therefore, children were group-wise matched on chronological age, $F(2, 81) = 0.362$, $p = .698$, and standard scores on the WISC-IV, which measured nonverbal cognition, $F(2, 81) = 0.614$, $p = .544$. It should be noted that cognitive scores varied greatly in the ASD group. While this is characteristic of this group, it is not ideal in terms of matching (Kover & Atwood, 2013). Of the 121 children who participated, 84 met inclusionary and matching criteria.

According to parent report, approximately 73.81% of participants with ASD, SLI, and typical development were Caucasian (Hispanic and Non-Hispanic), 11.90% of the participants were African American, 2.38% were Asian American, 1.19% were American Indian, and 10.71% identified as being Other (including multiracial). See Table 1 for participant characteristics.

Table 1

Participant Characteristics

	TD (n = 30)		ASD (n = 29)		SLI (n = 25)	
	Mean	SD	Mean	SD	Mean	SD
Chronological Age (in years)	10.36	(1.21)	10.08	(1.30)	10.43	(1.27)
WISC-4[1]	103.63	(8.91)	103.86	(16.41)	101.28	(11.14)
CELF-CL SS[2]	103.30	(11.99)	87.36	(20.29)	81.29	(14.10)
CELF-EL SS[3]	104.00	(12.89)	89.14	(20.51)	80.00	(13.97)
CELF-RL SS[4]	105.57	(14.32)	88.38	(19.69)	86.48	(15.73)
PPVT-4 SS[5]	111.27	(17.63)	105.79	(19.27)	93.36	(13.55)

Note. [1]Perceptual Reasoning Index Standard Score, [2]Core Language Standard Score, [3]Expressive Language Standard Score, [4]Receptive Language Standard Score, [5]Receptive Vocabulary Standard Score

Procedure

Participants completed the testing protocol over two separate visits. To control for order effects, approximately half of the children completed two of the experimental tasks during the first visit and the third experimental task during the second visit. Standardized assessments for cognition and language abilities were administered as part of the parent study during the first year; however, the receptive vocabulary assessment and hearing screening were administered at both year 1 and year 2. As such, CELF-4 language scores and cognitive scores were from a previous year for 20 children with typical development, 13 children with ASD, and 10 children with SLI. Previous work indicates that language and cognitive abilities remain relatively stable during the school-age years (Bishop, Farmer, & Thurm, 2015; Conti-Ramsden, Clair, Pickles, & Durkin, 2012; Pickles, Anderson, & Lord, 2014; Rapport & Weyandt, 2008).

Standardized Measures

Cognition. Nonverbal cognitive abilities were assessed using the Perceptual Reasoning Index of the *Wechsler Intelligence Scale for Children - Fourth Edition* (WISC-IV; Wechsler, 2003). Fluid reasoning skills such as visual perception, visual-motor integration, visuospatial

processing and coordination, and efficiency of task performance are measured through three subtests: Block Design, Picture Concepts, and Matrix Reasoning.

Receptive vocabulary. Receptive vocabulary abilities were measured using the *Peabody Picture Vocabulary Test – Fourth Edition* (PPVT-4; Dunn & Dunn, 2007). Children are presented with four pictures and asked to point to the image that depicts a word that the examiner provides.

Expressive and receptive language. The *Clinical Evaluation of Language Fundamentals-4th edition* (CELF-4; Semel & Wiig, 2003) was used to assess receptive and expressive lexical and grammatical skills. Subtests that contributed to the composite language scores (i.e., Core Language, Expressive Language, Receptive Language) were administered.

Autistic characteristics. Parents of children in the typically developing and SLI groups completed the *Social Communication Questionnaire* (SCQ; Rutter, Bailey, & Lord, 2003), a screening tool for ASD. Parents of children with ASD completed the *Childhood Autism Rating Scale – Second Edition, Questionnaire for Parents and Caregivers* (CARS2-QPC; Schopler, Van Bourgondien, Wellman, & Love, 2010). An experienced psychologist reviewed the CARS2-QPC, watched a video recording of the child completing the cognitive assessment, and then scored the *CARS2 High Functioning* rating booklet (CARS2-HF). The children with typical development and SLI did not score above the SCQ cutoff for core autism. Children with ASD received a score of 25 or higher on the CARS2-HS, confirming their community diagnosis of ASD.

Experimental Measures

Statistical learning. A segmenting task was used to directly assess statistical learning. The segmenting task was administered through a computer software program, E-Prime (version

2.0.10.242). Children were exposed to a continuous speech stream from one of two counterbalanced artificial languages used by Graf Estes and colleagues (2007) in Experiment 1 of their study. The artificial language consisted of four disyllabic novel words (version A: teemay [time], dobu [dobu], mano [mɑno], peega [pigɑ]; version B: nomay [nome], matee [mɑti], gabu [gɑbu], peedo [pido]). The words from version A were nonwords for children who received version B, and vice versa. In preparing the artificial languages, Graf Estes and colleagues had a trained female speaker read shortened sequences of the artificial language. The speaker was unfamiliar with the stimuli. Each sequence included one or two extra syllables at the beginning and end that were later cut before combining the recordings to create the final continuous speech stream of the artificial language. To keep the speaker blind to the stimulus words, the syllable sequences alternated between the two counterbalanced artificial language versions. The syllables were produced as a fluent speech stream, without pauses, at a constant pitch (mean F0 = 179 Hz) to prevent acoustic cues from signaling word boundaries. Syllable sequences were spliced together to form a continuous speech stream with the appropriate coarticulation. The final versions contained 120 repetitions of each word in pseudorandom order so words did not appear twice in succession. The only reliable cue for segmentation of words was the statistical structure of the artificial language (i.e., within-word transitional probabilities = 1.0, across-word probabilities = 0.0). The beginning of the artificial language faded in with increasing volume and the end of the artificial language faded out in volume to prevent onset and offset cues to word boundaries.

Children sat in front of a computer screen and watched a silent nature picture slide show while they listened to the artificial language for 4.75 minutes. The stimuli were presented at approximately 60dB from the computer speaker that was located directly below the computer

screen. Children were informed that they were going to listen to a "Martian language" and that their job was to sit and listen. Directly following the exposure period, children were given a two-alternative forced-choice (2AFC) practice test phase. In the practice phase, children were presented with two acoustic stimuli options (e.g., "bulltay," "doggy"). The number "1" appeared on the screen on the left side of the computer screen while the first stimulus option was presented auditorily and the number "2" appeared on right side of the computer screen while the second stimulus item played. Afterwards, a question mark appeared on the screen to prompt children to pick the item that was a real word in English by pushing one of two buttons on a buttonbox (Cedrus RB-530 Response Pad). If the child wished to select the first item, the child pressed the button on the left, with the number "1" above it. Conversely, the child pressed the button on the right with the number "2" above it if the child wished to select the second stimulus item. Five practice items were presented; feedback was provided. Following the practice phase, a 32 item 2AFC test phase ensued. Instead of selecting the stimulus item that was a real word in English, children were asked to select the item that sounded like the "Martian language."

Word learning task. Associative learning abilities were tested through an object-label association task with novel words. Four novel words that were similar in phonotactic probability were taught (teemo [timo], bolay [bole], dayno [deno], padu [pɑdu]) in a pre-recorded movie that lasted approximately 4.5 minutes. Children watched the word learning movie in a small testing booth while sitting in a chair approximately 60 inches from a flat-screen television mounted on the wall. There was a mounted video camera directly under the television screen to record the child's face as he/she watched the movie. The acoustic stimuli were presented at approximately 63dB.

Children first watched a teaching phase where each novel word was presented in isolation auditorily as a label for a novel object image. The same female speaker from the segmenting task recorded the auditory stimuli. All teaching labels were presented at a constant, monotone pitch. Each object had a distinct shape and color. Labels and their corresponding novel objects were presented three times in a pseudo randomized order without sequential labeling of the same object. After the teaching phase, a three-second movie with music and colorful lights was played to attract the child's attention. A test phase then followed, consisting of 16 test trials. During the test phase, yoked object pairs appeared at the opposite sides of the bottom of the screen. An auditory cue directed the child's attention to one of the two images (e.g., "Where's the bolay? Do you see it?"). The yoked design was used to be consistent with the third experimental study. In the yoked design, the same pairs of objects appeared in alternating trials (e.g., objects 1 and 2 always appeared together, as did objects 3 and 4). The target image and side were pseudo randomized so that the target side never remained the same for more than three trials. An additional 3 second attention-catching video played in the middle of the test phase to enhance child attention and diminish data loss. Each object-label association was tested in four test trials (e.g., "Where's the teemo?"). After the word learning movie finished, the examiner showed the child a display with the four object images in each corner and asked the child to point to the object that she named. Child responses were recorded for each of the four labels. This pointing task was much like the standardized assessment used to measure receptive vocabulary (PPVT-4). Trained students coded the videos offline using Looking-While-Listening coding procedures (Fernald & Marchman, 2012; Fernald, Zangl, & Marchman, 2008). Looking time to each object and reaction time data were calculated and used for analyses.

Combination task. The combination task was designed to investigate children's ability to map meaning onto newly segmented words and followed a similar design to experiments in Graf Estes et al. (2007). As the name suggests, the combination tasks includes both an artificial language presentation phase and a word learning phase. A different artificial language was created with the same statistical structure used in the segmenting task, but different syllables. Two counterbalanced artificial language versions were created. The same female speaker read sections of each artificial language version. Following the same procedures from the previous artificial language recording session, the speaker recorded the stimuli at a constant pitch (mean F0 = 170) without taking breaths between syllables. A different method was used to splice the artificial language together, which was also used in Experiment 2 of Graf Estes et al. (2007). Each unique syllable was spliced from the speech stream and saved with a descriptive name that identified the syllables preceding and following the target syllable. Once all versions of syllables were saved individually, they were combined to create a constant speech stream with the appropriate coarticulation. The beginning of the artificial language faded in with increasing volume and the end faded out in volume. As in the segmenting task, only statistical cues pointed to word boundaries (transitional probability within words = 1.0; transitional probability across words = 0.0). This artificial language consisted of four disyllabic novel words (version A2: patu [pɑtu], meeda [midɑ], geenay [gine], bodu [bodu]; version B2: tunay [tune], page [pɑgi], meepo [mipo], dadu [dɑdu]). Two of the four words in the artificial language, with transitional probabilities of 1 were recorded in isolation by the same female speaker (meeda, bodu, tunay, pagee). Similarly, two nonwords that were comprised of syllables from the artificial language, but never sequentially yielding a transitional probability of 0, were recorded in isolation. The words and nonwords were recorded at a constant pitch for the teaching condition; the test items,

however, were recorded in child-directed speech, to enhance attention (e.g., “Find the meeda. Do you see it?”). The stimuli in the word learning and combination tasks did not differ in phonotactic probability W = 10, $p = 0.686$.

During the combination task, children sat in the same testing booth and were instructed to watch the movie. The combination task consisted of an exposure phase, teaching phase, and test phase. In the exposure phase, children watched a silent movie depicting nature scenes while listening to the artificial language. The exposure phase lasted 4.75 minutes and was presented at approximately 63dB. Immediately after the exposure phase, children were taught four object-label associations. Two of the labels were words that should have been segmented from the artificial language (within word transitional probabilities = 1.0) and the other two labels were nonwords (transitional probabilities = 0.0). The objects had unique shapes and unique colors, but were similar in size. As in the word learning task, children were taught each object-label association three times in a pseudo randomized order with the same object-label association never appearing sequentially. A three-second silent movie played in between the teaching and test phase.

During the test phase, children were shown two paired images that followed a yoked design. To prevent influences of mutual exclusivity, within each test trial, children were shown either two of the objects that corresponded to words from the language, or two objects that corresponded to nonwords. Word and nonword pair trials alternated. The 16 test trials were pseudo randomized so that the target object appeared on the same side of the screen no more than three times. A three-second musical attention-getting movie played in the middle of the test phase. At the end of the test phase, the examiner showed a picture with the four objects depicted in each corner (in a 2 x 2 grid) and asked the child to point to each object that the examiner

labeled (e.g., “Find the meeda.”). Pointing data were collected for each label. As in the word learning task, trained coders coded child eye gaze following LWL procedures.

Eye gaze reliability coding. Twenty percent of the final participants within each group were randomly selected for eye gaze reliability coding. A second examiner independently coded eye gaze in the word learning and combination task videos. Word learning eye-gaze reliability group averages were high overall. Reliability within the typically developing group was on average 81.25% comparable trials 97.80% frame agreement and 97.48% shift agreement. The ASD group had an average of 92.86% comparable trials 97.16% frame agreement and 98.41% shift agreement and the SLI group had an average of 88.54% comparable trials 97.67% frame agreement and 97.82% shift agreement. Because frame and shift agreement are artificially inflated when comparable trials are below 100%, the primary and the reliability coder reviewed their codes together and came to a consensus code that rendered a trial non-comparable. Once coded movies reached 100% comparable trials reliability data were recalculated. With 100% comparable trials, the typically developing group had an average of 97.52% frame agreement and 98.51% shift agreement. The ASD group had 96.79% frame agreement and 97.79% shift agreement and the SLI group had 97.47% frame agreement and 98% shift agreement on average.

Similarly, eye gaze coding for the combination task yielded high group reliability averages. The typically developing group had an average of 72.70% comparable trials, 98.15% frame agreement, and 98.36% shift agreement. Reliability within the ASD group yielded an average of 88.39% comparable trials 97.79% frame agreement and 98.67% shift agreement. The SLI group reliability yielded an average 90.63% comparable trials, 97.88% frame agreement, and 97.78% shift agreement. Although the frame and shift agreement were extremely similar for all groups, the typically developing group had a slightly lower percent of comparable trials. This

lower percentage may be reflective of reduced child engagement in the task. Consensus coding was conducted on codes that rendered trials not comparable in order to calculate reliability data for all of the task trials. On average, there was 97.69% frame agreement and 98.56% shift agreement in the typically developing group. The ASD group had an average of 97.69% frame agreement and 98.85% shift agreement and the SLI group had an average of 97.15% frame agreement and 97.82% shift agreement.

Eye gaze data cleaning. The eye-gaze data from the word learning task were cleaned at the trial and child levels; data from the combination task was cleaned at the trial and condition levels. Children were required to contribute looking data that was directed towards the target or distractor image for at least 50% of the test window. Trials that contained more than 50% missing data were considered to provide insufficient data to provide a valid measure of the construct of interest and were therefore eliminated. Children also were required to contribute at least 2 of the 16 trials in the word learning task. One child with typical development failed to contribute a sufficient number of cleaned trials to be included in the analyses. The average number of trials contributed by the children across all of the groups was high, however. The children with typical development contributed an average of 14 trials (SD = 2.83); the children with ASD contributed on average 12.83 (SD = 2.52) trials. Similarly, children with SLI contributed an average of 13.54 (SD = 2.38) trials of eye-gaze data. Due to technical difficulties, the video recording did not record word learning data for two children, one child with typical development and one child with SLI. Both children, however, contributed pointing data and were therefore retained for the appropriate word learning analyses.

The same trial level cleaning criteria were applied to the data from the combination task. In addition, children were required to contribute at least two trials in each condition (i.e., word

condition and nonword condition). The maximum number of trials in each condition was 8. Three children with typical development did not meet this criteria, again possibly due to a lack of task engagement. On average, the children with typical development contributed 6.81 (SD = 1.52) trials in the nonword condition and 6.43 (SD = 1.77) trials in the word condition. Children with ASD contributed on average 6.11 (SD = 1.66) trials in the nonword condition and 5.68 (SD = 1.74) trials in the word condition. Lastly, the children with SLI contributed on average 6.76 (SD = 1.10) trials in the nonword condition and 6.84 (SD = 1.40) trials in the word condition. Figures 1 and 2 depict the number of trials each child contributed for the word learning task and the combination task.

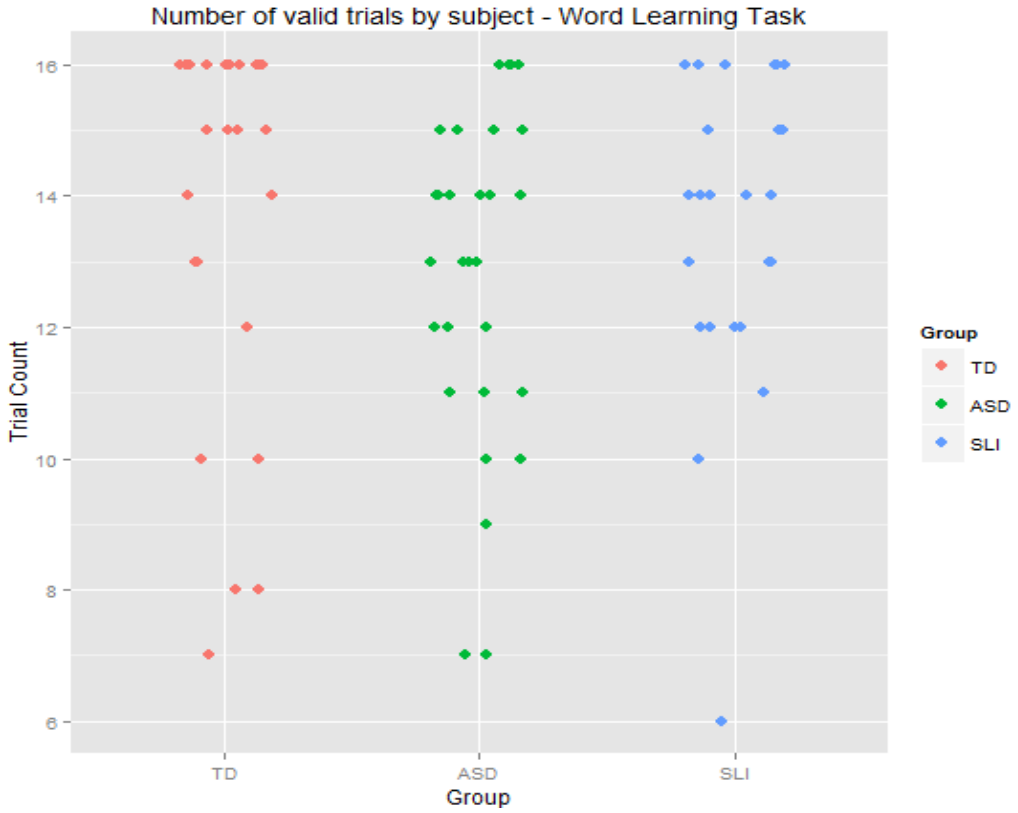


Figure 1. Word Learning trial count for each child.

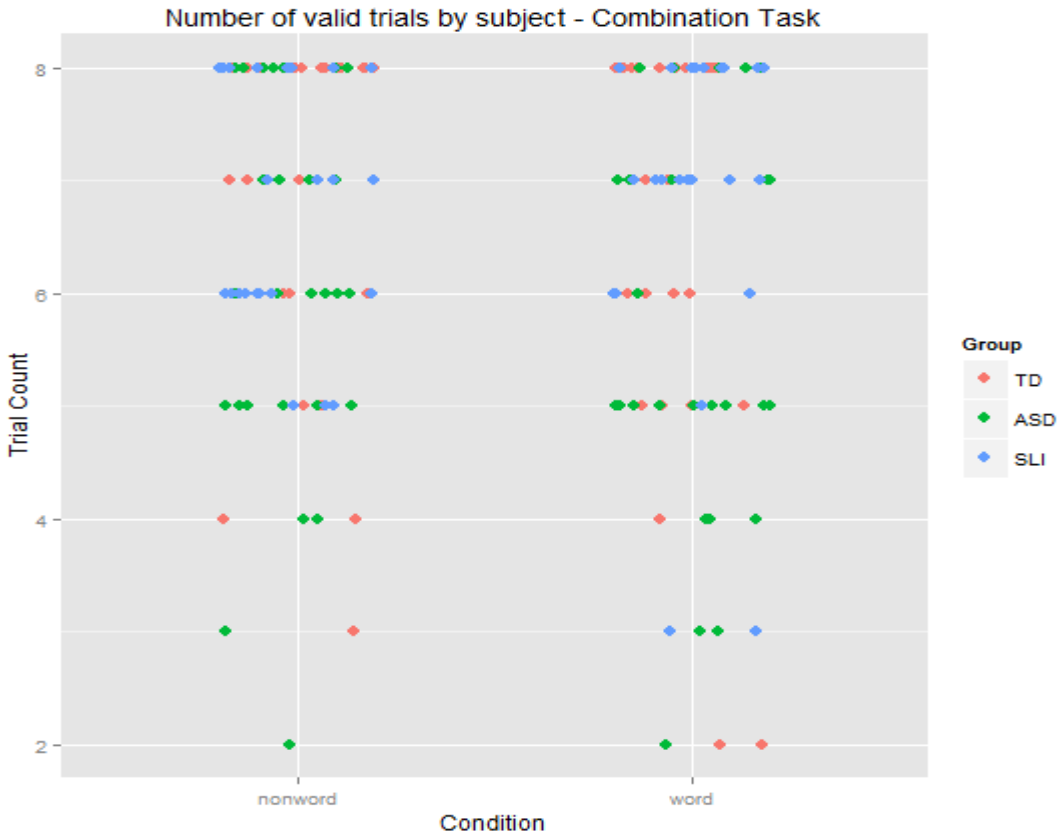


Figure 2. Combination task trial count for each child.

Chapter 3: Results

Analysis Approach

The main purpose of the current study was to examine word learning mechanisms in children with typical development, ASD, and SLI. Therefore, regression analyses were used to test for differences in group performance on the segmenting task, word learning task (pointing data), and combination task (pointing data). The typically developing (TD) group was set as the reference group. Differences between the ASD and SLI groups often could be inferred from observation of descriptive data. Despite this, to verify whether there was a statistical difference between the ASD and SLI groups, controlling for the typically developing group, the "linearHypothesis" function from the "car" package in R was used (Fox, Friendly, & Weisberg, 2013). Sometimes the research question of interest was not about group differences in performance. For example, research question 4 examined whether other skills such as vocabulary or cognitive abilities predicted task performance. When such questions were being assessed, groups were set using planned orthogonal contrasts so that the main effect of vocabulary, for instance, was yielded, instead of the simple effect of vocabulary on segmenting abilities in the typically developing group.

Growth curve analysis. Growth curve analyses were employed to test eye-gaze data collected during the word learning task and the combination task. Growth curve analysis (GCA) is a form of mixed effect modeling appropriate for time course data (Mirman, Dixon, & Magnuson, 2008; Mirman, 2014). In this case, GCA was used to model multiple data points for each child over the test window of the Looking-While-Listening task trials. Looks to the target image during the test window served as the outcome variable. Linear, quadratic, and other higher-order polynomials were also included in the model to accurately represent the shape of

the data (i.e., increased looking to the target image over time that plateau). GCA models allow not only for fixed effects, such as group or condition effects, but also random effects, that allow children to randomly vary from the mean at the intercept and in slope values, for instance. Additionally, GCA models can test predictors of random effects (e.g., whether cognitive scores are associated with random slope effects).

The dependent variable in the GCA models were average looks to the target image during incremental time intervals within the test window. One challenge of modeling looking values in each incremental window within the test window is that values are dichotomous (i.e., the child is or is not looking at the target image). Therefore, because the outcome variable is bounded between values of 0 and 1 and because variance over this range is not homogeneous, it is inappropriate to treat the outcome variable as continuous. As such, Mirman (2014) recommends that outcome values be transformed into empirical log odds of looking to the target image (Elog). An additional challenge of modeling time terms in GCA models is that they are correlated (e.g., $time^2$, $time^3$). In order to address this concern, time terms were re-scaled and centered, creating orthogonal polynomials (Mirman, 2014). Orthogonal time (ot) values represent the value of the outcome value (i.e., y) when x is equal to zero. Orthogonal time values also represent the overall average under the curve.

In determining the appropriate test window, an empirically based approach was employed (Barr, 2008). Visual inspection of the grand mean curves guided the test window boundaries. A test window of 200 ms to 3000 ms after the onset of the target word was selected for the word learning task and a 300 ms to 3000 ms for the combination task. The first time frame in each test window was the first time frame in which a consistent increase in looks to the target was observed across the groups. Since children maintained or increased their looks to the target

image throughout the remainder of the trial, the test window ended at the end of the trial. In addition, observations of the plotted data and previous analysis approaches of eye-gaze data indicated that the linear and quadratic time terms should be included in the GCA models. However, in following an empirically based approach, models with cubic terms were compared to models with linear and quadratic terms to identify the model that best fit the data. As with the previous analyses, the typically developing group was set as the reference group. Differences between the ASD and SLI groups were tested by using the linearHypothesis function noted earlier (Fox et al., 2013). Lastly, degrees of freedom are difficult to estimate for mixed-effects models; therefore, a *z*-distribution was used to evaluate the significance the t-values ($t >= +/-$ 1.96 was considered significant at the .05 level).

Segmenting Abilities

The first research question asked whether children with ASD and/or SLI have deficits in statistical learning, compared to typically developing children. To address this first research question, segmenting accuracy was compared across the groups. The typically developing group reached an average accuracy of 61.88% (SD = 15.05%), the ASD group reached 64.12% (SD = 12.51%) accuracy, and the SLI group reached 54.62% (SD = 11.59%) accuracy. A mixed-effect logistic regression model tested for group differences on the segmenting task while accounting for random variation at the child level. This assessment serves as a more conservative assessment of group differences because it accounts for child-level random variance. The typically developing group served as the reference group. Two children with ASD did not contribute data to the final analyses. The model revealed that the typically developing and ASD group performed significantly better on the segmenting task than the SLI group (typically developing vs. SLI group: *Estimate* = -0.361; *Std. Err* = 0.156; *z* = -2.316; ASD vs. SLI group: *Estimate* = -

0.420; *Std. Err* = 0.159; *z* = -2.646). The children with ASD and typical development did not differ significantly from each other on segmenting performance (*Estimate* = 0.059; *Std. Err* = 0.154; *t* = 0.703). Figure 3 depicts child performance on the segmenting task.

Each group was separately tested against chance performance (i.e., 50%). The typically developing and ASD groups performed significantly above chance on the segmenting task, $t(29) = 4.321$, $p < .001$, $t(26) = 5.865$, $p < .001$, respectively. The SLI group did not perform statistically above chance, $t(24) = 1.995$, $p = .058$.

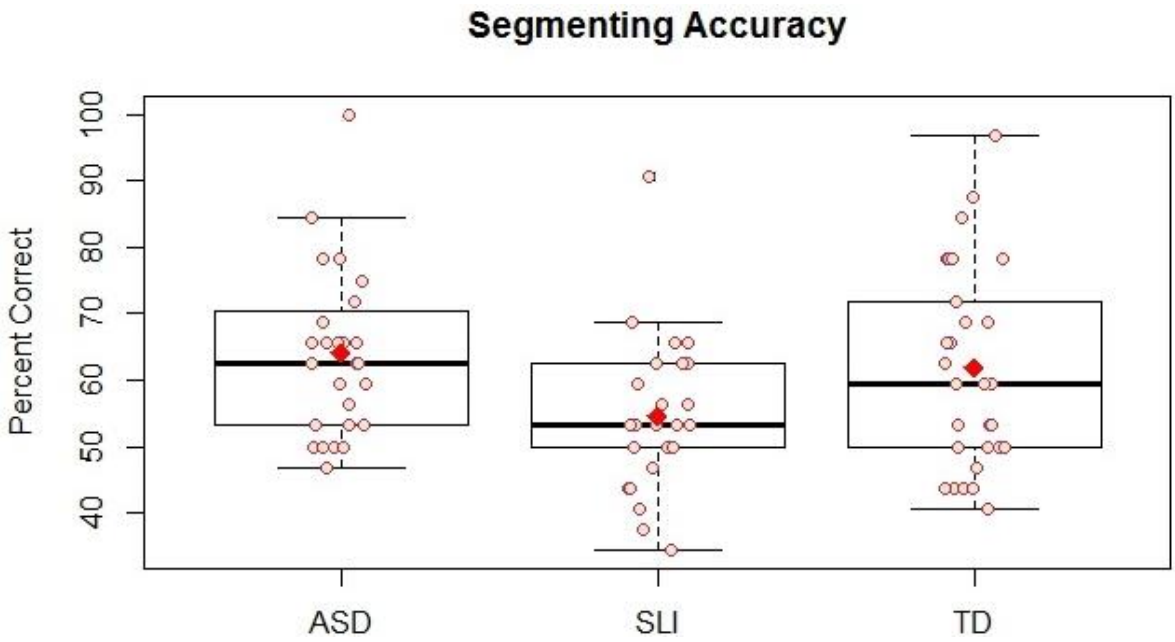


Figure 3. Child accuracy on two-alternative forced-choice segmenting task. The bold horizontal line represents the median and the red diamond represents the group mean. The whiskers represent the range within 1.5 times the interquartile range. There was one outlier who performed better than the group range in the ASD group and SLI group.

The binomial probability theorem offers a more conservative test against chance performance. Therefore, in addition to testing against 50% chance levels, performance was examined using binomial probabilities. In order to perform statistically above chance according

to binomial probabilities, at least 22 of the 32 segmenting test trials had to have been responded to accurately. According to this criterion, 11 of the 30 (36.67%) children with typical development, 8 of the 27 (29.63%) of the children with ASD, and 2 of the 25 (8%) children with SLI performed above chance. Children who performed the segmenting task above chance, according to the binomial probability criterion, were entered into a linear regression model that tested whether group membership predicted accuracy scores. There was no group difference in the accuracy scores that children who were above chance attained. However, a chi square test of independence was performed to examine whether group membership was independent of above chance performance on the segmenting task according to the binomial probability criterion. As indicated by the initial regression model, the number of children who performed above chance on the segmenting task did differ according to group, χ^2 (2, N = 82) = 6.224, p = .045.

Word Learning Task Performance

The second research question asked whether children with ASD and/or SLI have word learning deficits, compared to typically developing children. Therefore, fast mapping abilities were assessed through the word learning task. Two test phases measured learning: pointing test phase and a Looking-While-Listening eye-gaze test phase. Of the four items that were taught during the word learning task, the typically developing group had an average pointing accuracy of 2.80 (SD = 1.37). The ASD group pointed to an average of 2.90 (SD = 1.42) correct images and the SLI group pointed to an average of 1.88 (SD = 0.97) correct images. A linear regression model revealed that the typically developing and ASD groups had higher pointing accuracy scores than the SLI group ps < .011. The TD and ASD groups performed similarly p = .774. Although regression models are robust to violations of normality, follow-up non-parametric analyses were conducted because child responses were limited to five possible scores (0 – 4

correct). A Kruskal-Wallis test, similar to a one-way ANOVA, revealed that there were group differences (H = 9.234, p = .010), indicating that at least one group differed from the others in task performance. Follow-up pairwise comparisons were conducted using Mann Whitney U tests, which is the non-parametric equivalent of independent *t*-tests that test whether median pointing accuracy differed between groups. It is not ideal to run separate comparisons because the total variance across all groups is no longer present in the statistical model, which is an additional benefit of the previously presented regression model. Pairwise comparisons revealed that the typically developing group performed similarly to the ASD group (U = 412.5 p = .714) and that the typically developing group and the ASD group performed statistically better than the SLI group (U = 520.5 p = .010; U = 508.5 p = .007, respectively), replicating the regression analyses.

Individual groups were tested against chance accuracy on the pointing task (i.e., 25%). All groups had above-chance performance on the pointing task: TD $t(29) = 7.172$, $p < .001$, ASD $t(28) = 7.178$, $p < .001$, SLI $t(24) = 4.530$, $p < .001$ (see Figure 4).

Eye-gaze data were analyzed using GCA models. A model with linear, quadratic, and cubic orthogonal time terms explained the data significantly better than a model with linear and quadratic orthogonal time terms logLik = -3348.7, χ^2 (7) = 956.05, $p < .001$. Main effects included linear, quadratic, and cubic orthogonal time terms, group (using dummy coding, with the typically developing group as the reference group), and group by orthogonal time term interactions. A random effect was included to allow children to vary by the orthogonal time terms. The final model was:

Level 1: Y_{it} Elog = $\beta_{0i} + \beta_{1i}$ Linear + β_{2i} Quadratic + β_{3i} Cubic + R_{ij}

Sample of Level 2 equations: $\beta_{0j} = \Upsilon_{00} + \Upsilon_{01}$ ASD Group + Υ_{02} SLI Group + U_{0j}

$$\beta_{1i} = \Upsilon_{10}\,\text{Linear} + \Upsilon_{11}\,\text{ASD Group} + \Upsilon_{12}\,\text{SLI Group} + U_{1j}$$

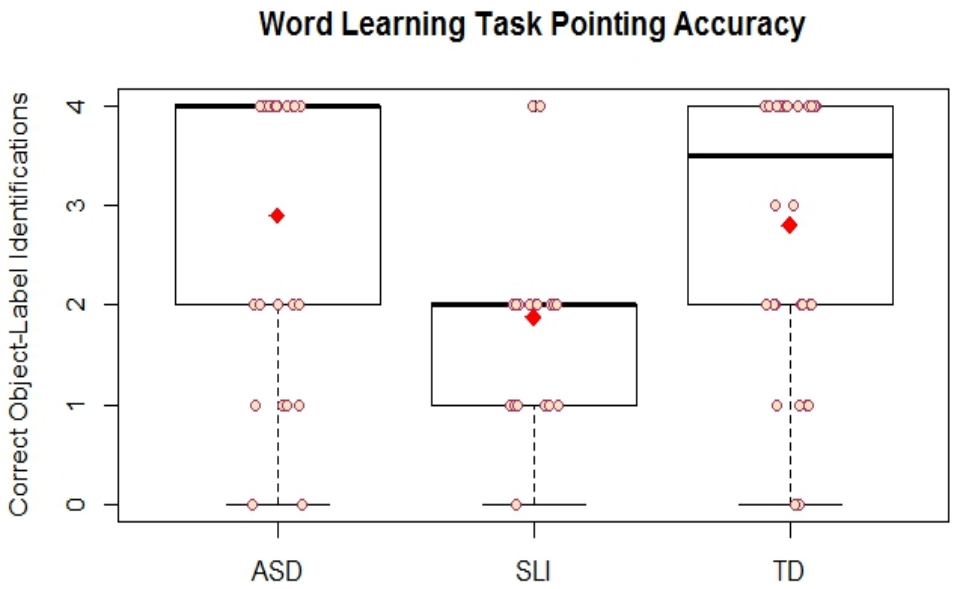


Figure 4. Pointing accuracy on the word learning task. The bold horizontal line represents the median and the red diamond represents the group mean. The whiskers represent the range within 1.5 times the interquartile range.

$$\beta_{2i} = \Upsilon_{20}\,\text{Quadratic} + \Upsilon_{21}\,\text{ASD Group} + \Upsilon_{22}\,\text{SLI Group} + U_{2j}$$

$$\beta_{3i} = \Upsilon_{30}\,\text{Cubic} + \Upsilon_{31}\,\text{ASD Group} + \Upsilon_{22}\,\text{SLI Group} + U_{3j}$$

$$Y_{ij}\ \text{Elog} = \Upsilon_{00} + \Upsilon_{10}\,\text{Linear} + \Upsilon_{20}\,\text{Quadratic} + \Upsilon_{30}\,\text{Cubic} + \Upsilon_{01}\,\text{ASD Group} + \Upsilon_{02}\,\text{SLI Group} + \Upsilon_{11}\,\text{Linear*ASD Group} + \Upsilon_{12}\,\text{Linear*SLI Group} + \Upsilon_{21}\,\text{Quadratic*ASD Group} + \Upsilon_{22}\,\text{Quadratic*SLI Group} + + U_{0j} + U_{1j}\,\text{Linear} + U_{2i}\,\text{Quadratic} + U_{3i}\,\text{Cubic} + R_{ij}$$

The random slope GCA model revealed that there was a significant effect of linear time (*Estimate* = 3.040; *Std. Err* = 0.620; *t* = 4.901), indicating that children increased their looking to the target image across the test window. In addition, there was a significant effect of quadratic time (*Estimate* = -.0725.040; *Std. Err* = 0.367; *t* = -1.977), indicating that looks to the target image plateaued during the progression of time in the test window. Moreover, as the pointing data indicated, the typically developing group looked to the target image significantly more than

the SLI group (*Estimate* = -0.426; *Std. Err* = 0.190; *t* = -2.249). However, looks to the target image were only marginally higher in the ASD group than the SLI group (*Estimate* = -.337; *Std. Err* = 0.188; *t* = -1.790). None of the interactions between group and time terms were significant (see Table 2). Figure 5 depicts the average group looking behavior.

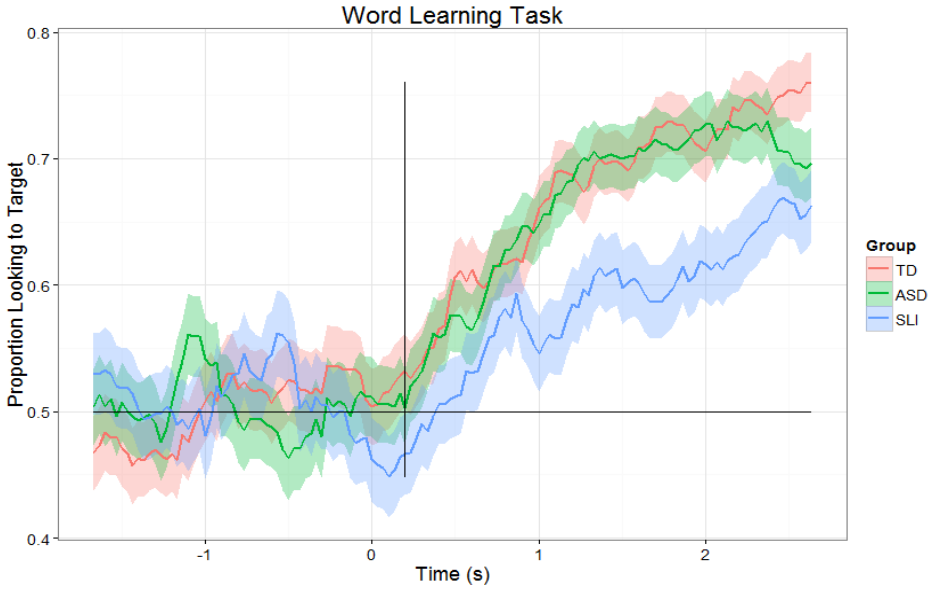


Figure 5. Eye gaze behavior on the word learning task.

Table 2

Group Comparisons of Eye Gaze Behavior in the Word Learning Task

Fixed Effects	**Estimate**	**Standard Error**	***t* value**	***p***
Intercept (γ_{00})	0.790	0.129	6.133	< .001
Linear (γ_{10})	3.040	0.620	4.901	< .001
Quadratic (γ_{20})	-0.725	0.367	-1.977	.048
Cubic (γ_{30})	-0.006	0.297	-0.021	.983
TD vs. ASD (γ_{01})	-0.090	0.181	-0.497	.619
TD vs. SLI (γ_{02})	-0.426	0.190	-2.249	.025
Linear x TD vs. ASD (γ_{11})	-0.778	0.869	-0.841	.400
Linear x TD vs. SLI (γ_{12})	-1.054	0.913	-1.154	.249
Quadratic x TD vs. ASD (γ_{21})	-0.433	0.514	-0.841	.400
Quadratic x TD vs. SLI (γ_{22})	0.540	0.540	1.000	.317
Cubic x TD vs. ASD (γ_{31})	-0.124	0.416	-0.297	.767
Cubic x TD vs. SLI (γ_{32})	0.345	0.437	0.790	.430

Random Effects		**Variance**	**Standard Deviation**	**Correlations**		
Child	Intercept (U_{0j})	0.463	0.680			
	Linear (U_{1j})	10.623	3.259	0.68		
	Quadratic (U_{2j})	3.621	1.903	-0.54	-0.37	
	Cubic (U_{3j})	2.321	1.524	-0.08	-0.22	-0.16

Residual (R_{tj})	0.147	0.383

Note. Approximated *p* values were used.

Combination Task Performance

The third research question examined whether children with ASD and/or SLI are able to map meaning onto newly segmented words and whether performance differed from typically developing children. The combination task addressed this question. Like the word learning task, learning was assessed through two test phases: pointing test phase and a Looking-While-Listening eye-gaze test phase. Of the four items that were taught during the combination task, the typically developing group had an average pointing accuracy of 3.07 (SD = 1.41). The ASD group pointed to an average of 2.83 (SD = 1.51) correct images and the SLI group pointed to an average of 2.44 (SD = 1.45) correct images. A linear regression model revealed that there were no significant group differences in pointing responses (mean centered accuracy) *p*s > .135. A Kruskal-Wallis test also was conducted and replicated the regression analysis results (H = 2.910, $p = .234$). The individual groups were tested against chance accuracy on the pointing task (i.e., 25%). All of the groups performed at above-chance levels on the pointing task: TD $t(29) = 7.655$, $p < .001$, ASD $t(28) = 6.503$, $p < .001$, SLI $t(24) = 4.980$ $p < .001$ (see Figure 6).

In addition, a mixed effect linear regression tested whether children more successfully learned words than nonwords (i.e., word type). Because the focus of this analyses was on performance on words type, planned orthogonal contrasts were used to derive the main effect rather than the simple effect of word type for the typically developing group. Therefore, one of the contrasts grouped children with ASD and typical development together and pointing performance was compared to children with SLI. The other planned orthogonal contrast compared children with ASD to children with typical development, controlling for children with

SLI. A random effect of child was included in the model. There was no main effect of word type $t = 0.068$, $p > .90$, indicating that children did not learn words from the artificial language better

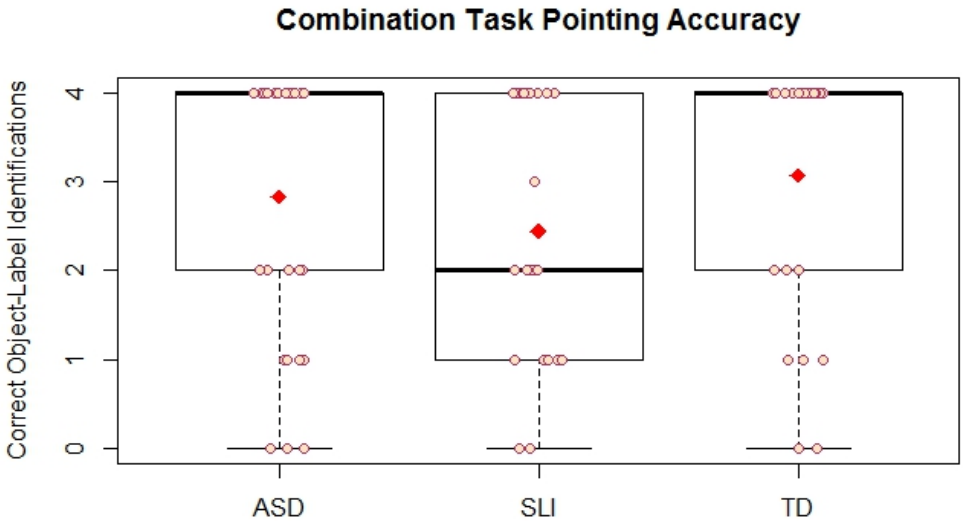


Figure 6. Child pointing performance on the combination task. The bold horizontal line represents the median and the red diamond represents the group mean. The whiskers represent the range within 1.5 times the interquartile range.

than nonwords. Additionally, as the original regression model testing for group differences found, there was no significant main effect of group *p*s > .05. Lastly, there was no word type and group interaction *p*s > .05. See Table 3.

Table 3

Word vs. Nonword Pointing Data in the Combination Task

Fixed Effects	**Estimate**	**Std. Error**	***t* value**	***p***
Intercept	-0.009	0.080	-0.107	.915
Word Type (word vs. nonword)	0.004	0.065	0.068	.946
Group: TD & ASD vs. SLI	0.222	0.174	1.279	.201
Group: TD vs. ASD	-0.102	0.189	-0.540	.589
TD & ASD vs. SLI x Word Type	-0.151	0.141	-1.065	.287
TD vs. ASD x Word Type	-0.168	0.154	-1.088	.277

Random Effects		**Variance**	**Std. Deviation**
Child	Intercept	0.442	0.665
Residual		0.176	0.419

Note. Approximated *p* values were used.

A GCA model tested eye-gaze data collected during the combination task. Fixed effects included linear, quadratic, and orthogonal time terms, group (dummy coded with the typically developing group as the reference group), word versus nonword condition, and interactions across all fixed effects. Condition (words versus nonwords) were coded using planned orthogonal contrasts, to allow for group performance to reflect performance across the entire task, instead of one condition in the task. Random effects were included to allow children to vary across time terms and children to vary by condition across time terms. As with the word learning GCA model, the model included the cubic orthogonal time term was significantly better than the model without it logLik = -9444.3, χ^2 (14) = 2676.5, $p < .001$. Therefore, the final model was:

Level 1: $Y_{it}\ \text{Elog} = \beta_{0i} + \beta_{1i}\ \text{Linear} + \beta_{2i}\ \text{Quadratic} + \beta_{3i}\ \text{Cubic} + R_{ij}$

Sample of Level 2 equations: $\beta_{0j} = \Upsilon_{00} + \Upsilon_{01}\ \text{ASD Group} + \Upsilon_{02}\ \text{SLI Group} + \Upsilon_{03}\ \text{Condition} + U_{0j}$

$$\beta_{1i} = \Upsilon_{10}\ \text{Linear} + \Upsilon_{11}\ \text{ASD Group} + \Upsilon_{12}\ \text{SLI Group} + \Upsilon 1_3\ \text{Condition} + U_{1j}$$

$$\beta_{2i} = \Upsilon_{20}\ \text{Quadratic} + \Upsilon_{21}\ \text{ASD Group} + \Upsilon_{22}\ \text{SLI Group} + \Upsilon_{23}\ \text{Condition} + U_{2j}$$

$$\beta_{3i} = \Upsilon_{30}\ \text{Cubic} + \Upsilon_{31}\ \text{ASD Group} + \Upsilon_{22}\ \text{SLI Group} + \Upsilon_{23}\ \text{Condition} + U_{3j}$$

The model yielded a significant effect of linear time (*Estimate* = 1.982; *Std. Err* = 0.454; *t* = 4.368), indicating that children increased their looks to the target image across the test window. Similar to the pointing data, there were no significant main effects of group or condition. None of the interactions across groups, conditions, and time terms were significant (see Table 4). Figure 7 depicts group performance within condition and Figure 8 depicts group performance collapsed across both conditions to facilitate visualizations of group comparisons.

Table 4

Group Comparisons of Eye Gaze Behavior in the Combination Task

Fixed Effects	**Estimate**	**Std. Error**	***t* value**	***p***
Intercept (γ_{00})	0.731	0.128	5.713	< .001
Linear (γ_{10})	1.982	0.454	4.368	< .001
Quadratic (γ_{20})	-0.558	0.387	-1.442	.149
Cubic (γ_{30})	0.258	0.323	0.800	.424
TD vs. ASD (γ_{01})	-0.077	0.180	-0.426	.670
TD vs. SLI (γ_{02})	0.001	0.186	0.007	.994
Condition (Word vs. Nonword) (γ_{03})	-0.020	0.193	-0.102	.919
Linear x TD vs. ASD (γ_{11})	-0.228	0.639	-0.357	.721
Linear x TD vs. SLI (γ_{12})	0.910	0.658	1.384	.166
Quadratic x TD vs. ASD (γ_{21})	-0.334	0.545	-0.612	.541
Quadratic x TD vs. SLI (γ_{22})	-0.345	0.561	-0.615	.539
Cubic x TD vs. ASD (γ_{31})	0.671	0.454	1.478	.139
Cubic x TD vs. SLI (γ_{32})	0.349	0.468	0.746	.456
Linear x Condition (γ_{13})	-0.216	0.832	-0.260	.795
Quadratic x Condition (γ_{23})	0.826	0.653	1.264	.206
Cubic x Condition (γ_{33})	-0.340	0.611	-0.557	.578
TD vs. ASD x Condition ($\gamma_{01*}\gamma_{03}$)	-0.043	0.271	-0.160	.873
TD vs. SLI x Condition ($\gamma_{02*}\gamma_{03}$)	-0.009	0.279	-0.032	.975
Linear x TD vs. ASD x Condition ($\gamma_{11*}\gamma_{03}$)	-0.390	1.170	-0.334	.738
Linear x TD vs. SLI x Condition ($\gamma_{12*}\gamma_{03}$)	0.105	1.204	0.088	.930
Quadratic x TD vs. ASD x Condition ($\gamma_{21*}\gamma_{03}$)	-1.460	0.919	-1.589	.112
Quadratic x TD vs. SLI x Condition ($\gamma_{22*}\gamma_{03}$)	-0.949	0.946	-1.004	.315
Cubic x TD vs. ASD x Condition ($\gamma_{31*}\gamma_{03}$)	0.505	0.860	0.588	.557
Cubic x TD vs. SLI x Condition ($\gamma_{31*}\gamma_{03}$)	0.378	0.885	0.427	.669

Random Effects		**Variance**	**Std. Deviation**	**Correlations**		
Child	Intercept (U_{0j})	0.198	0.445			
	Linear (U_{1j})	0.927	0.963	1.00		
	Quadratic (U_{2j})	1.210	1.100	-0.87	-0.87	
	Cubic (U_{3j})	0.301	0.549	-0.61	-0.61	0.92
Child x Condition	Intercept (W_{0jk})	0.506	0.711			
	Linear (W_{1jk})	9.246	3.041	0.46		
	Quadratic (W_{2jk})	5.600	2.367	-0.24	-0.17	
	Cubic (W_{3jk})	4.878	2.209	0.21	-0.14	-0.26
Residual (R_{tj})		0.248	0.498			

Note. Approximated *p* values were used.

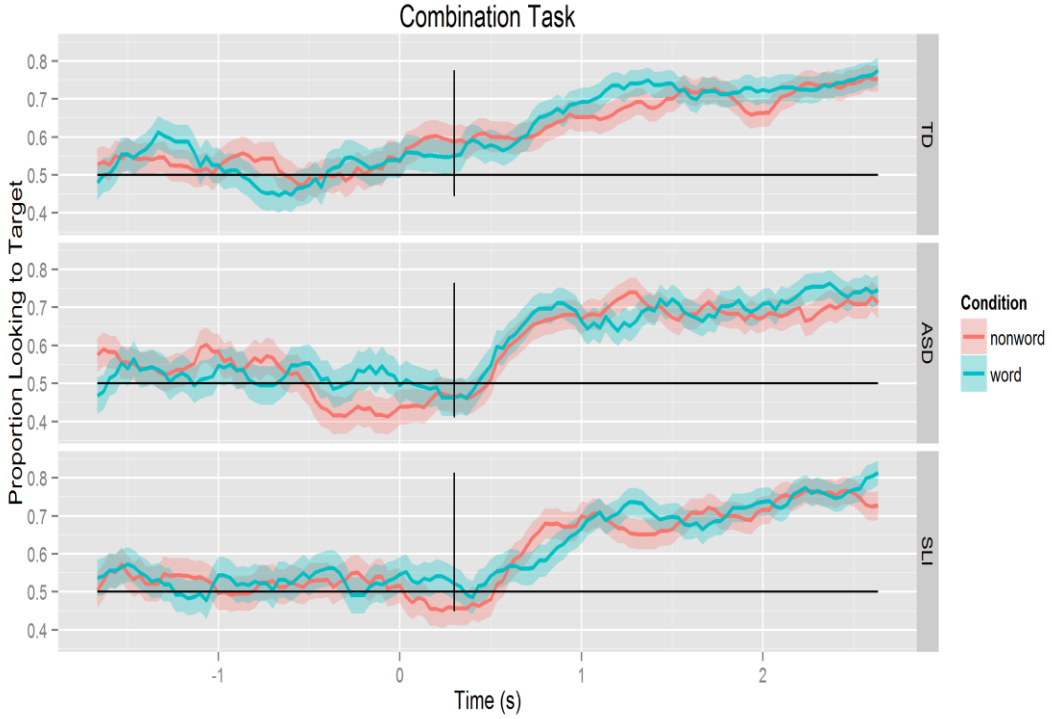


Figure 7. Eye gaze behavior on the combination task, including condition.

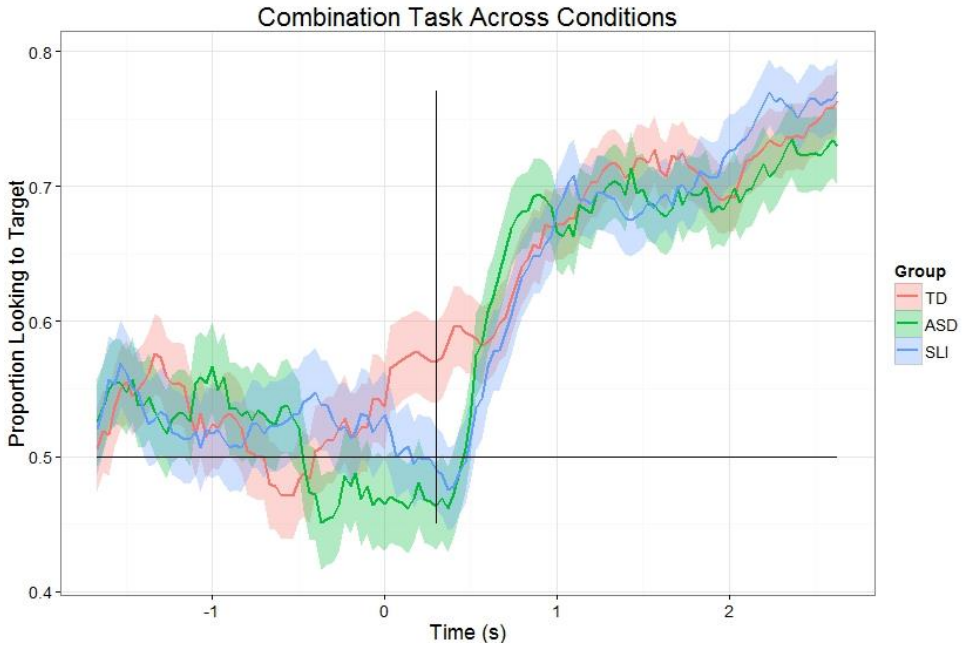


Figure 8. Eye gaze behavior on the combination task, collapsed across conditions.

The lack of a group difference in the combination task motivated a follow-up test for group differences across the word learning task and the combination task. A mixed effect linear

regression model was used on the pointing data. The mixed effect model included planned orthogonal contrasts that tested for differences across the ASD and typically developing groups versus the SLI group, and for differences between the ASD and typically developing groups. The model also allowed for a random effect of child. There was no main effect of task, $t = .072$, $p > .05$, indicating that overall, the children did not perform better on the combination task than the word learning task, or vice versa. However, there was a main effect of group, with the typically developing and the ASD groups performing significantly better than the SLI group across both tasks together, $t = 3.056$, $p < .01$. There was no group by task type interaction ps > .05. Although the SLI group performed similarly to the typically developing and ASD groups in the combination tasks, the improvement in performance was not robust enough to yield a significant group by task interaction (see Table 5).

Table 5

A Comparison of Pointing Responses on the Word Learning Task and Combination Task

Fixed Effects	**Estimate**	**Standard Error**	***t* value**	***p***
Intercept	-.0661	2.743	-0.241	.810
Task (Word Learning vs. Combination)	0.378	5.221	0.072	.943
Group: TD & ASD vs. SLI	18.276	5.980	3.056	.002
Group: TD vs. ASD	-1.448	6.526	-0.222	.824
TD & ASD vs. SLI x Task	-11.862	11.385	-1.042	.297
TD vs. ASD x Task	-7.724	12.423	-0.622	.534

Random Effects	**Variance**	**Standard Deviation**
Child	58.97	7.679
Residual	1137.86	33.732

Note. Approximated *p* values were used.

Cognitive and Linguistic Predictors of Statistical Learning and Word Learning

The fourth research question asked whether there is an association between concurrent cognitive and linguistic abilities measured through standardized assessments and online experimental task performance. Standardized scores from the receptive vocabulary measure

(PPVT-4), the omnibus language assessment (CELF-4, Core Language), and the cognitive assessment (WISC-4) were used. Experimental variables included segmenting accuracy scores and average proportion of looking to the target image in the test window from the word learning task and the combination task. First, bivariate correlations were run for each group separately.

In the typically developing group, receptive vocabulary standard scores only marginally correlated with mean proportions of looks. Performance on standardized assessments did not correlate with any of the experimental variables. However, segmenting performance significantly correlated with performance on the combination task. Conversely, performance on all of the standardized assessments significantly correlated with experimental task performance in the ASD group. Also, segmenting performance marginally correlated with average proportion of looks to the target image in the word learning task and significantly correlated with looking behavior in the combination task. Lastly, there were no significant correlations in the SLI group with the exception of a marginal correlation between receptive vocabulary scores and mean proportion of looking to target during the test window in the combination task (see Table 6).

Table 6

Group Correlations of Standardized and Experimental Assessment Performance

Variable	**Receptive Vocabulary[1]**	**Core Language[2]**	**Cognition[3]**	**Segmenting[4]**
		TD group		
Word Learning task[5]	.362†	.006	.240	.168
Combination task[5]	.338	.242	.034	.472*
Segmenting task[4]	.101	-.025	.104	
		ASD group		
Word Learning task[5]	.518*	.447*	.432*	.338†
Combination task[5]	.522*	.564*	.390*	.455*
Segmenting task[4]	.498*	.472*	.392*	
		SLI group		
Word Learning task[5]	.220	.162	-.219	.122
Combination task[5]	.387†	.204	-.184	.030
Segmenting task[4]	.102	.126	.022	

Note. Standard scores were used for the [1]PPVT-4, [2]CELF-4 CL, and [3]WISC-4, [4]percent correct, [5]average proportion of looking to target in test window. † $p < .10$, * $p < .05$ (two-tailed)

Although there were inconsistent patterns in the correlational analyses across the groups, receptive vocabulary tended to be the strongest predictor of experimental task performance, even if significance was not reached. This relationship was further assessed within each online measure. The purpose of these analyses was to identify whether receptive vocabulary skills explained unique and significant variance in task performance (i.e., a main effect of receptive vocabulary). Therefore, planned orthogonal contrasts were applied, contrasting children with typical development and ASD against children with SLI in the first contrast, and typically developing children versus children with ASD in the second contrast. A linear regression model tested for effects of group, mean-centered receptive vocabulary, and interactions between group and mean-centered receptive vocabulary. There was a marginal main effect of receptive vocabulary, indicating that higher vocabulary scores were marginally predictive of higher accuracy scores on the segmenting task. When vocabulary scores were included in the model, group effects were weakened. The typically developing and ASD groups performed only marginally better on the segmenting task than the SLI group (see Table 7 and Figure 9).

Table 7
Predictors of Segmenting Task Performance

Variable	**Estimate**	**Standard Error**	***t* value**	***p***
Group: TD & ASD vs. SLI	6.663	3.781	1.762	0.082
Group: TD vs. ASD	1.925	3.596	0.535	0.594
Receptive Vocabulary	0.168	0.091	1.840	0.070
TD & ASD vs. SLI x Receptive Vocabulary	0.121	0.217	0.558	0.578
TD vs. ASD x Receptive Vocabulary	0.245	0.192	1.277	0.206
Multiple R-squared: 0.1573, Adjusted R-squared: 0.1018				

Mean-centered receptive vocabulary standard scores were added to a growth curve model of the eye gaze data. Similar to the prior findings, there was a significant effect of linear and quadratic time (Linear: *Estimate* = 2.331; *Std. Err* = 0.386; *t* = 6.038; Quadratic: *Estimate* = -.689; *Std. Err* = 0.241; *t* = -2.859). In addition, there was a significant main effect of receptive

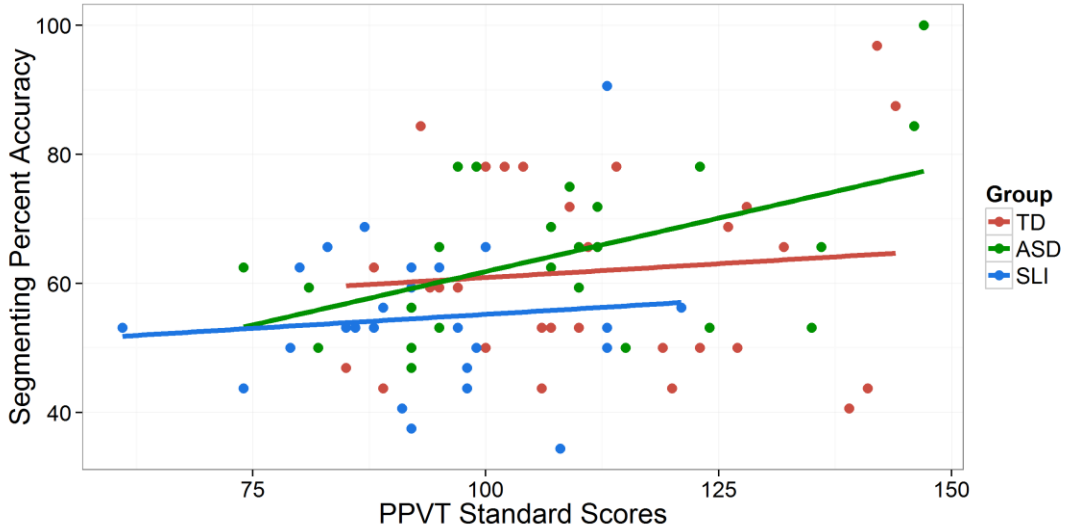


Figure 9. The relationship between receptive vocabulary and segmenting task performance.

vocabulary (*Estimate* = 1.982; *Std. Err* = 0.454; *t* = 4.368), indicating that children with higher receptive vocabulary scores looked more at the target image during the test window overall than peers with lower receptive vocabulary scores. There was also a significant two-way interaction between linear time and receptive vocabulary scores (*Estimate* = .064; *Std. Err* = 0.022; *t* = 2.888), indicating that children with higher receptive vocabulary scores increased their looks to the target image faster than their peers with lower receptive vocabulary scores. Interestingly, there was no significant effect of group when receptive vocabulary was included in the model. Additionally, there were no other significant two- or three-way interactions among group, time, and receptive vocabulary (see Table 8).

The effect of mean-centered receptive vocabulary was also tested in a growth curve model of looking behavior in the combination task. The random slope model revealed that there were main effects for the linear, quadratic and cubic time terms (Linear: *Estimate* = 2.352; *Std.*

Table 8

Receptive Vocabulary as a Predictor of Word Learning Eye Gaze Behavior

Fixed Effects	**Estimate**	**Std. Error**	***t* value**	***P***
Intercept (γ_{00})	0.612	0.079	7.772	< .001
Linear (γ_{10})	2.331	0.386	6.038	< .001
Quadratic (γ_{20})	-0.689	0.241	-2.859	.004
Cubic (γ_{30})	0.058	0.194	0.296	.767
TD & ASD vs. SLI (γ_{01})	0.200	0.182	1.099	.272
TD vs. ASD (γ_{02})	0.024	0.173	0.141	.888
Receptive Vocabulary (γ_{03})	0.015	0.005	3.339	< .001
Linear x TD & ASD vs. SLI (γ_{11})	-0.050	0.895	-0.056	.955
Linear x TD vs. ASD (γ_{12})	0.369	0.850	0.435	.664
Quadratic x TD & ASD vs. SLI (γ_{21})	-0.449	0.558	-0.804	.421
Quadratic x TD vs. ASD (γ_{22})	0.601	0.530	1.132	.258
Cubic x TD & ASD vs. SLI (γ_{31})	-0.104	0.450	-0.232	.817
Cubic x TD vs. ASD (γ_{32})	0.293	0.428	0.685	.493
Linear x Receptive Vocabulary (γ_{13})	0.064	0.022	2.888	.004
Quadratic x Receptive Vocabulary (γ_{23})	-0.019	0.014	-1.404	.160
Cubic x Receptive Vocabulary (γ_{33})	-0.017	0.011	-1.505	.132
TD & ASD vs. SLI x Receptive Vocabulary ($\gamma_{01*}\gamma_{03}$)	0.006	0.011	0.521	.602
TD vs. ASD x Receptive Vocabulary ($\gamma_{02*}\gamma_{03}$)	-0.005	0.009	-0.513	.608
Linear x TD & ASD vs. SLI x Rec. Vocab. ($\gamma_{11*}\gamma_{03}$)	0.040	0.053	0.752	.452
Linear x TD vs. ASD x Receptive Vocabulary ($\gamma_{12*}\gamma_{03}$)	0.004	0.047	0.078	.938
Quadratic x TD & ASD vs. SLI x Rec. Vocab. ($\gamma_{21*}\gamma_{03}$)	0.001	0.033	0.041	.967
Quadratic x TD vs. ASD x Rec. Vocab. ($\gamma_{22*}\gamma_{03}$)	-0.017	0.029	-0.572	.567
Cubic x TD & ASD vs. SLI x Rec. Vocab. ($\gamma_{31*}\gamma_{03}$)	0.006	0.026	0.238	.812
Cubic x TD vs. ASD x Receptive Vocabulary ($\gamma_{31*}\gamma_{03}$)	-0.022	0.023	-0.937	.349

Random Effects		**Variance**	**Std. Deviation**	**Correlations**		
Child	Intercept (U_{0j})	0.389	0.624			
	Linear (U_{1j})	9.253	3.042	0.63		
	Quadratic (U_{2j})	3.517	1.875	-0.54	-0.34	
	Cubic (U_{3j})	2.236	1.496	-0.03	-0.18	-0.20
Residual (R_{tj})		0.147	0.383			

Note. Approximated *p* values were used.

Err = 0.286; *t* = 8.235; Quadratic: *Estimate* = -.652; *Std. Err* = 0.245; *t* = -2.659; Cubic: *Estimate* = .475; *Std. Err* = 0.207; *t* = 2.298). In addition, there was a significant main effect of receptive vocabulary (*Estimate* = .015; *Std. Err* = 0.004; *t* = 3.503), indicating that children with higher receptive vocabulary scores looked more to the target image during the test window across both conditions overall than peers with lower receptive vocabulary scores. As before,

there was no significant effect of group. However, there was a significant two-way interaction between linear time and group such that children with typical development and ASD looked to the target image more quickly than children with SLI (Linear time x TD & ASD vs. SLI groups: *Estimate* = -1.652; *Std. Err* = 0.653; *t* = -2.506). Additionally, there was a significant two-way interaction between receptive vocabulary scores and linear time (*Estimate* = .034; *Std. Err* = 0.016; *t* = 2.077), indicating that children with higher receptive vocabulary scores increased their looks to the target image during the test window across both trials more quickly (i.e., steeper slope) than children with lower receptive vocabulary scores. There were no other interactions among groups, time terms, condition, or receptive vocabulary (see Table 9).

Table 9

Receptive Vocabulary as a Predictor of Combination Task Eye Gaze Behavior

Fixed Effects	**Estimate**	**Std. Error**	***t* value**	***p***
Intercept (γ_{00})	0.730	0.077	9.463	< .001
Linear (γ_{10})	2.352	0.286	8.235	< .001
Quadratic (γ_{20})	-0.652	0.245	-2.659	.008
Cubic (γ_{30})	0.475	0.207	2.298	.022
TD & ASD vs. SLI (γ_{01})	-0.267	0.176	-1.515	.130
TD vs. ASD (γ_{02})	0.046	0.173	0.268	.789
Condition (word vs. nonword) (γ_{03})	0.004	0.126	0.028	.978
Receptive Vocabulary (γ_{04})	0.015	0.004	3.503	< .001
Linear x TD & ASD vs. SLI (γ_{11})	-1.636	0.653	-2.506	.012
Linear x TD vs. ASD (γ_{12})	0.253	0.641	0.395	.693
Quadratic x TD & ASD vs. SLI (γ_{21})	0.094	0.560	0.168	.867
Quadratic x TD vs. ASD (γ_{22})	0.369	0.550	0.670	.503
Cubic x TD & ASD vs. SLI (γ_{31})	0.487	0.473	1.030	.303
Cubic x TD vs. ASD (γ_{32})	-0.638	0.464	-1.375	.169
Linear x Condition (γ_{13})	-0.541	0.540	-1.002	.316
Quadratic x Condition (γ_{23})	0.151	0.421	0.359	.720
Cubic x Condition (γ_{33})	0.003	0.394	0.006	.995
TD & ASD vs. SLI x Condition ($\gamma_{01*}\gamma_{03}$)	-0.069	0.287	-0.240	.810
TD vs. ASD x Condition ($\gamma_{02*}\gamma_{03}$)	0.070	0.283	0.247	.805
Linear x Receptive Vocabulary (γ_{14})	0.034	0.016	2.077	.038
Quadratic x Receptive Vocabulary (γ_{24})	-0.014	0.014	-1.009	.313
Cubic x Receptive Vocabulary (γ_{34})	-0.023	0.012	-1.957	.050
TD & ASD vs. SLI x Receptive Vocabulary ($\gamma_{01*}\gamma_{04}$)	-0.004	0.010	-0.370	.711
TD vs. ASD x Receptive Vocabulary ($\gamma_{02*}\gamma_{04}$)	-0.007	0.009	-0.801	.423
Condition x Receptive Vocabulary ($\gamma_{03*}\gamma_{04}$)	-0.000	0.007	-0.046	.963

Linear x TD & ASD vs. SLI x Condition ($\gamma_{11*}\gamma_{03}$)	0.445	1.234	0.361	.718
Linear x TD vs. ASD x Condition ($\gamma_{11*}\gamma_{03}$)	0.623	1.212	0.514	.607
Quadratic x TD & ASD vs. SLI x Condition ($\gamma_{21*}\gamma_{03}$)	-0.281	0.963	-0.292	.770
Quadratic x TD vs. ASD x Condition ($\gamma_{21*}\gamma_{03}$)	1.272	0.946	1.344	.179
Cubic x TD & ASD vs. SLI x Condition ($\gamma_{31*}\gamma_{03}$)	-0.245	0.901	1.344	.179
Cubic x TD vs. ASD x Condition ($\gamma_{31*}\gamma_{03}$)	-0.359	0.885	-0.406	.685
Linear x TD & ASD vs. SLI x Rec. Vocab. ($\gamma_{11*}\gamma_{04}$)	-0.034	0.039	-0.869	.385
Linear x TD vs. ASD x Receptive Vocabulary ($\gamma_{12*}\gamma_{04}$)	-0.028	0.035	-0.807	.420
Quadratic x TD & ASD vs. SLI x Rec. Vocab ($\gamma_{21*}\gamma_{04}$)	-0.050	0.033	-1.513	.130
Quadratic x TD vs. ASD x Rec. Vocab. ($\gamma_{22*}\gamma_{04}$)	0.024	0.030	0.800	.424
Cubic x TD & ASD vs. SLI x Rec. Vocab. ($\gamma_{31*}\gamma_{04}$)	0.035	0.028	1.266	.206
Cubic x TD vs. ASD x Receptive Vocabulary ($\gamma_{31*}\gamma_{04}$)	0.004	0.025	0.168	.867
Linear x Condition x Receptive Vocabulary ($\gamma_{13*}\gamma_{04}$)	-0.015	0.031	-0.478	.633
Quadratic x Condition x Rec. Vocab. ($\gamma_{23*}\gamma_{04}$)	0.013	0.024	0.537	.591
Cubic x Condition x Receptive Vocabulary ($\gamma_{33*}\gamma_{04}$)	0.011	0.022	0.483	.629
TD & ASD vs. SLI x Condition x Receptive Vocabulary ($\gamma_{01*}\gamma_{03*}\gamma_{04}$)	-0.012	0.017	-0.735	.462
TD vs. ASD x Condition x Rec. Vocab. ($\gamma_{02*}\gamma_{03*}\gamma_{04}$)	-0.000	0.015	-0.022	.982
Linear x TD & ASD vs. SLI x Condition x Receptive Vocabulary ($\gamma_{11*}\gamma_{03*}\gamma_{04}$)	0.089	0.073	1.226	.220
Linear x TD vs. ASD x Condition x Receptive Vocabulary ($\gamma_{12*}\gamma_{03*}\gamma_{04}$)	-0.066	0.065	-1.007	.314
Quadratic x TD & ASD vs. SLI x Condition x Receptive Vocabulary ($\gamma_{21*}\gamma_{03*}\gamma_{04}$)	-0.052	0.057	-0.906	.365
Quadratic x TD vs. ASD x Condition x Receptive Vocabulary ($\gamma_{22*}\gamma_{03*}\gamma_{04}$)	0.046	0.051	0.900	.368
Cubic x TD & ASD vs. SLI x Condition x Receptive Vocabulary ($\gamma_{31*}\gamma_{03*}\gamma_{04}$)	-0.003	0.053	-0.065	.948
Cubic x TD vs. ASD x Condition x Receptive Vocabulary ($\gamma_{32*}\gamma_{03*}\gamma_{04}$)	-0.044	0.048	-0.930	.352

Random Effects		**Variance**	**Std. Deviation**	**Correlations**		
Child	Intercept (U_{0j})	0.129	0.359			
	Linear (U_{1j})	0.560	0.749	1.00		
	Quadratic (U_{2j})	1.015	1.007	-0.85	-0.88	
	Cubic (U_{3j})	0.254	0.504	-0.44	-0.49	0.85
Child x Condition	Intercept (W_{0jk})	0.504	0.710			
	Linear (W_{1jk})	9.104	3.017	0.48		
	Quadratic (W_{2jk})	5.448	2.334	-0.27	-0.17	
	Cubic (W_{3jk})	4.737	2.177	0.23	-0.14	-0.25
Residual (R_{tj})		0.248	0.498			

Note. Approximated *p* values were used.

Diagnostic Group Comparisons

Previous studies have examined language processing abilities in children with ASD and found that performance differs from typically developing children if children with ASD also have a concomitant language impairment. Therefore, it has been suggested that language processes may differ not because of a child's autism status per se, but because of the child's language status (Brock et al., 2008; McGregor et al., 2012; Norbury, 2005). Therefore, in order to further examine if language learning mechanisms differed according to diagnostic group (i.e., ASD or SLI) or language status (i.e., language impaired or language normal), exploratory analyses were conducted. Children in the ASD group were subdivided according to standardized scores on the *Clinical Evaluation of Language Fundamentals* – 4th edition (CELF-4). Children who had higher than one standard deviation on all of the composite language scores (i.e., Core Language, Expressive Language, and Receptive Language) were categorized as having normal language skills (ASDLN, $n = 14$). Children with ASD who had at least one standard deviation below the mean on at least one of the CELF-4 composite scores were categorized as having a language impairment (ALI, $n = 15$). Participant characteristics are provided in Table 10.

In order to determine whether language status influenced performance in the ASD group, performance on the segmenting task, word learning task, and combination task were compared across children with ASDLN, ALI, and SLI. Regression analyses were used; the ALI group served as the reference group. As before, the LinearHypothesis function was used to compare the ALI and ASDLN groups. See Table 11 for group performance scores on the experimental measures.

Table 10

Diagnostic Group Characteristics

	ASDLN (*n* = 14)		ALI (*n* = 15)		SLI (*n* = 25)		Group
	Mean	SD	Mean	SD	Mean	SD	Differences[1]
Age[2]	10.05	(1.47)	10.1	(1.17)	10.43	(1.27)	
WISC-4[3]	113.50	(15.04)	94.87	(12.21)	101.28	(11.14)	ASDLN > SLI & ALI
CELF-CL SS[4]	103.62	(11.50)	73.27	(14.91)	81.29	(14.10)	ASDLN > SLI & ALI
CELF-EL SS[5]	103.54	(12.18)	76.67	(18.03)	80.00	(13.97)	ASDLN > SLI & ALI
CELF-RL SS[6]	104.29	(12.23)	73.53	(19.69)	86.48	(15.73)	ASDLN > SLI > ALI
PPVT-4 SS[7]	118.14	(17.54)	94.27	(12.72)	93.36	(13.55)	ASDLN > SLI & ALI
CARS-ST[8]	30.79	(3.71)	31.17	(4.42)			

Note. [1] $p < .05$, [2] Chronological age in years, [3] Perceptual Reasoning Index Standard Score, [4]Core Language Standard Score, [5] Expressive Language Standard Score, [6] Receptive Language Standard Score, [7] Receptive Vocabulary Standard Score, [8] Childhood Autism Rating Scale Total Score

Table 11

Diagnostic Group Experimental Task Performance

	ASDLN (*n* = 14)		ALI (*n* = 15)		SLI (*n* = 25)	
	Mean	SD	Mean	SD	Mean	SD
Segmenting Accuracy[1]	67.79	(14.79)	60.71	(9.23)	54.62	(11.59)
Word Learning Task Pointing Accuracy[2]	3.00	(1.47)	2.80	(1.42)	1.88	(0.97)
Combination Task Pointing Accuracy[2]	3.50	(1.29)	2.20	(1.47)	2.44	(1.45)

Note. [1] Percent Correct, [2] Out of 4 images

Segmenting task diagnostic group comparisons. First, mixed effect logistic regression was used to compare item level responses on the segmenting task. The ALI group was not statistically different from the ASDLN group ($p = .093$) or the SLI group ($p = .117$). However, the ASDLN group performed significantly better than the SLI group ($p < .001$). Within group analyses revealed that the ASDLN and the ALI groups performed statistically above chance (50%) on the segmenting task ($p < .001$), but the SLI group did not ($p = .058$). (See Figure 10.)

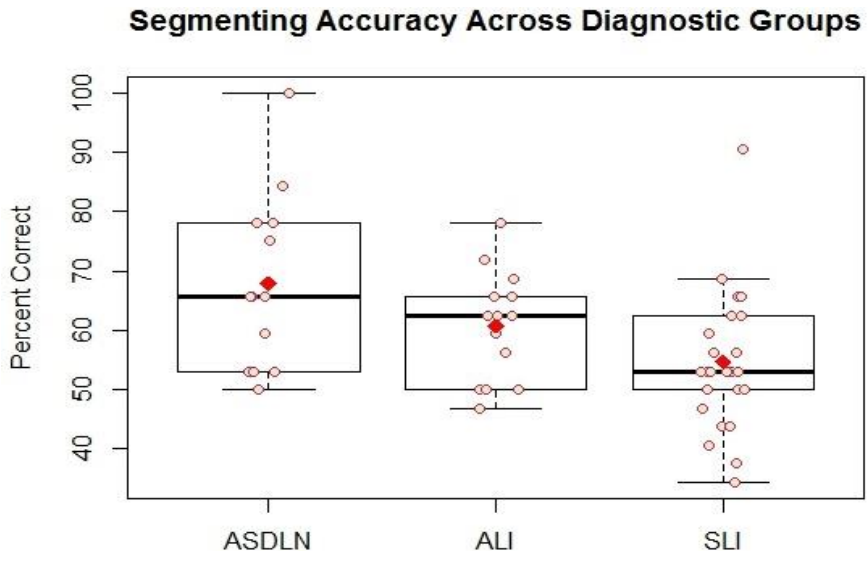


Figure 10. Child performance on the segmenting task, within diagnostic groups. The bold horizontal line represents the median and the red diamond represents the group mean. The whiskers represent the range within 1.5 times the interquartile range. There was one outlier who performed better than the group range in the SLI group.

Word learning task diagnostic group comparisons. Next, a regression model compared group performance on pointing accuracy from the word learning study. Both the ASDLN and ALI groups learned significantly more words than the SLI group ($p < .03$). A Kruskal-Wallis test was also conducted and confirmed that at least one group differed in task performance ($H = 7.330$, $p = .026$). Follow-up pairwise comparisons were conducted, confirming that that the ASDLN and ALI groups performed similarly ($U = 96.5$, $p = .694$) and the ASDLN and ALI groups performed statistically better than the SLI group ($U = 251$ $p = .019$; $U = 257.5$ $p = .038$, respectively). Lastly, all groups performed significantly better than chance (25%) on the word learning task (see Figure 11).

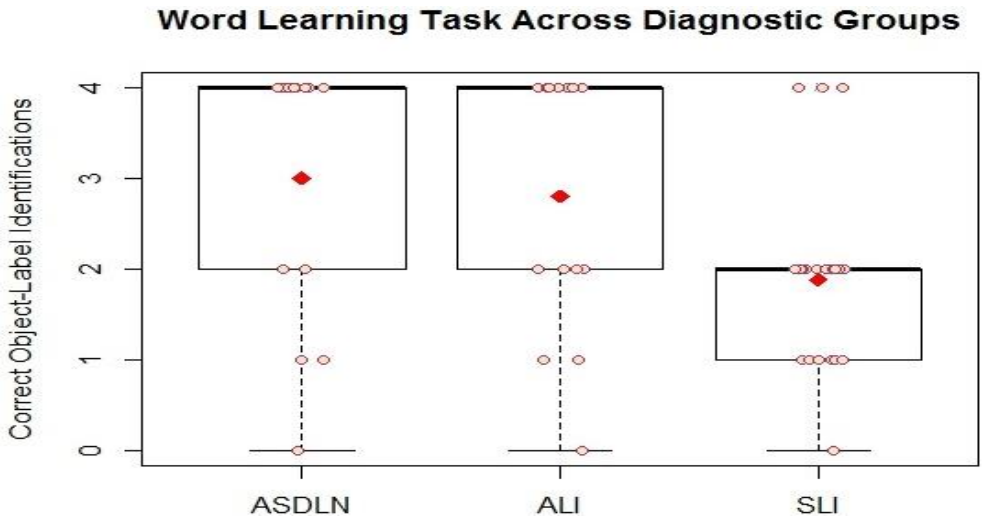


Figure 11. Child pointing performance on the word learning task. The bold horizontal line represents the median and the red diamond represents the group mean. The whiskers represent the range within 1.5 times the interquartile range. There were three children in the SLI group who performed above the range of rest of the group.

Eye-gaze data were analyzed using GCA models. Main effects included linear, quadratic, and cubic orthogonal time terms, group (using dummy coding, with the ALI group as the reference group), and group by orthogonal time term interactions. A random effect was included to allow children to vary by the orthogonal time terms. The final model was:

Level 1: $Y_{it}\ \text{Elog} = \beta_{0i} + \beta_{1i}\ \text{Linear} + \beta_{2i}\ \text{Quadratic} + \beta_{3i}\ \text{Cubic} + R_{ij}$

Sample of Level 2 equations: $\beta_{0j} = \Upsilon_{00} + \Upsilon_{01}\ \text{ASDLN Group} + \Upsilon_{02}\ \text{SLI Group} + U_{0j}$

$$\beta_{1i} = \Upsilon_{10}\ \text{Linear} + \Upsilon_{11}\ \text{ASDLN Group} + \Upsilon_{12}\ \text{SLI Group} + U_{1j}$$

$$\beta_{2i} = \Upsilon_{20}\ \text{Quadratic} + \Upsilon_{21}\ \text{ASDLN Group} + \Upsilon_{22}\ \text{SLI Group} + U_{2j}$$

$$\beta_{3i} = \Upsilon_{30}\ \text{Cubic} + \Upsilon_{31}\ \text{ASDLN Group} + \Upsilon_{22}\ \text{SLI Group} + U_{3j}$$

Y_{ij} Elog = Υ_{00} + Υ_{10} Linear + Υ_{20} Quadratic + Υ_{30} Cubic + Υ_{01} ASDLN Group + Υ_{02} SLI Group + Υ_{11} Linear*ASDLN Group + Υ_{12} Linear*SLI Group + Υ_{21} Quadratic*ASDLN Group + Υ_{22} Quadratic*SLI Group + + U_{0j} + U_{1j} Linear + U_{2i} Quadratic + U_{3i} Cubic + R_{ij}

The random slope GCA model revealed that there was a significant effect of linear time (*Estimate* = 1.635; *Std. Err* = 0.793; *t* = 2.062), indicating that children increased their looking to the target image across the test window. In addition, the ASDLN group looked to the target image significantly more than the ALI and SLI groups (*Estimate* = 0.544; *Std. Err* = 0.239; *t* = 2.273; *Estimate* = 0.618; *Std. Err* = 0.217; *t* = 2.853, respectively). However, looks to the target image did not differ between the ALI and SLI groups (*Estimate* = -0.074; *Std. Err* = 0.212; *t* = -0.348). None of the interactions between group and time terms were significant (see Table 12). Figure 12 depicts the average group looking behavior.

Table 12

Diagnostic Group Comparisons of Eye Gaze Behavior in the Word Learning Task

Fixed Effects	**Estimate**	**Standard Error**	***t* value**	***p***
Intercept (γ_{00})	0.438	0.166	2.631	.009
Linear (γ_{10})	1.635	0.793	2.062	.039
Quadratic (γ_{20})	-0.767	0.481	-1.595	.111
Cubic (γ_{30})	0.078	0.378	0.267	.836
ALI vs. ASDLN (γ_{01})	0.544	0.239	2.273	.023
ALI vs. SLI (γ_{02})	-0.074	0.212	-0.348	.728
Linear x ALI vs. ASDLN (γ_{11})	1.299	1.141	1.139	.255
Linear x ALI vs. SLI (γ_{12})	0.351	1.011	0.347	.728
Quadratic x ALI vs. ASDLN (γ_{21})	-0.809	0.692	-1.169	.242
Quadratic x ALI vs. SLI (γ_{22})	0.582	0.613	0.950	.342
Cubic x ALI vs. ASDLN (γ_{31})	-0.432	0.544	-0.793	.428
Cubic x ALI vs. SLI (γ_{32})	0.261	0.482	0.541	.589

Random Effects		**Variance**	**Standard Deviation**	**Correlations**		
Child	Intercept (U_{0j})	0.413	0.643			
	Linear (U_{1j})	9.280	3.046	0.67		
	Quadratic (U_{2j})	3.321	1.823	-0.60	-0.27	
	Cubic (U_{3j})	2.000	1.414	0.07	-0.21	-0.06
Residual	(R_{tj})	0.147	0.383			

Note. Approximated *p* values were used.

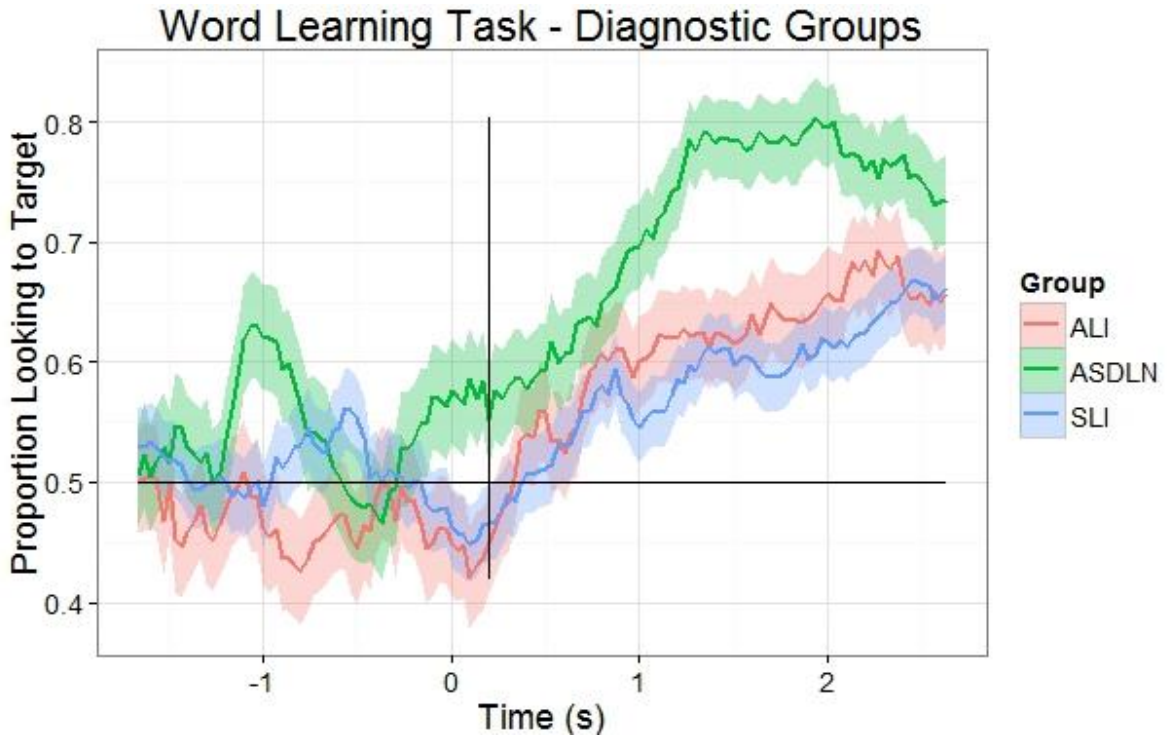


Figure 12. Diagnostic groups' eye gaze behavior on the word learning task.

Combination task diagnostic group comparisons. Lastly, performance on the combination task (pointing accuracy) was compared across the groups using a regression model. The ASDLN group learned significantly more words than the ALI group (p =.017) and the SLI group (p = .029). Again, a Kruskal-Wallis test was also conducted and confirmed that at least one group differed in task performance (H = 6.777, p = .034). Follow-up pairwise comparisons were conducted, confirming that that the ALI and SLI groups performed similarly (U = 127, p = .661) and the ASDLN group performed statistically better than the ALI and SLI groups (U = 55.5, p = .016; U = 246, p = .022, respectively). All groups performed significantly better than chance (25%) on the word learning task (see Figure 13).

A GCA model tested eye-gaze data collected during the combination task. Fixed effects included linear, quadratic, and orthogonal time terms, group (dummy coded with the ALI group as the reference group), word versus nonword condition, and interactions across all fixed effects.

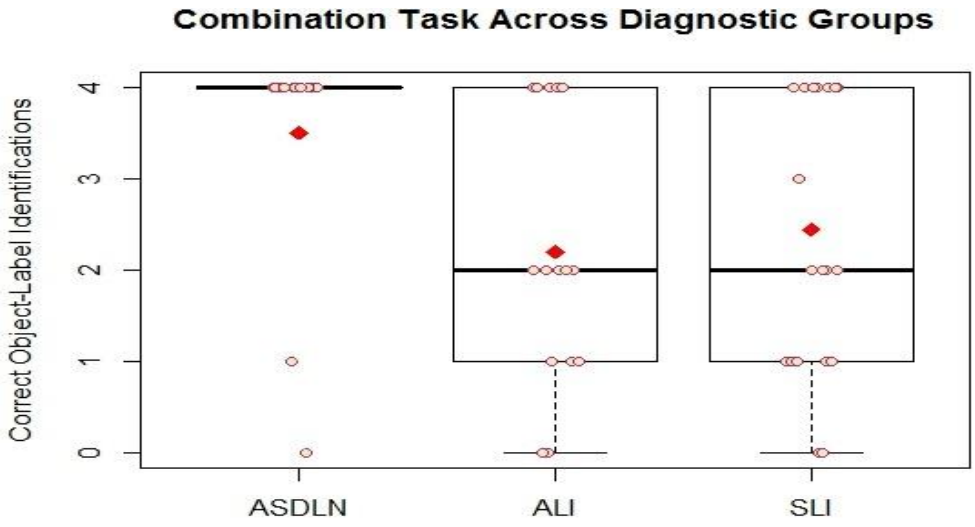


Figure 13. Child pointing performance on the combination task, within diagnostic groups. The bold horizontal line represents the median and the red diamond represents the group mean. The whiskers represent the range within 1.5 times the interquartile range. There were two children in the ASDLN group who performed below the range of rest of the group.

As before, condition (words versus nonwords) were coded using planned orthogonal contrasts, to allow for group performance to reflect performance across the entire task, instead of one condition in the task. Random effects were included to allow children to vary across time terms and children to vary by condition across time terms. The final model was:

Level 1: $Y_{it}\ \text{Elog} = \beta_{0i} + \beta_{1i}\ \text{Linear} + \beta_{2i}\ \text{Quadratic} + \beta_{3i}\ \text{Cubic} + R_{ij}$

Sample of Level 2 equations: $\beta_{0j} = \Upsilon_{00} + \Upsilon_{01}\ \text{ASDLN Group} + \Upsilon_{02}\ \text{SLI Group} + \Upsilon_{03}\ \text{Condition} + U_{0j}$

$\beta_{1i} = \Upsilon_{10}\ \text{Linear} + \Upsilon_{11}\ \text{ASDLN Group} + \Upsilon_{12}\ \text{SLI Group} + \Upsilon 1_{3}\ \text{Condition} + U_{1j}$

$\beta_{2i} = \Upsilon_{20}\ \text{Quadratic} + \Upsilon_{21}\ \text{ASDLN Group} + \Upsilon_{22}\ \text{SLI Group} + \Upsilon_{23}\ \text{Condition} + U_{2j}$

$\beta_{3i} = \Upsilon_{30}\ \text{Cubic} + \Upsilon_{31}\ \text{ASDLN Group} + \Upsilon_{22}\ \text{SLI Group} + \Upsilon_{23}\ \text{Condition} + U_{3j}$

The model yielded a significant effect of cubic time (*Estimate* = 0.643; *Std. Err* = 0.238; *t* = 2.696). Children with ASDLN looked to the target image more than children with ALI (*Estimate* = 0.377; *Std. Err* = 0.206; *t* = 1.833). In addition, there was a marginal difference between children with ALI and SLI indicating that children with SLI looked marginally more to the target image during the test window (*Estimate* = 0.935; *Std. Err* = 0.463; *t* = 2.019). There was no significant difference in looking behavior between the ASDLN and the SLI groups (*Estimate* = -0.266; *Std. Err* = 0.215; *t* = 1.237). Moreover, there was a significant interaction between group and linear time, indicating that children with ASDLN and SLI had significantly larger slopes in looking to the target image than the ALI group (*Estimate* = 1.937; *Std. Err* = 0.884; *t* = 2.191; *Estimate* = 2.038; *Std. Err* = 0.762; *t* = 2.674; respectively). No other interactions across groups, conditions, and time terms were significant (see Table 13). Figure 14 depicts group performance within condition and Figure 15 depicts group performance collapsed across both conditions to facilitate visualizations of group comparisons.

Table 13

Diagnostic Group Comparisons of Eye Gaze Behavior in the Combination Task

Fixed Effects	**Estimate**	**Std. Error**	***t* value**	***p***
Intercept (γ_{00})	0.356	0.162	2.190	.029
Linear (γ_{10})	0.855	0.603	1.419	.156
Quadratic (γ_{20})	-0.558	0.554	-1.006	.314
Cubic (γ_{30})	0.935	0.463	2.019	.044
ALI vs. ASDLN (γ_{01})	0.643	0.238	2.696	.007
ALI vs. SLI (γ_{02})	0.377	0.206	1.833	.067
Condition (Word vs. Nonword) (γ_{03})	-0.075	0.205	-0.366	.714
Linear x ALI vs. ASDLN (γ_{11})	1.937	0.884	2.191	.029
Linear x ALI vs. SLI (γ_{12})	2.038	0.762	2.674	.008
Quadratic x ALI vs. ASDLN (γ_{21})	-0.720	0.813	-0.885	.376
Quadratic x ALI vs. SLI (γ_{22})	-0.346	0.701	-0.494	.621
Cubic x ALI vs. ASDLN (γ_{31})	-0.013	0.680	-0.019	.985
Cubic x ALI vs. SLI (γ_{32})	-0.329	0.586	-0.561	.575
Linear x Condition (γ_{13})	-0.558	1.137	-0.491	.623
Quadratic x Condition (γ_{23})	-0.829	0.910	-0.910	.363
Cubic x Condition (γ_{33})	-0.682	0.825	-0.827	.408
ALI vs. ASDLN x Condition ($\gamma_{01*}\gamma_{03}$)	0.025	0.300	0.085	.933
ALI vs. SLI x Condition ($\gamma_{02*}\gamma_{03}$)	0.046	0.259	0.178	.858
Linear x ALI vs. ASDLN x Condition ($\gamma_{11*}\gamma_{03}$)	-0.105	1.668	-0.063	.950
Linear x ALI vs. SLI x Condition ($\gamma_{12*}\gamma_{03}$)	0.447	1.438	0.311	.756
Quadratic x ALI vs. ASDLN x Condition ($\gamma_{21*}\gamma_{03}$)	0.419	1.336	0.314	.754
Quadratic x ALI vs. SLI x Condition ($\gamma_{22*}\gamma_{03}$)	0.705	1.152	0.612	.540
Cubic x ALI vs. ASDLN x Condition ($\gamma_{31*}\gamma_{03}$)	1.825	1.210	1.508	.132
Cubic x ALI vs. SLI x Condition ($\gamma_{31*}\gamma_{03}$)	0.719	1.043	0.690	.490

Random Effects		**Variance**	**Std. Deviation**	**Correlations**		
Child	Intercept (U_{0j})	0.198	0.445			
	Linear (U_{1j})	0.927	0.963	1.00		
	Quadratic (U_{2j})	1.210	1.100	-0.87	-0.87	
	Cubic (U_{3j})	0.301	0.549	-0.61	-0.61	0.92
Child x Condition	Intercept (W_{0jk})	0.506	0.711			
	Linear (W_{1jk})	9.246	3.041	0.46		
	Quadratic (W_{2jk})	5.600	2.367	-0.24	-0.17	
	Cubic (W_{3jk})	4.878	2.209	0.21	-0.14	-0.26
Residual (R_{tj})		0.248	0.498			

Note. Approximated *p* values were used.

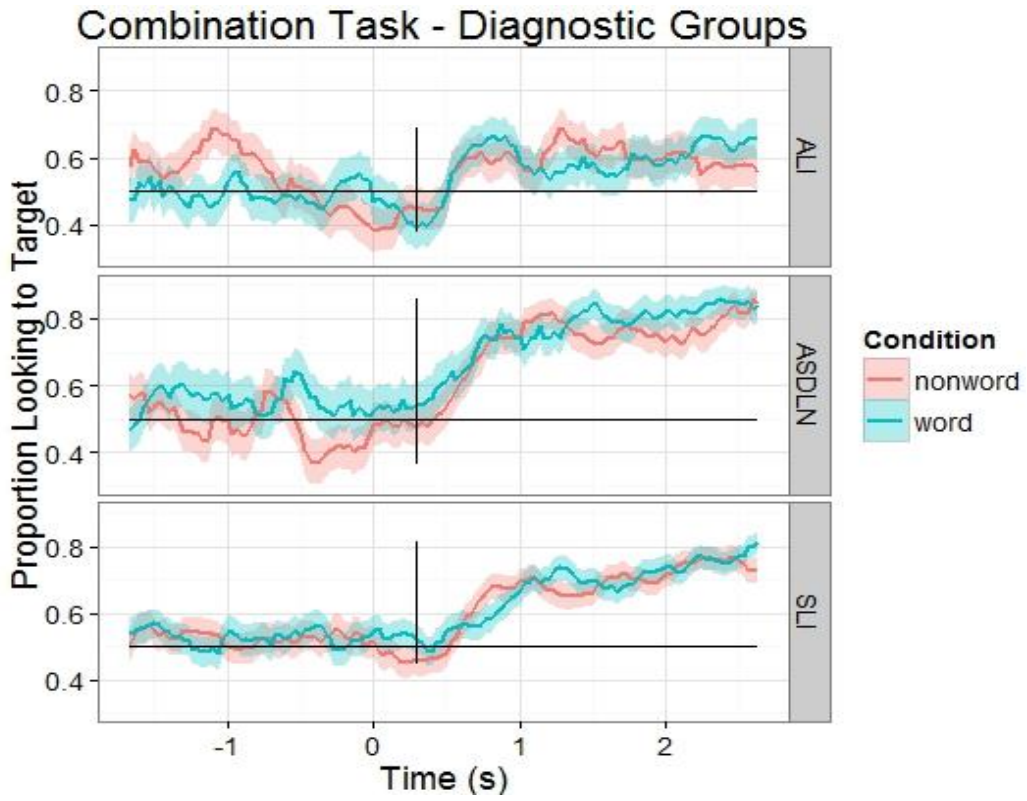


Figure 14. Diagnostic groups' eye gaze behavior on the combination task, including condition.

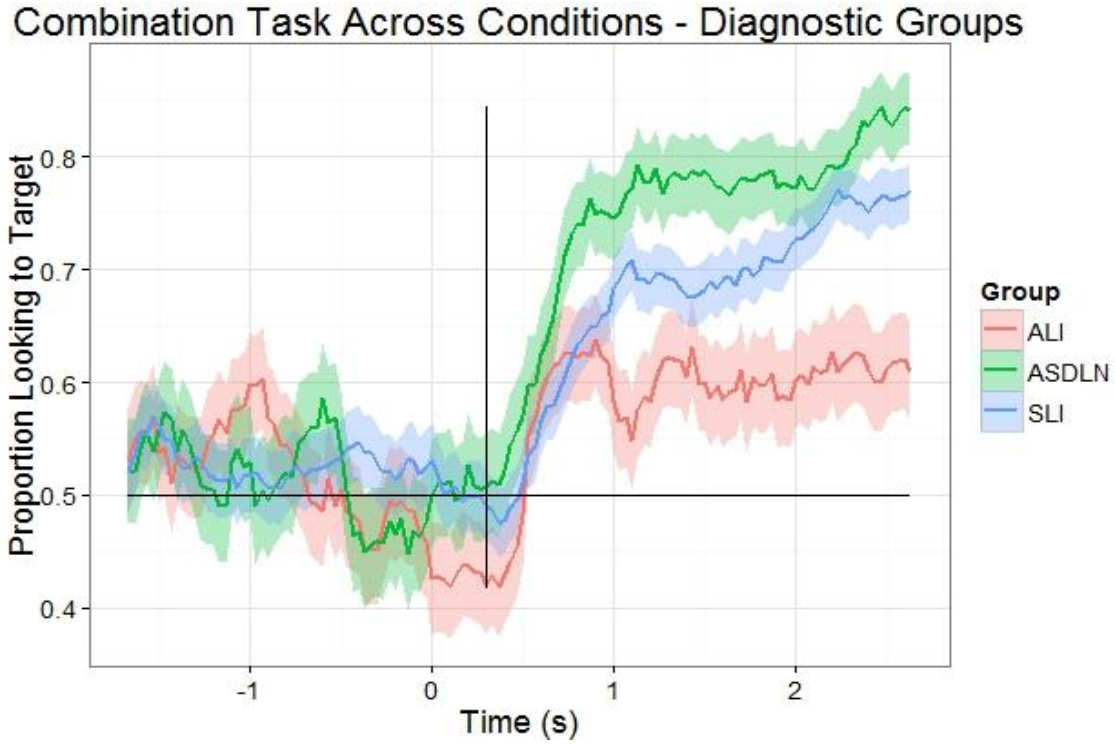


Figure 15. Diagnostic groups' eye gaze behavior on the combination task, across conditions.

Chapter 4: Discussion

This study examined word learning mechanisms in children with typical and atypical development (i.e., ASD and SLI). Specifically, statistical learning and fast mapping abilities were tested. Overall, poorer skills in statistical learning and fast mapping were seen in the children with SLI, compared to age and cognition-matched children with typical development and ASD. There was one exception, however; children with SLI benefited from exposure to an artificial language before being taught object-label associations, wherein labels were comprised of some of the words in the artificial language and other labels comprised of sounds from the artificial language. In order to unpack the overall findings, each task will be discussed separately first.

Statistical Learning across Groups

In agreement with previous studies, statistical learning abilities, measured through a two-alternative-forced choice segmenting task, were impaired in the SLI group but unimpaired in the groups of children with ASD and typical development (Evans et al., 2009; Mayo & Eigsti, 2012). Importantly, this finding was also found in the current study despite the fact that a different, less complex, artificial language was used. In the current study, words in the artificial language consisted of four disyllabic words (Graf Estes et al., 2007). Evans and colleagues (2009) and Mayo and Eigsti (2012) used an artificial language that comprised of six tri-syllabic words (Saffran et al., 1997). Given the reported deficits in phonological working memory in children with SLI (Gathercole & Baddeley, 1990), a reduction in the syllable length in words and number of words in the language could have possibly reduced phonological memory demands and improved statistical learning abilities. However, in the exposure time provided, most of the children with SLI were unable to sufficiently grasp the statistical structure of the language and

perform above chance during the test phase, although group performance did approach significance.

It is possible that the phonological information was too difficult to track for children with SLI. An alternative explanation could be that phonological representations of words in the artificial language were underspecified, causing children with SLI to be unable to differentiate words from nonwords that were phonologically similar. Previous work has suggested that children with SLI have poorly segmented and underspecified phonetic representations (Edwards & Lahey, 1996). In addition, other work has found that children with SLI have difficulties dismissing alternative candidates during language processing tasks (Mainela-Arnold, Evans, & Coady, 2008; McMurray, Munson, & Tomblin, 2014). Additionally, limiting working memory resources through highly demanding tasks has been found to negatively influence statistical learning abilities in typically developing adults (Ludden & Gupta, 2000). The two-alternative forced-choice task used in the segmenting task is a cognitively demanding task that also may have influenced performance, especially for the children with SLI who may have working memory deficits (Ellis Weismer, 1996). Despite this, impaired implicit learning in children with SLI has been found across a variety of tasks (Hsu et al., 2014; Tomblin et al., 2007). As such, it seems likely that reduced task performance observed in children with SLI may point to a specific deficit in statistical learning abilities, though other deficits may compound weaknesses in statistical learning.

Mayo and Eigsti (2012) were originally surprised to find that statistical learning abilities in high-functioning children with ASD were intact. They suggested that the lengthy exposure of the artificial language (21 minutes) may have been too long to uncover more subtle differences in statistical learning between children with typical development and children with ASD. They

suggested that neural evidence of statistical learning may not have been seen in the individuals with ASD in the study conducted by Scott-Van Zeeland and colleagues (2010) potentially because participants were exposed to the artificial language for only 2.5 minutes. This limited exposure possibly enabled the researchers to identify group differences because the typically developing group was efficient enough to yield neural evidence of statistical learning, but the children with ADS may have required additional input to yield such evidence. Evans and colleagues (2009) found that children with SLI were less efficient in picking up statistical cues; behavioral evidence of statistical learning was reached, but this required double the exposure to the artificial language. In the current study, the exposure period was significantly shorter (4.75 minutes); however, the artificial language was simpler. It is unclear whether children with ASD would have shown impairments in statistical learning had the exposure period been shorter or the artificial language been more complex.

Although the current study cannot determine that reduced statistical learning abilities would have been uncovered in the ASD group had the conditions been different, findings from some implicit learning studies indicate that this would not have been the case (Barnes et al., 2008; Brown et al., 2010; but see Gordon & Stark, 2007; Motofsky et al., 2000). It is possible that the different findings presented by Scott-Van Zeeland and colleagues (2010) and Mayo and Eigsti (2012) may, in part, be due to the fact that behavioral and neural evidence may provide different information. The link between brain and behavior is not well understood, especially in children with ASD (Wolff et al., 2012). Therefore, we may see similar behavioral performance on tasks, such as statistical learning segmenting tasks, but encounter different neural findings (McCleery et al., 2010; McNealy, Mazziotta, & Dapretto, 2006; Scott-Van Zeeland et al., 2010). In addition, differences in study findings may have reflected variations in child characteristics.

Some posit that heterogeneity in language abilities, cognitive aptitude, autism severity, or social adaptive skills may influence abilities in implicit learning or other language processing tasks (Gordon & Stark, 2007; Hampton Wray & Weber-Fox, 2013; Jeste et al., 2014).

Predictors of statistical learning. Variability in segmenting performance was observed across all of the groups, as in previous studies. An important question to ask is whether certain child characteristics, such as language or cognitive abilities, accounted for task performance. Evans et al. (2009) found that children with SLI who were above chance on the segmenting task did not differ in age, IQ, or language abilities, from children with SLI who were below chance. Furthermore, they found that of age, expressive vocabulary, and receptive vocabulary, only receptive vocabulary significantly correlated with segmenting performance in children with SLI. This correlation was only found after the children with SLI had experienced double the amount of exposure to the artificial language. In addition, Tomblin and colleagues (2007) found that sequential statistical learning related to grammatical deficits, but not vocabulary deficits in children with SLI. In the current study, receptive vocabulary (PPVT-4), receptive and expressive sentence-level language abilities (CELF-4 CL), and nonverbal cognitive abilities (WISC-4) did not significantly correlate with segmenting performance in the SLI group. It is possible that associations may have differed if additional exposure to the artificial language had been provided and the SLI group had performed statistically above chance, like in experiment 2 in the investigation by Evans et al. (2009).

Inconsistent findings of associations among segmenting performance and language abilities in children with typical development have also been reported. Evans and colleagues (2009) found that age, receptive vocabulary, and expressive vocabulary correlated with segmenting performance. Conversely, Mayo and Eigsti (2012) found that segmenting

performance did not correlate with age, nonverbal cognitive abilities, or receptive or expressive vocabulary in typically developing children. Similarly, in the current study, abilities in receptive vocabulary, sentence-level language, and nonverbal cognition were not associated with segmenting performance in the children with typical development. Previous studies have found that segmenting abilities are evident in typically developing infants, school-age children, and adults, despite vast differences in cognitive and linguistic skills (Saffran, Johnson, Aslin, & Newport, 1999; Saffran et al., 1997). It is possible that statistical learning skills are independent of cognitive and linguistic abilities in individuals with typical development.

Lastly, the correlation analyses revealed that receptive vocabulary, receptive and expressive sentence-level language, and nonverbal cognitive abilities correlated with segmenting performance in the ASD group. Scott-Van Zeeland and colleagues (2010) reported that parent-reported language skills correlated with neural data measuring statistical learning. However, Mayo and Eigsti (2012) failed to find correlations between segmenting performance and expressive and receptive vocabulary, expressive and receptive sentence-level language, and nonverbal cognitive abilities in their sample of children with high-functioning ASD. The children with high-functioning ASD in the Mayo and Eigsti study did not have language impairments, although they had a history of language delays. It is possible that variance was too limited to identify correlations in the sample. The lack of significant correlations between language and segmenting performance led Mayo and Eigsti to suggest that implicit learning deficits may not cause language impairments in individuals with ASD or that impairments in implicit leaning may resolve earlier in development along with the resolution of language delays.

In the current study, children with ASD, although relatively high-functioning, had a wider range of language abilities. Therefore, in an attempt to understand the relationship between

implicit learning in individuals with ASD who do and do not have concomitant language impairment, exploratory analyses were conducted. Subgroups of children with ASD and normal language (ASDLN) and children with ASD and language impairments (ALI) were created. Performance on the segmenting task were compared across children with ASDLN, ALI, and SLI revealing that children with ALI had overall lower performance on the segmenting task, but performance was not statistically worse than the ASDLN group and was not statistically better than the SLI group. The limited sample sizes may have led to these null findings. However, within group analyses found that both the ASDLN and ALI groups performed statistically above chance (50%), but the SLI group did not. This finding suggests that statistical learning abilities may be relatively robust to language impairments in children with ASD. This may potentially be due to enhanced attentional biases to low-level information seen in many children with ASD (Happé & Booth, 2008b; Happé & Frith, 2006; Järvinen-Pasley et al., 2008; Mottron, Dawson, Soulières, Hubert, & Burack, 2006). Jeste and colleagues (2014) found that individuals with low-functioning ASD demonstrate neural evidence of visual statistical learning, though such skills were rather heterogeneous in this group. Taken together, it seems that statistical learning abilities are generally preserved in individuals with ASD despite heterogeneity in cognitive and linguistic skills. Like Mayo and Eigsti (2012) suggest, statistical learning abilities may not underlie linguistic deficits seen in children with ASD. The suggestion that implicit learning deficits do not cause language impairments counters theories proposed in the Procedural Deficit Hypothesis (Ullman & Pierpont, 2005; Walenski et al., 2006). Additional work is needed to better understand the relationship between statistical learning abilities and language abilities in children with ASD, given the inconsistent findings.

Receptive vocabulary as a predictor of statistical learning. The role of receptive vocabulary in segmenting performance was examined across the three groups, despite the fact that receptive vocabulary was not significantly correlated with segmenting performance within each of the groups. As with phonological short term memory, it could be suggested that having a larger vocabulary size could allow children to apply knowledge of sound system patterns in language to enhance segmenting performance. However, the analysis revealed that receptive vocabulary explained segmenting performance only marginally; this trend seemed to be carried by the ASD group. Interestingly though, with receptive vocabulary included in the model, group no longer explained unique variance in segmenting performance. It is possible that statistical learning only contributes to some components of vocabulary knowledge (i.e., phonological), which weakens the overall association between word knowledge and segmenting performance (Mainela-Arnold & Evans, 2014). It is also possible that language abilities do not strongly influence domain-general learning mechanisms like statistical learning.

Statistical learning is a highly studied learning mechanism that is described as a form of implicit learning. The procedural/declarative model emphasizes that grammatical skills lend themselves primarily to procedural memory, and lexical skills to declarative memory. This appears to be an oversimplified description of the skills to which implicit abilities contribute. Statistical information has been tied to grammar and grammatical learning (Hsu et al., 2014; Kidd, 2012). However, phonological statistics also influence language learning and processing (Stokes, Kern, & Santos, 2012; Storkel, Bontempo, Aschenbrenner, Maekawa, & Lee, 2013). As such, the procedural/declarative model should be expanded to include deficits in other domains of implicit learning and acknowledge that procedural memory is associated with computational

aspects of language that include phonology that could support lexical development (Evans et al., 2009; Mainela-Arnold & Evans, 2014; Nation, 2014).

Word Learning

Word learning abilities were measured through a fast mapping task in the current study. Children were taught four words through only three teaching trials per word. The pointing data from the word learning task revealed that children learned words above chance levels; however, children with typical development and children with ASD learned significantly more words than children with SLI. The eye gaze data yielded similar information, except group differences between the ASD and SLI group were only marginally significant. The number of teaching trials provided were limited to three in order to prevent ceiling effects in the typically developing children. Usually, children with SLI require additional exposure to new words in order to learn them (Kan & Windsor, 2010; Rice et al., 1994). Fewer word learning studies have been conducted in children with ASD; therefore, frequency effects on word learning has not been identified in this population.

The limited number of teaching trials potentially contributed to the finding of group differences. It is possible that children with SLI were unable to form stable phonological representations of new words during the teaching phase. It is also possible that children with SLI have deficits in declarative memory, contrary to the Procedural Deficit Hypothesis (Ullman & Pierpont, 2005). A recent study by Ullman and colleagues suggested that verbal declarative memory is only impaired in children with SLI if children have concomitant working memory deficits (Lum, Ullman, & Conti-Ramsden, 2015). Phonological working memory and nonverbal working memory skills were not measured in the current study; therefore, this claim cannot be

directly addressed. Future studies should examine other cognitive predictors of fast mapping, such as nonverbal working memory.

Predictors of word learning. In considering predictors of word learning, correlation analyses were conducted. Proportion of looks to target in the test window of the word learning task were not significantly correlated to receptive vocabulary, receptive and expressive sentence-level language, or nonverbal cognition in the SLI group. Despite this, of the three standardized assessments that were included in the correlations, scores from the receptive vocabulary measure yielded the highest *r* values across the groups. Similarly, there were no significant correlations in the typically developing group; however, correlations between receptive vocabulary and looking behavior in the word learning study approached significance. Previous work has found that young children who have larger vocabulary sizes are better at learning words (Bion, Borovsky, & Fernald, 2013). In order to more closely observe potential influences of receptive vocabulary abilities on word learning abilities, mean-centered receptive vocabulary scores were included into the GCA model of eye gaze data from the word learning study. The model found that receptive vocabulary significantly predicted word learning performance. Additionally, there were no significant interactions of group and receptive vocabulary. Furthermore, as in the statistical learning analyses, the group effect was no longer significant; once receptive vocabulary was included in the model, performance did not significantly differ across the groups.

Notably, the children with SLI had significantly lower receptive vocabulary scores on the PPVT-4 than both the typically developing group and the ASD group. Despite this, receptive vocabulary standard scores were within the normal range for all of the children with SLI, with the exception of four children. Previous work has found that tests such as the PPVT-4 are often not sensitive enough to identify vocabulary impairments (Gray, Plante, Vance, & Henrichsen,

1999). Beyond breadth of lexical knowledge, studies have found that children with SLI have impairments in depth, resulting in rather superficial word knowledge (Mainela-Arnold & Evans, 2014; McGregor, Oleson, Bahnsen, & Duff, 2013; Sheng & McGregor, 2010). The current study did not measure depth of word learning, but future studies should explore this domain of word learning and speak to theoretical accounts that propose that skills in lexical-semantic knowledge and declarative memory are relative strengths in children with SLI.

A limited number of studies have examined word learning abilities in children with ASD. The majority of the studies have explored social learning during word learning tasks (Baron-Cohen et al., 1997; Luyster & Lord, 2009; Norbury et al., 2010; Preissler & Carey, 2005). Despite this, some studies suggest that word learning mechanisms that allow for abstraction, extension, and developing shape biases during word learning, for example, are impaired in children with ASD (McGregor & Bean, 2012; Preissler, 2008; Tek et al., 2008). Other studies propose that word learning mechanisms, such as cross-situational word learning and social cue use are intact in children with ASD (de Marchena et al., 2011; Luyster & Lord, 2009; McGregor, Rost, et al., 2013).

Associative learning is a learning mechanism that most closely relates to the current word learning task. It has been suggested that children with ASD have relative strengths in associative learning (Preissler, 2008). In addition, studies have found that children with ASD may be particularly good at learning the sound structure of language, such as the phonological information for words (Järvinen-Pasley et al., 2008; Norbury et al., 2010). The current findings support this claim for relatively high-functioning school-age children with ASD. This may not be the case for all children with ASD though. For example, McDuffie et al. (2013) conducted a fast mapping study and compared word learning performance in children with ASD and typical

development. Most of the school-age children with ASD in the sample had significant receptive and expressive vocabulary deficits and a concomitant intellectual disability. McDuffie and colleagues found that the children with ASD had above-chance learning, but learned fewer words than the younger typically developing children after controlling for nonverbal cognitive abilities. Given that word learning difficulties are sometimes, but not always observed in the literature, child characteristics may play role. The extent of autism severity, intellectual impairments, and language impairments may influence the strength of associative learning in children with ASD. In addition, it is possible that the social context in which a word learning task is conducted also may influence task performance. This may even be the case when children are not required to use social cues, such as following an examiner's eye gaze, for successful word learning. In the current study, a non-social word learning task was administered. This may have enhanced child performance.

Other child characteristics beyond characteristics specific to ASD can influence learning. Receptive vocabulary, receptive and expressive sentence-level language, and nonverbal cognition significantly correlated with online word learning performance in the ASD group. In an effort to examine the role of receptive vocabulary in word learning and whether language impairments influence word learning abilities, pointing data were compared across the two ASD subgroups and the SLI group. Like the children with SLI, most children with ALI had lower receptive vocabulary PPVT-4 scores but they fell within the normal range, with the exception of four children. Children with ASD who had normal language abilities and impaired language performed significantly better than children with SLI on the word learning task. Importantly, children with ALI and SLI were matched on receptive vocabulary scores. Despite this, however, fast mapping skills in the ALI group were superior to the SLI group, when observing pointing

data. However, results were not consistent with the eye gaze data. The growth-curve models revealed that children with ASD and normal language abilities performed significantly better than both the SLI and ALI subgroups. Pointing data was collected at the end of the Looking-While-Listening word learning task. It is possible that children with ALI continued to learn during the test trials and were only able to demonstrate their knowledge on the pointing task. It is also possible that children with ALI required additional processing time to demonstrate their newly acquired word knowledge. Previous work has found that some children with ASD have impairments in lexical-semantic knowledge, which may co-occur with syntactic impairments (Brock et al., 2008; Kjelgaard & Tager-Flusberg, 2001; McGregor et al., 2012). As previously noted, the current study only examined superficial word learning without directly teaching semantic characteristics of novel words. The word learning task may not have been sensitive enough to detect subtle word learning weaknesses in children with ALI. Therefore, these exploratory findings provide partial support to the claim that children with ASD have relative strengths in associative learning abilities, even when higher-level structural language is impaired. Additional work in word learning is needed in children with ASD who have concomitant language impairments. In addition, more in-depth tasks teaching additional semantic information may be helpful in more accurately portraying lexical difficulties in school-age children with ASD.

The Role of Segmenting in Subsequent Word Learning Experiences

The combination task tested whether the output of statistical learning facilitated word learning experiences. The results were somewhat mixed. Children with SLI learned more words in the combination task than the word learning task. Word learning, which was not at ceiling, remained relatively stable between the word learning study and the combination task in the

typically developing and ASD groups. As such, there were no group differences in word learning in the combination task in both the pointing and eye gaze data. An aim of this task was to determine whether words from the artificial language (the output of statistical learning) were learned more easily than the nonwords, which only were comprised of syllables from the artificial language. It was hypothesized that more subtle differences between word and nonword learning would have potentially been seen in condition effects or possibly interactions of slope and condition in the eye gaze data. This was not the case. These findings differ from studies of young children with typical development, who showed enhanced word learning on words from an artificial language, compared to nonwords (Graf Estes et al., 2007; Hay, Pelucchi, Graf Estes, & Saffran, 2011).

It is possible that statistical learning derived from segmenting tasks facilitates word learning only in earlier points of development. Alternatively, it is possible that children did not successfully segment words in the artificial language presented in the combination task. This interpretation seems unlikely given that the structure of the artificial language used in the segmenting task was the same as the structure in the artificial language in the combination task; only sounds differed. Furthermore, it is unlikely that at least the majority of the children with ASD and typical development did not segment words successfully because performance on the segmenting task significantly correlated with eye gaze data from the combination task in the ASD and typically developing groups.

If the statistical structure of the words taught during the teaching phase of the combination task did not influence word learning performance, what did? This question is particularly relevant for the SLI group. What caused the children with SLI to evidence improved learning? Building on phonological explanations used earlier in this discussion, exposure to the

artificial language may have helped the children with SLI to develop more secure segmented phonetic representations (Edwards & Lahey, 1996). The more stable phonetic representations may have allowed children with SLI to develop secure representations of words during the teaching phase. Furthermore, the more stable phonological representations may have been easier to map to visual referents and to be differentiated from foil images during the test phase (Riches, Tomasello, & Conti-Ramsden, 2005). Dismissing alternative candidates in lexical processing tasks can be difficult in children with SLI (Mainela-Arnold et al., 2008; McMurray et al., 2014; McMurray, Samelson, Lee, & Tomblin, 2010). Importantly, all of the syllables that made up the words and nonwords were present in the artificial language. Another possibility is that attention during the teaching phase may have been primed because of the pre-exposure of the syllables in the artificial language.

Previous work in language learning in children with SLI have utilized therapy strategies that provide targeted input to facilitate language development. Such therapeutic strategies include: auditory bombardment (Alt, Meyers, & Ancharski, 2012), recast intervention (Hassink & Leonard, 2010; Leonard, Camarata, Brown, & Camarata, 2004; Nelson, Camarata, Welsh, Butkovsky, & Camarata, 1996; but see Proctor-Williams & Fey, 2007), and focused stimulation (Ellis Weismer & Robertson, 2006). In addition, prior word learning studies demonstrated that multiple exposures to novel words facilitates word learning in children with SLI (Ellis Weismer & Hesketh, 1996; Gray, 2005; Kan & Windsor, 2010; Rice et al., 1994). Future work should examine the types of exposure that facilitate word learning. For example, is exposure to the sounds/syllables of words that will be taught equally as effective in enhancing word learning as exposure to novel words in isolation before object-label associations are presented?

Predictors of word learning in the combination task. As in the word learning study, receptive vocabulary abilities strongly correlated with looking behavior in the combination task in the ASD group. Associations were weaker and non-significant in the typically developing and SLI groups. When mean-centered receptive vocabulary scores were included in the eye gaze GCA model, receptive vocabulary was a significant predictor of word learning in the combination task. As before, it could be that children who know more words are better at learning words. This was not completely the case in the ASD group during the word learning task. Children with ASD and language impairment, who were matched on receptive vocabulary skills to the children with SLI, had significantly better pointing performance on the word learning task than the children with SLI. However, eye gaze data did not demonstrate an advantage in word learning. A different pattern yet was observed in the combination task.

Exploratory analyses compared combination task pointing performance in the ASDLN, ALI, and SLI groups. An unexpected finding emerged. Analyses of pointing data indicated that children with ASD and normal language abilities learned more words in the combination task than children with ALI and SLI. This pattern differed from the word learning task results. Analysis of the eye gaze data told a different story. There was a significant effect of group, with children with ASDLN looking to the target image significantly more than the ALI group and children with SLI looking to the target image marginally more than the children with ALI. Furthermore, both the ASDLN and SLI groups increased their looks to the target image significantly faster (slope) than the ALI groups.

It was unclear why pointing and eye gaze data did not converge on the same findings in these exploratory analyses. These differences may point to methodological strengths of one testing method over the other. These findings also may reflect differences in the number of times

children were tested on each item. In the Looking-While-Listening task, children were tested on each label four times, but were only asked to point to the pictured object of each label once. Had children been tested multiple times during the pointing task, additional information about the stability of object-label associations could have been gathered. Lastly, the extra time between the eye gaze test phase and the pointing test phase may have influenced task performance. It may have hindered performance in the SLI group, in particular, because of weaknesses in working memory. Also, performance in the SLI group may have been affected because they were required to select the target out of four images instead of two during the pointing task, which introduced more competing images during testing.

In the pointing data at least, it seemed odd that children with ALI would have slightly reduced associative learning abilities during the combination task. One potential explanation is that the children with ALI became overstimulated during the artificial language exposure phase, which negatively impacted their attention or processing skills during the subsequent word learning phase. An alternative explanation is that the children with ALI may have had shorter attention spans than children with ASD and normal language, causing them to be less engaged in the combination task, which was approximately 5 minutes longer than the word learning task. Interestingly, children with ASDLN and ALI did not differ in autism severity, measured by the *Childhood Autism Rating Scale*. Additional work is needed to better understand the types of input that benefit learning in children with ASD who have concomitant language impairments.

Limitations of the Current Study

The current study sought to better understand learning mechanisms that influence word learning in children with typical and atypical development. Interpretations were slightly limited by the lack of a language-matched group with typical development and a language-matched

group with ASD. The exploratory analyses that included the ALI and ASDLN subgroups provided initial insights into questions of language learning and processing differences between children with ASD and SLI; however, additional work is needed. Furthermore, it would have been more ideal to have data for all of the experimental measures for all of the children. Despite this, data retention was relatively high across all of the groups.

This study examined word learning mechanisms in school-age children. As such, findings from this study cannot explain vocabulary deficits observed earlier in development in children with ASD or SLI. Additional work should be completed to better understand the role of development in word learning abilities. Furthermore, the current study tested word learning directly after teaching. It is not clear whether or not children retained object-label associations after the testing phase. Future work should explore word learning retention, consolidation, and slow mapping.

Additionally, this study did not teach rich semantic meanings for novel words. Previous work has noted differences in the learning of semantic information in children with ASD and SLI (McGregor et al., 2012; Norbury et al., 2010; Sheng & McGregor, 2010). Future work should more closely examine semantic learning and depth of word learning in children with ASD and SLI.

Conclusion

Word learning mechanisms including associative word learning and statistical learning are impaired in children with SLI, relative to their age- and nonverbal cognition-matched peers with typical development and ASD. These findings only partly agreed with the Procedural Deficit Hypothesis. Declarative learning, measured through the fast mapping studies, also seems to be impaired in children with SLI. In contrast, children with ASD demonstrated intact

statistical learning, even when children with ASD had concomitant language impairments. This finding counters suggestions in the literature that language impairments seen in children with ASD stem from deficits in procedural learning. In addition, associative learning abilities were intact in children with ASD who had normal language abilities, but findings were less clear in the children with ASD who had concomitant language impairments. Like our findings in our SLI group, the current study suggests that the Procedural Deficit Hypothesis does not seem to explain language impairments seen in some children with ASD.

Lastly, the current study provided an initial step in examining whether the output of statistical learning relates to subsequent word learning opportunities. Word learning during the combination task remained relatively stable in the typically developing children, when comparing performance on the word learning task. Conversely, children with SLI benefitted from exposure to the artificial language before word learning in the combination task. However, improvements in performance were not unique to the word type condition (words vs. nonwords), suggesting that exposure to the sounds, but not the statistical structure, may have facilitated word learning. In the ASD group, there seemed to be little effect of receiving exposure to the artificial language before word learning. This study contributed important information about word learning mechanisms in children with atypical development, but the specific mechanisms that contribute to lexical weaknesses in children with ASD and SLI warrants additional research. In addition, this study provides insights into broader language impairments seen in children with ASD and SLI and the ways in which they may differ between the groups. Additional work will help researchers and clinicians better understand the nature of language impairments across different diagnostic groups, which may lead to the development of more effective clinical practices.

Works Cited

Alt, M., Meyers, C., & Ancharski, A. (2012). Using principles of learning to inform language therapy design for children with specific language impairment. *International Journal of Language & Communication Disorders*, *47*(5), 487–98. doi:10.1111/j.1460-6984.2012.00169.x

Alt, M., & Plante, E. (2006). Factors that influence lexical and semantic fast mapping language impairment. *Journal of Speech Language and Hearing Research*, *49*, 941–955.

Alt, M., Plante, E., & Creusere, M. (2004). Semantic Features in Fast-Mapping: Performance of preschoolers with specific language impairment versus preschoolers with normal language. *Journal of Speech, Language, and Hearing Research*, *47*(2), 407–420.

Amato, M. S., & MacDonald, M. C. (2010). Sentence processing in an artificial language: Learning and using combinatorial constraints. *Cognition*, *116*(1), 143–8. doi:10.1016/j.cognition.2010.04.001

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington DC: Author.

American Speech-Language-Hearing Association. (1997). Guidelines for audiologic screening. Retrieved from Available from www.asha.org/policy.

Archibald, L. M. D., & Gathercole, S. E. (2006). Short-term and working memory in specific language impairment. *International Journal of Language & Communication Disorders / Royal College of Speech & Language Therapists*, *41*(6), 675–93. doi:10.1080/13682820500442602

Baddeley, A. D., Gathercole, S. E., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review*, *105*(1), 158–73.

Baddeley, A. D., & Hitch, G. (1974). Working Memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (8th ed., pp. 47–89). New York: Academic Press.

Barnes, K. A., Howard, J. H., Howard, D. V, Gilotty, L., Kenworthy, L., Gaillard, W. D., & Vaidya, C. J. (2008). Intact implicit learning of spatial context and temporal sequences in childhood autism spectrum disorder. *Neuropsychology*, *22*(5), 563–70. doi:10.1037/0894-4105.22.5.563

Baron-Cohen, S., Baldwin, D. A., & Crowson, M. (1997). Do children with autism use speaker's direction of gaze strategy to crack the code of language? *Child Development*, *68*(1), 48–57.

Barr, D. J. (2008). Analyzing "visual world" eyetracking data using multilevel logistic regression. *Journal of Memory and Language*, *59*(4), 457–474. doi:10.1016/j.jml.2007.09.002

Barrett, M., Harris, M., & Chasin, J. (1991). Early lexical development and maternal speech: a comparison of children's initial and subsequent use of words. *Journal of Child Language*, *18*, 21–40.

Bashir, A. S., & Scavuzzo, A. (1992). Children with language disorders: natural history and academic success. *Journal of Learning Disabilities*, *25*(1), 53–65.

Bedford, R., Gliga, T., Frame, K., Hudry, K., Chandler, S., Johnson, M. H., & Charman, T. (2013). BIROn - Birkbeck Institutional Research Online Failure to learn from feedback underlies word learning difficulties in toddlers at risk for autism. *Journal of Child Language*, *40*(1), 29–46. doi:10.1017/S0305000912000086

Bennett, T., Szatmari, P., Bryson, S., Volden, J., Zwaigenbaum, L., Vaccarella, L., … Boyle, M. (2008). Differentiating autism and Asperger syndrome on the basis of language delay or impairment. *Journal of Autism and Developmental Disorders*, *38*(4), 616–25. doi:10.1007/s10803-007-0428-7

Bion, R. a H., Borovsky, A., & Fernald, A. (2013). Fast mapping, slow learning: disambiguation of novel word-object mappings in relation to vocabulary learning at 18, 24, and 30months. *Cognition*, *126*(1), 39–53. doi:10.1016/j.cognition.2012.08.008

Bishop, D. V. M. (2006). What causes specific language impairment in children? *Psychological Science*, *15*(5), 217–221. doi:10.1111/j.1467-8721.2006.00439.x

Bishop, S. L., Farmer, C., & Thurm, A. (2015). Measurement of nonverbal IQ in autism spectrum disorder: Scores in young adulthood compared to early childhood. *Journal of Autism and Developmental Disorders*, *45*(4), 966–974. doi:10.1007/s10803-014-2250-3

Bloom, P. (2000). Bloom_FastMapping.pdf. In *How children learn the meanings of words* (pp. 25–53).

Boucher, J. (2012). Research Review: Structural languiage in autistic spectrum disorder - characteristics and causes. *The Journal of Child Psychology and Psychiatry*, *53*(3), 219–233.

Boucher, J., Bigham, S., Mayes, A., & Muskett, T. (2008). Recognition and language in low functioning autism. *Journal of Autism and Developmental Disorders*, *38*(7), 1259–69.

Boucher, J., Mayes, A., & Bigham, S. (2008). Memory, language and intellectual ability in low-functioning autism. In J. Boucher & D. M. Bowler (Eds.), *Memory in Autism* (pp. 268–290). Cambridge: Cambridge University Press.

Brock, J., Norbury, C., Einav, S., & Nation, K. (2008). Do individuals with autism process words in context? Evidence from language-mediated eye-movements. *Cognition*, *108*(3), 896–904.

Brown, J., Aczel, B., Jiménez, L., Kaufman, S. B., & Grant, K. P. (2010). Intact implicit learning in autism spectrum conditions. *Quarterly Journal of Experimental Psychology*, *63*(9), 1789–812. doi:10.1080/17470210903536910

Bryson, S. (1996). Brief Report: Epidemiology of Autism. *Journal of Autism and Developmental Disorders*, *26*(2), 165–167.

Caselli, M. C., Monaco, L., Trasciani, M., & Vicari, S. (2008). Language in Italian children with Down syndrome and with specific language impairment. *Neuropsychology*, *22*(1), 27–35.

Charman, T., Baron-Cohen, S., Swettenham, J., Baird, G., Drew, A., & Cox, A. (2003). Predicting language outcome in infants with autism and pervasive developmental disorder. *International Journal of Language & Communication Disorders / Royal College of Speech & Language Therapists*, *38*(3), 265–85. doi:10.1080/136820310000104830

Charman, T., Taylor, E., Drew, A., Cockerill, H., Brown, J.-A., & Baird, G. (2005). Outcome at 7 years of children diagnosed with autism at age 2: predictive validity of assessments conducted at 2 and 3 years of age and pattern of symptom change over time. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *46*(5), 500–13. doi:10.1111/j.1469-7610.2004.00377.x

Chomsky, N. (1959). Review of B. F. Skinner, Verbal learning. *Language*, *35*(1), 26–58.

Clarke, P. J., Snowling, M. J., Truelove, E., & Hulme, C. (2010). Ameliorating children's reading-comprehension difficulties: a randomized controlled trial. *Psychological Science*, *21*(8), 1106–16. doi:10.1177/0956797610375449

Coady, J. a. (2013). Rapid Naming by Children with and without Specific Language Impairments. *Journal of Speech, Language, and Hearing Research : JSLHR*, *56*(2), 604–617. doi:10.1044/1092-4388(2012/10-0144)

Conti-Ramsden, G., Clair, C. S., Pickles, A., & Durkin, K. (2012). Developmental trajectories of verbal and nonverbal skills in individuals with a history of specificlLanguage impairment: From childhood to adolescence. *Journal of Speech, Language, and Hearing Research*, *55*(December), 1716–1735.

De Giacomo, A., & Fombonne, E. (1998). Parental recognition of developmental abnormalities in autism. *European Child & Adolescent Psychiatry*, *7*(3), 131–136.

De Marchena, A., Eigsti, I.-M., Worek, A., Ono, K. E., & Snedeker, J. (2011). Mutual exclusivity in autism spectrum disorders: testing the pragmatic hypothesis. *Cognition*, *119*(1), 96–113. doi:10.1016/j.cognition.2010.12.011

Dollaghan, C. A. (1987). Fast mapping in normal and language-impaired children. *Journal of Speech and Hearing Disorders*, *52*(3), 218–222.

Dollaghan, C., & Campbell, T. F. (1998). Nonword repetition and child language impairment. *Journal of Speech, Language, and Hearing Research*, *41*(5), 1136–46.

Dunn, L. M., & Dunn, D. M. (2007). *Peabody Picture Vocabulary Test - 4th edition* (4th ed.). Bloomington, MN: NCS Pearson.

Durkin, K., Conti-Ramsden, G., & Simkin, Z. (2012). Functional outcomes of adolescents with a history of specific language impairment (SLI) with and without autistic symptomatology. *Journal of Autism and Developmental Disorders*, *42*(1), 123–138.

Edwards, J., Beckman, M. E., & Munson, B. (2004). Vocabulary Size and Phonotactic Production Accuracy and Fluency in Nonword Repetition. *Journal of Speech, Language, and Hearing Research*, *47*(2), 421–436.

Edwards, J., & Lahey, M. (1996). Auditory lexical decisions of children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *39*(6), 1263–73.

Edwards, J., & Lahey, M. (2008). Nonword repetitions of children with specific language impairment: Exploration of some explanations for their inaccuracies. *Applied Psycholinguistics*, *19*(02), 279. doi:10.1017/S0142716400010079

Eigsti, I.-M., & Bennetto, L. (2009). Grammaticality judgments in autism: deviance or delay. *Journal of Child Language*, *36*(5), 999–1021. doi:10.1017/S0305000909009362

Eigsti, I.-M., Bennetto, L., & Dadlani, M. B. (2007). Beyond pragmatics: Morphosyntactic development in autism. *Journal of Autism and Developmental Disorders*, *37*(6), 1007–1023.

Ellis Weismer, S. (1996). Capacity limitations in working memory: The impact on lexical and morphological learning by children with language impairment. *Topics in Language Disorders*, *17*(1), 33–44.

Ellis Weismer, S. (2013). Developmental language disorders: Challenges and implications of cross-group comparisons. *Folia Phoniatr Logop*, *65*(2), 68–77. doi:10.1016/j.biotechadv.2011.08.021.Secreted

Ellis Weismer, S., Evans, J., & Hesketh, L. J. (1999). An examination of verbal working memory capacity in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *42*(5), 1249–60.

Ellis Weismer, S., & Evans, J. L. (2002). The role of processing limitations in early identification of specific language impairment. *Topics in Language Disorders*, *22*(3), 15–29.

Ellis Weismer, S., Gernsbacher, M. A., Stronach, S., Karasinski, C., Eernisse, E. R., Venker, C. E., & Sindberg, H. (2011). Lexical and grammatical skills in toddlers on the autism spectrum compared to late talking toddlers. *Journal of Autism and Developmental Disorders, 41*, 1065–1075. doi:10.1007/s10803-010-1134-4

Ellis Weismer, S., & Hesketh, L. J. (1993). The influence of prosodic and gestural cues on novel word acquisition by children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 36*(5), 1013–25.

Ellis Weismer, S., & Hesketh, L. J. (1996). Lexical learning by children with specific language impairment: effects of linguistic input presented at varying speaking rates. *Journal of Speech, Language, and Hearing Research*, *39*(1), 177–190.

Ellis Weismer, S., & Kover, S. T. (2015). Preschool language variation, growth, and predictors in children on the autism spectrum. *Journal of Child Psychology and Psychiatry*.

Ellis Weismer, S., Lord, C., & Esler, A. (2010). Early language patterns of toddlers on the autism spectrum compared to toddlers with developmental delay. *Journal of Autism and Developmental Disorders*, *40*(10), 1259–1273. doi:10.1007/s10803-010-0983-1

Ellis Weismer, S., Plante, E., Jones, M., & Tomblin, J. B. (2005). Imaging investigation of verbal working memory in adolescents with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *48*(2), 405–426.

Ellis Weismer, S., & Robertson, S. (2006). Focused stimulation approach to language intervention. In R. J. McCaule & M. E. Fey (Eds.), *Treatment of language disorders in children* (pp. 175–202). Baltimore, MD: Paul H. Brookes.

Ellis Weismer, S., Tomblin, J. B., Zhang, X., Buckwalter, P., Chynoweth, J. G., & Jones, M. (2000). Nonword repetition performance in school-age children wtih and without language impairment. *Journal of Speech, Language, and Hearing Research*, *43*, 865–878.

Estigarribia, B., Roberts, J. E., Sideris, J., & Price, J. (2011). Expressive morphosyntax in boys with fragile X syndrome with and without autism spectrum disorder. *International Journal of Language & Communication Disorders*, *46*(2), 216–230.

Evans, J. L., Saffran, J. R., & Robe-Torres, K. (2009). Statistical learning in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *52*(2), 321–336.

Fernald, A., & Marchman, V. a. (2012). Individual differences in lexical processing at 18 months predict vocabulary growth in typically developing and late-talking toddlers. *Child Development*, *83*(1), 203–222. doi:10.1111/j.1467-8624.2011.01692.x

Fernald, A., Zangl, R., & Marchman, V. A. (2008). Looking while listening: Using eye movements to monitor spoken language comprehension in infants and young children. In H.

(2008) Sekerina, I.A., Fernández, E.M., & Clahsen (Ed.), *Developmental Psycholonguistics: On-line methods in children's language processing* (pp. 184–218). Amsterdam: John Bejamins.

Filipek, P. A., Accardo, P. J., Baranek, G. T., Cook, E. H., Dawson, G., Gordon, B., … Volkmar, F. R. (1999). The screening and diagnosis of autistic spectrum disorders. *Journal of Autism and Developmental Disorders*, *29*(6), 439–484.

Fox, J., Friendly, M., & Weisberg, S. (2013). Hypothesis tests for multivariate linear models using the car package. *The R Journal*, *5*(1), 39–52.

Gathercole, S. E. (1995). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory & Cognition*, *23*(1), 83–94.

Gathercole, S. E. (2006). Nonword repetition and word learning: The nature of the relationship. *Applied Psycholinguistics*, *27*(04), 513–543. doi:10.1017/S0142716406060383

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological Memory Deficits in Language Disordered Children: Is There a Causal Connection? *Journal of Memory and Language*, *29*, 336–360.

Gidley Larson, J. C., & Mostofsky, S. H. (2008). Evidence that the pattern of visuomotor sequence learning is altered in children with autism. *Autism Research : Official Journal of the International Society for Autism Research*, *1*(6), 341–53. doi:10.1002/aur.54

Gomez, R. L., & Gerken, L. (1999). Artificial grammar learning by 1-year-olds leads to specific and abstract knowledge. *Cognition*, *70*(2), 109–35.

Gordon, B., & Stark, S. (2007). Procedural learning of a visual sequence in individuals with autism. *Focus on Autism and Other Developmental Disabilities*, *22*(1), 14–22.

Graf Estes, K., Evans, J. L., Alibali, M. W., & Saffran, J. R. (2007). Can infants map meaning to newly segmented words? Statistical segmentation and word learning. *Psychological Science*, *18*(3), 254–260.

Gray, S. (2004). Word learning by preschoolers with specific language impairment: predictors and poor learners. *Journal of Speech, Language, and Hearing Research : JSLHR*, *47*(5), 1117–32. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15603466

Gray, S. (2005). Word learning by preschoolers with specific language impairment: Effect of phonological or semantic cues. *Journal of Speech, Language, and Hearing Research*, *48*(December), 1452–1468.

Gray, S. (2006). The relationship between phonological memory, receptive vocabulary, and fast mapping in young children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *49*(5), 955–69. doi:10.1044/1092-4388(2006/069)

Gray, S., Plante, E., Vance, R., & Henrichsen, M. (1999). The diagnostic accuracy of four vocabulary tests administered to preschool-age children. *Language, Speech, and Hearing Services in the Schools*, *30*(2), 196–207.

Haebig, E., Matthews, M. E., Venker, C. E., & Ellis Weismer, S. (2012). Early receptive-expressive language profiles and outcomes in children with ASD. In *Early Receptive-Expressive Language Profiles and Outcomes in Children with ASD*. Atlanta: ASHA Convention.

Hahn, N., Snedeker, J., & Rabagliati, H. (2015). Rapid linguistic ambiguity resolution in young children with autism spectrum disorder: Eye tracking evidence for the limits of weak central coherence. *Autism Research*. doi:10.1002/aur.1487

Hall, D. G., Williams, S. G., & Bélanger, J. (2010). Learning count nouns and adjectives: Understanding the contributions of lexical form class and social-pragmatic cues. *Journal of Cognition and Development*, *11*(1), 86–120.

Hampton Wray, A., & Weber-Fox, C. (2013). Specific aspects of cognitive and language proficiency account for variability in neural indices of semantic and syntactic processing in children. *Developmental Cognitive Neuroscience*, *5*(1), 149–171.

Happé, F., & Booth, R. D. L. (2008a). The power of the positive: Revisiting weak coherence in autism spectrum disorders The power of the positive : Revisiting weak coherence in autism spectrum disorders. *The Quarterly Journal of Experimental Psychology*, *61*(November 2012), 50–63. doi:10.1080/17470210701508731

Happé, F., & Booth, R. D. L. (2008b). The power of the positive: revisiting weak coherence in autism spectrum disorders. *Quarterly Journal of Experimental Psychology*, *61*(1), 50–63. doi:10.1080/17470210701508731

Happé, F., & Frith, U. (2006). The weak coherence account: detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *36*(1), 5–25. doi:10.1007/s10803-005-0039-0

Hart, B., & Risley, T. R. (1992). American parenting of language-learning children: Persisting differences in family^child interactions observed in natural home environments. *Developmental Psychology*, *28*(6), 1096–1105. doi:10.1037//0012-1649.28.6.1096

Hassink, J. M., & Leonard, L. B. (2010). Within-treatment factors as predictors of outcomes following conversational recasting. *American Journal of Speech-Language Pathology*, *19*(3), 213–224. doi:10.1044/1058-0360(2010/09-0083)

Hay, J. F., Pelucchi, B., Graf Estes, K., & Saffran, J. R. (2011). Linking sounds to meanings: Infant statistical learning in a natural language. *Cognitive Psychology*, *63*(2), 93–106. doi:10.1016/j.cogpsych.2011.06.002

Haynes, C., & Naidoo, S. (1991). *Children with specific speech and language impairment*. London, UK: MacKeith Press.

Hsu, H. J., Tomblin, J. B., & Christiansen, M. H. (2014). Impaired statistical learning of non-adjacent dependencies in adolescents with specific language impairment. *Frontiers in Psychology*, *5*(March), 175.

Hudry, K., Leadbitter, K., Temple, K., Slonims, V., McConachie, H., Aldred, C., … Charman, T. (2010). Preschoolers with autism show greater impairment in receptive compared with expressive language abilities. *International Journal of Language & Communication Disorders / Royal College of Speech & Language Therapists*, *45*(6), 681–690.

Hurtado, N., Marchman, V. a, & Fernald, A. (2008). Does input influence uptake? Links between maternal talk, processing speed and vocabulary size in Spanish-learning children. *Developmental Science*, *11*(6), F31–9. doi:10.1111/j.1467-7687.2008.00768.x

Järvinen-Pasley, A., Wallace, G. L., Ramus, F., Happé, F., & Heaton, P. (2008). Enhanced perceptual processing of speech in autism. *Developmental Science*, *11*(1), 109–121. doi:10.1111/j.1467-7687.2007.00644.x

Jeste, S. S., Kirkham, N., Senturk, D., Hasenstab, K., Sugar, C., Kupelian, C., … Johnson, S. P. (2014). Electrophysiological evidence of heterogeneity in visual statistical learning in young children with ASD. *Developmental Science*, *18*(1), 90–105. doi:10.1111/desc.12188

Joanisse, M. F., & Seidenberg, M. S. (1998). Specific language impairment: a deficit in grammar or processing? *Trends in Cognitive Sciences*, *2*(7), 240–7. doi:10.1016/S1364-6613(98)01186-3

Joanisse, M. F., & Seidenberg, M. S. (2003). Phonology and syntax in specific language impairment: Evidence from a connectionist model. *Brain and Language*, *86*(1), 40–56. doi:10.1016/S0093-934X(02)00533-3

Joseph, R. M., McGrath, L. M., & Tager-Flusberg, H. (2005). Executive dysfunction and its relation to language ability in verbal school-age children with autism. *Developmental Neuropsychology*, *27*(3), 361–78. doi:10.1207/s15326942dn2703_4

Kail, R., & Salthouse, T. A. (1994). Processing speed as a mental capacity. *Acta Psychologica*, *86*, 199–225.

Kail, R. V. (1994). A method for studying the generalized slowing hypothesis in children with specific language. *Journal of Speech, Language, and Hearing Research*, *37*(2), 418.

Kan, P. F., & Windsor, J. (2010). Word learning in children with primary language impairment: A meta-analysis. *Journal of Speech, Language, and Hearing Research*, *53*(3), 739–757.

Kidd, E. (2012). Implicit statistical learning is directly associated with the acquisition of syntax. *Developmental Psychology*, *48*(1), 171–84. doi:10.1037/a0025405

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.

Kover, S. T., & Atwood, A. K. (2013). Establishing equivalence: methodological progress in group-matching design and analysis. *American Journal on Intellectual and Developmental Disabilities*, *118*(1), 3–15.

Kover, S. T., McDuffie, A. S., Hagerman, R. J., & Abbeduto, L. (2013). Receptive vocabulary in boys with autism spectrum disorder: Cross-sectional developmental trajectories. *Journal of Autism and Developmental Disorders*, *43*, 2696–2709.

Kwok, E. Y. L., Brown, H. M., Smyth, R. E., & Oram Cardy, J. (2015). Meta-analysis of receptive and expressive language skills in autism spectrum disorder. *Research in Autism Spectrum Disorders*, *9*, 202–222.

Lahey, M., & Edwards, J. (1999). Naming errors of children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *42*(1), 195–205.

Lahey, M., Edwards, J., & Munson, B. (2001). Is processing speed related to severity of language impairment? *Journal of Speech, Language, and Hearing Research*, *44*(6), 1354–1361.

Landry, S. H., Smith, K. E., Miller-Loncar, C. L., & Swank, P. R. (1997). Predicting cognitive-language and social growth curves from early maternal behaviors in children at varying degrees of biological risk. *Developmental Psychology*, *33*(6), 1040–53.

Leonard, L. B. (1989). Language learnability and specific language impairment in children. *Applied Psycholinguistics*, *10*, 179–202.

Leonard, L. B. (2014). *Children with Specific Language Impairment* (2nd ed.). Cambridge, MA: MIT Press.

Leonard, L. B., Bortolini, U., Caselli, M. C., McGregor, K. K., Taylor, P., & Leonard, B. (1992). Morphological deficits in children with specific language impairment: The status of features in the underlying grammar. *Language Acquisition*, *2*(2), 151–179.

Leonard, L. B., Camarata, S. M., Brown, B., & Camarata, M. N. (2004). Tense and agreement in the speech of children with specific language impairment: Patterns of generalization through intervention. *Journal of Speech, Language, and Hearing Research*, *47*(6), 1363–1379. doi:10.1044/1092-4388(2004/102)

Leonard, L. B., Ellis Weismer, S., Miller, C. A., Francis, D. J., Tomblin, J. B., & Kail, R. V. (2007). Speed of processing, working memory, and language impairment in children. *Journal of Speech, Language, and Hearing Research*, *50*(2), 408–428.

Leonard, L. B., Eyer, J. A., Bedore, L. M., & Grela, B. G. (1997). Three accounts of the grammatical morpheme difficulties of english-speaking children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *40*(4), 741–753.

Leonard, L. B., Nippold, M. A., Kail, R. V, & Hale, C. A. (1983). Picture naming in language-impaired children. *Journal of Speech and Hearing Research*, *26*(4), 609–615.

Lindgren, K. a, Folstein, S. E., Tomblin, J. B., & Tager-Flusberg, H. (2009). Language and reading abilities of children with autism spectrum disorders and specific language impairment and their first-degree relatives. *Autism Research : Official Journal of the International Society for Autism Research*, *2*(1), 22–38.

Liss, M., Harel, B., Fein, D., Allen, D., Dunn, M., Feinstein, C., … Rapin, I. (2001). Predictors and correlates of adaptive functioning in children with developmental disorders. *Journal of Autism and Developmental Disorders*, *31*(2), 219–230.

Lord, C., & Pickles, A. (1996). Language level and nonverbal social-communication behaviors in autistic and language-delayed children. *American Academy of Chhild and Adolescent Psychiatry*, *35*(11), 1542–1550.

Ludden, D., & Gupta, P. (2000). Zen in the art of language acquisition: Statistical learning and the less is more hypothesis. In L. Gleitman & A. K. Joshi (Eds.), *Proceedings of the Twenty-second Annual Conference of the Cognitive Science Society.* (pp. 812–817). Hillsdale, NJ: Erlbaum.

Lum, J. A. G., Ullman, M. T., & Conti-Ramsden, G. (2015). Verbal declarative memory impairments in specific language impairment are related to working memory deficits. *Brain and Language*, 76–85. doi:doi:10.1016/j.bandl.2015.01.008

Luyster, R., Lopez, K., & Lord, C. (2007). Characterizing communicative development in children referred for Autism Spectrum Disorders using the MacArthur-Bates Communicative Development Inventory (CDI). *Journal of Child Language*, *34*(03), 623. doi:10.1017/S0305000907008094

Luyster, R., & Lord, C. (2009). Word learning in children with autism spectrum disorders. *Developmental Psychology*, *45*(6), 1774–86. doi:10.1037/a0016223

Mainela-Arnold, E., & Evans, J. L. (2014). Do statistical segmentation abilities predict lexical-phonological and lexical-semantic abilities in children with and without SLI? *Journal of Child Language*, *41*(2), 327 – 351. doi:10.1017/S0305000912000736

Mainela-Arnold, E., Evans, J. L., & Coady, J. A. (2008). Lexical representations in children with SLI: Evidence from a frequency-manipulated gating task. *Journal of Speech, Language, and Hearing Research*, *51*(2), 381–394.

Maljaars, J., Noens, I., Scholte, E., & van Berckelaer-Onnes, I. (2012). Language in low-functioning children with autistic disorder: Differences between receptive and expressive skills and concurrent predictors of language. *Journal of Autism and Developmental Disorders*, *42*(10), 2181–91.

Maye, J., Werker, J. F., & Gerken, L. (2002). Infant sensitivity to distributional information can affect phonetic discrimination. *Cognition*, *82*(3), B101–11.

Mayo, J., & Eigsti, I.-M. (2012). Brief Report: A Comparison of Statistical Learning in School-Aged Children with High Functioning Autism and Typically Developing Peers. *Journal of Autism and Developmental Disorders*, *42*, 2476–2485. doi:10.1007/s10803-012-1493-0

McCleery, J. P., Ceponiene, R., Burner, K. M., Townsend, J., Kinnear, M., & Schreibman, L. (2010). Neural correlates of verbal and nonverbal semantic integration in children with autism spectrum disorders. *Journal of Child Psychology and Psychiatry*, *51*(3), 277–286. doi:10.1111/j.1469-7610.2009.02157.x

McDuffie, A., Kover, S. T., Hagerman, R., & Abbeduto, L. (2013). Investigating word learning in fragile X syndrome: A fast-mapping study. *Journal of Autism and Developmental Disorders*, *43*(7), 1676–1691. doi:10.1007/s10803-012-1717-3

McGregor, K. K., & Bean, A. (2012). How children with autism extend new words. *Journal of Speech, Language, and Hearing Research*, *55*(February), 70–84. doi:10.1044/1092-4388(2011/11-0024)b

McGregor, K. K., Berns, A. J., Owen, A. J., Michels, S. a, Duff, D., Bahnsen, A. J., & Lloyd, M. (2012). Associations between syntax and the lexicon among children with or without ASD and language impairment. *Journal of Autism and Developmental Disorders*, *42*(1), 35–47. doi:10.1007/s10803-011-1210-4

McGregor, K. K., Oleson, J., Bahnsen, A., & Duff, D. (2013). Children with developmental language impairment have vocabulary deficits characterized by limited breadth and depth. *International Journal of Language & Communication Disorders*, *48*(3), 307–319.

McGregor, K. K., Rost, G., Arenas, R., Farris-Trimble, A., & Stiles, D. (2013). Children with ASD can use gaze in support of word recognition and learning. *Journal of Child Psychology and Psychiatry*, *54*(7), 745–753.

McGregor, K. K., Rost, G. C., Guo, L. Y., & Sheng, L. (2010). What compound words mean to children with specific language impairment. *Applied Psycholinguistics*, *31*(3), 463–487. doi:10.1017/S014271641000007X

McMurray, B., Munson, C., & Tomblin, J. B. (2014). Individual differences in speech perception and word recognition: Evidence from eye-movements. *Journal of Speech, Language, and Hearing Research*, *57*(3), 1344–1362.

McMurray, B., Samelson, V. M., Lee, S. H., & Tomblin, J. B. (2010). Individual differences in online spoken word recognition: Implications for SLI. *Cognitive Psychology*, *60*(1), 1–39. doi:10.1016/j.cogpsych.2009.06.003

McNealy, K., Mazziotta, J. C., & Dapretto, M. (2006). Cracking the language code: Neural mechanisms underlying speech parsing. *The Journal of Neuroscience*, *26*(29), 7629–39. doi:10.1523/JNEUROSCI.5501-05.2006

Mirman, D. (2014). *Growth curve analysis and visualization using R*. Chapman and Hall/CRC.

Mirman, D., Dixon, J. A., & Magnuson, J. S. (2008). Statistical and computational models of the visual world paradigm: Growth curves and individual differences. *Journal of Memory and Language*, *59*(4), 475–494. doi:10.1016/j.jml.2007.11.006.Statistical

Montgomery, J. W. (1999). Recognition of gated words by children with specific language impairment: an examination of lexical mapping. *Journal of Speech, Language, and Hearing Research*, *42*, 735–743.

Montgomery, J. W., & Evans, J. L. (2009). Complex sentence comprehension and working memory in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *52*(2), 269–88. doi:10.1044/1092-4388(2008/07-0116)

Motofsky, S. H., Goldberg, M. C., Landa, R. J., & Denckla, M. B. (2000). Evidence for a deficit in procedural learning in children and adolescents with autism: Implications for cerebellar contribution. *Journal of International Neuropsychological Society*, *6*, 752–759.

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders*, *36*(1), 27–43. doi:10.1007/s10803-005-0040-7

Müller, R.-A., Cauich, C., Rubio, M. a, Mizuno, A., & Courchesne, E. (2004). Abnormal activity patterns in premotor cortex during sequence learning in autistic patients. *Biological Psychiatry*, *56*(5), 323–32. doi:10.1016/j.biopsych.2004.06.007

Mundy, P., Sigman, M., & Kasari, C. (1990). A longitudinal study of joint attention and language development in autistic children. *Journal of Autism and Developmental Disorders*, *20*(1), 115–28. doi:10.1007/BF02206861

Naigles, L. R., Kelty, E., Jaffery, R., & Fein, D. (2011). Abstractness and continuity in the syntactic development of young children with autism. *Autism Research : Official Journal of the International Society for Autism Research*, *4*(6), 422–37. doi:10.1002/aur.223

Nation, K. (2014). Lexical learning and lexical processing in children with developmental language impairments. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *369*(20120387), 1–10. doi:10.1098/rstb.2012.0387

Nelson, K. E., Camarata, S. M., Welsh, J., Butkovsky, L., & Camarata, M. (1996). Effects of imitative and conversational recasting treatment on the acquisition of grammar in children with specific language impairment and younger language-normal children. *Journal of Speech, Language, and Hearing Research*, *39*(4), 850–859.

Norbury, C. F. (2005). Barking up the wrong tree? Lexical ambiguity resolution in children with language impairments and autistic spectrum disorders. *Journal of Experimental Child Psychology*, *90*(2), 142–71. doi:10.1016/j.jecp.2004.11.003

Norbury, C. F., Griffiths, H., & Nation, K. (2010). Sound before meaning: Word learning in autistic disorders. *Neuropsychologia*, *48*(14), 4012–4019.

Oetting, J. B., Rice, M. L., & Swank, L. K. (1995). Quick incidental learning (QUIL) of words by school age children with and without SLI. *Journal of Speech and Hearing Research*, *38*, 434–445.

Ouellette, G. P. (2006). What's meaning got to do with it: The role of vocabulary in word reading and reading comprehension. *Journal of Educational Psychology*, *98*(3), 554–566. doi:10.1037/0022-0663.98.3.554

Paul, R., Fischer, M. L., & Cohen, D. J. (1988). Brief Report: Sentence comprehension strategies in children with autism and specific language disorders. *Journal of Autism and Developmental Disorders*, *18*(4), 669–679.

Pelucchi, B., Hay, J. F., & Saffran, J. R. (2009a). Learning in reverse: eight-month-old infants track backward transitional probabilities. *Cognition*, *113*(2), 244–7. doi:10.1016/j.cognition.2009.07.011

Pelucchi, B., Hay, J. F., & Saffran, J. R. (2009b). Statistical learning in a natural language by 8-month-old infants. *Child Development*, *80*(3), 674–85. doi:10.1111/j.1467-8624.2009.01290.x

Perruchet, P., & Desaulty, S. (2008). A role for backward transitional probabilities in word segmentation? *Memory & Cognition*, *36*(7), 1299–305. doi:10.3758/MC.36.7.1299

Pickles, A., Anderson, D. K., & Lord, C. (2014). Heterogeneity and plasticity in the development of language: A 17-year follow-up of children referred early for possible autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *55*(12), 1354–1362. doi:10.1111/jcpp.12269

Pinker, S. (1994). *The Language Instinct*. (S. Pinker, Ed.)*The Language Instinct*. New York: William Morrow.

Plante, E., Gomez, R., & Gerken, L. (2002). Sensitivity to word order cues by normal and language/learning disabled adults. *Journal of Communication Disorders*, *35*(5), 453–62. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12194564

Preissler, M. A. (2008). Associative learning of pictures and words by low-functioning children with autism. *Autism*, *12*(3), 231–248. doi:10.1177/1362361307088753

Preissler, M. A., & Carey, S. (2005). The role of inferences about referential intent in word learning: evidence from autism. *Cognition*, *97*(1), B13–23. doi:10.1016/j.cognition.2005.01.008

Prior, M. R., & Hall, L. C. (1979). Comprehension of transitive and intransitive phrases by autistic, retarded, and normal children. *Journal of Communication Disorders*, *12*, 103–111.

Proctor-Williams, K., & Fey, M. E. (2007). Recast density and acquisition of novel irregular past tense verbs. *Journal of Speech, Language, and Hearing Research*, *50*(6), 1029–1048.

Rapin, I., Dunn, M. A., Allen, D. A., Stevens, M. C., & Fein, D. (2009). Subtypes of language disorders in school-age children with autism. *Developmental Neuropsychology*, *34*(1), 66–84. doi:10.1080/87565640802564648

Rapport, L. J., & Weyandt, L. L. (2008). The development and measurement of intelligience. In J. M. Sattler (Ed.), *Assessment of Children: Cognitive Foundation* (5th ed., pp. 245–264). San Diego: Jerome M. Sattler, Publisher, Inc.

Reber, A. S. (1967). Implicit Learning of Artificial Grammars 1. *Journal of Verbal Learning and Verbal Behavior*, *6*(6), 855–863.

Rice, M. L. (2004). Growth models of developmental language disorders. In M. L. Rice & S. F. Warren (Eds.), *Developmental language disorders: From phenotypes to etiologies* (pp. 207–240). Mahwah, NJ: Lawrence Erlbaum Associates.

Rice, M. L., Buhr, J. C., & Nemeth, M. (1990). Fast mapping word-learning abilities of language-delayed preschoolers. *The Journal of Speech and Hearing Disorders*, *55*(1), 33–42.

Rice, M. L., Oetting, J. B., Marquis, J., Bode, J., & Pae, S. (1994). Frequency of input effects on word comprehension of children with specific language impairment. *Journal of Speech and Hearing Research*, *37*(1), 106–122.

Rice, M. L., Tomblin, J. B., Hoffman, L., Richman, W. A., & Marquis, J. (2004). Grammatical tense deficits in children with SLI and nonspecific language impairement: Relationships with nonverbal IQ over time. *Journal of Speech, Language, and Hearing Research*, *47*(4), 816–834.

Rice, M. L., Warren, S. F., & Betz, S. K. (2005). Language symptoms of developmental language disorders: An overview of autism, Down syndrome, fragile X, specific language impairment, and Williams syndrome. *Applied Psycholinguistics*, *26*(01), 7–27.

Rice, M. L., & Wexler, K. (1996). Toward tense as a clinical marker of specific language impairment in English-speaking children. *Journal of Speech, Language, and Hearing Research*, *39*(6), 1239–57.

Rice, M. L., Wexler, K., & Cleave, P. L. (1995). Specific language impairment as a period of extended optional infinitive. *Journal of Speech and Hearing Research*, *38*, 850–863.

Rice, M. L., Wexler, K., & Redmond, S. M. (1999). Grammaticality judments of extended optional infinitive grammar: evidence from english-speaking children with specific langauge impairment. *Journal of Speech, Language, and Hearing Research*, *42*, 943–961.

Riches, N. G., Loucas, T., Baird, G., Charman, T., & Simonoff, E. (2010). Sentence repetition in adolescents with specific language impairments and autism: An investigation of complex syntax. *International Journal of Language & Communication Disorders*, *45*(1), 47–60.

Riches, N. G., Loucas, T., Baird, G., Charman, T., & Simonoff, E. (2011). Non-word repetition in adolescents with specific language impairment and autism plus language impairments: a qualitative analysis. *Journal of Communication Disorders*, *44*(1), 23–36.

Riches, N. G., Tomasello, M., & Conti-Ramsden, G. (2005). Verb learning in children with SLI: Frequencey and spaking effects. *Journal of Speech, Language, and Hearing Research*, *48*, 1397–1412.

Roberts, J. A., Rice, M. L., & Tager-Flusberg, H. (2004). Tense marking in children with autism. *Applied Psycholinguistics*, *25*(03), 429–448.

Rutter, M., Bailey, A., & Lord, C. (2003). *Social communication questionnaire*. Los Angeles: CA: Western Psychological Services.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science*, *274*(5294), 1926–1928.

Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (1999). Statistical learning of tone sequences by human infants and adults. *Cognition*, *70*(1), 27–52. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10193055

Saffran, J. R., Newport, E. L., Aslin, R. N., Tunick, R. A., & Barrueco, S. (1997). Incidental language learning: Listening (and learning) out of the comer of your ear. *Psychological Science*, *8*(2), 101–106.

Schopler, E., Van Bourgondien, M., Wellman, G., & Love, S. (2010). *Childhood autism rating scale* (2nd ed.). Los Angeles: CA: Western Psychological Services.

Scott-Van Zeeland, A. A., McNealy, K., Wang, A. T., Sigman, M., Bookheimer, S. Y., & Dapretto, M. (2010). No neural evidence of statistical learning during autism spectrum disorders. *Biological Psychiatry*, *68*, 345–351. doi:10.1016/j.biopsych.2010.01.011

Seger, C. a. (1994). Implicit learning. *Psychological Bulletin*, *115*(2), 163–96. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/19283555

Semel, E., & Wiig, E. H. (2003). *Clinical Evaluation of Language Fundamentals* (4th ed.). San Antonio, TX: Harcourt Assessment.

Sheng, L., & McGregor, K. K. (2010). Lexical-semantic organization in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *53*(1), 146–159. doi:10.1044/1092-4388(2009/08-0160)

Siller, M., & Sigman, M. (2002). The behaviors of parents of children with autism predict the subsequent development of their children's communication. *Journal of Autism and Developmental Disorders*, *32*(2), 77–89.

Smith, L. B., Jones, S. S., & Landau, B. (1992). Count Nouns, Adjectives, and Perceptual Properties in Children's Novel Word Interpretations. *Developmental Psychology*, *28*(2), 273–286.

Smith, L., & Yu, C. (2008). Infants rapidly learn word-referent mappings via cross-situational statistics. *Cognition*, *106*(3), 1558–68. doi:10.1016/j.cognition.2007.06.010

Sterling, A. M., Rice, M. L., & Warren, S. F. (2012). Finiteness marking in boys with fragile x syndrome. *Journal of Speech, Language, and Hearing Research*, *55*(6), 1704–1715.

Stokes, S. F., Kern, S., & Santos, C. Dos. (2012). Extended statistical learning as an account for slow vocabulary growth*. *Journal of Child Language*, *39*(01), 105–129. doi:10.1017/S0305000911000031

Storkel, H. L., Bontempo, D. E., Aschenbrenner, A. J., Maekawa, J., & Lee, S. (2013). The effect of incremental changes in phonotactic probability and neighborhood density on word learning by preschool children. *Journal of Speech, Language, and Hearing Research*, *56*(5), 1689–1701. doi:10.1044/1092-4388(2013/12-0245)sound

Stothard, S. E., Snowling, M. J., Bishop, D. V. M., Chipchase, B. B., & Kaplan, C. A. (1998). Language-impaired preschoolers: A follow-up into adolescence. *Journal of Speech, Language, and Hearing Research*, *41*, 407–418.

Swensen, L. D., Kelley, E., Fein, D., & Naigles, L. R. (2007). Processes of Language Acquisition in Children With Autism : Evidence from Preferential Looking. *Child Development*, *78*(2), 542–557.

Tager-Flusberg, H. (1981). Sentence comprehension in autistic children. *Applied Psycholinguistics*, *2*(1), 5–24.

Tager–Flusberg, H. (2000). The challenge of studying language development in autism. In L. Menn & N. Bernstein Ratner (Eds.), *Methods for studying language production* (pp. 313–332). Mahwah, NJ: Erlbaum.

Tager-Flusberg, H., Calkins, S., Nolin, T., Baumberger, T., Anderson, M., & Chadwick-Dias, A. (1990). A longitudinal study of language acquisition in autistic and Down syndrome children. *Journal of Autism and Developmental Disorders*, *20*(1), 1–21. doi:10.1007/BF02206853

Tager-Flusberg, H., & Kasari, C. (2013). Minimally verbal school-aged children with autism spectrum disorder: The neglected end of the spectrum. *Autism Research*, *6*(6), 468–478. doi:10.1002/aur.1329

Tallal, P., Miller, S., & Fitch, R. H. (1993). Neurobiological Basis of Speech : A Case for the Preeminence of Temporal Processing. *Annals of the New York Academy of Sciences*, *682*, 27–47.

Tannenbaum, K. R., Torgesen, J. K., & Wagner, R. K. (2006). Relationships Between Word Knowledge and Reading Comprehension in Third-Grade Children. *Scientific Studies of Reading*, *10*(4), 381–398.

Tek, S., Jaffery, G., Fein, D., & Naigles, L. R. (2008). Do children with autism spectrum disorders show a shape bias in word learning? *Autism Research : Official Journal of the International Society for Autism Research*, *1*(4), 208–222. doi:10.1002/aur.38

Toichi, M., & Kamio, Y. (2002). Long-term memory and levels-of-processing in autism. *Neuropsychologia*, *40*(7), 964–969. doi:10.1016/S0028-3932(01)00163-4

Toichi, M., & Kamio, Y. (2003). Long-term memory in high-functioning autism: Controversy on episodic memory in autism reconsidered. *Journal of Autism and Developmental Disorders*, *33*(2), 151–161. doi:10.1023/A:1022935325843

Tomasello, M., & Todd, J. (1983). Joint Attention and Lexical Acquisition Style. *First Language*, *4*(12), 197–212.

Tomblin, J. B. (2011). Co-morbidity of autism and SLI: kinds, kin and complexity. *International Journal of Language & Communication Disorders / Royal College of Speech & Language Therapists*, *46*(2), 127–37.

Tomblin, J. B., Mainela-Arnold, E., & Zhang, X. (2007). Procedural learning in adolescents with and without specific language impairment. *Language Learning and Development*, *3*(4), 269–293.

Tomblin, J. B., Records, N. L., Buckwalter, P., Zhang, X., Smith, E., & O'Brien, M. (1997). Prevalence of specific language impairment in kindergarten children. *Journal of Speech, Language, and Hearing Research*, *40*(6), 1245–1260.

Ullman, M. T. (2001). A neurocognitive perspective on language: the declarative/procedural model. *Nature Reviews. Neuroscience*, *2*(10), 717–26. doi:10.1038/35094573

Ullman, M. T., & Gopnik, M. (1999). Inflectional morphology in a family with inherited specific language impairment. *Applied Psycholinguistics*, *20*(01), 51–117. doi:10.1017/S0142716499001034

Ullman, M. T., & Pierpont, E. I. (2005). Specific language impairment is not specific to language: The procedural deficit hypothesis. *Cortex*, *41*, 399–433.

Van der Lely, H. K. J. (2005). Domain-specific cognitive systems: insight from Grammatical-SLI. *Trends in Cognitive Sciences*, *9*(2), 53–59. doi:10.1016/j.tics.2004.12.002

Van der Lely, H. K. J., & Ullman, M. T. (2001). Past tense morphology in specifically language impaired and normally developing children. *Language and Cognitive Processes*, *16*(2-3), 177–217. doi:10.1080/01690960042000076

Venker, C. E. (2013). *Statistical word learning and non-social visual attention in children with autism*. University of Wisconsin - Madison.

Von Koss Torkildsen, J., Dailey, N. S., Aguilar, J. M., Gomez, R., & Plante, E. (2013). Exemplar Variability Facilitates Rapid Learning of an Otherwise Unlearnable Grammar by Individuals With Language-Based Learning Disability. *Journal of Speech, Language, and Hearing Research*, *56*(2), 618–629. doi:10.1044/1092-4388(2012/11-0125)perspective

Walenski, M., Tager-Flusberg, H., & Ullman, M. T. (2006). Language in autism. In *Understanding autism: from basic neuroscience to treatment* (pp. 175–203). Boca Raton; CRC/Taylor & Frances.

Walley, A. C., Metsala, J. L., & Victoria, M. (2003). Spoken vocabulary growth : Its role in the development of phoneme awareness and early reading ability. *Reading & Writing Quarterly*, *16*, 5–20.

Wechsler, D. (2003). *Wechsler Intelligence Scale for Children-Fourth edition* (4th ed.). San Antonio: TX: The Psychological Coorporation.

Werker, J. F., Cohen, L. B., Lloyd, V. L., & Casasola, M. (1998). Acquisition of Word-Object Associations by 14-Month-Old Infants. *Developmental Psychology*, *34*(6), 1289 – 1309.

Wexler, K. (1994). Optional infinitives, head movement and the economy of derivations. In N. Hornstein & D. Lightfoot (Eds.), *Verb Movement* (pp. 305–350). New York: Cambridge University Press.

Williams, D., Botting, N., & Boucher, J. (2008). Language in autism and specific language impairment: where are the links? *Psychological Bulletin*, *134*(6), 944–63.

Williams, D., Payne, H., & Marshall, C. (2013). Non-word repetition impairment in autism and specific language impairment: evidence for distinct underlying cognitive causes. *Journal of Autism and Developmental Disorders*, *43*(2), 404–417.

Wilson, S. (2003). Lexically specific constructions in the acquisition of inflection in English. *Journal of Child Language*, *30*(1), 75–115. doi:10.1017/S0305000902005512

Windfuhr, K. L., Faragher, B., & Conti-Ramsden, G. (2002). Lexical learning skills in young children with speci c language impairment (SLI). *International Journal of Communication Disorders*, *37*(4), 415–432. doi:10.1080/136828202100000775

Wolff, J. J., Gu, H., Gerig, G., Elison, J. T., Styner, M., Botteron, K. N., … Piven, J. (2012). Differences in white matter fiber tract development present from6 to 24 months in infants with autism. *American Journal of Psychiatry*, *169*(6), 589–600.

Zhao, J., Al-Aidroos, N., & Turk-Browne, N. B. (2013). Attention Is Spontaneously Biased Toward Regularities. *Psychological Science*, (April). doi:10.1177/0956797612460407

Appendix A
Instructions for the Segmenting Task

Open: Segmenting_L2_W.NW_4.76min.es2 in E-Prime
(desktop/sharedfolder/Eileen/Segmenting/ Segmenting_L2_W.NW_4.76min.es2)

Start the experiment and enter in the child's participant number, then click yes or next until the experiment starts.

Exposure

Have the child sit in front of the screen and listen to the stimuli and watch the video.

A written prompt that says "LISTEN" will appear. Say to the child:
"Now you're going to listen to a Martian language for 5 minutes. All you need to do is sit and listen."
Press the SPACE BAR. The movie will start.

Practice Phase

After the exposure period (5 minutes), the screen will say "Let's practice." Read these instructions for the practice phase.

Practice Phase Script: "Now I want you to listen to two things and pick the one that sounds like what you heard. Push this button (point to left button with the number 1 above it) if you think it's the first one and push this button (point to right button with the number 2 above it) if you think it's the second one. Listen to both and answer when you see a question mark (?). First we'll practice with real words. Listen to both things and pick the one that sounds like a real word in English."

Press the SPACE BAR and the practice phase will start.

After each practice trial, auditory feedback will be given (e.g., "great!" or "oops!"). You may provide feedback on the first two items and discontinue giving feedback if they get the first two items correct. Press the SPACE BAR after each practice trial/after you give feedback (total = 4):

Correct Feedback: "That's right! 'Table' sound like an English word, 'gee daw' doesn't."
Incorrect Feedback: "Hm, 'bull tay' doesn't sound like an English word to me, but 'doggy' does."

Test Phase

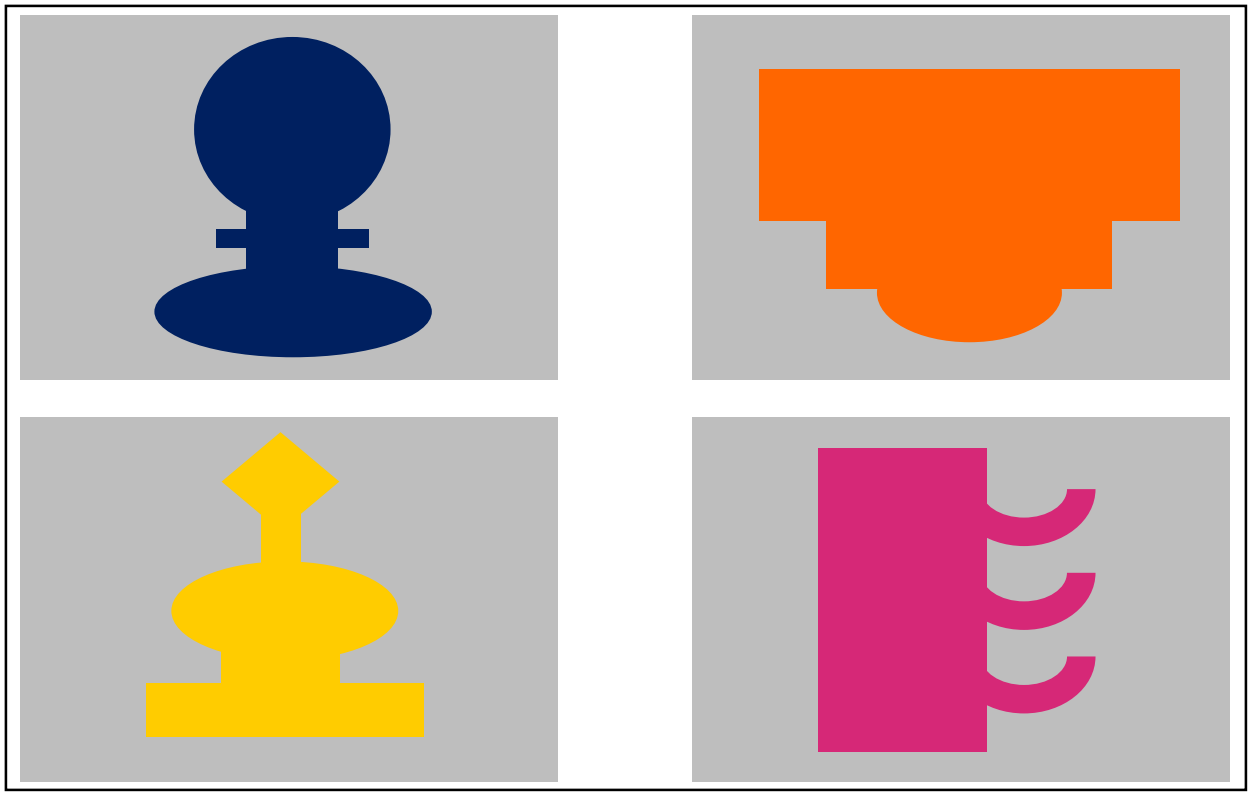
A prompt that says "Let's try some more!" will appear before the test phase starts.

Read this to the child:
"Great! Now you're going to pick something different. Pick the one that sounds more like the Martian language you heard when you were listening and watching. It's ok to guess if you're not sure."
Push the SPACE BAR.

Wait for the child to answer all 16 test trials. A smiley face will pop up at the end of the study.
Press the SPACE BAR and the experiment will close.

Appendix B

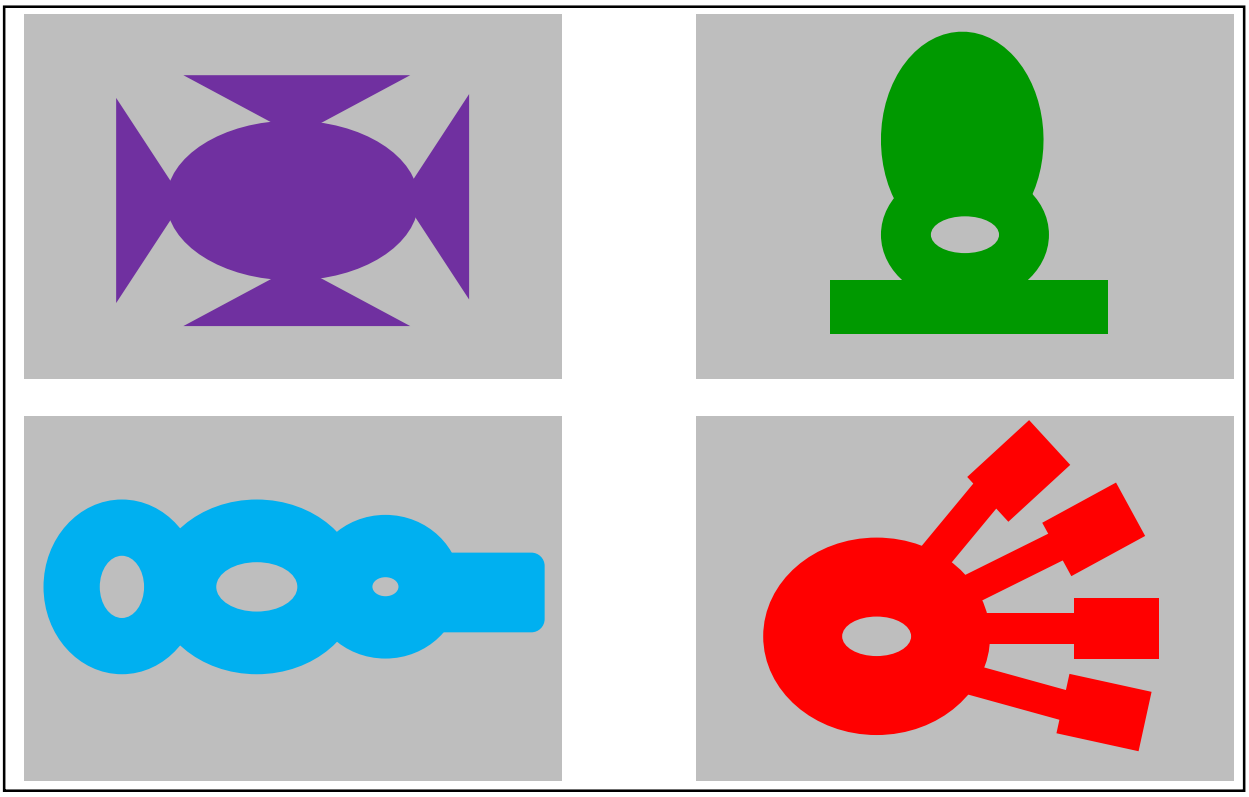
Word Learning Task Pointing Form and Script



1. “Where’s the teemo?”
2. “Find the dayno.”
3. “Find the padu.”
4. “Where’s the bolay?”

Appendix C

Combination Task Pointing Form and Script



1. “Find the meeda.”
2. “Where’s the pagee?
3. “Where’s the bodu?”
4. “Find the tunay.”

Appendix D

Word Learning and Combination Task Pointing Form

Word Learning and Combination Tasks Haebig

Participant ID:_____ Examiner: 1st visit:_____ 2nd visit:_____

Session ____ Date: _____ **Word Learning Task**

Show the child the laminated page with the four object images. From the child's view, the blue and orange images should be on the top of the page and the gold and pink should be on the bottom half of the page.

Ask the following questions and record where the child points. Self-corrections are allowed.

	Upper Left 1	Upper Right 2	Lower Left 3	Lower Right 4
1. Where's the teemo? /timo/				
2. Find the dayno. /deno/				
3. Find the padu. /padu/				
4. Where's the bolay? /bole/				

Session ____ Date: _____ **Combination Task**

Show the child the laminated page with the four object images. From the child's view, the purple and green images should be on the top of the page and the light blue and red should be on the bottom half of the page.

Ask the following questions and record where the child points. Self-corrections are allowed.

Version: A B (circle one)

	Upper Left 1	Upper Right 2	Lower Left 3	Lower Right 4
1. Find the meeda. /mida/				
2. Where's the pagee? /pagi/				
3. Where's the bodu? /bodu/				
4. Find the tunay. /tune/				

Note: You may repeat the questions if the child asks for a repetition. Also, the child may change his or her answer. If the child changes the answer, just cross off the old response and write the second response (don't erase the first response though).