Lexical and Cognitive Processing in Early Language Delay

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Language and Communicative Disorders by Erica Michelle Ellis

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University of California, San Diego
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2013
DEDICATION

For my incredible family - my parents, Herman and Amanda, my sister Brianna and my brother Terence
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Young children who have difficulty learning words compared to their peers are at risk for continued language delays as they grow older. While most late talkers (LT) will move into the normal range of language abilities by school age, approximately 17-26% of LTs will be identified with SLI by 5 years of age (Paul, 1996; Rescorla, 2002, Rescorla & Dale, 2013). Accordingly, one critical question is how to best identify which LTs will have SLI at school age, in order to maximize the opportunity for early and appropriate intervention and support.

Longitudinal studies of language outcomes in LTs have had only moderate success at accurately predicting which LTs will be identified as having SLI by 5-6 years of age. Research shows that the individual's lexical and cognitive processing abilities (e.g., speed of processing, memory and implicit learning) play an important role in language development (Fernald & Marchman, 2012; Graf Estes et al., 2007) and in language deficits in children with SLI (e.g., Ellis
Weismer et al., 1999; Evans et al., 2009; Leonard et al., 2007; Montgomery, 2000; Montgomery & Evans, 2009; Tomblin et al., 2007). Therefore, using the lexical and cognitive processing deficits characteristic of children with SLI to inform the study of lexical and cognitive processing in infants may prove more successful than traditional static measures of vocabulary alone, in identifying LTs at the greatest risk for SLI.

This dissertation utilizes fine-grained eye tracking methods to examine multiple real-time measures of lexical and cognitive processing to begin to identify characteristics of Late Talkers who may be at risk for Specific Language Impairment. Chapter 1 provides the general background and support for the questions addressed in this dissertation. In Chapters 2-5, data from four studies are presented. Specifically, speed and accuracy of processing familiar real words in a group of LT (N = 14) and TYP (N = 14) 18 month old infants is compared (Study 1). In study 2, speed and accuracy of processing of newly learned novel words in a group of LT (N =14) and TYP (N = 14) 18 month old infants is examined. Study 3 further examines infants’ abilities to use transitional probabilities to discover word boundaries within a stream of speech is compared in the same group of LT (N = 14) and TYP (N = 14) 18 month old infants. Study 4 examines lexical processing, novel word learning and implicit learning in a larger group of 54, 18-months, using an alternative distributional approach. Finally, Chapter 6 informs both theoretical models and clinical implications of word learning and vocabulary development in LTs and provides insight into the mechanisms that underlie individual differences in language abilities.
CHAPTER 1: LEXICAL AND COGNITIVE PROCESSING IN EARLY LANGUAGE DELAY

INTRODUCTION

Typical young infants have remarkable abilities to understand and communicate before they reach their first birthday. At around 12 months of age, most infants are able to understand dozens of words and can also express their needs through gestures and producing their first words. By the time most young infants reach 18 months, they have successfully developed multiple systems used for cognitive and lexical processing (e.g., attention, vision, sound segmentation, motor planning, word-object mapping, etc.). How, though, do young infants and toddlers become expert word learners? Alternatively, why do some young infants and toddlers struggle with word learning? Which aspect of word learning is the problem? Are there multiple processing components causing difficulty in learning new words? Most importantly, can we identify and predict which young infants and toddlers are at the greatest risk for continued language learning difficulties?

Studying lexical and cognitive processing - that is, how individuals think about, learn and process characteristics of words - in a large sample of infants allows us to better understand typical language development. More importantly, it also allows us to have a basis for determining what is the normal variability for lexical and cognitive processing and what may be at-risk indicators of later language disorders. Through the multiple investigations of this dissertation, I explored the lexical and cognitive processing abilities of infants who are at risk for continued language delays with the hope of beginning to identify possible predictors of SLI and to determine possible clinical implications for the children at the greatest risk for SLI.

In this first chapter, I summarize relevant research on infants who are LTs as well as the research on children with Specific Language Impairment, discuss certain word learning and lexical and cognitive processing studies, and outline the specific studies and goals of the research underlying this dissertation.
**Late Talkers**

The term *Late Talkers* (LT) refers to a group of healthy full-term toddlers, usually 18- to 24-months-old, who are delayed in the onset of their first words, despite having normal cognitive development, normal hearing and no significant birth history (e.g. Ellis & Thal, 2008; Ellis Weismer & Evans, 2002; Paul, 1991; Rescorla & Dale, 2013; Rescorla & Schwartz, 1990; Zubrick, Taylor, Rice & Slegers, 2007). Generally, researchers, clinicians and pediatricians identify LTs based on parent report measures of productive vocabulary. While measures and criteria vary between studies, most often LTs can be identified at 24 months if they have fewer than 50 words in their productive vocabulary and no word combinations (Paul, 1991; Rescorla & Schwartz, 1990) or at or below 10th percentile on parent report measures of vocabulary (Dale, Price, Bishop, & Plomin, 2003; Thal & Bates, 1988; Ellis Weismer & Evans, 2002; Ellis Weismer, Venker, Evans, & Moyle, 2011).

**Language Outcomes in Late Talkers**

Approximately 10-20% of children will be identified as LTs by the time they are 24-months old. Interesting patterns emerge when behaviors and outcomes of LTs who will be typical by school age (LT-TYP) are compared to LT who will be identified and classified as having SLI at school age (LT-SLI). By definition, both LT-TYP and LT-SLI have vocabulary skills below the 10th percentile in productive vocabulary at 18-24 months, but predicting which children within this lower percentile group of LTs will have SLI and which will "catch up" and have language abilities in the normal range by school age has been an almost impossible task for researchers (Rescorla & Dale, 2013).

For example, a series of studies by Paul found that by school age, most LTs have vocabulary scores in the normal range. Paul (1993) investigated language skills in preschool children who are late talkers as well as typically developing peers. Participants were children (N=37) between 20 and 34 months of age, all with fewer than 50 words in their productive
vocabulary. Paul initially administered a battery of language assessments and then followed-up with the participants at ages three and four, and at kindergarten. Findings suggested that LTs who showed normal receptive abilities by age three are more likely to have normal language development at age four. However, despite some gains in vocabulary, some LTs continued to show deficits in other areas such as in syntax, articulation, and social skills as they entered kindergarten. Paul (1996) did a follow-up investigation on a group of children with expressive language delays (N=31) and a typical group (N=27) and measured speech and narrative samples as well as standardized language testing results. The majority (74%) of the children with language delay had scored within the normal range, but was still performing below the typical group in kindergarten.

Rescorla and colleagues also conducted a series of studies (Rescorla, Mirak, and Singh, 2000; Rescorla, 2005; Rescorla, 2009) investigating outcomes of late talking toddlers on various measures at three, 13 and 17 years of age. Rescorla, Mirak, and Singh (2000) investigated vocabulary growth in LTs from two to three years of age using the Language Development Survey (LDS) in 28 LTs, as well as other assessments of language and vocabulary. Results suggested that although LTs vocabulary growth was delayed, they showed a developmental pattern similar to typically developing younger children. For example, LTs have a vocabulary spurt, but at a later time point than typical children. These findings also suggested that the vocabulary development between 2:0 and 2:6 predicted language and vocabulary abilities at age three.

In another follow-up study of the same cohort of LTs, Rescorla (2005) examined age 13 outcomes of 28 LTs (identified at 24-31 months) compared to a typical group. Rescorla found that the LT group performed in the average range on all assessments of standardized language and reading tasks at age 13, but scored significantly lower than typical peers on measures of vocabulary, grammar, memory and reading comprehension. Although by age 13 the LTs were in
the normal range, their two-year-old vocabulary scores were a significant predictor of their teenage vocabulary, grammar, memory and reading comprehension abilities.

Rescorla (2009) completed another follow-up of the same LTs and typical peers again four years later at 17 years of age. Language and reading outcomes were measured in the original LTs (N=26) and typical children (N=23). Results suggested that again, LTs performed in the normal range on language and reading tasks at 17 years of age. However, as they did at age 13, the LT group had significantly lower vocabulary, grammar, and memory scores than their age-matched peers. The findings further support that measures at age three predict later language outcomes in adolescents (Rescorla, 2009). Despite being in the normal range years later in language and reading tasks, children identified as LTs were still significantly lower than their typical peers generally and with respect to certain measurements as they grew older. Rescorla's studies provide additional interesting information on outcomes of LTs into adolescence, however, these studies also reveal that it is difficult to differentiate between LTs who will have SLI and LTs who will be typical based on language classification at 3 years of age.

One large epidemiological study (Zubrick et al., 2007) investigated maternal, family and child variables in children with late language emergence in 24-months-olds (N=1766). In this study, questionnaires were sent home to families and returned when children were two years old. Findings suggest the most powerful predictors of late language emergence include family history of delay, gender (i.e. male), and premature births. As a follow-up to Zubrick et al. (2007), Rice, Taylor and Zubrick (2008) investigated language outcomes of seven-year-olds who had a history of late language emergence at 24 months old. Of the original sample (N=1766), researchers were able to examine speech and language abilities in 128 children with a history of late language emergence and 109 typical children. Language measures at age seven included tests of articulation, grammar, language, and vocabulary abilities. Findings indicate that at age seven the children with late language emergence were within the typical range on measures of general
language abilities; however, most of the children with late language emergence were still below the typical group on certain measures of general language, especially measures of syntax and morphosyntax. These findings are consistent with the patterns of outcomes found in Rescorla’s longitudinal data.

Very few research studies have focused on younger LTs (e.g., 16 months) to systematically examine aspects of language development that precede the onset of first words such as gesture and word comprehension (e.g., Thal, 2000; 2005). Research studies examining this earlier age suggest that children who are LTs are able to represent objects symbolically; however, they seem to have more difficulty than typical peers in their ability to use gestures spontaneously and flexibly (Thal & Tobias, 1994). Research suggested that including measures of gesture and comprehension abilities may prove better at predicting outcomes of groups of children (Thal & Tobias, 1992). Specifically, Thal (2005) found that approximately 8.6% of infants at 16 months who were identified as late comprehenders (i.e. below the 10th percentile in both comprehension and production) were diagnosed as having SLI at six years old. Overall, in Thal’s studies late talking 16-month-old infants who had a combination of low gesture, low comprehension and low production scores were at the greatest risk for SLI (Ellis & Thal, 2008).

Although extremely informative, taken together longitudinal studies of behavioral outcomes have not been too successful at accurately predicting which LTs will be diagnosed with SLI at school age. In particular, even though 10-20% of toddlers will be classified as LTs at 16-to 24-months, the majority of LTs “catch up” and only 17-26% of the LTs will continue to have persistent SLI by 4-6 years of age (Paul, 1996; Rescorla, 2002; Rescorla & Dale, 2013). The inclusion of parent variables such as maternal education, socioeconomic status (SES), and a family history of language delay helps account for additional variance; however, the predictive power of these combined variables still remains low (Hadley & Holt, 2006; Law, Boyle, Harris, Harkness & Nye, 2000; Zubrick et al., 2007).
The earliest years of language development are characterized by a huge amount of normal variability (see, for example, Bates, Bretherton & Snyder, 1988; Fenson, Dale, Reznick, Bates, Thal, & Pethick, 1994). One possible reason it has been difficult to differentiate LTs who will have SLI from LTs who will catch up may be that standardized static parent report measures of vocabulary may not be the best approach for classifying these children nor to predict their outcomes. Ellis Weismer and colleagues note, “Late talkers…simply represent the lower end of the normal distribution in terms of their expressive language skills” (Ellis Weismer et al., 2011, pg. 2.). Overall, these findings suggest a different approach may need to be considered to predict outcomes of LTs.

**Word Learning in Late Talkers**

One possible alternative to static vocabulary measures is to focus instead on defining the characteristics of word learning and word processing deficits in children with SLI, and utilizing those characteristics to study LTs. Thus, to examine word-learning abilities in LTs, some researchers have used similar experimental paradigms as used in SLI research. Like school-aged children with SLI, late talking 18- to 24-month-olds have difficulty linking novel labels to novel objects (Ellis Weismer et al., 2011; Ellis & Evans, 2009; Ellis et al., 2010). For example, Ellis Weismer and Evans (2002) investigated the performance on language processing tasks of LTs at two years of age. The focus of this study was to examine whether word-learning processes in LTs was impaired compared to typical controls. In two groups of children, (LTs: N=15; typical: N=15) a novel word-learning task was used. In this task children were exposed to two novel words and two familiar words (presented three times each) during a play activity. After exposure to the words, children were tested using probes to examine both production and comprehension of the words. Ellis Weismer and Evans found the LT group was similar to typical children in their comprehension of familiar words, but worse on comprehension of novel words. Further, the LT group performed worse than the typical group on production of both familiar and novel words.
Ellis Weismer and Evans then completed a secondary analysis on response times and found the LT group had significantly longer response times to novel words than typical children. These data suggest that LTs may have speed of processing limitations that are related and possibly contributing to their word learning difficulties and poor language abilities.

In another novel word learning task, Ellis and Evans (2009) observed that although LTs at 18-months required the same number of trials to reach criteria during training, they showed evidence of not having learned the novel word-object pairs as well as age and nonverbal IQ matched typical controls during the test phase of the study. In a follow-up novel word learning study, Ellis et al. (2010) observed that a 20-month-old infant, classified as LT at 18 months, required twice the number of training trials to show the same level of performance as compared to an age-matched 20-month-old typical infant with a history of normal language development. This study revealed qualitative differences in looking patterns between LT and typical infants, suggesting LT may have shorter looking durations when learning new words (Ellis et al., 2010).

Ellis Weismer et al. (2011) used a novel word-learning task to measure fast-mapping abilities in LTs and typical 24-month-olds to examine developmental outcomes. They found that LTs at 24 months were less accurate after three exposures in both comprehending and producing the labels for novel objects as compared to age and IQ matched typical controls. Further, when investigators used performance from the word-learning task at 24 months old combined with other standardized language measures they found that the novel word learning performance contributed only a small amount to distinguish LTs from typical children at 30 months.

One recent study trained two-year old late talking and typical toddlers on non-words with varying phonotactic probabilities (high vs. low). After multiple exposures to the novel words, children's comprehension, production and detection of mispronunciation of the words were measured using a preferential looking paradigm. Results suggested that typical children were better in production and detection of high probability words, while LTs did not show a preference
for and were less accurate with high probability words. In addition, LTs did not show sensitivity to different phonotactic properties of words. These findings suggest that young LTs have difficulties in recognizing the phonotactic properties of their language, which may be a factor in their word learning (MacRoy-Higgins, Schwartz, Shafer, & Marton, 2013).

Similar to school-aged children with SLI, 18-months-old LTs also appear to be significantly slower and less accurate when looking at pictures of spoken familiar words in their vocabulary as compared to their normal language age-matched peers (Fernald & Marchman, 2012). Further, individual differences in LT and typical infants’ speed and accuracy of recognizing spoken familiar words at 18 months predicts individual differences in vocabulary knowledge at 30 months (Fernald & Marchman, 2012). The individual differences in typical infants’ speed and accuracy of recognizing spoken familiar words at 25 months predicts individual differences in cognitive and language outcomes at 8;0 years of age (Marchman & Fernald, 2008). These findings suggested LTs are slower to recognize familiar words as compared to their peers (Fernald & Marchman, 2012). Together these studies suggest that LTs have difficulty both understanding and producing familiar as well as novel words and these deficits predict later language abilities.

**CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT**

Children with SLI exhibit various language deficits, including delayed onset and slower acquisition of language, delayed use of lexical and grammatical forms, smaller lexicons, and particular difficulty with comprehending and producing inflectional morphology and complex syntax (cf. Bishop, 1997; Leonard, 1998). Although children with SLI have normal nonverbal intelligence, they have difficulties with social skills, and have continued language delay and academic problems throughout adolescence and into adulthood. Additionally, older adolescents and adults with SLI are at a greater risk for academic and career failure, as well as social and emotional distress (Clegg, Hollis, Mawhood, & Rutter, 2005; Johnson, Beitchman, & Brownlie,
In older adolescents and adults with SLI, the behavioral profile can change and some of the deficits appear to "resolve" despite persistent deficits in lexical and cognitive processing abilities. Many individuals with language disorders continue to have a very difficult time with language and communication in adulthood. Nevertheless, when adaptive communication strategies are available, adults with language disorders can function very well in day-to-day settings and can contribute greatly to society (Johnson et al., 2010). It is therefore critically important to identify children with SLI early in order to give them the most appropriate intervention services and teach them the best strategies for achieving a fulfilling and productive life.

Stark and Tallal (1981) introduced the term Specific Language Impairment (SLI) to refer to a group of children who have difficulty acquiring and using language in the absence of any identifiable etiology. While some researchers have argued that the language impairments in SLI are specific to the linguistic system and the result of missing features in grammar (Rice & Wexler, 1996; Rice, 2003; van der lely, 1996, 1998), there is now considerable evidence that nonverbal cognitive mechanisms external to the linguistic system may underlie the language impairments seen in these children. Two cognitive mechanisms that have been examined extensively are working memory capacity and the speed with which information can be manipulated (Bishop, 1997; Ellis Weismer, Evans, & Hesketh, 1999; Gillam, Cowan, & Marler, 1998; Leonard et al. 2007; Montgomery, 2000; Montgomery & Evans, 2009).

In slower speed of processing accounts of SLI, the language impairments are secondary to an impaired global timing mechanism that results in children with SLI processing each unit of information at a slower rate than their typically developing peers (Kail, 1994). In this account, processing speed is not viewed as a fixed pool of operational resources, but the maximum rate at which a given cognitive operation can be executed (e.g., Kail & Salthouse, 1994). In children
with SLI, speed of processing – as measured by reaction time data– consistently is 18% - 30% slower than normal language controls. Slower reaction times have been observed in the verbal, nonverbal cognitive, motor, and visual modalities for children with SLI, suggesting that it is a domain general speed of processing deficit (Johnston, 1994; Johnston & Ellis Weismer, 1983; Kail, 1994; Miller, Kail, Leonard, & Tomblin, 2001; Miller et al., 2006; Windsor & Hwang, 1999).

Limited working memory capacity models of SLI typically assume a multidimensional system, which is comprised of several distinct but interactive mechanisms. Two of these components are a phonological short-term memory (STM) storage buffer and an attentional resource capacity/allocation function. Phonological STM is a capacity-limited storage buffer responsible for momentarily storing speech input during comprehension (Baddeley, 2003). The attentional resource capacity/allocation function includes the amount of cognitive/mental capacity (i.e., mental energy) individuals have available to perform cognitive tasks, and their ability to divide or allocate attentional resources between two or more different concurrent mental activities.

Children with SLI are able to simultaneously allocate their attentional resources to process and store verbally complex material. However, relative to their typical peers, they have marked limitations in cognitive/mental capacity (cf. Coady & Evans, 2008; Ellis Weismer, et al., 1999; Mainela-Arnold & Evans, 2005; Montgomery, 2000; 2002). Similar to the data suggesting that deficits in processing speed may be domain-general in SLI, resource capacity/limitations in SLI appear to be domain-general as well, as these children have reduced processing capacity for visual-spatial as well as auditory stimuli (Gillam et al., 1998; Hoffman & Gillam, 2004; Johnston & Ramstad, 1983; Johnston & Smith, 1989).

Clearly, the speed at which one can process information and the amount of information one can retain at a given time are tightly integrated. Faster processing means faster rehearsal,
which in turn can result in more information being successfully held in memory with less expenditure of mental resources (e.g., greater processing capacity). Research suggests that these two cognitive components are distinct and separable and are independently impaired in children with SLI (Gillam & Ellis Weismer, 1997; Leonard et al., 2007).

Although much of the research on children with SLI has focused on determining whether the language deficits in these children are domain specific (and the result of deficits in the grammatical system), or domain general (and secondary to deficits in nonlinguistic cognitive processing mechanism), other research has focused on determining the youngest age at which children with SLI can be reliably identified. In particular, this line of work has focused on early language delay (late talking) as a possible first diagnostic indicator of later language impairment.

**Word Learning and Lexical Processing in Specific Language Impairment**

Children with SLI are known to have word learning difficulties and have deficits in the skills that support word learning. They often exhibit problems discovering word boundaries in a stream of speech (Evans, Saffran & Robe-Torres, 2009), difficulty linking words to meaning (Dollaghan, 1987), and slower and less accurate abilities at accessing and recognizing words in their lexicon (Lahey & Edwards, 1996). Although word learning is difficult for children with SLI, studies have shown that children with SLI can link novel words to referents and learn vocabulary, but not in the same efficient way as their peers (Dollaghan, 1987; Ellis Weismer & Hesketh, 1996; Gray 2003; Rice, Buhr, & Oetting, 1992).

Other evidence suggests that semantic and conceptual representations in children with SLI are significantly different than those of typical peers, and specifically that children with SLI have representational “gaps” in the degree of semantic knowledge contained in the conceptual representations of words (McGregor, Newman, Reilly & Capone, 2002). Word learning studies (e.g., fast mapping) have provided extensive support for the theory that children with SLI are slower and less accurate at linking novel labels to novel objects (Alt & Plante, 2006; Dollaghan,
and often require twice the number of training trials before they are able to show the same level of performance as typical controls (Ellis Weismer & Hesketh, 1996, 1998; Gray 2005; Rice, Buhr, & Oetting, 1992). In particular, children with SLI are significantly slower and less accurate recognizing words from nonwords and recalling words from their lexicon as compared to normal language controls (Katz, Curtiss, & Tallal, 1992; Lahey & Edwards, 1996; Leonard, Nippold, Kail, & Hale, 1983; Leonard, 1998). The lexicons of children with SLI also seem to be poorly organized, and their ability to recognize spoken words is slower and more vulnerable to interference from other words in their lexicon as compared to their peers (Mainela-Arnold, Evans, & Coady, 2008; McMurray, Samuelson, Lee, & Tomblin, 2010).

Fast mapping has been hypothesized to be the initial step in lexical acquisition. To fast map, one must be able to link a new word to its appropriate referent after a single exposure (or very few exposures). Using the initial word learning research by Carey and Bartlett (1978) as a foundation, Dollaghan (1987) was the first to investigate fast-mapping abilities in children with language impairment. After a single exposure to a novel word and referent pair, both the SLI and typical groups of children were able to infer and comprehend the novel word. However, there were differences between groups in the ability to produce the novel words. Specifically, children with SLI were less accurate in producing novel words than typical controls. Ellis Weismer and Hesketh also conducted a series of studies investigating various influences of novel word learning. Results of their studies suggest varied speaking rate and emphatic stress of novel words are important factors in SLI group performance of novel word learning and may suggest that children with SLI may have limitations in processing abilities (Ellis Weismer & Hesketh, 1993, 1996, 1998).

Research over the last decade has explored other factors that influence word learning in children with SLI. Not only do children with SLI have difficulty learning labels, they also have
difficulty learning the related semantic features that need to be linked to a novel label (Alt, Plante & Creusere, 2004). During fast mapping tasks, Gray (2004) found that children with SLI needed more exposure to a novel word before they could learn to comprehend as well as produce the word, and that their existing lexical knowledge predicted comprehension and production performance. Research also suggests phonological or semantic encoding cues assisted word learning for preschool children with and without SLI and different cues may help different aspects of word learning, especially for children with SLI (Gray, 2005). Together these various fast mapping studies give us important information about word learning behaviors in preschool and school-age children with SLI. Overall, children with SLI have difficulty linking words to referents. A range of factors, including characteristics and types of words, such as frequency of exposure, seem to contribute to these difficulties.

Children with SLI also have significant implicit statistical word learning deficits (Evans et al., 2009). The ability to extract and segment words from fluent speech appears effortless for typical infants despite the fact that the speech stream is characterized by a great deal of speaker variability. The speech stream contains cues that infants appear to rely on to discover word boundaries within a stream of speech (Saffran, Aslin, & Newport, 1996). In particular, infants are able to rely on the transitional probabilities of sound sequences that are higher within words than across word boundaries (e.g., pre#ty#ba#by versus pretty#baby). Typical infants, children and adults are able to effortlessly track these statistical regularities between sound sequences to discover word boundaries within a stream of speech, and it appears that infants’ ability to implicitly track transitional probability may be a key mechanism in the process of word learning and vocabulary knowledge (Evans et al., 2009; Graf Estes et al., 2007). In contrast to typical children who are able to listen to an artificial language comprised of six, three-syllable nonsense words (e.g., dutaba patubi tutibu...) for 21 minutes and discover all six words within the speech stream, children with SLI are at chance and require double the amount of exposure before they
are able to discover any of the words (Evans et al., 2009). To date, statistical word learning abilities have not been investigated in a group of LTs; however, the recent work by MacRoy-Higgins and colleagues (2013) suggests that LTs are not able to distinguish important characteristics of words (i.e., phonotactics). Consistent with slower speed of processing in recognizing real words and poor novel word learning abilities seen in these children, one might anticipate that statistical word learning would also be impaired in LTs.

**Speed of Processing in Specific Language Impairment**

Behavioral evidence suggests that children with SLI have difficulty accessing words from their lexicon. These children are significantly slower and less accurate in distinguishing words from nonwords and recalling words from their lexicon as compared to their typical peers (Katz, Curtiss & Tallal, 1992; Lahey & Edwards, 1996). For example, one study used a picture-naming task to examine word-finding problems in children with language impairment. Three groups of children (language impaired, typical, and a younger group matched on language ability) were asked to name pictures of various objects as fast as possible. Researchers found that objects with more frequently heard labels were named faster overall, and children with language impairment were slower naming these pictures than their typical peers (Leonard, Nippold, Kail, & Hale, 1983). Another investigation of picture naming found that children with SLI were slower than typical controls; however, their response times were faster with increasing amounts of supportive linguistic information to help guide word retrieval (Kail & Leonard, 1986).

Similar results were produced in an investigation of lexical representations in children with SLI and their typical peers. Mainela-Arnold et al. (2008) used a gating task to examine if children with and without SLI were vulnerable to competing lexical items. In this task, children listened to progressively longer chunks of words that varied in word frequency and neighborhood density. After hearing each chunk, the children had to guess what words they heard. Researchers found that children in both groups were equal on the durations needed to first accurately identify
words for low frequency and dense neighborhood words. Interestingly, children with SLI continued to vacillate between multiple word possibilities at later gate times while typical children settled on a word candidate at early gate durations. These results suggest that children with SLI are more vulnerable to competing words than typical peers. Using other methodologies like eye-tracking, researchers have found that adolescents with SLI were distracted more by competitor pictures after hearing a target word and had fewer looks to target pictures than typical controls (McMurray et al., 2010). Overall these studies suggest that children and adolescents with SLI may be influenced by competing words in their lexicon and this may be causing difficulties in their processing of words.

**Late Talker to SLI: The Problem**

Although researchers now know much more about the lexical and cognitive processing behaviors in school age children with SLI as well as additional predictive information about outcomes from the longitudinal studies of LTs, researchers still have difficulty accurately identifying and predicting which LTs will have SLI. As a result, Speech-Language Pathologists are unable to confidently discern which LTs to target for additional intervention and support. There are still many questions to be answered about how and why some LTs catch up to their peers while others continue to have language difficulties. To better distinguish which LT will have SLI, additional new approaches, methods and questions need to be considered.

As mentioned earlier, there is a large empirical gap in the research connecting LTs to SLI (Zubrick et al., 2007). In particular, researchers have been able to correctly identify only less than 30% of those LTs who will have persistent SLI by four to six years of age (Dale et al., 2003; Ellis & Thal, 2008; Hadley & Holt, 2006; Law et al., 2000; Paul & Ellis Weismer, 2013; Rescorla, 2013; Rescorla & Dale, 2013; Rice et al., 2008; Taylor, Zubrick, & Rice, 2013; Thal, Marchman, & Tomblin, 2013; Zubrick et al., 2007). Even when researchers include variables such as parents’ reports of infants’ productive vocabulary, gesture use, comprehension, SES (e.g., education) and
family history of language impairments, they still have had only limited success in identifying those LTs who will have SLI (Ellis & Thal, 2008; Thal, 2005). One reason may be that the significant variability in the earliest stages of language development (cf. Bates, Bretherton, & Snyder, 1988; Fenson, Dale, Reznick, Bates, Thal, & Pethick, 1994) makes it difficult for clinicians and researchers to determine which LTs will have SLI (Ellis Weismer, 2007; Paul, 1996; Rescorla, 2000; Rescorla, 2002; Rescorla & Lee, 2000; Rice, et al., 2008; Whitehurst & Fischel, 1994). Another possible reason is that these variables are highly correlated and have low sensitivity and specificity in correctly classifying LTs who will have SLI and LTs who will move into the normal range (Dale et al., 2003). Further, children can be late talkers and at the bottom of the normal distribution for a variety of reasons and using the criteria of low or no words essentially means no data to begin to address the problem differentiating which LT will have SLI.

**ARE LATE TALKERS BETTER CHARACTERIZED FROM A DIMENSIONAL APPROACH?**

Implicit in much of the LT research is the assumption that SLI constitutes a discrete diagnostic category and by extension there should be a subset of LTs who will have a diagnosis of SLI by school age (Ellis & Thal, 2008; Ellis Weismer et al., 2011). Being a “Late Talker” is not, in and of itself, a clinical diagnosis. It only means that the child is at the bottom end of the normal distribution with respect to his or her language development. Dollaghan has suggested that “SLI” represents those children who fall at the tail end of the continuum across multiple language related skills (2011, 2013). In particular, she suggests that if SLI is a discrete category, then researchers need to focus on specifying a unique phenotype, (i.e. linked to verb tense), for the condition. Alternatively, if researchers assume a multi-dimensional view of SLI, there is the potential for heterogeneity in symptoms and origins, and researchers need to focus instead on the cluster of *causal influences* underlying these individual differences in language skill.

As described above, research suggests that language impairments in SLI are multidimensional and secondary to several impaired cognitive processing mechanisms that
support language learning and use in children with and without SLI (e.g., Ellis Weismer, Evans, & Hesketh, 1999; Evans, Saffran, & Robe, 2009; Leonard et al., 2007; Montgomery, 2000; Montgomery & Evans, 2009; Tomblin et al., 2007). These language-related cognitive processing abilities, such as speed of processing, working memory, and implicit statistical learning that appear to play important roles in children’s language development (e.g., Fernald & Marchman, 2012; Graf Estes et al., 2007) and language deficits in children with SLI (e.g., Ellis Weismer, Evans, & Hesketh, 1999; Evans, Saffran, & Robe, 2009; Leonard, Ellis Weismer, Miller, Francis, Tomblin, & Kail, 2007; Montgomery, 2000; Montgomery & Evans, 2009; Tomblin et al., 2007), may be part of the causal influences that are possibly contributing to language difficulties in children with SLI. If children with SLI cluster together on the tail end of the continuum of multiple lexical and cognitive processing skills, this would suggest that LTs at risk for SLI might also fall on the tail end of the continuum across multiple measures of language-related cognitive processing skills. Accordingly, a dimensional approach that directly measures multiple aspects of language-related cognitive processing abilities in LTs – in addition to examining groups - may be more successful in identifying those LT who will have SLI than the research to date.

**Goal of Dissertation**

The purpose of this dissertation was to identify LTs at 18 months of age who are at-risk for SLI based on real-time measures of lexical and cognitive processing during real word recognition, novel word learning, and statistical word learning. This dissertation begins to address the gap in our understanding of the relationship between lexical processing abilities and predicting critical outcomes; that is, which LTs are at greatest risk for SLI?

Using detailed eye-tracking methods and a new design, the questions addressed in this dissertation are whether there are similarities or differences (LT vs. TYP) in 18-month olds lexical and cognitive processing abilities, specifically:
(1) Do LT differ from TYP in their speed and accuracy in processing known words (Chapter 2)?

(2) Do LT differ from TYP in their learning of novel words (Chapter 3)?

(3) Do LT differ from TYP in their learning of implicit words (Chapter 4)?; and

(4) In a large group of 18-month olds, does eye tracking and resulting processing measures (e.g. real word recognition, novel and implicit word learning) better identify those LTs who are at risk for SLI as defined by being below age expectations on rate of vocabulary growth from 18-24 months, as compared to standardized measures of vocabulary (Chapter 5)?

This dissertation provides a direct examination of the heterogeneity in language learning abilities in infants, and will provide the foundation for future research that focuses on characterizing the different developmental trajectories of language delay in LTs using the multiplicity of dimensions that underlie individual differences in language development. It is the hope that aspects of this research may begin to help close the empirical gap that currently exists in identifying and predicting which LTs will have SLI.
REFERENCES


CHAPTER 2: REAL WORD RECOGNITION IN LATE-TALKING AND TYPICAL 18-MONTH OLDS- AN EYE-TRACKING STUDY

ABSTRACT

This investigation examined online moment-by-moment processing of real word recognition in 18-month old infants. A late-talking group (LT, N=14) and a matched typical group (TYP, N=14) of infants participated in an experimental eye-tracking study as well as behavioral and standardized testing. Each infant’s vocabulary scores were obtained by parent report on the MacArthur Bates Communicative Development Inventory: Words & Sentences (Fenson et al., 2007) and cognitive abilities were measured using the Bayley Scales of Infant Development-III (Bayley, 2005).

During the eye-tracking task, infants heard a real word while seeing two picture options on a monitor. Eye movements were recorded using the Eyelink 2000 Remote Eyetracker (SR Research, 2011). While our results suggest that there are no significant group differences in accuracy, our data parallel the accuracy performance of previous work (Fernald & Marchman, 2012). The timing of the two groups’ target fixations is similar to earlier work as well.

Using eye-tracking methods we were able to further examine the pattern of looking behavior in late talking and typical infants to determine whether there are differences in more detailed online processing measures during recognition of real words. These eye-tracking results suggest that when LTs understand a familiar word they are as fast and as accurate as typical infants. However, when analyzing group patterns using the additional fine-grained processing measures there are emerging differences between groups.
INTRODUCTION

One of the most consistent characteristics of early language development is the high variability in the number of words produced by young infants and toddlers during the first years of life (Fenson et al., 1994). Some infants have hundreds of words in their productive vocabularies while others have just a few. Infants with only a few words in their productive vocabularies may be considered Late Talkers and at risk for continued language delay and impairment.

Late Talkers are healthy full-term toddlers, usually 18- to 24-months-old, who are delayed in the onset of their first words, despite having normal cognitive development, normal hearing and no significant birth history (e.g. Ellis & Thal, 2008; Ellis Weismer & Evans, 2002; Paul, 1991; Rescorla & Dale, 2013; Rescorla & Schwartz, 1990; Zubrick, Taylor, Rice & Slegers, 2007). Most often, 18-24 month old Late Talkers (LT) have fewer than 50 words in their productive vocabulary with no two-word combinations, and are at risk for continued language delay. Persistent language delay in young children can result in Specific Language Impairment (SLI). Children with SLI exhibit various language deficits, including delayed onset and slower acquisition of language, delayed use of lexical and grammatical forms, smaller lexicons, and particular difficulty with comprehending and producing inflectional morphology and complex syntax (cf. Bishop, 1997; Leonard, 1998). Although children with SLI have normal nonverbal intelligence, they have difficulties with social skills, and have continued language delays and academic problems throughout adolescence and into adulthood (e.g., Bishop & Edmundson, 1987; Tomblin, Zhang, Buckwalter, & O’Brien, 2003) placing them at risk for continued social, academic, and employment failure.

Of the infants classified as LTs at 18-24 months of age, a subset will have SLI by age five and six (Paul, 1996; Rescorla, 2002). A key question for Speech-Language Pathologists, researchers, and, most importantly, parents, is how do we determine which late talking infants
will have SLI versus those who will ‘catch up’ by school age? Infant vocabulary levels combined with factors such as socioeconomic status (SES) and family history of impairment have low sensitivity and specificity in correctly classifying children as having SLI at age five (Dale et al., 2003; Thal, 2000, 2005; Thal, Marchman, & Tomblin, 2013), and only correctly identify less than 30% of LTs who will have SLI (Ellis & Thal, 2008; Zubrick et al., 2007). Additionally, extreme variability in the rates of word learning may contribute to the difficulty differentiating LTs at risk for SLI from LTs who are typically developing.

**Lexical and Cognitive Processing Children in SLI**

In order to begin to address the difficulty in identifying and predicting which LTs will continue to have language-learning problems, we must understand the lexical and cognitive processing abilities in children with SLI. Children with SLI are significantly slower and less accurate in accessing words from their lexicon as compared to typical language controls, and spoken word recognition is more vulnerable to interference from other words in their lexicon as compared to their peers (Katz, Curtiss, & Tallal, 1992; Lahey & Edwards, 1996; Leonard, 1998; Leonard et al., 2007; Leonard, Nippold, Kail, & Hale, 1983; Mainela-Arnold, Evans, & Coady, 2008; McMurray, Samuelson, Lee & Tomblin, 2010). In slower speed of processing accounts of SLI, the language impairments are secondary to an impaired global timing mechanism, which results in children with SLI processing each unit of information at a slower rate than typically developing peers (Kail, 1994). Processing speed is not viewed as a fixed pool of operational resources, but the maximum rate at which a given cognitive operation can be executed (e.g., Kail & Salthouse, 1994). Additionally, work by Windsor & Hwang (1999) suggests that children with SLI have consistent limited processing capacity in lexical tasks. Specifically, in children with SLI, speed of processing – as measured by reaction time data – consistently ranges from 18% to 30% slower than typical language controls. Slower reaction times have been observed in the verbal, nonverbal cognitive, motor, and visual modalities for children with SLI, suggesting that
they have a domain-general speed of processing deficit (Johnston, 1994; Johnston & Ellis Weismer, 1983; Kail, 1994; Miller, Kail, Leonard, & Tomblin, 2001; Miller et al., 2006; Windsor & Hwang, 1999).

Although there are consistent delays in reaction times for children with SLI in behavioral experimental studies, the neurological evidence for a global speed of processing delay is inconsistent. A majority of studies comparing children with SLI to typical children only report amplitude differences, not latency differences—regardless of modality (i.e. visual or auditory). For example, event-related potential (ERP) research examining semantic and lexical processing has shown latency differences in children with SLI; specifically, children with SLI had later peak N400 latencies to visually presented words than typical children (Neville, Coffey, Holcomb, & Tallal, 1993). Overall these differences may be a result of children with SLI relying more on context to recognize words, expending greater effort to integrate incoming words into the sentence context. Interestingly, other ERP studies using words and sentences presented auditorially have similar latency patterns between children with SLI and typical groups (Cummings & Ceponiene, 2010; Fonteneau & van der Lely, 2008; Sizemore & Evans, 2009).

Further, in one longitudinal retrospective ERP study of 19-month-old infants, pictures were presented and infants subsequently heard spoken words that matched the picture (e.g., congruous words), spoken words that did not match the picture (i.e., incongruous words), or non-words (Friedrich & Friederici, 2006). At 30 months a language assessment was completed and the participants’ 19-month data were grouped by their 30 month language ability. Both the at-risk and typical language groups showed an N400 effect (by amplitude differences) for congruous words; however, the at-risk group did not show any effect for the incongruous or non-word conditions. Friedrich and Friederici (2006) suggest that this finding indicates that the N400 develops earlier in typically developing children than in children who are at-risk for later language impairment. These data suggest that similar to some of the research in older children with SLI, infants who are
at-risk for SLI may be relying more on the picture context during word processing than typical infants, and that processing a word without a picture context may be more effortful for those infants and toddlers who are at-risk for SLI.

**Lexical and Cognitive Processing in Infants**

In other infant research, real word recognition and cognitive processing have been explored by using various preferential looking paradigms (i.e., looking-while-listening or habituation paradigms). In one study by Fernald and Marchman (2012), researchers asked whether children’s early online language comprehension would differentiate their trajectories of vocabulary growth. The infants were presented with sets of two pictures and heard one of the picture’s labels. Infants’ looking patterns were videotaped and later coded offline frame-by-frame, with experimenters coding infant eye movements and location for each 33 ms interval. In this study, trials were classified as either target-initial or distractor-initial, depending on which picture the child fixated on during the onset of the target noun. The dependent variables were “accuracy” (the mean proportion of looking to the named picture on target- and distractor-initial trials averaged over the time window of 300-1800 ms from noun onset) and “mean RT” (the shift to the correct referent for the distractor-initial trials where infant shifted their gaze from distractor to target picture within 300-1800 ms from target onset). Using the looking-while-listening paradigm, researchers found 18-month-old LTs are significantly slower and less accurate at recognizing real words in their vocabulary as compared to their typical peers (Fernald & Marchman, 2012).

Further, additional research found individual differences in infants’ speed and accuracy of recognizing spoken familiar words at 18 months and 25 months predicted individual differences in vocabulary knowledge at 30 months and cognitive and language outcomes at eight years of age, respectively (Fernald & Marchman, 2012; Marchman & Fernald, 2008; 2013). This research suggests that LTs, like older children with SLI, have slower behavioral RTs than their
typical peers in recognizing and understanding real words (Fernald & Marchman, 2012). It may be that LTs are slower, like older children with SLI, due to the downstream slowing of lexical processing (Windsor & Hwang, 1999). However, while LTs may have slower RTs in some behavioral tasks, this observation does not give us the entire picture of where and why the slowness is occurring.

**Eye-Tracking**

Eye-tracking is an online experimental method that allows for a tighter link between real time processing and recognition of lexical items. By using very detailed and precise eye-tracking methodology we can begin to explore the moment-by-moment lexical and cognitive processing in infants and toddlers. This detailed peek into lexical processing may enable researchers to better understand the patterns of recognizing and understanding words, and then to more accurately predict why some infants are at a greater risk for language impairment. Unlike previous infant looking paradigm studies, eye tracking allows us various advantages for clinical infant research. First, eye-tracking records looking data automatically and gives us the exact location of the saccades and fixations as well as providing information about the latency and duration of each fixation. Using eye-tracking methods we are able to pre-define regions of interest and can be more confident in knowing when and where the infant actually looks within a region or area of interest. Additionally, we are able to focus more precisely on the speed and timing of looks, which may be able to give information about where the possible group differences may be occurring in the process of recognizing real words.

Previous eye-tracking studies have found that both infants and children appear to have different gaze patterns during language processing and word learning tasks (Borovsky, Elman & Fernald, 2012; Yu & Smith, 2011). For example, Yu and Smith (2011) found differences in eye gaze fixation patterns between weak and strong novel word learners at 14 months, consistent with our prior work (Ellis et al., 2010), showing less stable looking patterns for an LT as compared to
a typical infant. Specifically, in our 2010 work - a microgenetic habituation study examining novel word learning and looking patterns in one late-talking and one typical toddler at 20 months of age – we found that the LT toddler had a different and more varied looking and learning style than the typical toddler (Ellis et al., 2010). The LT had significantly shorter first look durations and, overall more total looks across the study than the typical toddler.

Recent eye-tracking studies have been used to examine lexical processing in SLI (Andreu et al., 2012; McMurray et al., 2010). In addition to finding both interesting similarities and differences in how SLI and typical groups process words, these studies have confirmed the advantage of using eye-tracking tasks in clinical populations. McMurray and colleagues (2010) found that adolescents with SLI had fewer fixations to the target picture than other pictures, while in a younger group of children with and without SLI, Andreu et al., (2012) found that the group of children with SLI was just as fast as the control group in recognizing pictures of nouns, but slower with more difficult stimuli (i.e., verbs).

Another recent study examined sentence comprehension abilities in adolescents with and without SLI using eye tracking. In this study, researchers examined online time course measures and found both similarities and differences between groups (Borovsky, Burns, Elman & Evans, in press). Specifically, the SLI group was just as fast as the typical group to integrate information while listening to a simple sentence, but showed differences in looking behavior to distractor picture items. Interestingly, in a preliminary analysis to exploring spatial gaze patterns, researchers found the SLI group had a more diffuse looking pattern than typical peers. Taken together, these previous studies suggest that in addition to traditional cognitive processing variables such as accuracy and speed of processing, examining the details of gaze fixations in clinical populations may be an important component to explore.
THE PRESENT STUDY

The primary purpose of this study was to investigate real-time processing of real familiar words in late talkers and typical infants at 18 months using eye-tracking. This study design was adapted from Fernald and Marchman’s *Looking-While-Listening* paradigm (2012; see also Fernald, Perfors & Marchman, 2006; Marchman & Fernald, 2008) and as well as used aspects of Mather and Plunkett’s (2010) experimental method to examine speed and accuracy of processing real words.

The first step was to determine, using a different experimental method and slightly different design than Fernald and Marchman (2012), whether 18-month-old LTs will be slower and less accurate than typical infants in recognizing familiar words. Further, the motivation of the current study was to determine if – similar to recent studies on older children with SLI - we see qualitative differences in looking patterns between LT and typical groups that may begin to inform us about where differences in processing occur. It is predicted that, like Fernald and Marchman (2012) reported, LTs will be slower and less accurate than the typical group in recognizing and understanding real words. Additionally, it is predicted that examining infant gaze patterns more closely should begin to open a window into where processing differences between groups may be occurring.

METHODS

Participants

Two groups of fourteen 18-month-old infants (M = 550.71 days, SD = 8.96) and their parents from monolingual English-speaking homes were recruited in San Diego, California and the surrounding metropolitan region.

The infant participants were 18 months of age at the initial time of testing and came into the lab for two separate sessions. Each infant session was approximately 1.5 hours long. Regardless of the infant’s abilities and performance during testing, the infant received a
children’s book and parents received $10 per session in return for their time, travel, and participation.

All of the infants included in the analysis were reported to have normal hearing and vision. Additionally, all infants were reported to have normal medical histories with no serious complications at birth, as well as no known neurological impairments or developmental disabilities. All mothers reported a near-term or full-term pregnancy with at least 36 weeks gestation. In addition to the parent report of normal hearing, all infants were reported to have passed infant hearing screenings at birth and had no report of recent or chronic ear infections. During the lab visits, the infants’ middle ear function was assessed using tympanometry and all had normal middle ear function.

**Late Talking and Typical Groups**

The late talking group included 14 infants (7 girls and 7 boys, M = 549.78 days, SD = 7.49) (visit 1) with productive vocabulary scores below the 20th percentile\(^1\) (M = 8.5, SD = 4.25, range 1-15th percentile). The typical group included 14 infants (7 girls and 7 boys, M = 549.92 days, SD = 10.2 (visit 1) with an average productive vocabulary score at the 46th percentile (SD = 21.74, range 23-93rd percentile). Groups were matched on cognitive scores, gender, age, and maternal education (see Table 2.1)\(^2\).

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\(^1\) Fernald and colleagues also use the 20th percentile on the MBCDI: WS to establish LT vs. TYP groups.

\(^2\) The typical group of infants were randomly matched to the LT group from a total sample of 54 infants who participated in the project (see Chapter 5 for vocabulary percentile distributions and z-scores of all infants).
Table 2.1. Group descriptive information: Means and SDs: MacArthur Bates Communicative Development Inventory-Words & Sentences, BSID-III, Maternal Education, Age

<table>
<thead>
<tr>
<th></th>
<th>LT (N=14)</th>
<th>TYP (N=14)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayley Cognitive</td>
<td>100.71 (8.73)</td>
<td>101.42 (7.18)</td>
<td>.82</td>
</tr>
<tr>
<td>Bayley Language</td>
<td>95 (7.18)</td>
<td>104.28 (10.76)</td>
<td>.01</td>
</tr>
<tr>
<td>Words &amp; Sentences</td>
<td>8.5 (4.25)</td>
<td>46.85 (21.74)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Production Percentile</td>
<td>15.21 (8.16)</td>
<td>89.42 (66.86)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Words &amp; Sentences</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Words Produced</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mom’s Education</td>
<td>16.42 years</td>
<td>16.57 years</td>
<td>.81</td>
</tr>
<tr>
<td>Age in Days</td>
<td>549.78 (7.49)</td>
<td>551.64 (10.42)</td>
<td>.59</td>
</tr>
</tbody>
</table>

**Procedure**

Each infant participant was seen individually for standardized language and cognitive development assessment as well as for the experimental tasks. Infant test sessions took place in the Eye-Tracking testing rooms within the Center for Research in Language at UCSD. There were two visits lasting ~1.5 hours each. During the session, parents first signed the consent forms and returned the MBCDI: WS form (which was sent home prior to the visit to complete). After the infants were comfortable, the experimental testing was completed followed by behavioral testing.

**Materials**

Offline behavioral measures were completed during the sessions including the *Bayley Scales of Infant Development-III (BSID-III) Cognitive and Language subscales* (Bayley, 2005), and the *MacArthur Bates Communicative Development Inventory-Words & Sentences* (Fenson et al., 2007). Infants in the LT group had an average standard score of 100.71 (SD= 8.73) on the

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3 MBCDI: WS were obtained from the parent, but were scored after the visit by a research assistant blind to the experimental questions and details of the test session.
Cognitive Scale of the \textit{BSID-III}, and an average standard score of 95 (SD = 7.18) on the Language Scale of the \textit{BSID-III}, and were at the 8.5\textsuperscript{th} percentile (SD = 4.25) on \textit{Words & Sentences}. Infants in the typical group had an average standard score of 101.42 (SD = 7.18) on the Cognitive Scale of the \textit{BSID-III}, an average standard score of 105.35 (SD = 11.04) on the Language Scale of the \textit{BSID-III}, and were at the 48\textsuperscript{th} percentile (SD = 22.5) on \textit{Words & Sentences} (see Table 2.1).

\textbf{EXPERIMENTAL TASKS}

The infant participants sat in his/her parent's lap or in a child booster seat approximately 24 inches from a 17” LCD display monitor.\footnote{To prevent parents from influencing their infants’ responses, parents wore headphones during the tasks.} A small sticker was placed on each infant’s forehead to allow the eye-tracker to measure eye movements. Before each task, a manual five-point calibration and validation routine was completed, using a standard black and white bull’s-eye image. Calibration allows for the eye-tracker to measure specific characteristics of the eyes that are required to accurately calculate eye fixations and gaze direction. Even with minimal infant attention and quick infant movements this process typically took less than two minutes.

Once calibration was completed, stimuli were presented using a PC computer running SR Research Eyelink Experiment Builder software (SR Research Ltd, Mississauga, Ontario, Canada, 2011). In between trials a dot (i.e. bull’s eye) appeared in the center of the screen and served as a drift correction before each trial. Once the participants fixated on this center dot location, the experimenter began the trial.

\textit{Eye Movement Recordings}

Eye movements were recorded using an Eyelink 2000 Remote Eyetracker with remote arm configuration at 500 Hz (SR Research, Ltd, see Figure 2.1). The Eyelink system automatically classifies eye movements as saccades, fixations and blinks using the eye-tracker’s default threshold set. For each infant participant the display and eye-tracking camera were placed approximately 580–620 mm from the face. Fixations were recorded automatically every 2ms for
each trial from the onset of the images until the end of the task. Offline, the data were binned by the examiner, into 10ms intervals, then analyses were performed based on predefined regions of interest.

![Figure 2.1. Example of infant seat with monitor and eye tracking camera](image)

**Real Word Recognition Task**

The real word recognition task design was adapted from Fernald and Marchman’s (2012) *Looking-While-Listening* paradigm and also used aspects of Mather and Plunkett’s (2010) experimental method. To control for potential memory differences between the LT and typical groups, during the task, a preview period occurred where infant participants saw two pictures (target and distractor) on the screen. This preview period alleviated any possible memory demands placed on the infant by establishing a window of time for all infants to look at the picture options before the test trials began. After two seconds a center attention-getter picture (such as a small picture of a teddy bear or toy duck) appeared between the two pictures. The purpose of this center attention-getter was to control the start point of all infants for each test trial (i.e. start at the center fixation point for each trial) before they heard the target label. Once the
participant looked to the attention-getter picture in the center of the screen for a minimum of 100 ms the target word label was played over speakers. Specifically, the participant first heard, “Look” (at the same time the center attention-getter picture appeared), the participants then looked for 100 ms at the attention-getter and the center picture disappeared as they then heard “(target word)!" using infant directed speech. The target and distractor pictures remained on screen for a total of four seconds after the label was played. There were a total of 16 real word test trials. Each trial (including preview) lasted a total of six seconds (see Figure 2.2 for example).

![Figure 2.2. Example of a real word task design](image)

**Stimuli**

The stimuli consisted of eight real words in the same yoked pairs as used in Fernald and colleagues Looking-While-Listening task (Fernald & Marchman, 2012; i.e., doggie-baby, book-car, ball-shoe, kitty-bird). On a separate form parents rated how well their child understood each
of the eight words using a 0-4 scale\(^5\) (See Appendix A for list of words).

The auditory stimuli were recorded by an adult female American English speaker in an infant-directed voice and sampled at 44,100 Hz on a single channel. Words were recorded in a soundproof room and were later edited using Praat and Audition. The mean intensity of all audio stimuli was normalized to 70 dB. Object pictures consisted of bright and colorful real object images that are typical exemplars of target items in JPG files edited to fit a 400 x 400 pixel square. Each object served equally often as target and distractor and location of the pictures were counterbalanced on the screen.

**Time Period and Variables of Interest**

*Time Period*

Similar to previous research (Fernald & Marchman, 2012), the 300-1800 ms time window was used for analyses. This time window was also selected because previous research suggests the minimum latency to initiate an eye movement in infants is approximately 233-367 ms, with mean latencies considerably longer (e.g. Canfield, Smith, Brezsnyak, & Snow, 1997).

*Variables of Interest*

For the current study, before we examined the potential qualitative time course differences we first examined two primary dependent variables – accuracy and reaction time. There are many different ways we can potentially assess accuracy (e.g. Fernald & Marchman, 2012; Swingley & Aslin, 2000; Borovsky et al., 2012). In this study a target word is counted as accurate if infants looked more to the target than the distractor (Yu & Smith, 2011).

The second variable of interest is reaction time, defined as the first saccade latency shift (after label onset) to the correct target picture within the 300-1800 ms time window. This variable

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\(^5\) Post-hoc analyses revealed there were no significant differences between groups overall (LT = 3.43, TYP = 3.62, p = .16) or by word (word rates range: LT= 3.0-3.64, TYP= 3.07-3.85, p = .09-1.0). (See Appendix A for list of words).
has been used to measure reaction time in many other eye tracking studies (e.g., Borovsky et al., 2012; Borovsky et al., in press).

To address our second question of exploring possible group differences using time course measures in detailed analyses, we examined a number of other variables of interest. **Target divergence time** is defined as the time at which fixations to the "target" object diverges from fixations to the "distractor" (Borovsky et al., 2012; Borovsky et al., in press). This variable allows for visual inspections as well as statistical distinction between looking to the target and distractor. Similar to our prior work (Ellis et al., 2010), we were also interested in **average first fixation duration**, which is the average duration of the first fixation to the target picture (in milliseconds); **average number of fixations to the target**, which is the average number of times the infant fixates on the target picture during the specified time window; and **average number of fixations during the trial**, which is the number of times the infant fixates anywhere during the time window.

**RESULTS**

We first assessed the data to determine if previous research, (i.e. Fernald & Marchman, 2012) was replicated despite using the slightly different method and design. Next, we plotted and characterized the data by examining processing speed and timing of fixations to the target pictures in response to the label. We then completed a set of analyses to assess the additional characteristics of timing, latency duration, and number of fixations in the groups. Finally, we completed an exploratory analysis to determine if, like in recent SLI work (Borovsky et al., in press), we see differences in spatial distributions of fixations between groups.

**Accuracy**

In this study, a trial is defined as accurate if there is a greater amount of looking to the target picture than the distractor picture (Yu & Smith, 2011). For the purposes of the following

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6 The two groups are assumed to be independent for the following analyses.
analyses, every trial for each individual infant was analyzed for accuracy before group comparisons were conducted. To determine overall accuracy, the number of correct trials of the total 16 test trials was calculated for each infant. The LT group was 62.5% (SD = 16.4) accurate while the typical group was 67.4% (SD = 11.2) accurate, (see Figure 2.3). Between group differences were not significant ($z (26) = -.72, p = .46$). Our results are very similar to the accuracy results reported by Fernald and Marchman (2012), (i.e., LT = 61% vs. TYP = 66%).

![Figure 2.3. Real Word Recognition Accuracy: Total correct out of 16 trials by group](image)

**Proportion of Looking**

The proportion of looking to the target versus distractor pictures for accurate test trials only for each group was examined next. Both groups looked significantly more to the target pictures than the distractor pictures (LT: M = 56.6% (SD = 18.4) target vs. M = 14.1% (SD = 13.5) distractor; TYP: M = 55.1% (SD = 18.6) target vs. M = 13.7% (SD = 14.3) distractor). There were no between group differences ($z (26) = .62, p = .53$) in proportion of looking to the
target picture for the LT (M = 56.6%, SD = 18.4) and TYP (M = 55.1%, SD = 18.6) groups (see Figure 2.4).

Time-Course Measurements

The mean proportion of time that the LT and typical participants fixated on each of the images was calculated (target, distractor) at each 10-ms time window during the time course of interest (Figure 2.4). Visual inspection of these time-course plots indicates overall similar patterns with slight differences. Both groups showed increased looking fixations to the target and distractor pictures, but interestingly, in the LT group there seemed to be slightly more fixations to the distractor picture than the target picture initially. However, the time point at which fixations to the target object diverges from distractor fixations appears to be similar between groups. These
patterns are discussed in more detail below.

**Time-Course of Target Fixations**

As described above, to examine additional time course of incremental lexical processing in both the LT and typical groups, the mean proportion of time spent fixating to the target and distractor images at each 10-ms time window across all participants in each group were calculated. The resulting time course plots are helpful to visualize qualitative differences in looking patterns (see Figure 2.5). To test whether there may in fact be differences in looking patterns by each group, point-by-point t-tests\(^7\) at each 100 ms bin between mean looking proportions to the target object and mean looking proportions to the distractor object were calculated. Using these analyses, it is evident that the LT (870 ms, \(t = 2.34, p = .034\)) and TYP

\[\text{LT} = 870 \text{ ms. bin} \quad t = 2.34, p = .034\]

\[\text{TYP} = 750 \text{ ms. bin} \quad t = 2.51, p = .024\]

\(7\) As done in earlier work, to minimize the possibility that differences may arise due to multiple comparisons by chance, a criterion was used. Specifically, the time point reported is the earliest time point that a minimum of five subsequent and consecutive two tailed t-tests with an alpha level of \(p < .05\) indicate a significant difference between the fixation to the target compared to distractor (see Borovsky, Elman & Fernald, 2012).
(750 ms, \( t = 2.38, p = .032 \)) patterns are relatively similar between groups, and the group differences in time of divergence are slight. When we calculated the target divergence time for each individual infant, using the same procedure, there were no differences between the two groups \( (t (26) = -.147, p = .88) \). Despite the fact that our design and method are slightly different from Fernald’s work, we found similarities in the divergent times of our groups and the speed of processing measure utilized in her work (i.e. in Fernald & Marchman, 2012: LT = 844.9 ms; TYP = 785.9 ms).

Although results of the two groups are similar, there could be more subtle differences that are not reflected in accuracy and speed but instead are due to differences in looking behavior and processing. While there were no significant group differences in this point-by-point timing measure, the pattern mirrored similar timing results as seen in Fernald and Marchman (2012). Since we found interesting similarities in accuracy and timing, it was important to further examine more detailed time-course measures. For example, both groups might be fast at initially gazing at the target, however, one group may shift more quickly to the other image resulting in more looks overall. Alternatively, one group might look longer to the target and not show additional fixations. The next set of analyses examined these possibilities. (See Table 2.2).

**Reaction Time: Timing of Initial Looks**

The between group differences were examined for reaction time of initial looks. There were no significant differences between groups for reaction time to the target picture (LT: \( M = 453.87, SD = 350.76 \); TYP: \( M = 495.03, SD = 382.67 \)), \( t (26) = -.89, p = .373 \).

**Duration of First Look Fixation**

The measure of duration of the first fixation was approaching a significant difference between groups with the LT group having shorter durations of looking during the first fixation (LT: \( M = 575.27 \text{ ms}, (SD = 439.08) \); TYP: \( M = 687.48 \text{ ms}, (SD = 595.1) \), \( t (26) = 1.81, p = .07 \).
**Number of Fixations**

Finally, when comparing number of fixations, there are significant differences between groups in the number of fixations to the target picture, with LTs having significantly more fixations to the target during the accurate trials, (LT: $M = 2.02$ (SD = .87) and TYP: $M = 1.8$ (SD = .78), $t(26) = 2.19, p = .028$). However, there are no differences in the total number of fixations across the correct test trials, LT = 3.92 (1.27) and typical 3.72 (1.11), $t(26) = 1.42, p = .15$.

**Table 2.2. Group comparisons for fixation measures of speed of processing, mean duration, mean number of fixations to target picture and mean number of fixations trial**

<table>
<thead>
<tr>
<th>Fixations to Target Picture</th>
<th>LT N=14</th>
<th>TYP N=14</th>
<th>t-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction Time (1st Saccade)</td>
<td>453.87 (350.76)</td>
<td>495.03 (382.67)</td>
<td>-.89</td>
<td>.373</td>
</tr>
<tr>
<td>Duration (1st Fixation) in ms</td>
<td>575.27 (439.08)</td>
<td>687.48 (595.1)</td>
<td>-1.81</td>
<td>.07</td>
</tr>
<tr>
<td># Fixation to Target</td>
<td>2.02 (.87)</td>
<td>1.80 (.78)</td>
<td>2.19</td>
<td>.028*</td>
</tr>
<tr>
<td># of Fixations during trial</td>
<td>3.92 (1.27)</td>
<td>3.72 (1.11)</td>
<td>1.42</td>
<td>.15</td>
</tr>
</tbody>
</table>

**Fixation Distribution Maps**

Examining the additional time-course measures above revealed that there are emerging differences between LT and typical groups in looking patterns. Recent work in older adolescents suggests there are more global differences between SLI and typical groups in what we might call variations in gaze styles (Borovsky et al., in press). We conducted an exploratory analysis in our infant groups to examine whether there are differences in eye-movement behavior on a finer spatial scale within predefined areas of interest. To our knowledge, this analysis has been carried out between SLI and typical groups, but not yet in infant group.

Similar to Borovsky et al. (in press), we calculated fixation distribution maps for each group using iMap software (Caldara & Miellet, 2011). Maps were generated by summing the coordinates of mean fixation durations for each participant across the relevant time window and
then normalizing these durations to z-scores. These data were smoothed with a 20-pixel filter (approximately 1-degree visual angle) and the areas of dark red in the first two columns of Figure 2.6. indicate regions that were fixated the most by each group (LT and TYP) in eye movements over the 300-1800 ms time window.

Figure 2.6. Group and differential fixation maps across the 300-1800 ms time window

The general differences between the groups are also shown in the spatial gaze maps in the third column of Figure 2.6. Here, areas of dark red indicate regions where the typical group fixated more than did the LT group, whereas dark blue regions signify the opposite pattern where the LT group fixated more than the typical group. In general, these maps indicate that the LT group did not fixate as much as the typical group. The LT group focused on a more narrowed area and relatively less time fixating on the details of the picture.

DISCUSSION

The overall goal of this study was to examine the real-time processing abilities of recognizing real/familiar words in late talking and typical infants at 18-months. First, we asked whether 18-month old LTs would be slower and less accurate than typical infants in recognizing familiar words utilizing a different experimental method and slightly different design than Fernald and Marchman (2012). The evidence from the current study of LT and typical 18-month
olds suggest that there are no statistically significant differences between groups in speed and accuracy of recognizing real words. This finding was somewhat surprising given our predictions and other prior research. Why are we not seeing the same group difference as in previous research studies? To answer this there are a few design and methodological considerations that should be considered.

The current study used a slightly different design (i.e., gaze contingent) to ensure that every infant began each trial at the same location. Importantly, after the two second picture preview (to control memory load), a center picture appears while infants simultaneously hear “Look”, which serves as an attention-getter. Once the infant looks to the center picture for 100 ms the target word plays (e.g., doggie). The shift or latency of the first saccade begins at the center point, whereas in the “Looking while Listening” task, Fernald and Marchman measured reaction times from the distractor picture to the target picture. As a result, Fernald and Marchman’s design results in a larger distance between pictures than in our study, which measures the reaction time from the center to the target picture. The benefit of the gaze contingent modification used in the current study is that each test trial can be used to look at speed, accuracy, and other important variable measures.

Despite the differences between studies, our data was in line with what Fernald and Marchman reported in their 2012 study. First, our accuracy results (LT = 62.5%, TYP = 67.4%,) were similar to their previous findings (i.e. LT = 61%, TYP = 66%). Second, the significant points of divergence between target and distractor pictures for each group (LT = 870 ms; TYP = 750 ms) in our study were similar to the reported speed of processing times in their study (LT = 844.9 ms, TYP = 785.9 ms).

Further, with our second question - examining fine-grained eye tracking measures to explore differences in looking patterns between LT and typical groups - we began to see some emerging group differences. Specifically, the moment-by-moment processing in the time-course
plots revealed that the pattern of the time point of differentiation between the target and distractor pictures was similar between groups. This finding is consistent with previous research in older children with and without SLI where researchers found similarities in divergent times between groups (Borovsky et al., in press). While our data show slightly earlier divergent times for the typical group than the LT group, there were no significant differences and the patterns were similar. Additionally, we saw significant group differences in the number of looks to the target picture, with LT infants fixating more often. Finally, our exploratory analyses of spatial gaze fixations revealed that the pattern of looking may in fact be different between LT and typical infants, since we see different areas of looking with LT showing a more narrowed look pattern than the typical group.

While this study did not find any significant differences between groups for the two main variables of interest - accuracy and reaction time - results were consistent with prior work and allowed us to gain a baseline of real word processing in infants with varying vocabulary levels. It is important to consider that the words used in this study were all common nouns often heard by infants during this age\(^8\). It is possible that LT infants had had enough previous experience with each word that the processing differences were not fully captured by the variables examined. Different patterns of looking between the groups suggests there may be more instability in recognizing real word-object pairs for the late talking infants than in typical infants at 18 months. The performance of both groups suggests, however, that when LT infants know a word they are as efficient and accurate at looking toward a picture as their typical peers. The next step will be to explore whether group differences emerge when infants encounter novel words.

\(^8\) In addition to the infant vocabulary checklists completed by parents at 18-months, in a separate form parents rated how well their child understood each of the eight words using a 0-4 scale. Post-hoc analyses revealed there were no significant differences between groups overall (LT = 3.43, TYP = 3.62, p = .16) or by word (word rates range: LT= 3.0-3.64, TYP= 3.07-3.85, p = .09-1.0).
REFERENCES


Acknowledgement

Chapter 2, in part, is currently being prepared for submission for publication of the material. Ellis, E, Elman, J, & Evans, J. (In Preparation). Lexical and Cognitive Processing in Early Language Delay. The dissertation author was the primary investigator and primary author of this material.
Appendix 2.A. List of real word stimuli

Words in alphabetical order
baby
ball
bird
book
car
doggie
kitty
shoe

Pairs presented to participants
doggie-baby
book-car,
bball-shoe
kitty-bird
CHAPTER 3: NOVEL WORD LEARNING IN LATE-TALKING AND TYPICAL 18-MONTH-OLDS - AN EYE-TRACKING STUDY

ABSTRACT

This investigation examined online moment-by-moment processing of novel word learning in 18-month-old infants. A late-talking group (LT, N=14) and a matched typical group (TYP, N=14) of infants participated in an experimental eye-tracking study as well as behavioral and standardized testing. Each infant’s vocabulary scores were obtained by parent report on the MacArthur Bates Communicative Development Inventory: Words & Sentences, and cognitive ability was measured using the Bayley Scales of Infant Development-III. During the eye-tracking task, infants were trained on two novel word-picture pairs and then were tested by hearing a novel word while seeing two picture options on a monitor. Eye movements were recorded using the Eyelink 2000 Remote Eyetracker. Results suggest that there are differences between groups in accuracy as well as the time-course of looking to the novel target picture during testing. These results, using eye-tracking methods, confirm previous research and suggest that LTs are less accurate than typical infants in learning novel words. When analyzing group patterns using additional fine-grained processing measures, additional interesting differences between the groups emerge.
INTRODUCTION

Typical children usually begin saying their first words around 12 months of age. At 18 months infants have approximately 50 words in their productive vocabulary and are beginning to produce two words together. This ability to learn new words can seem simple, but it actually is a complex process that involves many skills, utilizing visual, auditory and other modalities. Through this process, infants and toddlers learn to link a set of sound sequences to the appropriate referent, often without explicit feedback.

By the time most toddlers have reached their second birthday, they are able learn words quickly and seem to increase the number of words in their vocabulary on a daily basis. At the same time, between 18-24 months, some infants and toddlers have difficulty understanding and producing words. These children are often called Late Talkers. Late talking infants with only a few words in their productive vocabularies are at-risk for continued language delay.

Late Talkers are healthy full-term toddlers, typically 18-24 months old, with normal cognitive development, normal hearing and no significant birth history; however, they have delays in the onset of their first words (Ellis Weismer & Evans, 2002; Ellis & Thal, 2008). Most often, Late Talkers (LT) are defined by having fewer than 50 words in their productive vocabulary, with no two-word combinations. LTs are at risk for continued language delay. Persistent language delay in young children can result in Specific Language Impairment (SLI). Children with SLI have consistent difficulty acquiring and using language despite the absence of hearing, intellectual, emotional, or frank neurological impairments (cf. Bishop, 1997; Leonard, 1998). They often continue to have clinically significant language problems throughout adolescence and adulthood (e.g., Bishop & Edmundson, 1987; Tomblin, Zhang, Buckwalter, & O’Brien, 2003), placing them at risk for continued social, academic, and employment failure.

Of the infants classified as LTs at 18-24 months of age, a subset will have SLI by age six (Paul, 1996; Rescorla, 2002). A key question for Speech-Language Pathologists, researchers and
most importantly, parents, is: How do we determine which late talking infants will have SLI versus those who will be typical by school age? Infant vocabulary levels combined with factors such as socioeconomic status (SES) and family history of impairment have low sensitivity and specificity in correctly classifying children as having SLI at age five (Dale, Price, Bishop, & Plomin, 2003), and correctly identify less than 30% of LTs who will have SLI (Ellis & Thal, 2008; Zubrick, Taylor, Rice, & Slegers, 2007). Additionally, extreme variability in the rates of word learning may contribute to the difficulty differentiating LTs at risk for SLI from LTs who are developing typically.

**Novel Word Learning in Children with SLI**

In order to begin to address the difficulty in correctly identifying and predicting which LTs will continue to have language-learning problems, we must understand the lexical and cognitive processing abilities in children with SLI – specifically, their novel word learning abilities – at a more detailed level. Why is it that children with SLI have difficulty learning words? Research has found that children with SLI are slower and less accurate in accessing known words in their lexicon (Lahey & Edwards, 1996; Leonard, Ellis Weismer, Miller, Francis, Tomblin, & Kail, 2007). Children with SLI also are known to have word learning difficulties and to have deficits in the skills that support novel word learning, including difficulty linking words to meaning (Dollaghan, 1987). Although word learning is difficult for children with SLI, studies have shown that children with SLI can link novel words to referents and learn vocabulary, but not at the same level as their peers (Dollaghan, 1987; Ellis Weismer & Hesketh, 1996; Gray, 2003; Rice, Buhr, & Oetting, 1992).

One important step in learning novel words is the ability to link words to their referents. Carey and Bartlett (1978) first examined typical preschoolers’ abilities to “fast map.” Fast mapping – where the listener constructs a representation after a single exposure to a novel word – has been thought to be one of the initial steps in lexical acquisition. Later, Dollaghan (1987)
examined how SLI and typical groups of children “fast map” words to referents after a single exposure to a novel word and referent pair. Both groups of children were able to infer and comprehend the novel word at approximately the same level. However, there were differences between groups in the ability to produce the novel word. Specifically, children with SLI were less accurate in producing novel words than typical controls.

Word learning and conceptual representations in children with SLI reflect a significantly different degree of semantic knowledge than their normal peers (McGregor, Newman, Reilly & Capone, 2002). For example, in word learning studies (i.e., fast mapping), children with SLI are slower and less accurate at linking novel labels to novel objects (Alt & Plante, 2006; Dollaghan, 1987; Ellis Weismer & Evans, 2002; Gray, 2004, 2005, 2006; Oetting, Rice & Swank, 1995), and often require twice the number of training trials before they are able to show the same level of performance as typical controls (Ellis Weismer & Hesketh, 1996, 1998; Gray, 2005; Rice, Buhr, & Oetting, 1992). In particular, they are significantly slower and less accurate recognizing words from non-words and recalling words from their lexicon as compared to normal language controls (Katz, Curtiss & Tallal, 1992; Lahey & Edwards, 1996; Leonard, Nippold, Kail, & Hale, 1983; Leonard, 1998). The lexicons of children with SLI seem to be poorly organized, and their ability to recognize spoken words is slower and more vulnerable to interference from other words in their lexicon as compared to their peers (Mainela-Arnold, Evans, & Coady, 2008; McMurray, Samuelson, Lee, & Tomblin, 2010). Further, these deficits in novel word learning are significantly correlated with working memory capacity (Alt & Plante, 2006).

Other novel word learning research has found that not only do children with SLI have difficulty learning new labels, they also have difficulty learning the related semantic features that need to be linked to a novel label (Alt, Plante & Creusere, 2004). Children with SLI also have trouble learning new words within various linguistic and non-linguistic contexts (Ellis Weismer & Hesketh, 1996; 1998). In research investigating whether certain cues support word learning,
researchers found that even an inserted pause did not improve comprehension performance (Rice, Buhr & Oetting, 1992). Other research showed that certain cues may help different aspects of word learning, especially for children with SLI, specifically, semantic cues help comprehension and phonological cues help production of novel words (Gray, 2005).

These previous research studies provide important information about word learning behaviors in children with SLI. Clearly, there is no “quick fix” that can improve word-learning performance in children with SLI. Rather, there are a myriad of factors – including deficits in working memory, poorly organized lexicons, fast-mapping deficiencies, and the utilization of cues – that contribute to these difficulties and need to be examined and addressed.

**Novel Word Learning in Infants**

Similar to school-aged children with SLI, late talking 18- to 24-month-olds have difficulty linking novel labels to novel objects (Ellis Weismer, Venker, Evans, & Moyle, 2012; Ellis & Evans, 2009; Ellis, Evans, Travis, Elman, Thal, & Lin, 2010). In an earlier study, Ellis Weismer and Evans (2002) investigated the performance of LTs at two years of age on language processing tasks. The focus of this study was to examine whether word learning in LTs was impaired compared to typical infants, using a novel word-learning task. Researchers examined response latency and found that the LT group was significantly longer in response time to novel words than the typical control group, suggesting that LTs may have processing limitations that are related to their word learning difficulties.

Ellis Weismer et al. (2012) used a novel word learning task to measure fast mapping abilities in LTs and typical 24-month-olds and to examine developmental outcomes at 30 months. They found that after three exposures, LTs at 24 months were less accurate in comprehending and producing the labels for novel objects as compared to age and IQ matched typical controls. However, using performance from the word learning task combined with other standardized
language measures, they found that the novel word learning performance contributed only slightly in distinguishing LTs from typical children at 30 months.

Similarly, Ellis and Evans (2009) observed that LTs at 18 months required the same number of trials as typical infants to reach criterion during training in a novel word learning task. However, during the test phase LTs showed no evidence of having linked the novel words to novel objects, unlike the typical group. In a follow-up novel word learning study, Ellis et al. (2010) observed that a 20-month-old infant, classified as a LT at 18 months, required twice the number of training trials to show the same level of performance as compared to an age-matched 20-month-old typical infant with a history of normal language development.

A more recent study examined how phonological factors (i.e., phonological probabilities and neighborhood density) influence word learning in late talking and typical preschoolers (MacRoy-Higgins, Schwartz, Shafer, & Marton, 2013). In this study children were trained on novel non-words with varying phonotactic probabilities (low versus high probability). Children were exposed to the words ten times and then their comprehension and production of the words was measured using a preferential looking paradigm to examine looking preference to the novel sequences. Results suggest that typical children prefer and are more accurate at comprehending and producing high probability words. In contrast, phonotactic probabilities did not influence the learning performance of LTs. Overall the LT group performed worse than the typical group in comprehension and production regardless of low and high probability sequences, suggesting that LTs may not be perceiving the underlying statistical properties of the language.

Ultimately, these studies show that children who are LTs have difficulty learning new words. LTs, like children with SLI, are slower and less accurate at linking novel labels to novel objects and often require twice the number of training trials before they are able to show the same level of performance as typical controls (Ellis et al., 2010; Ellis Weismer & Hesketh, 1996, 1998; Gray, 2005; Rice, et al., 1992; Rice, Wexler, Marquis, & Hershberger, 2000). While research has
confirmed LTs have difficulty learning words, we still do not fully understand why, nor do we understand which particular aspect of the word learning process is challenging for LTs. Utilizing eye tracking during a novel word learning task, we will be able to look at a more detailed level at the processing behaviors in LTs and typical infants.

**Eye-Tracking**

Eye-tracking is an online method that allows for a tighter link between real time processing and learning of novel lexical items. By using very detailed and precise eye-tracking methodology, we can begin to explore the moment-by-moment lexical and cognitive processing in infants and toddlers. Examining more detailed lexical processing may enable us to better understand the patterns of recognizing and understanding words, and then to more accurately predict why some infants are at a greater risk for language impairment. Unlike previous infant looking paradigm studies, eye-tracking allows us various advantages for clinical infant research. For example eye-tracking records looking data automatically and gives us the exact location of the saccade and fixation, as well as providing information about the latency and duration of each fixation. Using eye-tracking methods, we are able to pre-define regions of interest to be more confident the infant is actually looking at the picture or area of interest. Additionally, using eye-tracking we are able to more acutely focus on questions about the speed and timing of looks, which may give us information about where the possible group differences may be in the process of learning new words.

Previous eye-tracking studies have found that both infants and children appear to have different gaze patterns during language processing and word learning tasks (Borovsky, Elman & Fernald, 2012; Yu & Smith, 2011). For example, Yu and Smith (2011) found differences in eye gaze fixation patterns between weak and strong novel word learners at 14 months, consistent with our prior work (Ellis et al., 2010) showing less stable looking patterns for an LT as compared to a typical infant.
In our earlier work, using a microgenetic habituation study examining novel word learning and looking patterns in one late-talking and one typical toddler at 20-months, we found that the LT had a different and more varied learning and looking style than the typical toddler (Ellis et al., 2010). Specifically, the LT had significantly shorter first look durations than the typical toddler and overall the LT had more total looks than the typical toddler.

More recent eye-tracking methods have been used to examine lexical processing in children and adolescents with SLI (Andreu et al., 2012; McMurray et al., 2010). In addition to finding both interesting similarities and differences in how SLI and typical groups process words, these studies confirmed the advantage of using eye-tracking tasks and methods in clinical populations. McMurray and colleagues (2010) found that adolescents with SLI showed fewer fixations to the target picture than other pictures. In a younger group of children with and without SLI, Andreu et al. (2012) found that a group of children with SLI was just as fast as the control group in recognizing pictures of nouns, but slower with verbs.

Taken together, these previous studies suggest that in addition to traditional cognitive processing variables such as accuracy and speed of processing, examining the details of gaze fixations in LTs during novel word learning is an additional important component of processing to explore.

**The Present Study**

The primary purpose of the present study was to examine the real-time processing abilities of LTs and typical infants at 18 months when learning novel words.

The specific questions include: (1) Using a different experimental method and slightly different design than previous studies, are 18-month-old LTs slower and less accurate than typical infants in learning novel words, and (2) using additional fine-grained eye-tracking measures, do differences in looking patterns between LT and typical groups emerge? It is predicted that, like previous work, that with the same number of training trials LTs will be less accurate in learning
novel words than the typical group. Additionally, we predict examining more fine-grained details of infant gaze patterns during novel word learning will help us identify where group differences may be occurring.

**METHODS**

**Participants**

Two groups of 14 18-month-old infants (M = 550.71 days, SD = 8.96) from monolingual English-speaking homes and their parents were recruited in the surrounding metropolitan region of San Diego, California. Parents had responded to flyers and ads posted in the community.

The infant participants were 18 months of age at initial time of testing and came into the lab for two separate sessions. Each infant session was approximately 1.5-hours long. Regardless of the infant’s abilities and performance during testing, the infant received a children’s book and parents received $10 per session in return for their time, travel and participation.

All of the infants included in the analysis were reported to have normal hearing and vision and to be primarily hearing and learning English at home. Additionally, all infants were reported to have normal medical history with no serious complications at birth, and no known neurological impairments or developmental disabilities. All mothers reported a near-term or full-term pregnancy with at least 36 weeks gestation. In addition to the parent report of normal hearing, all infants were reported to have passed infant hearing screenings at birth and had no report of recent or chronic ear infections. During the lab visit infants’ middle ear function was assessed using tympanometry.

**Late Talking and Typical Groups**

The late-talking group was comprised of 14 infants (7 girls and 7 boys, M = 549.78 days, SD = 7.49) (visit 1) with productive vocabulary scores below the 20th percentile\(^1\) (M = 8.5, SD = 4.25, range 1-15th percentile). The typical group was comprised of 14 infants (7 girls and 7 boys, \(^1\)Fernald and colleagues also use the 20th percentile on the MacArthur Bates Communicative Development Inventory: Words & Sentences to establish LT vs. TYP groups.}
M = 549.92 days, SD = 10.2 (visit 1) with an average productive vocabulary score of 46th percentile (SD = 21.74, range 23-93rd percentile). Groups were matched on cognitive scores, gender, age, and maternal education (see Table 3.1).

Table 3.1. Group descriptive information: Means and SDs: MacArthur Bates Communicative Development Inventory: Words & Sentences, BSID-III, Maternal Education, Age

<table>
<thead>
<tr>
<th></th>
<th>LT (N=14)</th>
<th>TYP (N=14)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayley Cognitive</td>
<td>100.71 (8.73)</td>
<td>101.42 (7.18)</td>
<td>.82</td>
</tr>
<tr>
<td>Bayley Language</td>
<td>95 (7.18)</td>
<td>104.28 (10.76)</td>
<td>.01</td>
</tr>
<tr>
<td>Words &amp; Sentences</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production Percentile</td>
<td>8.5 (4.25)</td>
<td>46.85 (21.74)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Words &amp; Sentences</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Words Produced</td>
<td>15.21 (8.16)</td>
<td>89.42 (66.86)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Mom’s Education</td>
<td>16.42 years</td>
<td>16.57 years</td>
<td>.81</td>
</tr>
<tr>
<td>Age in Days</td>
<td>549.78 (7.49)</td>
<td>551.64 (10.42)</td>
<td>.59</td>
</tr>
</tbody>
</table>

**PROCEDURE**

Each infant participant was seen individually for standardized language and cognitive development assessment as well as for the experimental tasks. Infant test sessions took place in the Eye-Tracking testing rooms within the Center for Research in Language at UCSD. There were two visits lasting ~1.5 hours each. During the session, parents signed the consent forms and returned the Words & Sentences form (which was sent home prior to the visit to complete), and infants completed the experimental and behavioral tasks.

**Materials**

Offline behavioral measures were completed during the sessions. These measures included the Bayley Scales of Infant Development-III (BSID-III) Cognitive and Language

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2 MacArthur Bates Communicative Development Inventory: Words & Sentences were obtained from the parent, but were scored after the visit by a research assistant blind to the experimental questions and details of the test session.
subscales (Bayley, 2005), and MacArthur Bates Communicative Development Inventory-Words & Sentences (Fenson, Marchman, Thal, Dale, Reznick, & Bates, 2007). Infants in the LT group had an average standard score of 100.71 (SD= 8.73) on the Cognitive Scale of the BSID-III, and an average standard score of 95 (SD= 7.18) on the Language Scale of the BSID-III, and were at the 8.5th percentile (SD = 4.25) on the Words & Sentences. Infants in the typical group had an average standard score of 101.42 (SD = 7.18) on the Cognitive Scale of the BSID-III, an average standard score of 105.35 (SD = 11.04) on the Language Scale of the BSID-III, and were at the 48th percentile (SD = 22.5) on Words & Sentences (see Table 3.1).

**Experimental Tasks**

The infant participant sat in his/her parent's lap or in a child booster seat approximately 24 inches from a 17” LCD display monitor. A small sticker was placed on each participant’s forehead to allow the eye-tracker to measure eye movements. Before each task, a manual five-point calibration and validation routine was completed, using a standard black and white bull’s-eye image. Calibration allows for the eye-tracker to measure specific characteristics of the eyes that are required to accurately calculate eye fixations and gaze direction. Even with minimal infant attention and quick infant movements this process typically took less than two minutes.

Once calibration was completed, stimuli were presented using a PC computer running SR Research Eyelink Experiment Builder software (SR Research, 2011). In between trials, a dot/bull’s eye appeared in the center of the screen and served as a drift correction before each trial. Once the participants fixated on this center dot location, the experimenter began the trial.

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3 To prevent parents from influencing their infants’ responses, the parents wore headphones during the tasks.
Eye Movement Recordings

Eye movements were recorded using an Eyelink 2000 Remote Eyetracker with remote arm configuration at 500 Hz (SR Research, 2011) (see Figure 3.1). The Eyelink system automatically classifies eye movements as saccades, fixations and blinks using the eye-tracker’s default threshold set. For each infant participant the display and eye-tracking camera was placed approximately 580–620 mm from the face. Fixations were recorded automatically every 2 ms for each trial from the onset of the images until the end of the task. Offline, the data were binned by the examiner, into 10ms intervals, then analyses were performed based on predefined regions of interest.

![Figure 3.1. Example of infant seat with monitor and eye-tracking camera](image)

Novel Word Learning Task

The purpose of this study was to investigate real-time processing of novel word learning in late talking and typical 18-month-old infants using eye-tracking. There were three phases in the task: (1) novel word-object training; (2) preview; and (3) test phase.

1) Training. The training phase consisted of two novel label-object pairs trained over four trials. During the training trials the novel object moved back and forth across the screen for 20
seconds while the novel word label played over speakers seven times (therefore each word was heard 14 times over two 20-second exposures). The training trials were fixed at four trials, instead of the trials to criterion approach, to control the number of exposures to the novel label object pair and allow for potential to explore differences in learning during the training phase.

2) Preview. After training, a preview period occurred where participants saw the two novel object pictures on the screen (whether the picture appeared on the left or right side of the screen was counterbalanced across trials). This preview period alleviated any possible memory demands placed on the infant by establishing a preview for all infants to look at the pictures options before the test trials began.

3) Test Phase. Following the preview period, a center attention-getter picture (such as a small picture of a teddy bear or toy duck) appeared between the two pictures. The purpose of this center attention-getter was to control the start point for all infants before they heard the target label (i.e., start at the center fixation point for each trial). See center contingent cue in Figure 3.2 below.

Once the participant looked to the attention-getter picture in the center of the screen for a minimum of 100 ms, the actual test began. Specifically, the participant first heard, “Look” (at the same time the center attention-getter picture appeared). The participants then looked for 100 ms at the attention-getter and finally the center picture disappeared as they then heard “(target novel word)!” After the novel label was played the novel object pictures remained on screen for a total of four seconds. There were a total of eight novel word test trials. Each trial (including preview) lasted a total of six seconds (see Figure 3.2 for example). This design combined aspects of Fernald and Marchman’s (2012) and Mather and Plunkett’s (2010) methods.
Figure 3.2. Example of Novel Word Task Design

*Stimuli*

The stimuli consisted of two words that were two-syllable nonsense words with the same low phonotactic frequency (e.g., “pimo” and “moku”). Each of the object pictures\(^4\) were bright and colorful, but differed in form and color. The pictures were JPG files edited to fit a 400 x 400 pixel square. Each object served equally often as target and distracter and location of the pictures were counterbalanced on the screen. These words were stimuli used in Graf Estes et al., (2007) study and were not heard or exposed previously.

**Time Period and Variables of Interest**

**Time Period**

Previous research suggests the minimum latency to initiate an eye movement in infants is approximately 233-367 ms, with mean latencies considerably longer (Canfield, Smith, Brezsnyak, & Snow, 1997). Previous research suggests that novel word learning takes longer in children and toddlers; therefore, for these analyses utilized the time window of 500-2300 ms. Additionally as a preliminary analysis, the time-course of the entire test phase suggested the time window between 500-2300ms would capture the infant’s data.

**Variables of Interest**

Eye-tracking affords us with many options for examining data. In each trial, a target word was counted as accurate if infants looked more to the target than the distracter. This measure of accuracy has been used previously (Yu & Smith, 2011). After we determine accuracy for the two groups, we examine the proportion of looking to the target and distractor pictures during accurate trials. The next variable of interest is reaction time, defined as the first saccade latency shift (after label onset) to the correct target picture within the 500-2300 ms time window. This variable has been used for the RT measure in other eye-tracking studies (Borovsky et al., 2012).

To address our second question - exploring the possible group differences using time course measures, we examined a number of other variables of interest. The target divergence time measure is defined as the time at which fixations to the "target" object diverges from fixations to the "distractor" (Borovsky et al., 2012; Borovsky et al., in press). This variable allows for visual inspections as well as statistical distinction between looking to the target and distractor. Similar to our prior work (Ellis et al., 2010), we were also interested in the average first fixation duration, which is the average length of duration the first fixation is to the target picture; average number of fixations to the target, which is average number of times the infant fixates to the target picture.
during the time window; and *average number of fixations during the trial* which is defined as the number of times the infant fixates anywhere during the time window\(^5\).

**RESULTS**

We first plotted the data to characterize the processing speed and timing of fixations to the target pictures in response to the label. We then completed a set of analyses to assess the additional characteristics of timing, latency duration and number of fixations in the groups.

**Accuracy**

As mentioned earlier, similar to previous studies, a trial is defined as accurate if there is a greater amount of looking to the target picture than the distractor picture (Yu & Smith, 2011). For the purposes of the following analyses, every trial for each individual infant was analyzed for accuracy before group comparisons were conducted.

![Figure 3.3. Accuracy: Total correct out of 8 trials by group](image)

\(^5\) The two groups are assumed to be independent for the following analyses.
To determine overall accuracy, the number of correct trials of the total eight novel test trials was calculated for each infant. When we look at the total eight novel test trials, we see that the LT group was at chance; that is, only 50% accurate, with 9 of 14 LTs at or below 50% correct, while the typical group was 57.1% accurate. The between group differences were not significant ($z (26) = -1.23, p = .21$). See Figure 3.3.

**Proportion of Looking**

When examining the proportion of looking to the target versus distractor pictures for correct test trials for each group, we note as expected for accurate trials, both groups looked significantly more to the target pictures than the distractor pictures: LT, $M = 71\%$ (SD = 19.9)

![Figure 3.4. Novel Word Learning: Proportion of Looking by group](image)
target vs. M = 14.7% (SD = 17.1), distractor; t = -12.92, \( p < 0.001 \) and TYP, M = 59.7% (SD = 19.5) vs. M = 17.7% (SD = 16.5) distractor\(^5\). While both groups looked more to the novel target than the distractor, there were group differences in proportion of looking to the target picture between the LT (M = 71%, SD = 19.9) and typical (M = 59.7%, SD = 19.4) groups (z (26) = 2.9, \( p = 0.003 \))\(^6\). These data suggest that when LTs were accurate they spent a greater amount of time looking at the target and a shorter amount of time looking at the distractor than the typical group, see Figure 3.4.

**Reaction Time: Timing of Initial Looks**

The between-group differences were then examined for reaction time or timing of initial saccade fixation. There were no significant differences between groups for time of initial look to the novel target picture (LT: M = 360.87, SD = 392.54; TYP: M = 460.19, SD = 412.13; t (26) = -0.953, \( p = 0.343 \)).

**Time Course Measurements**

Next, the mean proportion of time that the LT and typical participants fixated on each of the images (target and distractor) was then calculated at each 10-ms time window during the time course (Figure 3.5). Visual inspection of these time-course plots indicates overall slight differences between groups. In the LT group, initially there seems to be slightly more looking fixations to the distractor picture than the target picture. Later in the time-course, the timing at which fixations to the target object diverges from distractor fixations also appears different between groups. These patterns are discussed in more detail below.

**Time- Course of Target Fixations**

To examine additional time-course of incremental lexical processing of novel words in both the LT and typical groups, the mean proportion of time spent fixating to the target and

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\(^5\) LT had 56 out of 112 trials correct while TYP has 64 out of 112 trials correct.
distractor images at each 10 ms time window was calculated across all participants in each group. These time course plots are helpful to visualize qualitative differences in looking patterns (see Figure 3.5). To test whether there may in fact be differences in looking patterns by each group, point-by-point t-tests at each 100 ms bin between mean looking proportions to the target object and mean looking proportions to the distractor object were calculated. Using these analyses, we see different patterns of divergence between groups. Specifically, the typical group showed distinction between target and distractor at the 1500 ms bin (approximately 2000 ms post label onset, $t = 2.19, p = .045$), whereas the LTs did not have the five consecutive points of significant divergence during the time window (see Figure 3.3). When we calculated a target divergence time for each individual infant using the same procedure as above, it was revealed that only 3 of 14 LTs showed a significant divergence between the novel target and distractor pictures, while 11 of 14 typical infants displayed a significant divergent time between the two pictures.

As done in earlier work, to minimize the possibility that differences may arise due to multiple comparisons by chance, a criterion was used. Specifically, the time point reported is the earliest time point that a minimum of five subsequent and consecutive two tailed t-tests with an alpha level of $p < .05$ indicate a significant difference between the fixation to the target compared to distractor (see Borovsky, Elman & Fernald, 2012).

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Figure 3.5. Novel word learning time-course plots by group
Since we see interesting differences in accuracy and timing, it is important to further examine these differences using more detailed time-course measures. The next set of analyses will examine additional time-course variables. (See Table 3.2.)

**Duration of First Look Fixation**

There was no significant difference between groups in the measure of duration of the first fixation (LT: M = 541.64 ms (SD = 488.72); TYP: M = 433.62 ms (SD = 241.41), t (26) = 1.56, p = .12).

**Number of Fixations**

Finally, when comparing number of looks, there are no significant differences between groups in the number of fixations to the target picture, (LT: M = 2.48 (SD = .95) and TYP: M = 2.48 (SD = .93), t (26) = -.012, p = .989). However, there are differences that approach significance in the total number of fixations across the correct test trials (LT: M = 3.98 (SD = 1.25) and TYP: M = 4.35 (SD = 1.13) t (26) = -1.72, p = .086).

| Table 3.2. Group comparisons for fixation measures of mean duration, and mean number of fixations to target picture and mean number of fixations during trial |
|-------------------------------------------------|-----------------|-----------------|------|-----------------|
| Fixations to Target Picture                     | LT N=14         | TYP N=14        | t-ratio | p-value |
| Duration of 1st Fixation (in ms)                | 541.64 (488.72) | 433.62 (241.41) | 1.56   | .12    |
| # of Fixations to Target                        | 2.48 (.93)      | 2.48 (.95)      | -.012  | .989   |
| # of Fixations during Trial                     | 3.98 (1.25)     | 4.35 (1.13)     | -1.72  | .086   |

**DISCUSSION**

The overall goal of this study was to examine the real-time online processing abilities of novel word learning in late talking and typical infants at 18 months. First, we asked whether 18-month-old LTs are slower and less accurate than typical infants in learning novel words, using a
different experimental method and slightly different design than previous studies. The evidence from the current study of late talking and typical 18-month-olds suggest that there are differences between groups in accuracy of learning novel words. Although we did not see differences in speed of fixating to the novel target picture, we did see interesting differences between groups in the significant points of divergence between target and distractor pictures.

Unlike previous research, the current study used eye-tracking methodology, which is a more detailed technology (measuring every 2 ms rather than every 17 or 33 ms). The eye-tracking data is automatically classified as a saccade or fixation during the task. The current study also used a slightly different design (i.e., gaze contingent) to ensure that every infant begins each trial at the same location. The shift or latency of the first saccade, starting at a center point, then measures the reaction time from the center to the target picture. The benefit of this modification is that the data from each test trial can be used to analyze speed, accuracy and other important variables.

Despite having no differences in reaction time (i.e., the initial latency shift) to target, we did find that the significant point of divergence between target and distractor pictures for each group was different (LT = ns\(^8\); TYP = 1500 ms bin). Further, the moment-by-moment processing in the time-course plots revealed the time of differentiation between the target and distractor pictures was significantly earlier for the typical group, while the LT group did not differentiate fixations between target and distractor pictures overall. Additionally, we see approaching significant group differences in the number of looks overall during the test trials with typical infants fixating more often, but no difference in looks to target picture alone. Like previous work (Ellis et al., 2010) this suggests that LTs do not learn novel words like typical infants.

\(^8\) ns = non-significant. The LT group did not have the five consecutive points of significant divergence during the time window.
In conclusion, although our findings confirmed previous research (typical infants are better at learning novel words than late talking infants), our study also found differences between groups for accuracy and time-course measures, and emerging differences in additional fine-grained processing measures. Specifically, adding an additional dimension by examining details of looking behavior reveals interesting similarities and differences between groups. The next step will be to explore whether group differences emerge when infants are challenged with implicitly exposed words.
REFERENCES


Acknowledgement

Chapter 3, in part, is currently being prepared for submission for publication of the material. Ellis, E, Elman, J, & Evans, J. (In Preparation). Lexical and Cognitive Processing in Early Language Delay. The dissertation author was the primary investigator and primary author of this material.
CHAPTER 4: IMPLICIT WORD LEARNING IN LATE-TALKING AND TYPICAL 18-MONTH-OLDS - AN EYE-TRACKING STUDY

ABSTRACT

This investigation examined online moment-by-moment processing of implicit word learning in 18-month-old infants. A late-talking group (LT, N=14) and a matched typical group (TYP, N=14) of infants participated in an experimental eye-tracking study as well as behavioral and standardized testing. Infant vocabulary scores were obtained by parent report on the MacArthur Bates Communicative Development Inventory: Words & Sentences (Words & Sentences), (Fenson et al., 2007), and cognitive ability was measured using the Bayley Scales of Infant Development-III, (BSID-III), (Bayley, 2005). During the eye-tracking task, infants were exposed to an implicit statistical language, trained on two novel word-picture pairs (one word from the implicit language) and tested by hearing an implicit word while seeing two picture options on a monitor. Eye movements were recorded using the Eyelink 2000 Remote Eyetracker.

Results suggest that LTs are less accurate and not learning the implicit words in the same way at the typical infants. Specifically, there were differences in accuracy, but no differences between groups in speed of looking to the target implicit picture at test. There were also interesting differences in the time-course of looking to the implicit and non-word target pictures during testing. Additionally, the results suggest that typical infants are using the underlying statistical properties of the implicit language to help with word learning while the late-talking infants are not using the statistical properties in the same way. Further, we found that the RT to the implicit target is related to vocabulary ability at 18-months. These results, using eye-tracking methods, suggest that LTs and typical infants may use the underlying statistical properties of the language differently to implicitly learn words. Interestingly, when analyzing group patterns using additional fine-grained processing measures, there are emerging differences between groups.
**INTRODUCTION**

Fast mapping - the ability to link a label to its referent - has been hypothesized to be the initial step in lexical acquisition (Carey & Bartlett, 1978; Dollaghan, 1985 and 1987). More recent work with typical infants (GrafEstes et al., 2007) suggests, however, that the ability to extract and segment word candidates from a continuous stream of speech may be a predicate to fast mapping, and thus is a critical part of the language learning process that must occur before infants can link a word to the referent.

A growing body of work shows that infants, children and adults are skilled at implicit learning tasks. *Statistical word learning* - the unconscious ability to track patterns and regularities in the input - is one type of implicit learning that has been studied in children. Infants at very young ages are able to rapidly and effortlessly discover word boundaries within a stream of speech using only statistical regularities hypothesized to be useful for certain aspects of language learning (Saffran, 2003). The transitional probabilities between syllables and phonemes assist learners in discovering which sounds cohere together into words and which sounds span word boundaries (e.g., Saffran, Aslin, Newport, 1996; Thiessen & Saffran, 2003). The ability to track statistical regularities in the speech stream and to use this information to discover word boundaries appears also to be connected to word learning in infants (GrafEstes, Evans, Alibali, & Saffran, 2007) and vocabulary knowledge in school-aged children (Evans, Saffran, & Robe-Torres, 2009).

In the seminal paper by Saffran and colleagues, eight-month-old infants successfully acquired language by segmenting words from fluent speech based on statistical regularities of the sounds in the language (Saffran, Aslin, & Newport, 1996). Later, Saffran (2001) investigated how infant language learners segment and discover the boundaries between words by exploring the extent to which statistical learning generates novel word-like units, rather than only probabilistically related strings of sounds. Young infants were familiarized with a continuous
stream of novel words with no acoustic cues to word boundaries. After the familiarization phase, the test phase compared the infants' responses to words and part-words. Saffran’s (2001) findings suggested that statistical learning mechanisms are used to perceive and generate word-like units, and therefore are important factors that may contribute to language learning.

In the visual domain, Fiser and Aslin (2002) investigated the ability to extract the probabilities of successive shape co-occurrences during passive viewing. Over time, participants became sensitive to several temporal-order statistics; this occurred rapidly and with no overt task or explicit instructions. Results suggested that lower-order statistics were retained during the extraction of higher-order statistics. Therefore, participants automatically extracted multiple statistics of temporal events that are suitable for efficient associative learning of new temporal features. Other work by Newport and Aslin (2004) has shown that adults, young children, and infants are capable of computing transitional probabilities among adjacent syllables in rapidly presented streams of speech and capable of using those statistics to group adjacent syllables into word-like units.

Other research has also shown that infants can parse speech into word-like units according to biases that develop in the first year. In examining how clusters of syllables are statistically learned, Swingley (2005) found that extracted word-forms showed distributional characteristics allowing the sorting of words into syntactic categories. These results suggested that during the first year of language learning young infants show preferences for words. That is, infants begin to learn the sound patterns of their language at a very young age before they are able to reliably produce words.

In one study, Graf Estes et al. (2007) examined typically developing 17-month-old infants after they listened to a 2.5-minute artificial statistical language where only the segmentation cue available to the infants was the transitional probability from one syllable to the next (e.g., pigatimaydoubu...), with the transitional probabilities within words (1.0) being
markedly higher than across words (.33). After listening to the language, infants participated in a label-object association task. Graf Estes et al. (2007) observed that the infants treated the nonsense words they had extracted from the exposure language (e.g., *timay*) as word candidates, linking these words to meaning, unlike nonsense words they had not heard before (e.g., *mati*). These findings support the view that implicit learning mechanisms that are available to very young infants and toddlers seems to be useful for language development. Specifically, the implicit learning mechanism is used by young infants in the first stages of word learning and is also a mechanism that can be explored in disordered populations.

**Implicit Learning in Clinical Populations**

Specific language impairment (SLI) refers to children who have consistent difficulty acquiring and using language in the absence of hearing, intellectual, emotional, or frank neurological impairments (cf. Bishop, 1997; Leonard, 1998). Children with SLI continue to have clinically significant language problems throughout adolescence and adulthood (e.g., Bishop & Edmundson, 1987; Tomblin, Zhang, Buckwalter, & O’Brien, 2003), placing them at risk for continued social, academic, and employment failure. In particular, it has been proposed that children with SLI have procedural learning deficits. The procedural deficit hypothesis (PDH) account suggests that the deficits observed in children with SLI can be explained by abnormal development of brain structures that support the procedural aspects of the implicit memory system (Ullman & Pierpont, 2005). The PDH account suggests that although children with SLI have significant procedural learning deficits, knowledge acquired by the declarative system should be a relative strength for those children with SLI (Ullman & Pierpont, 2005).

More specifically, Ullman proposes that the brain structures that support the declarative memory system also support the acquisition and use of lexical conceptual knowledge in children with SLI and that they rely adaptively on the declarative system to learn language. In contrast, the acquisition and use of syntax is supported by the brain systems responsible for implicit procedural
learning. Thus, according to Ullman, because the declarative system is spared in SLI, children with SLI should have intact lexical acquisition and use.

On the other hand, however, there is extensive research relating to word learning and lexical processing which suggests that PDH may not account for all aspects of the deficits in SLI; specifically, children with SLI do not have lexical abilities similar to their peers (Alt & Plante, 2006; Dollaghan, 1987; Ellis Weismer & Evans, 2002; Gray, 2004; Katz, et al., 1992; Lahey & Edwards, 1996; Leonard, Nippold, Kail, & Hale, 1983; Leonard, 1998). Research shows that children with SLI have significant difficulties learning novel words (Alt & Plante, 2006; Dollaghan, 1987; Ellis Weismer & Evans, 2002; Gray, 2004, 2005, 2006; Oetting, Rice, & Swank, 1995), requiring up to double the number of exposure trials before they are able to show the same level of performance as typical controls (Ellis Weismer & Hesketh, 1996, 1998; Rice et al., 1992; Rice et al., 2000). Further, these deficits in novel word learning are significantly correlated with working memory capacity (Alt & Plante, 2006).

Consistent with Ullman's PDH account, however, research in adolescents with and without SLI found performance differences using a procedural learning task. Tomblin, Mainela-Arnold, and Zhang (2007) used a serial reaction time task to measure learning rates of patterned and random sequences in the two groups. Findings suggested adolescents with SLI were slower than controls during the pattern sequence learning, confirming that deficits in implicit procedural learning may underlie problems in adolescents with SLI.

Another study on implicit learning abilities in children with language disorders confirms that implicit learning is an area of difficulty for children with SLI. This study examined implicit word learning in school age children with and without SLI and found differences between the SLI and typical groups (Evans et al., 2009). In contrast to typical children - who were able to listen to an artificial language comprised of six, three-syllable nonsense words (e.g., dutabapatubitibu...) for 21 minutes and discover all six words within the speech stream -
children with SLI were at chance and require *double* the amount of exposure before they were able to discover any of the words (Evans et al., 2009). Additionally, performance on the implicit learning task was correlated with vocabulary knowledge in both groups.

There is little prior work examining this initial stage of segmenting and extracting word candidates in late talking infants and toddlers. To efficiently learn vocabulary infants and toddlers must learn to link a set of sound sequences to its appropriate referent, often without explicit feedback. However, before they link a set of sound sequences, infants must somehow determine which set of sounds within a speech stream go together to make a word and which do not. For example, sounds that make up the speech stream (“thatissuchaprettybaby”) must be segmented and then extracted for each word to be understood, (e.g., “that is such a pretty baby”). The within word transitional probabilities between phonemes must be higher than the between word probabilities.

One study examined how phonological factors (i.e., phonological probabilities and neighborhood density) influence word learning in LTs and typical preschoolers (MacRoy-Higgins et al., 2013). In this study, children were trained on novel non-words with varying phonotactic probabilities (low versus high probability). Children were exposed to the words ten times and then their comprehension and production of the words were measured. A preferential looking paradigm was used to measure looking preference to the sound sequences. Results from this study suggested that typical children prefer and are more accurate at high probability words. On the other hand, phonotactic probabilities did not influence the performance of learning in LTs and they performed worse than the typical group in both comprehension and production of the new words regardless of low and high probability sequences. Overall these results suggested that LTs may not be perceiving the underlying statistical properties of the language like typical infants.

Typical infants, children and adults are able to effortlessly track statistical regularities between sound sequences to discover word boundaries within a stream of speech, and it appears
that infants’ ability to implicitly track transitional probabilities may be a key mechanism in the
process of word learning and vocabulary knowledge (Evans et al., 2009; Graf Estes et al., 2007).
To date, implicit statistical word learning abilities have not been investigated in a group of LTs;
however, consistent with slower speed of processing in recognizing real words and poor novel
word learning abilities seen in these children, one might anticipate that statistical word learning
also would be impaired in LTs.

Eye-Tracking in Clinical Populations

Eye-tracking studies have found that both LTs and children with SLI appear to have
different gaze patterns during language processing and word learning tasks than typical peers
(Borovsky et al., 2012; Yu & Smith, 2011). For example, Yu and Smith (2011) found differences
in eye gaze fixation patterns between weak and strong novel word learners at 14 months,
consistent with our prior work (Ellis et al., 2010) showing less stable looking patterns for an LT
as compared to a typical infant. In our earlier work, a microgenetic habituation study examining
novel word learning and looking patterns in one late-talking and one typical toddler at 20-months
of age, we found that the LT had a more varied learning and looking style than the typical toddler
(Ellis et al., 2010). Specifically, the LT had significantly shorter first look durations and overall
more looks across the study.

Other recent eye-tracking studies have examined lexical processing in SLI (Andreu et al.,
2012; McMurray et al., 2010). In addition to confirming the advantages of using eye-tracking
tasks and methods in clinical populations, these studies found both interesting similarities and
striking differences in how SLI and typical groups process words. McMurray and colleagues
(2010) found that adolescents with SLI had fewer fixations to the target picture than other
pictures than the typical group. In a younger group of children with and without SLI, Andreu et
al. (2012) found that a group of children with SLI was just as fast as the control group in
recognizing pictures of nouns, but slower with verbs.
A recent study examined sentence comprehension abilities in adolescents with and without SLI using eye-tracking. In this study, researchers examined online time-course measures and found both interesting similarities and differences between groups (Borovsky et al., in press). Specifically, the SLI group was just as fast as the typical group to integrate information while listening to a simple sentence, but showed differences in looking behaviors to distractor picture items. Researchers explored spatial gaze patterns and found the SLI group had a more diffuse looking pattern than typical peers. Taken together, these studies suggest that in addition to traditional cognitive processing variables such as accuracy and speed of processing that are analyzed in most studies, examining additional details of gaze fixations in LTs may be an additional important component of processing to explore.

Eye-tracking allows for a tighter link between real time processing and learning of lexical items. By using the detailed and precise eye-tracking methodology, we can begin to explore the moment-by-moment lexical and cognitive processing in infants and toddlers. Using this more detailed peak into lexical processing, researchers may be able to better understand the patterns of implicit word learning and more accurately predict why some infants are at a greater risk for language impairment. Unlike previous infant looking paradigm studies, eye-tracking allows us various advantages for clinical infant research. Specifically, eye-tracking records looking data automatically and gives us the exact location of the saccade fixation, and information about the latency and duration of each of those fixations. Using eye-tracking methods we are able to pre-define regions of interest, which allows us to be more confident that the infant is actually looking at the picture or area of interest. Additionally, using these methods we are able to focus closely on possible questions about speed and timing of looks, which may be able to give us the information about if and where the possible group differences may be occurring in the process of implicit word learning.
**THE PRESENT STUDY**

The primary purpose of the present study was to examine the real-time processing abilities of implicit word learning in late talking and typical infants at 18 months using eye-tracking.

The specific questions posed were: (1) are both late talking and typical infants able to learn implicitly exposed words; and (2) using additional fine-grained eye-tracking measures, can we discern differences in looking patterns between LT and typical groups? Based on previous work with older children with SLI, it is predicted that LTs will have more difficulty learning implicitly exposed words than the typical group. Additionally, it is predicted that examining the details of infant gaze patterns during implicit word learning will give us insight into where and why group differences may be occurring.

**METHODS**

**Participants**

Two groups of 14, 18-month old infants (M = 550.71 days, SD = 8.96) from monolingual English-speaking homes and their parents were recruited in the surrounding metropolitan region of San Diego, California. Parents had responded to flyers and ads posted in the community.

The infant participants were 18 months of age at initial time of testing and came into the lab for two separate sessions. Each infant session was approximately 1.5-hours long. Regardless of the infant’s abilities and performance during testing, the infant received a children’s book and parents received $10 per session in return for their time, travel and participation.

All of the infants included in the study were reported to have normal hearing and vision and to be primarily hearing and learning English at home. Additionally, all infants were reported to have a normal medical history with no serious complications at birth, and no known neurological impairments or developmental disabilities. All mothers reported a near-term or full-term pregnancy with at least 36 weeks gestation. In addition to the parent report of normal
hearing, all infants were reported to have passed infant hearing screenings at birth and had no report of recent or chronic ear infections. During the lab visit, each infants’ middle ear function was assessed using tympanometry.

**Late Talking and Typical Groups**

The late talking group included 14 infants (7 girls and 7 boys, M = 549.78 days, SD = 7.49) (visit 1) with productive vocabulary scores below the 20th percentile\(^1\) (M = 8.5, SD = 4.25, range 1-15th percentile). The typical group included 14 infants (7 girls and 7 boys, M = 549.92 days, SD=10.2) (visit 1) with an average productive vocabulary score at the 46th percentile (SD = 21.74, range 23-93rd percentile). Groups were matched on cognitive scores, gender, age, and maternal education (see Table 4.1).

**Procedure**

Each infant participant was seen individually for standardized language and cognitive development assessment as well as for the experimental tasks. Infant test sessions took place in the Eye-tracking testing rooms within the Center for Research in Language at UCSD. There were two visits lasting approximately 1.5 hours each. During the first session, parents signed the

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\(^1\) Fernald and colleagues also use the 20th percentile on the MacArthur Bates Communicative Development Inventory: Words & Sentences to establish LT vs. TYP groups
consent forms and returned the *Words & Sentences* form (which was sent home prior to the visit to complete). Infants participated in the experimental and behavioral tasks during both sessions.

**Materials**

Offline behavioral measures were completed during the sessions. These measures included the *Bayley Scales of Infant Development-III (BSID-III)* Cognitive and Language subscales (Bayley, 2005), and *MacArthur Bates Communicative Development Inventory-Words & Sentences (Words & Sentences)* (Fenson et al., 2007). Infants in the LT group had an average standard score of 100.71 (SD = 8.73) on the Cognitive Scale of the *BSID-III*, and an average standard score of 95 (SD = 7.18) on the Language Scale of the *BSID-III*, and were at the 8.5th percentile (SD = 4.25) on *Words & Sentences*. Infants in the typical group had an average standard score of 101.42 (SD = 7.18) on the Cognitive Scale of the *BSID-III*, an average standard score of 105.35 (SD = 11.04) on the Language Scale of the *BSID-III*, and were at the 48th percentile (SD = 22.5) on *Words & Sentences* (see Table 4.1).

**Experimental Tasks**

During the experimental eye-tracking tasks, each infant participant sat in his/her parent's lap or in a child booster seat approximately 24 inches from a 17” LCD display monitor. A small sticker was placed on each participant’s forehead to allow the eye-tracker to measure eye movements. Before each task, a manual five-point calibration and validation routine was completed, using a standard black and white bull’s-eye image. Calibration allows for the eye-tracker to measure specific characteristics of the eyes that are required to accurately calculate eye fixations and gaze direction. Even with minimal infant attention and quick infant movements this process typically took less than two minutes.

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2 MacArthur Bates Communicative Development Inventory: Words & Sentences were obtained from the parent, but were scored after the visit by a research assistant blind to the experimental questions and details of the test session.

3 To prevent parents from influencing their infants’ responses, the parents wore headphones during the tasks.
Once calibration was completed, stimuli were presented using a PC computer running SR Research Eyelink Experiment Builder software (SR Research, 2011). In between trials a dot (i.e., the bull’s eye) appeared in the center of the screen and served as a drift correction before each trial. Once the participants fixated on this center dot location, the experimenter began the trial.

**Eye Movement Recordings**

Eye movements were recorded using an Eyelink 2000 Remote Eyetracker with remote arm configuration at 500 Hz (SR Research Ltd., see Figure 4.1). For each infant participant the display and eye-tracking camera was placed approximately 580–620 mm from the face. Fixations were recorded automatically every 2 ms for each trial from the onset of the images until the end of the task. The Eyelink system automatically classifies eye movements as saccades, fixations and blinks using the eye-tracker’s default threshold set. Offline, the data were binned by the examiner into 10 ms intervals, then analyses were performed based on predefined regions of interest.

![Figure 4.1. Example of infant seat with monitor and eye-tracking camera](image)

**Implicit Word Learning Task**

The purpose of this study was to investigate real-time processing of implicit word learning in late talking and typical 18-month-old infants using eye-tracking. There are four phases
in the task: (1) language exposure; (2) label-object training; (3) preview; and (4) testing (see Figure 4.2).

(1) During the language exposure phase, infants listened to a 2.5-minute artificial statistical language while sitting on their parent’s lap or booster seat and watching a silent cartoon.

(2) The label-object training phase consisted of two different label-object pairs (one word that was previously exposed in the artificial statistical language and one that was not previously exposed) presented one at a time for 20 seconds. Each label-object pair was presented during two trials for a total of four trials. During the training trials, the object moved back and forth across the screen for 20 seconds while the label played over speakers seven different times (therefore each word was heard 14 times over two 20-second exposures).

(3) During the preview phase infants saw a two-second preview of the two object pictures on the screen, after the two-second preview an attention getter picture appeared in the center of the two pictures and the infants heard “Look.” Once the infant looked to the center picture for 100 ms, the center attention-getter picture disappeared.

(4) The test phase began immediately after the center picture disappeared and the infants heard the target label as they simultaneously continue to see the pictures of both objects. There were a total of 12 test trials (six implicit words and six non-word trials).

Stimuli

Stimuli were the same as used in Graf Estes et al. (2007). Two words were two-syllable nonsense words (with low phonotactic frequency) from either Language 1 (e.g., timay) or Language 2 (e.g. mati). Both Language 1 and 2 from Graf Estes et al. (2007) were counterbalanced across infants to control for frequency of exposure of syllables and possible infant biases in preference to particular nonsense words. One of the two words was a previously exposed nonsense word from the artificial statistical language the infant heard during the
exposure phase (e.g., Language 1 \textit{timay}). The second novel word was a \textit{non-exposed} non-word the infant did not listen to prior to the training phase from the second artificial language (e.g., Language 2, \textit{mati}).

![Diagram](image)

\textbf{Figure 4.2. Example of implicit word task design}

All of the novel words in each language have the same phonotactic frequency and each version of the language contains the same syllables in a different arrangement. To control for arbitrary infant word-object preferences, the exposure language, the segmented exposed implicit words and non-exposed words and the objects were counterbalanced across the infants. None of the words used in the study had been heard previously by the infants (See Appendix 4.A. for list of words).

Each of the novel object pictures\textsuperscript{4} was bright and colorful, but differed in form and color. These pictures were in JPG files edited to fit a 400 x 400 pixel square. Each object served equally often as target and distractor and location of the pictures were counterbalanced on the screen.

\textsuperscript{4} Object pictures were adapted Fribbles images. Tarr, M. (2011) Fribbles. [\textit{Stimulus images}]. Available from the \textit{Center for the Neural Basis of Cognition and Department of Psychology, Carnegie Mellon University}, \url{http://www.tarrlab.org/}.  

**Time Period and Variables of Interest**

*Time Period.* Previous research suggests the minimum latency to initiate an eye movement in infants is approximately 233-367 ms, with mean latencies considerably longer (e.g., Canfield, Smith, Brezsnyak, & Snow, 1997). Also, research suggests it takes longer for children with SLI to begin to extract implicit words (Evans et al., 2009); accordingly, we extended the time window of analyses to 500-2500 ms.

*Variables of Interest*

In each trial, a target word was counted as accurate if infants looked more to the target than the distractor. This measure of accuracy has been used previously (Yu & Smith, 2011). After we determined accuracy for the two groups, we examined the proportion of looking to the target and distractor pictures during accurate implicit trials. If implicit learning is an area of relative weakness in LTs as predicted earlier, we would expect to see slower reaction times to the implicit target pictures than we see in typical infants. *Reaction time* is defined as the latency shift after label onset from the first saccade to the correct target picture, within the 500-2500 ms time window. This variable has been used for the reaction time measure in many other eye-tracking studies (Borovsky et al., 2012; Borovsky et al., in press).

To explore the possible group differences using detailed time-course measures, we examined additional variables of interest. For example, the *Target Divergence Time* measure is defined as the time at which fixations to the "target" object diverge from fixations to the "distractor" (Borovsky et al., 2012; Borovsky et al., in press). This variable allows for visual inspections as well as statistical distinction between looking to the target and distractor. Similar to our prior work (Ellis et al., 2010), we were also interested in the *average first fixation duration*, which is the average length of duration the first fixation is to the target picture; the *average number of fixations to the target*, which is defined as the average number of times the infant looks and fixates to the target picture during the time window; and the *average number of fixations*
during the trial, defined as the number of times the infant fixates anywhere during the time window\textsuperscript{5}.

Additionally, to examine whether the ability to segment the statistical probabilities of language is used as an advantage during language learning, we examined whether there was a difference in typical and late talking infants’ target divergent times between conditions (implicit word vs. non-word). Finally, similar to the work with school age children with and without SLI, we examined whether implicit learning abilities are related to infant vocabulary.

**RESULTS**

The first set of results assessed accuracy and proportion of looking to the implicit target word. Next we examined the reaction time data between groups to determine if there were group differences in looking to the implicitly exposed words. We then plotted the time-course of looking to analyze the data and to characterize the processing speed and timing of fixations to the implicit target pictures in response to the word label. A set of analyses was then completed to determine whether we see group differences in the additional characteristics of first fixation duration and number of fixations in the groups for implicit target words. Finally, we examined whether implicit learning abilities is in fact related to vocabulary knowledge.

**Accuracy**

To determine accuracy, the total number of correct trials out of the six implicit test trials was calculated for each infant. The LT group was below chance - only 47.37% accurate, with 11 of 14 LTs at or below 50% correct, while the TYP group was 52.63% accurate. The between group differences were not significant ($z (26) = .45, p = .65$; see Figure 4.3).

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\textsuperscript{5} The two groups are assumed to be independent for the following analyses.
The proportion of looking to the target versus distractor pictures for correct implicit test trials for each group was examined next. As expected for accurate trials, both groups greater proportions of looking to the implicit target picture than the distractor picture: (LT, M = 67.1% (SD = 20.6) target vs. M = 19.1% (SD = 16.0) distractor); and (TYP, M = 61.9% (SD = 22.0) target vs. M = 19.9% (SD = 16.5) distractor⁶). There are no group differences in the proportion of looking to the implicit target picture (z (26) = -1.12, p = .26) (see Figure 4.4).

⁶ In this analysis data are used from accurate trials. The LT group had a total of 36 accurate trials of 76 trials, and the TYP group had 40 accurate trials of 76 trials. A total of six test trials from each group were unable to be analyzed.
Figure 4.4. Proportion of looking during the accurate implicit test trials by group

**Reaction Time: Speed of Processing of Initial Saccades**

The between group differences were examined for initial saccade fixation (i.e., reaction time) to the implicit pictures at test. The data reveal that the LT group had an average first saccade time of 947.92 ms and the typical group had an average first saccade time of 763.71 ms. While seemingly different, there were no significant statistically differences between groups for time of initial look to the implicit word trials (LT: $M = 947.92$, SD = 555.98; TYP: $M = 763.71$, SD = 510.76, $t(26) = 1.58, p = .11.$)

**Time-Course Measurements and Time-Course of Target Fixations**

The mean proportion of time that the late-talking and typical participants fixated on each of the images was then calculated (for target and distractor) at each 10-ms time window during the time course of interest. Visual inspection of these time-course plots indicates overall similar patterns; however, the timing at which fixations to the target object diverges from distractor fixations appears different between groups. These patterns are discussed in more detail below.
To examine additional time-course of incremental lexical processing in the LT and typical groups, the mean proportion of time spent fixating to the target word and distractor images at each 10-ms time window across all participants in each group were calculated separately for each condition (e.g., implicit and non-word). These time-course plots are helpful to visualize qualitative differences in looking patterns. To test whether there may in fact be differences in looking patterns by each group, point-by-point t-tests at each 100 ms bin between mean looking proportions to the target word object and mean looking proportions to the distractor object were calculated for each group and each condition.

We see different patterns of divergence points between groups and between conditions (implicit and non-word test trials; see Figure 4.5 below). Specifically, the LTs showed distinction between the implicit (exposed word) target and distractor at the 1310 ms bin (approximately 1810 ms post label onset, \( t = 2.23, p = .042 \)) and showed distinction between non-word (non-exposed) target and distractor approximately at the 1290 ms bin (approximately at 1790 ms post label onset), and the typical group showed distinction between implicit (exposed word) target and distractor at the 1190 ms bin (approximately 1690 ms post label, \( t = 2.17, p = .047 \)), and showed distinction between non-word (non-exposed word) target and distractor much later at the 1800 ms bin (approximately at 2300 ms post label onset). These data suggest the LT group was not using and learning the statistical properties of the language in the same way as the typical group. However, for the LT group, the exposure to the implicit statistical language may have reduced the difficulty of the word learning process since significant divergence points occurred in each condition.

As done in earlier work, to minimize the possibility that differences may arise due to multiple comparisons by chance, a criterion was used. Specifically, the time point reported is the earliest time point that a minimum of five subsequent and consecutive two tailed t-tests with an alpha level of \( p < .05 \) indicate a significant difference between the fixation to the target compared to distractor (see Borovsky, Fernald & Elman, 2012).
Alternatively, for the typical group, the statistical properties of the implicit language seem to be beneficial to help distinguish between a target implicit word compared to the times of distinction for the non-word target words.

Since we are beginning to see interesting differences in the time-course of looking in each condition, it is important to further examine these differences using other detailed time course measures. The next set of analyses will examine additional time course variables. (See Table 4.2.)

*Duration of First Look Fixation*

There were no significant differences between groups for the measure of duration of the first fixation. However, the results are trending in the expected direction (LT = 425.01 ms (SD = 266.17), TYP= 502.55 ms (SD = 255.27), t (26) = -1.76, p = .07).
**Number of Fixations**

Next, when comparing number of looks there are no significant differences between groups in the number of fixations to the implicit target picture (LT = 1.84 (SD = 1.36) and TYP = 1.77 (SD = 1.27), t (26) = .34, p = .73). Additionally, there are no differences between the total number of fixations during the implicit test trials (LT = 4.44 (SD = 1.74) and TYP = 4.36 (SD = 1.59), t (26) = .29, p = .76.)

**Table 4.2. Group comparisons for fixation measures of mean duration, and mean number of fixations to target object and mean number of fixations during time-course**

<table>
<thead>
<tr>
<th>Fixations to Implicit Target</th>
<th>LT N=14</th>
<th>TYP N=14</th>
<th>t-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of 1&lt;sup&gt;st&lt;/sup&gt; Fixation (in ms)</td>
<td>425.01 (266.17)</td>
<td>502.55 (255.27)</td>
<td>-1.76</td>
<td>.07</td>
</tr>
<tr>
<td># of Looks to Target</td>
<td>1.84 (1.36)</td>
<td>1.77 (1.27)</td>
<td>.34</td>
<td>.73</td>
</tr>
<tr>
<td># of Looks during Trial</td>
<td>4.44 (1.74)</td>
<td>4.36 (1.59)</td>
<td>.29</td>
<td>.76</td>
</tr>
</tbody>
</table>

**Vocabulary Knowledge**

Finally, similar to the work with school age children with and without SLI we examined whether implicit learning abilities were related to infant vocabulary knowledge. The speed of the first saccade to the implicit target picture was correlated to vocabulary at 18 months. Specifically, the faster the first saccade to the implicit target, the more words the infants produced at 18 months (r = -.336, p = .043, 1-tailed).

**DISCUSSION**

The overall goal of this study was to examine the real-time online processing abilities of implicit word learning in late talking and typical infants at 18 months. First, using a different experimental method and slightly different design than previous studies, we asked whether 18-month-old LTs and typical infants are able to implicitly learn words. The evidence from the
current study of 18-month-old late talking and typical infants suggests that both groups showed learning of implicit words. However, there seem to be slight differences between groups in speed of distinguishing the target implicit words from distractors. We also see different patterns of looking during our time-course analysis, and differences between groups in the significant points of divergence between target and distractor pictures across conditions (implicit and non-word). The LTs distinguish between target and distractor around the same point in time despite condition, while the typical group distinguishes target and distractor earlier for the implicit condition compared to the non-word condition. This finding suggests that typical infants are able to track the implicit characteristics of the artificial statistical language and use those cues to assist in linking the label to the target object at an earlier time point in the implicit condition.

Further, when considering our second question of examining fine-grained eye-tracking measures to explore differences in looking patterns in implicit word learning between late talking and typical groups, we begin to see some emerging group differences. Although not significant we see results trending in the expected direction for first fixation duration. We also did not find any difference in number of fixations to target or total number of fixations during the test trials. Additionally, when we examined RT to the implicit picture and number of words produced we see, like in school age children with and without SLI, a relationship between implicit learning abilities and vocabulary. The infants with faster RT to implicit targets are also the infants with more words in their productive vocabulary.

Overall, this study found both interesting similarities and differences between groups in patterns of implicit learning and emerging differences in additional fine-grained measures. This work shows some promising results. The results suggest that both LTs and typical infants are able to implicitly learn words. However, for the late talking infants, while the exposure to statistical properties of the language may be easing the task of learning words, they do not seem to perceive and apply the statistical properties in the same way as typical infants.
REFERENCES


**Acknowledgement**

Chapter 4, in part, is currently being prepared for submission for publication of the material. Ellis, E, Elman, J, & Evans, J. (In Preparation). Lexical and Cognitive Processing in Early Language Delay. The dissertation author was the primary investigator and primary author of this material.
Appendix 4.A. List of implicit word stimuli.

Implicit words in Language A
Piga
Dobu
Timay
Mano

Trained words if heard Language A
Timay (implicit exposed word)
Gabu (non-exposed word)

Implicit words in Language B
Pido
Gabu
Mati
Nomay

Trained words if heard Language B
Nomay (implicit exposed word)
Dobu (non-exposed word)
CHAPTER 5: A DIMENSIONAL Approach OF Late-Talking AND Typical Infants: CAN WE Predict Outcomes USING LexICAL & Cognitive Processing Abilities AT 18-Months-Old?

ABSTRACT

This exploratory investigation used a dimensional approach to examine whether online processing of real word recognition, novel word learning and implicit word learning abilities differs from standardized vocabulary measures in identification of 18-month-old late talkers who may be at risk for SLI. A total of 54 infants participated in experimental eye-tracking tasks as well as behavioral and standardized testing at 18 months. Each infant’s vocabulary scores were obtained by parent report on the MacArthur Bates Communicative Development Inventory (Fenson et al., 2007), and cognitive ability was measured using the Bayley Scales of Infant Development-III (Bayley, 2005). Eye movements were recorded using the Eyelink 2000 Remote Eyetracker. The eye-tracking tasks examined lexical and cognitive processing skills important for language learning. The distributions of lexical and cognitive processing scores in a sample of 18-month old infants were examined to begin to determine if a multi-dimensional clustering approach might better identify those infant’s who may be at risk for SLI and also have slow rate of language acquisition as compared to standardized vocabulary scores at 24 months. Specifically, we examined whether fine-grained lexical and cognitive processing variables may better identify infants who have the slowest rate of vocabulary growth and therefore may be at risk for continued language delay. Our preliminary results suggest that for a subset infants, certain processing variables characterize future language outcomes and may potentially identify those infants who will continue to have language difficulties as they grow older.
INTRODUCTION

Developmental researchers have studied Late Talkers and have attempted to determine the best ways to identify and predict the long-term outcomes of young infants who have language delays for many years (Thal, 2000; 2005; Thal, Marchman, & Tomblin, 2013, Rescorla, 2013; Zubrick, Taylor & Rice, 2007). “Late Talkers” are, by definition, healthy full-term toddlers, typically 18-24 months old, with normal cognitive development, normal hearing and no significant birth history; however, they have delays in the onset of their first words (Ellis Weismer & Evans, 2002; Ellis & Thal, 2008). Most often, Late Talkers (LT) are identified by having fewer than 50 words in their productive vocabulary, with no two-word combinations, and are at risk for continued language delay (i.e., Specific Language Impairment (SLI)). Importantly, while most LTs will move into the typical range by school age, a proportion of the infants classified as LTs at 18-24 months of age will have SLI by age six (Paul, 1996; Rescorla, 2002).

One of the critical clinical questions is how do Speech-Language Pathologists and researchers determine which late talking infants will have SLI versus those who will catch up to their peers by school age? In the past, examining only infant vocabulary levels combined with factors such as socioeconomic status (SES) and family history of impairment proved to have low sensitivity and specificity in correctly classifying children with SLI at age five (Dale, Price, Bishop & Plomin, 2003), and correctly identified less than 30% of LTs who will have SLI (Ellis & Thal, 2008; Zubrick et al., 2007). Adding to this early identification and prediction problem is the fact that extreme normal variability in the rates of word learning during early development may contribute to the difficulty differentiating LTs at risk for SLI from LTs who are developing typically.

PREDICTORS OF OUTCOME

Several longitudinal studies have examined predictors of LT outcomes and while informative, results are inconsistent and not terribly accurate in predicting outcomes (Horwitz,
Irwin, Briggs-Gowan, Heenan, Mendoza, & Carter, 2003; Zubrick et al., 2007). There are a number of variables that have been examined such as socioeconomic status (SES), gender, early expressive ability and processing skills (i.e., reaction time (RT)) that seem to account for some but not all of the variance in later language outcomes (Rescorla, 2011; Zubrick et al., 2007). Research suggests that while the predictive power increases slightly when variables are combined, the overall predictive power still remains low (Hadley & Holt, 2006; Law, Boyle, Harris, Harkness, & Nye, 2000; Zubrick et al., 2007). In addition, even though approximately 10-20% of toddlers will be classified as LTs at 16- to 24-months, the majority of will “catch up” and 17-26% of the LTs will continue to have persistent SLI by four to six years of age (Paul, 1996; Rescorla, 2002, Rescorla & Dale, 2013).

Rescorla’s review chapter (2011) found that there are only a few significant predictors of later language outcomes of LTs. Two factors that she deemed consistent across studies are a combination of receptive and productive delays, which together most often predicted continued language delays in children. In one large scale longitudinal study, young infants were assessed using various standardized tests of language across time points. Unlike other LT studies, this particular project also examined the early non-linguistic skills (e.g., gestures) that are relevant for language development. Specifically, children’s gestures, word comprehension, word production and rate of vocabulary growth were assessed between 10-28 months, and their cognitive and language skills were assessed at four and seven years. In these studies, Thal (2005) and Thal, Marchman and Tomblin (2013) examined various predictors of continued delay from 10-16 and 28-months in a cohort of 1,100 children sampled with the CDI (a parent report measure of infant vocabulary). Thal’s work found different measures predicted language status at 28 months and later outcomes at age four and seven years (Thal, Marchman, & Tomblin, 2013). Specifically, words comprehended, words produced and vocabulary growth each significantly predicted language status at 28 months and together these measures predicted language impairment at
school age. Adding factors such as SES (as indexed by education level) and family history of language impairments to the low gesture, comprehension, and production profile appear to be the best predictors of continued language delay over and above any one of these measured viewed in isolation (Thal, 2005; Thal, Marchman, & Tomblin, 2013). However, even with this increased predictive power, combined factors correctly identify less than 30% of those LTs who will have persistent SLI at 4-6 years of age (Ellis & Thal, 2008; Zubrick et al., 2007).

While most predictors of outcomes have been static measures (i.e., parent report of vocabulary or standardized tests) or external factors (i.e., SES), only a few studies have examined infants’ processing variables as predictors for later outcomes. Response speed was first examined in LTs during a novel word learning task. The LT group had significantly longer response times to novel words than the typical control group (Ellis Weismer & Evans, 2002). In this study the lexical processing performance was related to language measures at 30 months of age; results suggest that performance on processing measures combined with static language measures may prove useful for predicting outcomes in young children (Ellis Weismer & Evans, 2002). More recently, Fernald and Marchman (2012) found a relationship between accuracy, speed of processing in a real word recognition task and vocabulary growth between 18-30 months of age, and further that reaction times at 25 months predicted outcomes at age eight (Marchman & Fernald, 2008). These studies suggest that using processing measures in addition to static measures may better predict language outcomes.

**A Dimensional Approach**

Implicit in much of the LT research is the assumption that SLI constitutes a discrete diagnostic category and, by extension, there should be a subset of LTs who will have a diagnosis of SLI by school age (Ellis & Thal, 2008; Ellis Weismer, Venker, Evans, & Moyle, 2011). However, being a “Late Talker” is not, in and of itself, a clinical diagnosis. It only means that the child is at the tail end of the normal distribution with respect to his or her language development.
Further, a late talking child could be late to talk for a variety of reasons, such as having poor environmental factors (i.e., low language input,) being on the autism spectrum, or in fact having a language disorder (to name just a few possibilities). Recently, researchers have argued a dimensional account of language delay needs to be reconsidered to further examine outcomes of LTs (Dollaghan, 2004, 2011, 2013; Rescorla, 2009, 2011; Rescorla & Dale, 2013; Thal, Marchman, & Tomblin, 2013). This idea was originally discussed as a dimensional construct of SLI in late 1980’s (Leonard, 1987). Since then researchers who argue for a distinct taxon with one specific cause for SLI have failed to identify a single gene specifically responsible for the impairment (Bishop, 2009), which would have suggested the possibility of a distinct unique identifier group. Instead research has found the heterogeneous characteristics of children with SLI suggest a more multi-dimensional view of the impairment. Dollaghan has suggested that the term “SLI” represents those children who fall at the lower end of the continuum across multiple language related skills (2011, 2013). In particular, she suggests that if SLI is a discrete category, then researchers need to focus on specifying a unique phenotype (i.e., linked to verb tense), for the condition. Alternatively, if researchers assume a multi-dimensional view of SLI, there is the potential for heterogeneity in symptoms and origins, and researchers need to focus instead on the cluster of causal influences underlying these individual differences in language skill.

It is well established that the language-related cognitive processes such as speed of processing, working memory and implicit statistical learning also appear to play roles in children’s language development (e.g., Marchman & Fernald, 2008; Fernald & Marchman, 2012; Graf Estes, Evans, Alibali, & Saffran, 2007) and language deficits in children with SLI (e.g., Ellis Weismer, Evans, & Hesketh, 1999; Evans, Saffran, & Robe-Torres, 2009; Leonard, Ellis Weismer, Miller, Francis, Tomblin, & Kail, 2007; Montgomery, 2000; Montgomery & Evans, 2009; Tomblin, Mainela-Arnold, & Zhang., 2007). This suggests that a potential better approach
to identifying those LTs who are at risk for SLI might be to focus on language-related cognitive processing mechanisms in infants and toddlers using a dimensional research design.

**THE PRESENT STUDY**

The purpose of this project was to use a multi-dimensional approach to determine if, in a group of 54 18-month-olds, there is a subset of infants whose performance at the tail end of the distribution for language-related processing of real words, learning of novel words, and implicit statistical word learning, also places them at risk for continued language impairment (as defined by slowest rate of vocabulary growth at 24 months compared to standardized vocabulary scores). We predict that there will be a subset of infants who fall at the tail end of the distribution across multiple measures of language-related cognitive processing, consistent with Dollaghan’s findings for children with SLI (2004; 2011) and that these infants are at the greatest risk for continued language impairment.

We first examined the relationship of the processing variables and vocabulary scores (e.g. correlations) and then examined distributions of z-scores across a sample of 18-month-olds to determine if infants at the most risk for continued language delay cluster at the tail end of the distribution across multiple measures of lexical and cognitive processing. This study allowed us to explore the relationship between lexical and cognitive processing variables that are important for language learning in infants at 18 months of age.

**METHODS**

*Participants*

Fifty-four, 18-month-old infants (M = 554.18 days, SD = 12.72) (on visit 1), 28 girls and 26 boys) from primarily monolingual English-speaking homes and their parents were recruited in the surrounding metropolitan region of San Diego, California. Parents had responded to flyers and ads posted in the community, parenting magazines/newsletters and websites, pediatrician offices, retail stores, and on bulletin boards at children and family play centers. Recruitment and
advertisement of the study was also conducted through booths at family swap meets, personal communication and other contacts throughout the San Diego community.

The 54 infant participants included in all analyses were approximately 18 months of age at initial time of testing and came into the lab for two separate sessions (about one week apart depending on family schedules). Each infant session was approximately 1.5-hours long. Regardless of the infant’s abilities and performance during testing, parents received $10 per session and the infant received a children’s book. An additional eight infant participants began the testing but ultimately were excluded from all analyses -- three infants for not completing all three experimental tasks, three for only participating in the first visit and then dropping from the study, one for possible hearing difficulties, and one for low cognitive ability.

All of the 54 infants included in analyses were reported to have normal hearing and vision. Additionally, all infants were reported to have a normal medical history with no serious complications at birth, and no known neurological impairments or developmental disabilities. All mothers reported a near-term or full-term pregnancy with at least 36 weeks gestation. In addition to parent report of normal hearing, all infants were reported to have passed infant hearing screenings at birth and had no report of recent or chronic ear infections. During the lab visit, each infant’s middle ear function was assessed using tympanometry.

Thirty-eight infants were reported to be first-born or only children, and 16 infants had at least one sibling. Minority participation within the sample was consistent with the demographics of the San Diego area. Caucasian participants represented 72% of the sample (of which 14% were reported to be Hispanic), 5% reported an African-American background, 4% identified as Asian or Other and 19% were of a bi- or multi-racial background.

At 18 months the sample of 54 infants had an average standard score of 102.68 (SD = 11.56) on the Cognitive Scale of the Bayley Scales of Infant Development (BSID-III, Bayley, 2005) and an average standard score of 103.05 (SD = 11.31) on the Language Scale (BSID-III,
Bayley, 2005). As a group vocabulary measures were skewed below average at 18 months. Specifically, for words comprehended the average number of words understood was 212.92 (SD = 88.63) which is the 38.22\textsuperscript{th} percentile based on the MacArthur Bates Communicative Development Inventory: Words & Gestures (Fenson et al., 2007). The average number of words produced was 80.98 (SD = 66.28), which is at the 39.24\textsuperscript{th} percentile based on the 18 months MacArthur Bates Communicative Development Inventory: Words & Gestures (Fenson et al., 2007).

At 18 months, based on the MacArthur Bates Communicative Development Inventory: Words & Sentences (Fenson et al., 2007), the sample produced an average 80.11 (SD = 77.03) words, which is at the 38.87\textsuperscript{th} percentile (SD = 26.03). At 24 months, using the MacArthur Bates Communicative Development Inventory: Words & Sentences (Fenson et al., 2007) the sample mean had a normal distribution for words produced, M = 337.53 (SD = 163.42) words, which is the 56.16\textsuperscript{th} (SD = 28.05) percentile based on the Words & Sentences. The sample had an average rate of vocabulary growth of 257.43 (SD = 124.96) words between 18 and 24 months (see Table 5.1 for sample means and see appendices 5A for distributions of percentiles for all infants).

At 18 months, of the 54 infants tested, 14 infants were LTs using the 20\textsuperscript{th} percentile or below criteria on the Words & Sentences. At 18 months, these late talking infants had productive vocabularies below the 15\textsuperscript{th} percentile (M = 8.5, SD = 4.25). At 24 months, based on the Words & Sentences, seven of the 14 infants who were classified as LT at 18 months moved into the “typical” range in productive vocabulary measures. There were eight infants who were identified as LTs at 24 months with vocabulary percentiles on the Words & Sentences below the 20\textsuperscript{th} percentile (M = 8.5, SD = 6.06, range 1-18\textsuperscript{th}), seven of the original LTs identified at 18 months and one additional participant who moved into the LT percentile range. The remaining 39 infants had vocabulary production percentiles in the typical range at both time points (M = 64.5, SD = 21.03, range 23-99\textsuperscript{th}).
Mothers of the infants were an average 33.75 years of age, while fathers were an average 37.13 years old. Mothers had 16.67 (SD = 1.55) years of education and fathers had 15.96 (SD = 1.86) years of education (see Appendix 5.B. for distribution of maternal education). Thirty-seven percent of mothers worked full-time, 23% worked part-time and 40% stayed at home or were on leave. Eighty-eight percent of fathers worked full-time, 4% worked part-time, and 8% stayed at home. Approximately 15% of the families received financial assistance through various organizations (e.g., Veterans benefits, WIC, or unemployment). Of the 54 infant participants used
in all subsequent analyses, 94% of infants lived in homes with both biological parents, and 6% of infants lived in a home headed by a single parent.

*Procedures*

Parents who were interested in the study responded to the posted flyers and announcements in the community by calling or emailing the primary investigator (E.E.). During the initial contact with the parent, the investigator described the study and answered any questions. A brief screening was used to determine if the infant and parents were eligible to participate. Once eligibility was determined, two sessions were scheduled for soon after the infant turned 18 months of age. Approximately one week before the scheduled testing session, a packet was mailed to the parent(s). This packet included a confirmation letter with the date and time of the first scheduled visit, a map and directions, and a long-form version of the MacArthur Bates Communicative Development Inventory: Words & Sentences (Fenson et al., 2007). The letter reminded the parents to complete the Words & Sentences form prior to the first lab visit. A reminder call or email was sent the day before the session.

Each infant was seen individually for standardized language and cognitive development assessment as well as for the experimental tasks. Infant test sessions took place in the Eye-tracking rooms within the Center for Research in Language at UCSD. Lab visits were scheduled approximately one week apart at the family’s convenience. During Visit 1, parents signed the consent forms, returned the Words & Sentences form (Fenson et al., 2007) (which was sent home prior to the visit to complete)\(^1\) and infants completed the experimental and behavioral tasks. At the end of the first visit, parents were given additional forms to take home and complete. These forms included background history forms and the Words & Gestures form (Fenson et al., 2007). During Visit 2, parents returned those forms and infants completed another experimental task and

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\(^1\) MacArthur Bates Communicative Development Inventory: Words & Sentences were obtained from the parent, but were scored after the visit by a research assistant blind to the experimental questions and details of the test session.
behavioral tasks and were given a hearing screening.

**Behavioral Testing**

During the infant visits, various offline behavioral measures were completed. These measures included the Bayley Scales of Infant Development-III Cognitive and Language subscales (*BSID-III*), Bayley, 2005).

**EXPERIMENTAL TASKS**

The same experimental procedures discussed in Chapters 2-4 were used for this study. (See also Figure 5.1 below).

**Study 1: Real Word Recognition**

The purpose of the real word recognition task was to investigate real-time processing of real word recognition in 18-month-old infants using eye-tracking. The same procedure and design as used in the real word recognition task described in Chapter 2 were used (see Chapter 2, page 37 for a more detailed description of real word recognition).

**Study 2: Novel Word Learning Task**

The purpose of the novel word learning task was to investigate real-time processing of novel word learning in 18-month-old infants using eye-tracking. The same procedure and design as used in the novel word learning task described in Chapter 3 were used (see Chapter 3, page 65 for details).

**Study 3: Implicit Word Learning Task**

The purpose of this task was to investigate real-time processing of implicit word learning in 18-month old infants using eye-tracking. The same procedure and design as used in the implicit word learning task described in Chapter 4 were used (see Chapter 4, page 91 for details).
RESULTS

Variables of Interest

For our analyses, we examined six variables from each task (i.e., real, novel and implicit): accuracy, reaction time, proportion of looking to target, first fixation duration, number of target fixations, and total fixations during the trial (see Table 5.2 below). We also examined the relationship between vocabulary measures (i.e., comprehension, production and rate of change) and the processing variables.
Next we report the sample means for each of the variables of interest by condition (see Table 5.3).

Table 5.3. Group means and standard deviations for reaction time, % of looking to target, 1st fixation duration, and mean number of fixations to target and mean number of fixations during trial

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>64.5% (13.4)</td>
<td>52.0% (15.6)</td>
<td>48.7% (20.4)</td>
</tr>
<tr>
<td>Reaction Time (RT in ms)</td>
<td>467.00 (139.66)</td>
<td>507.21 (321.70)</td>
<td>808.55 (350.16)</td>
</tr>
<tr>
<td>% Looking to Target</td>
<td>30.1% (8.2)</td>
<td>67% (14.5)</td>
<td>43.4% (13.7)</td>
</tr>
<tr>
<td>Duration of 1st Fixation (in ms)</td>
<td>611.02 (209.09)</td>
<td>497.97 (248.07)</td>
<td>466.31 (173.62)</td>
</tr>
<tr>
<td># Fixations to Target</td>
<td>1.94 (.391)</td>
<td>2.53 (.58)</td>
<td>1.82 (.65)</td>
</tr>
<tr>
<td># of Fixations during Trial</td>
<td>3.85 (.473)</td>
<td>4.18 (.79)</td>
<td>4.26 (.88)</td>
</tr>
</tbody>
</table>

**Correlations**

For each task, we first conducted correlational analyses between vocabulary measures (raw numbers reported by parents) and each processing variable; this enabled us to better understand the relationship between vocabulary and each measure for the sample.
Study 1: Real Word Recognition

There are no significant correlations between any of the vocabulary measures and any of the real word recognition processing variables (see Table 5.4).

Table 5.4. Correlations between real word processing variables and vocabulary measures*

<table>
<thead>
<tr>
<th>Real Word Processing Variables</th>
<th>18-mos Words &amp; Gestures Comprehension</th>
<th>18-mos Words &amp; Gestures Production</th>
<th>18-mos Words &amp; Sentences Production</th>
<th>24-mos Words &amp; Sentences Production</th>
<th>Rate of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>.204</td>
<td>.145</td>
<td>.065</td>
<td>.133</td>
<td>.134</td>
</tr>
<tr>
<td>Reaction Time (RT in ms)</td>
<td>-.017</td>
<td>.146</td>
<td>.047</td>
<td>.084</td>
<td>.081</td>
</tr>
<tr>
<td>% Looking to Target</td>
<td>.116</td>
<td>.061</td>
<td>.035</td>
<td>.058</td>
<td>.024</td>
</tr>
<tr>
<td>Duration of 1st Fixation (in ms)</td>
<td>-.171</td>
<td>.006</td>
<td>.001</td>
<td>.029</td>
<td>.037</td>
</tr>
<tr>
<td># Fixations to Target</td>
<td>.228</td>
<td>-.073</td>
<td>-.012</td>
<td>-.156</td>
<td>-.196</td>
</tr>
<tr>
<td># of Fixations during Trial</td>
<td>.162</td>
<td>.090</td>
<td>-.056</td>
<td>-.171</td>
<td>-.188</td>
</tr>
</tbody>
</table>

*In each correlation raw counts of number of words reported for each vocabulary measure were used.

Study 2: Novel Word Learning

There are significant correlations between the average number of fixations to the target novel picture and 18-month comprehension ability \( (r = .273, p = .048) \) and words produced \( (r = .283, p = .040) \) using Words & Gestures, as well as for words produced on the Words & Sentences at 18 months \( (r = .300, p = .027) \). This suggests that the more words an infant understands and produces at 18 months, the more the infant will fixate on the novel target picture at test. There are no other significant correlations between novel word learning processing variables and vocabulary measures (see Table 5.5).
Table 5.5. Correlations between novel word processing variables and vocabulary measures

<table>
<thead>
<tr>
<th>Novel Word Learning Variables</th>
<th>18-mos Words &amp; Gestures Comprehension</th>
<th>18-mos Words &amp; Gestures Production</th>
<th>18-mos Words &amp; Sentences Production</th>
<th>24-mos Words &amp; Sentences Production</th>
<th>Rate of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>.178</td>
<td>.166</td>
<td>-.098</td>
<td>.077</td>
<td>-.009</td>
</tr>
<tr>
<td>Reaction Time (RT in ms)</td>
<td>-.125</td>
<td>-.107</td>
<td>-.084</td>
<td>.016</td>
<td>.075</td>
</tr>
<tr>
<td>% Looking to Target</td>
<td>.013</td>
<td>-.060</td>
<td>-.038</td>
<td>.158</td>
<td>.220</td>
</tr>
<tr>
<td>Duration of 1st Fixation (in ms)</td>
<td>-.205</td>
<td>-.144</td>
<td>-.165</td>
<td>.002</td>
<td>.104</td>
</tr>
<tr>
<td># Fixations to Target</td>
<td>.273</td>
<td>.283</td>
<td>.300</td>
<td>.184</td>
<td>.056</td>
</tr>
<tr>
<td># of Fixations during Trial</td>
<td>.166</td>
<td>.218</td>
<td>.222</td>
<td>-.062</td>
<td>-.218</td>
</tr>
</tbody>
</table>

In each correlation we used raw counts of number of words reported for each vocabulary measure.

Study 3: Implicit Word Learning

There is a significant correlation between the average proportion of looking to the target implicit picture and 24-month production ability ($r = .307, p = .024$), suggesting that the more an 18-month-old infant spent looking at the implicit target picture at test the more words the infant will produce at 24 months of age. There is also a significant correlation between proportion of looking to the implicit target word at 18 months and rate of change in vocabulary, ($r = .282, p = .039$), suggesting the infants with greater proportion looking to the implicit target word at 18 months had greater vocabulary growth between 18 and 24 months. There are no other significant correlations between implicit word learning processing variables and vocabulary measures (see Table 5.6).
Table 5.6. Correlations between implicit word learning processing variables and vocabulary measures\(^c\)

<table>
<thead>
<tr>
<th>Implicit Word Learning Variables</th>
<th>18-mos Words &amp; Gestures Comprehension</th>
<th>18-mos Words &amp; Gestures Production</th>
<th>18-mos Words &amp; Sentences Production</th>
<th>24-mos Words &amp; Sentences Production</th>
<th>Rate of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>-.043</td>
<td>.134</td>
<td>.095</td>
<td>.239</td>
<td>.255</td>
</tr>
<tr>
<td>Reaction Time (RT in ms)</td>
<td>.089</td>
<td>-.061</td>
<td>-.030</td>
<td>-.046</td>
<td>-.042</td>
</tr>
<tr>
<td>% Looking to Target</td>
<td>.138</td>
<td>.216</td>
<td>.195</td>
<td>.307</td>
<td>.282</td>
</tr>
<tr>
<td>Duration of 1st Fixation (in ms)</td>
<td>-.033</td>
<td>.035</td>
<td>-.023</td>
<td>.105</td>
<td>.152</td>
</tr>
<tr>
<td># Fixations to Target</td>
<td>-.073</td>
<td>.088</td>
<td>.146</td>
<td>.186</td>
<td>.153</td>
</tr>
<tr>
<td># of Fixations during Trial</td>
<td>-.196</td>
<td>-.034</td>
<td>.080</td>
<td>-.044</td>
<td>-.107</td>
</tr>
</tbody>
</table>

\(^c\)In each correlation we used raw counts of number of words reported for each vocabulary measure.

**Distributional Analysis: Predicting Later Language**

For each of the six variables of interest, for each task described above, infants’ individual raw scores were converted to z-scores. The infants’ z-scores were rank ordered to determine if the same subset of infants fell at the bottom of the continuum for each of the variables of interest. For each variable we separately examined the z-score distribution of the entire sample to determine whether the same infants were at the bottom across measures and across tasks. Similar to previous research used to diagnose children with SLI in kindergarten (Tomblin et al., 1996), we set a cut off of 1.12 SD for each variable measure to identify those with at risk performance.

Overall, these analyses will allow us (1) to identify those infants who consistently have lower z-scores across a set of processing tasks; (2) if we observe a clustering pattern, to determine whether clustered performance on particular variables can identify infants who are likely to fall below the LT identification criteria of low vocabulary ability at 24 months (i.e., below the 20\(^{th}\) percentile); and (3) to determine whether a clustering pattern also identifies infants with the slowest rate of vocabulary growth from 18-24 months. Using the prevalence of SLI
found at kindergarten (Tomblin et al. 1997), it is predicted that a subset (approximately 7%) of infants will consistently fall at the tail end of the distribution for at least two of the six the variables of interest and that this subset of infants will cluster across studies. The infants that consistently fall at the bottom are predicted to be the infants at the greatest risk for SLI.

We therefore examined the z-score distributions for each variable by task to determine if (1) a subset of infants cluster across processing variables or across tasks and (2) whether individual infant processing variables at 18 months can be used to identify infants later language outcomes. These subsequent distribution analyses describe the lexical and cognitive processing profiles of a subset of infants compared to the entire sample. Specifically, to best characterize the infants, we list a subset of ten participants who have fallen at the tail end of the distribution (1.12 SD) for each of the variables. The z-scores for each processing variable across tasks are summarized below for the ten infants (see Appendix 5.C. for z-score distributions for all infants (N = 54) sorted by task).

For each variable, subjects’ raw scores were standardized and compared to the sample mean to obtain a z-score. In the summaries below, the variable of reaction time displays z-scores that are larger, which represent slower reaction times. For proportion of looking, smaller or negative z-scores represent less time overall looking to the target picture. In the first fixation duration measure, negative z-scores represent shorter first look durations. For number of fixations to target, negative z-scores represent fewer looks to target, while for total # of fixations during trial, positive or larger z-scores represent more looks overall, which may represent instability or uncertainty.

Next we address our second question: Can an infant’s lexical and cognitive processing abilities at 18-months be used to identify later language ability (as measured by the traditionally used percentile score for words produced at 24 months) and their vocabulary growth (as measured by rate of change on productive vocabulary at 18 and 24 months (on Words & Sentences))? The
following tables list the ten participants whose scores were the worst compared to the sample for each experimental variable. The dark bolded line under each variable represents the 1.12 SD cut-off (similar to what was used in the EpiSLI study, Tomblin et al., 1996). The first set of tables for each task displays cells marked in yellow to denote who within the subset of ten infants had fallen below our 1.12 SD cut off and also had language scores that were below the 20th percentile on productive vocabulary at 24 months. In the second set of tables for each task, cells marked in purple denote the subset of infants who had fallen below the 1.12 SD cut off for the experimental processing variable and had scores 1.12 SD or more below the group as a whole with respect to rate of vocabulary growth. We discuss the implications of these outcomes in our discussion.

**STUDY 1: REAL WORD RECOGNITION**

The summary of z-scores below displays the individual subjects and their corresponding z-scores for each variable of the real word recognition task. For real word processing, accuracy distribution shows two infants (20, 55) were below the cut off in the distribution and below the 20th percentile in productive vocabulary at 24 months. The reaction time distribution shows that of the ten infants at the tail end of the distribution (1.12 SD) at 18 months, none of the infants were below the 20th percentile at 24 months. The bottom of the distribution of proportion of looking to target had two infants (20, 30) who were also below the 20th percentile at 24 months. The first fixation duration distribution also had one infant (55) who was identified as below the 20th percentile at 24 months. The target fixation count distribution had no infants below 20th percentile and the total fixation count distribution had three infants (27, 33, 55) with percentiles below the 20th at 24-months (see Table 5.7).
Table 5.7. Individual z-scores for real word variables from a subset of infants at 18 months, highlighted in yellow are the infants who were below the 20\textsuperscript{th} percentile at 24 months.

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>RT</th>
<th>% looking to target</th>
<th>1\textsuperscript{st} Fix Duration</th>
<th>Target Fix Count</th>
<th>Total Fix Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>Z-score</td>
<td>Subject</td>
<td>Z-score</td>
<td>Subject</td>
<td>Z-score</td>
</tr>
<tr>
<td>41</td>
<td>-2.48</td>
<td>51</td>
<td>3.12</td>
<td>62</td>
<td>-2.33</td>
</tr>
<tr>
<td>55</td>
<td>-2.48</td>
<td>39</td>
<td>1.99</td>
<td>39</td>
<td>-2.21</td>
</tr>
<tr>
<td>20</td>
<td>-2.01</td>
<td>18</td>
<td>1.75</td>
<td>20</td>
<td>-1.84</td>
</tr>
<tr>
<td>16</td>
<td>-1.55</td>
<td>40</td>
<td>1.41</td>
<td>51</td>
<td>-1.55</td>
</tr>
<tr>
<td>50</td>
<td>-1.55</td>
<td>30</td>
<td>1.09</td>
<td>30</td>
<td>-1.54</td>
</tr>
<tr>
<td>39</td>
<td>-1.08</td>
<td>61</td>
<td>1.06</td>
<td>6</td>
<td>-1.53</td>
</tr>
<tr>
<td>43</td>
<td>-1.08</td>
<td>28</td>
<td>0.91</td>
<td>18</td>
<td>-1.40</td>
</tr>
<tr>
<td>51</td>
<td>-1.08</td>
<td>9</td>
<td>0.87</td>
<td>50</td>
<td>-1.12</td>
</tr>
<tr>
<td>6</td>
<td>-1.08</td>
<td>58</td>
<td>0.78</td>
<td>25</td>
<td>-0.94</td>
</tr>
<tr>
<td>10</td>
<td>-1.08</td>
<td>45</td>
<td>0.77</td>
<td>61</td>
<td>-0.86</td>
</tr>
</tbody>
</table>

Next, in purple we highlighted those infants who are at the tail end of the distributions (1.12 SD marked by the bolded dark line) for real word processing as well as have the slowest rate of growth in vocabulary from 18-24 months (1.12 SD below). In the accuracy distribution we see two infants (20, 55) have poor accuracy as well as slow vocabulary growth. We see the reaction time distribution shows that of the ten infants at the tail end of the distribution at 18 months, only one infant (39) had slow RT and slow vocabulary growth. The bottom of the distribution of proportion of looking to target had three infants (20, 30, 39) with slow growth from 18-24 months. The first fixation duration distribution had two infants (39, 55) with slow rate of change. The target fixation count distribution had one infant (14) and the total fixation count distribution had three infants (27, 33, 55) with slow growth of vocabulary (see Table 5.8).
Table 5.8. Individual z-scores for real word variables from a subset of infants at 18 months, highlighted in purple are the infants who had the slowest rate of vocabulary growth from 18-24 months at 1.12 SD below the sample mean

<table>
<thead>
<tr>
<th>Subject</th>
<th>Z-score</th>
<th>Subject</th>
<th>Z-score</th>
<th>Subject</th>
<th>Z-score</th>
<th>Subject</th>
<th>Z-score</th>
<th>Subject</th>
<th>Z-score</th>
<th>Subject</th>
<th>Z-score</th>
<th>Subject</th>
<th>Z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>-2.48</td>
<td>51</td>
<td>3.12</td>
<td>62</td>
<td>-2.33</td>
<td>55</td>
<td>-1.86</td>
<td>14</td>
<td>-1.90</td>
<td>27</td>
<td>2.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>-2.48</td>
<td>39</td>
<td>1.99</td>
<td>39</td>
<td>-2.21</td>
<td>11</td>
<td>-1.55</td>
<td>10</td>
<td>-1.77</td>
<td>34</td>
<td>2.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>-2.01</td>
<td>18</td>
<td>1.75</td>
<td>20</td>
<td>-1.84</td>
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<td>-1.28</td>
<td>51</td>
<td>-1.77</td>
<td>55</td>
<td>1.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>-1.55</td>
<td>40</td>
<td>1.41</td>
<td>51</td>
<td>-1.55</td>
<td>29</td>
<td>-1.23</td>
<td>62</td>
<td>-1.56</td>
<td>16</td>
<td>1.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>-1.55</td>
<td>30</td>
<td>1.09</td>
<td>30</td>
<td>-1.54</td>
<td>39</td>
<td>-1.16</td>
<td>40</td>
<td>-1.13</td>
<td>33</td>
<td>1.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>-1.08</td>
<td>61</td>
<td>1.06</td>
<td>6</td>
<td>-1.53</td>
<td>49</td>
<td>-1.15</td>
<td>6</td>
<td>-1.13</td>
<td>38</td>
<td>1.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>-1.08</td>
<td>28</td>
<td>.91</td>
<td>18</td>
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<td>-1.11</td>
<td>45</td>
<td>-.92</td>
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<td>1.35</td>
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<td></td>
</tr>
<tr>
<td>51</td>
<td>-1.08</td>
<td>9</td>
<td>.87</td>
<td>50</td>
<td>-1.12</td>
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<td>-1.04</td>
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<td>-.88</td>
<td>61</td>
<td>1.26</td>
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<td></td>
</tr>
<tr>
<td>6</td>
<td>-1.08</td>
<td>58</td>
<td>.78</td>
<td>25</td>
<td>-.94</td>
<td>34</td>
<td>-1.02</td>
<td>42</td>
<td>-.88</td>
<td>29</td>
<td>1.26</td>
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<td></td>
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<td>10</td>
<td>-1.08</td>
<td>45</td>
<td>.77</td>
<td>61</td>
<td>-.86</td>
<td>27</td>
<td>-.99</td>
<td>18</td>
<td>-.84</td>
<td>50</td>
<td>1.20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Study 2: Novel Word Learning

The summary of z-scores below displays the individual subjects and their corresponding z-scores for each variable of the novel word learning task. Highlighted in yellow are the infants who below our cut off of 1.12 SD (marked by the bolded dark line) for each processing variable and were below the 20th percentile at 24 months. The accuracy distribution shows that none of the infants with lowest accuracy were below the 20th percentile at 24 months. For novel word learning the reaction time distribution shows that of the ten infants at the tail end of the distribution, only one infant (17) was below the 20th percentile at 24 months. The distribution of proportion of looking, first fixation duration and target fixation count did not have any infants who were at the tail end of the distribution at 18 months fall below the 20th percentile fall at 24 months. Total fixation count had one infant (27) who was at the tail end of the distribution at 18 months and also below the 20th percentile in productive vocabulary at 24 months (see Table 5.9).
Table 5.9. Individual z-scores for novel word variables from a subset of infants at 18 months, highlighted in yellow are the infants who were below the 20th percentile at 24 months

<table>
<thead>
<tr>
<th>Subject</th>
<th>Z-score</th>
<th>RT</th>
<th>Z-score</th>
<th>% looking to target</th>
<th>Z-score</th>
<th>1st Fix Duration</th>
<th>Z-score</th>
<th>Subject</th>
<th>Z-score</th>
<th>Target Fix Count</th>
<th>Z-score</th>
<th>Subject</th>
<th>Z-score</th>
<th>Total Fix Count</th>
<th>Z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>-1.72</td>
<td>25</td>
<td>2.83</td>
<td>-1.19</td>
<td>16</td>
<td>-1.15</td>
<td></td>
<td>1</td>
<td>-1.77</td>
<td>39</td>
<td>2.27</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>-1.72</td>
<td>48</td>
<td>2.27</td>
<td>-1.60</td>
<td>27</td>
<td>-1.04</td>
<td></td>
<td>19</td>
<td>-1.77</td>
<td>27</td>
<td>1.77</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-1.72</td>
<td>40</td>
<td>2.10</td>
<td>-1.30</td>
<td>5</td>
<td>-0.89</td>
<td></td>
<td>51</td>
<td>-1.77</td>
<td>49</td>
<td>1.33</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>51</td>
<td>-1.72</td>
<td>17</td>
<td>1.53</td>
<td>-0.98</td>
<td>52</td>
<td>-0.87</td>
<td></td>
<td>26</td>
<td>-1.48</td>
<td>53</td>
<td>1.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>49</td>
<td>-1.72</td>
<td>51</td>
<td>1.32</td>
<td>-0.94</td>
<td>53</td>
<td>-0.85</td>
<td></td>
<td>54</td>
<td>-1.48</td>
<td>55</td>
<td>1.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-0.92</td>
<td>36</td>
<td>1.10</td>
<td>-0.86</td>
<td>49</td>
<td>-0.82</td>
<td></td>
<td>2</td>
<td>-1.34</td>
<td>9</td>
<td>1.02</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>55</td>
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<td>27</td>
<td>0.99</td>
<td>-0.86</td>
<td>10</td>
<td>-0.78</td>
<td></td>
<td>25</td>
<td>-1.25</td>
<td>37</td>
<td>1.02</td>
<td></td>
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<td></td>
</tr>
<tr>
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<td>38</td>
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<td>-0.80</td>
<td>39</td>
<td>-0.77</td>
<td></td>
<td>14</td>
<td>-1.25</td>
<td>51</td>
<td>1.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>-0.92</td>
<td>11</td>
<td>0.89</td>
<td>-0.80</td>
<td>6</td>
<td>-0.71</td>
<td></td>
<td>16</td>
<td>-0.91</td>
<td>45</td>
<td>0.76</td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td>-0.92</td>
<td>52</td>
<td>0.88</td>
<td>-0.75</td>
<td>50</td>
<td>-0.66</td>
<td></td>
<td>20</td>
<td>-0.91</td>
<td>43</td>
<td>0.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Next, for novel word learning we highlighted those infants who were at the tail ends of the distributions (1.12 SD marked by the bolded dark line) and had the slowest rate of growth in vocabulary from 18-24 months (1.12 SD below). The accuracy distribution does not have any infants with the slowest rate of vocabulary growth. We see the reaction time distribution shows that of the ten infants at the tail end of the distribution one infant (17) had slow vocabulary growth. The bottom of the distribution of proportion of looking to target and first fixation duration did not have any infants with slow growth from 18-24 months. The target fixation count distribution had one infant (14) and the total fixation count distribution had two infants (27, 39) with slow growth of vocabulary (see Table 5.10).
Table 5.10. Individual z-scores for novel word learning variables from a subset of infants at 18 months, highlighted in purple are the infants who had the slowest rate of vocabulary growth from 18-24 months at 1.12 SD below the sample mean

<table>
<thead>
<tr>
<th>Subject</th>
<th>Accuracy Z-score</th>
<th>RT Z-score</th>
<th>% Looking to Target Z-score</th>
<th>1st Fix Duration Z-score</th>
<th>Target Fix Count Z-score</th>
<th>Total Fix Count Z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-1.72</td>
<td>25</td>
<td>20.83</td>
<td>-3.19</td>
<td>16</td>
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<td>48</td>
<td>2.27</td>
<td>-1.60</td>
<td>27</td>
<td>-1.04</td>
</tr>
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<td>3</td>
<td>-1.72</td>
<td>40</td>
<td>2.10</td>
<td>-1.30</td>
<td>5</td>
<td>-0.89</td>
</tr>
<tr>
<td>51</td>
<td>-1.72</td>
<td>17</td>
<td>1.53</td>
<td>-0.98</td>
<td>26</td>
<td>-1.48</td>
</tr>
<tr>
<td>40</td>
<td>-1.72</td>
<td>51</td>
<td>1.32</td>
<td>-0.94</td>
<td>55</td>
<td>-0.85</td>
</tr>
<tr>
<td>26</td>
<td>-0.92</td>
<td>36</td>
<td>1.10</td>
<td>-0.86</td>
<td>39</td>
<td>-0.82</td>
</tr>
<tr>
<td>5</td>
<td>-0.92</td>
<td>27</td>
<td>0.99</td>
<td>-0.84</td>
<td>9</td>
<td>-0.78</td>
</tr>
<tr>
<td>17</td>
<td>-0.92</td>
<td>38</td>
<td>0.93</td>
<td>-0.80</td>
<td>42</td>
<td>-0.77</td>
</tr>
<tr>
<td>30</td>
<td>-0.92</td>
<td>11</td>
<td>0.89</td>
<td>-0.80</td>
<td>56</td>
<td>-0.71</td>
</tr>
<tr>
<td>33</td>
<td>-0.92</td>
<td>52</td>
<td>0.88</td>
<td>-0.75</td>
<td>37</td>
<td>-0.66</td>
</tr>
</tbody>
</table>

Study 3: Implicit Word Learning

The summary of z-scores below displays the individual subjects and their corresponding z-scores for each variable of the implicit word learning task. Highlighted in yellow are the infants who were at the tail end of the distribution at 18 months (1.12 SD marked by the bolded dark line) and were below the 20th percentile on productive vocabulary at 24 months.

For implicit word learning accuracy we see three infants (27, 33, 45) who have accuracy below 1.12 SD and are below the 20th percentile at 24 months. The reaction time distribution shows that of the ten infants at the tail end of the distribution one infant (33) was below the 20th percentile at 24 months. The bottom of the distribution of proportion of looking to target had three infants (20, 33, 45) who were below the 20th percentile at 24 months. The first fixation duration distribution had one infant (20) who was identified as below the 20th percentile at 24 months. The target fixation count distribution had two infants (33, 45), and the total fixation count distribution had one infant (33) below the 20th percentile at 24 months (see Table 5.11).

Finally for implicit word learning we highlighted in purple those infants who are at the tail ends of the distributions (1.12 SD, as marked by a bolded dark line) as well as have the slowest rate of growth in vocabulary from 18-24 months (1.12 SD).
Table 5.11. Individual z-scores for implicit word learning variables from a subset of infants at 18 months, highlighted in yellow are the infants who were below the 20th percentile at 24 months

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>RT</th>
<th>% looking to target</th>
<th>1st Fix Duration</th>
<th>Target Fix Count</th>
<th>Total Fix Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>Z-score</td>
<td>Subject</td>
<td>Z-score</td>
<td>Subject</td>
<td>Z-score</td>
</tr>
<tr>
<td>33</td>
<td>-2.38</td>
<td>28</td>
<td>2.66</td>
<td>33</td>
<td>-2.13</td>
</tr>
<tr>
<td>37</td>
<td>-1.57</td>
<td>54</td>
<td>2.40</td>
<td>39</td>
<td>-1.06</td>
</tr>
<tr>
<td>45</td>
<td>-1.57</td>
<td>33</td>
<td>2.06</td>
<td>62</td>
<td>-1.49</td>
</tr>
<tr>
<td>3</td>
<td>-1.57</td>
<td>13</td>
<td>1.84</td>
<td>45</td>
<td>-1.49</td>
</tr>
<tr>
<td>11</td>
<td>-1.57</td>
<td>61</td>
<td>1.77</td>
<td>32</td>
<td>-1.41</td>
</tr>
<tr>
<td>27</td>
<td>-1.57</td>
<td>24</td>
<td>1.09</td>
<td>20</td>
<td>-1.24</td>
</tr>
<tr>
<td>29</td>
<td>-.75</td>
<td>29</td>
<td>1.08</td>
<td>50</td>
<td>-1.21</td>
</tr>
<tr>
<td>49</td>
<td>-.75</td>
<td>3</td>
<td>.96</td>
<td>37</td>
<td>-1.21</td>
</tr>
<tr>
<td>61</td>
<td>-.75</td>
<td>32</td>
<td>.94</td>
<td>27</td>
<td>-.96</td>
</tr>
<tr>
<td>10</td>
<td>-.75</td>
<td>17</td>
<td>.81</td>
<td>4</td>
<td>-.89</td>
</tr>
</tbody>
</table>

The accuracy distribution has three infants (27, 33, 45) with poor accuracy as well as slowest rate of vocabulary growth from 18-24 months. We see the reaction time distribution shows that of the ten infants at the tail end of the distribution, one infant (33) had slow vocabulary growth. The bottom of the distribution of proportion of looking to target had four infants (20, 33, 39, 45) with slow growth from 18-24 months. The first fixation duration distribution also had two infants (20, 39) with slow rate of change. The target fixation count distribution had three infants (33, 39, 45) and the total fixation count distribution had one infant (33) with slow growth of vocabulary (see Table 5.12).
Table 5.12. Individual z-scores for implicit word learning variables from a subset of infants at 18 months, highlighted in purple are the infants who had the slowest rate of vocabulary growth from 18-24 months (1.12 SD)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Accuracy</th>
<th>RT</th>
<th>% looking to target</th>
<th>1st Fix Duration</th>
<th>Target Fix Count</th>
<th>Total Fix Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>-2.38</td>
<td>28</td>
<td>2.90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>-1.57</td>
<td>54</td>
<td>2.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>-1.57</td>
<td>33</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-1.57</td>
<td>13</td>
<td>1.84</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>-1.57</td>
<td>61</td>
<td>1.77</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>-1.57</td>
<td>24</td>
<td>1.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>-0.75</td>
<td>29</td>
<td>1.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>49</td>
<td>-0.75</td>
<td>3</td>
<td>0.96</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>61</td>
<td>-0.75</td>
<td>32</td>
<td>0.94</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>-0.75</td>
<td>17</td>
<td>0.81</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Patterns of Performance**

Our distribution analyses allowed us to explore the patterns of performance in infants’ abilities during three different lexical and cognitive processing tasks. Below is a table that summarizes performance by task and vocabulary outcome (see Table 5.13). Infants listed are those who fell below the cut off of 1.12 SD for each variable and was also identified by vocabulary outcome with productive vocabularies below the 20th percentile at 24 months or who had the slowest rate of growth. This information allows us to see how processing variables in combination with language scores may in fact begin to cluster infants who may be at the greatest risk for SLI.
Table 5.13. Summary of infants who had z-scores at the tail end of the distributions (1.12 SD) for the processing variables by task and vocabulary outcome

<table>
<thead>
<tr>
<th></th>
<th>Real</th>
<th>Novel</th>
<th>Implicit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accuracy</td>
<td>Reaction Time</td>
<td>% looking to Target</td>
</tr>
<tr>
<td>20th Percentile</td>
<td>20, 55</td>
<td>NA</td>
<td>20, 30</td>
</tr>
<tr>
<td>Rate of Change</td>
<td>20, 55</td>
<td>39</td>
<td>20, 30, 39</td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td>17</td>
<td>NA</td>
</tr>
<tr>
<td>Rate of Change</td>
<td>NA</td>
<td>17</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>27, 33, 45</td>
<td>33</td>
<td>20, 33, 45</td>
</tr>
<tr>
<td>Rate of Change</td>
<td>27, 33, 45</td>
<td>33</td>
<td>20, 33, 39, 45</td>
</tr>
</tbody>
</table>

**DISCUSSION**

The overall goal of this study was to use a multidimensional approach of language delay to examine lexical and cognitive processing measures in infants to determine if, in a group of 18-month-old infants, there is a subset whose performance is at the tail end of the distribution for language related processing of real words, learning of novel words, and implicit statistical word learning. We predicted that there would be a subset of late talking infants who fall at the tail end of the distribution across multiple measures of language-related cognitive processing, consistent with Dollaghan’s findings for children with SLI (2004; 2011).
Given the prevalence of SLI, for our sample we would expect approximately four of the 54 infants may actually have SLI. There could be many reasons why some infants exhibit clustering, and it may be that the differences in combinations of clustering may begin to differentiate who is at continued risk. For example, some infants may cluster for certain variables that are important for language learning and have low vocabulary profiles, which may put those infants at a greater risk for SLI than others. Alternatively, other infants may cluster at the bottom for some tasks, but have normal vocabulary levels; these infants may just be at the tail end of the normal distribution overall, but not at risk for SLI.

We explored whether processing measures alone can identify infants who have low vocabulary based on static measure of percentiles on the Words & Sentences at 24 months and also on a more dynamic measure of learning, rate of growth in vocabulary. This allowed us to investigate whether the clustering performance of individual infants across processing variables could be used in combination with their vocabulary percentiles and rate of growth, to identify those infants who are at risk for SLI. Our results exhibit interesting patterns consistent with a heterogeneous sample, and also suggest that multiple measures of lexical and cognitive processing may be able to identify later language abilities.

When we look at each processing task individually, we see that some variables better identify or cluster infants than other variables. Specifically, for real word recognition variables, one specific variable identifies infants with low language abilities based on the 20th percentile more than the other variables, that is, the number of fixations during the trial. If we use a more dynamic measure of growth as the language outcome measures we see three variables -- proportion of looking to target, first fixation duration, and number of fixations during the trial -- identifies infants with the slowest rate of change. When we examine the novel word learning variables we do not see any clear clusters of infants. The variable of total number of fixations may better identify those infants with slow vocabulary growth but the other variables do not
clearly identify clusters of outcomes. The implicit learning variables seem to identify and cluster more infants who may be at risk. Specifically, accuracy and proportion of looking to implicit target cluster infants who later are below the 20th percentile at 24 months, while those two variables, along with number of looks to target, seem to cluster infants who have the slowest vocabulary growth at 24 months.

When we examined the variables across studies that identified the infants with the lowest vocabulary or rate of growth we see that regardless of outcome measure and regardless of task, a few variables seem to capture infants at the tail end of the distributions. The measures of proportion of looking, accuracy, and total number of fixations during the trial also seem to identify infants with later language delays more than other variable across the tasks.

Overall across the variables and different tasks, there is a subset of infants who seem to pattern together. Based on this clustering of performance across the combination of processing variables, these infants would be predicted to be the infants who will be identified as having SLI as they grow older. Specifically, infants 20, 33 and 39 consistently performed poorly across variables and in at least two tasks. Additionally, infant numbers 45 and 55 also clustered at the tail end across certain variables, but not across tasks and therefore may or may not be at the most risk. This subset of three infants (20, 33, 39), are the participants that I predict have the most need for early identification and intervention. Infants 45 and 55 may be at risk but are possibly more likely to catch up since they do not show the same consistent pattern across the different task conditions.

**Conclusions**

We examined distributions of z-scores across a large sample of 18-month-olds to determine if infants at the most risk for continued language delay cluster at the tail end of the distribution across multiple measures of lexical and cognitive processing. While we examined the entire distribution of 54 infants, the results in this study focused on a subset of ten infants who
had the tail end of performance compared to the sample. The ten infants we focused on showed interesting similarities as well as differences across measures and across task conditions. This study also allowed us to explore the relationship between lexical and processing variables important for language learning in infants showing language delays at 18- and 24-months of age.

The correlational analysis revealed there were no significant relationships between vocabulary measures and processing variables during real word recognition. In the novel word learning task, the number of fixations to the target picture showed significant correlation to comprehension ability and production ability at 18 months. The strongest relationship was between the implicit word learning variable of proportion of time to target picture at 18 months and vocabulary production and rate of vocabulary growth at 24 months.

Further, the descriptive analyses of z-score distributions across processing variables and by task gave valuable insight into the lexical and cognitive processing skills at 18 months. First, the data support the idea that these infants are a heterogeneous group with many individual differences among them. Second, the data allow us to explore the variables and tasks that may be useful in identifying and predicting future language outcomes in infants at-risk for continued language delay. Specifically, three of the 54 infants in our sample have poor vocabulary at 24 months and/or slow vocabulary growth are on the lower end of the distributions across variables and tasks and another two infants show consistent clustering in a specific task condition compared to the sample. Overall, across the multiple processing and vocabulary measures we see a clustering of infants at a rate (approximately 7.4%) that is comparable to the prevalence of children with SLI (Tomblin et al. 1997).

The results from this study are promising. As a first step, we went beyond using only static measures of vocabulary and examined possible lexical and cognitive processing predictors of language delay in infants using a dimensional approach. Using this approach we were able to see an emerging pattern of poor performance across processing variables that can be used to
identify infants who also have low vocabulary and rate of growth from 18-24 months. The results begin to open a window into other possible identifiers and predictors of continued language beyond only static measures of vocabulary. The findings suggest there may be a certain processing measures that in combination with vocabulary measures may better identify and predict which infants are at the greatest risk of delay. Future work will continue to examine these processing variables, along with external environmental variables known to be factors useful to predict language delay (such as family history of delay and SES) to better inform clinicians about identification of LTs who are at the greatest risk for SLI.
REFERENCES


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**Acknowledgement**

Chapter 5, in part, is currently being prepared for submission for publication of the material. Ellis, E, Elman, J, & Evans, J. (In Preparation). An alternative approach to identifying children at risk for language delay. The dissertation author was the primary investigator and primary author of this material.
Appendix 5.A. Vocabulary Distributions
Words & Gestures: Words Comprehended at 18 months (percentiles)²

² Infant subject codes are consistent and correspond to the last two numbers listed for each task (i.e. subject 14 is subject 14 across vocabulary distributions and “iwlb014” in the real and novel word task and “iilb014” in the implicit task.)
18-months Words Produced Percentile: Words & Gesture

Subject Code

Percents

Words & Gestures: Words Produced at 18 months (percentiles)
Rate of vocabulary growth (words produced from 18-24 months) z-scores
Appendix 5.B.

![Histogram of Mother's Education in Years]

- Mean = 16.67
- Std. Dev. = 1.554
- N = 54
Appendix 5.C: Distributions of processing variables by task

5.C.1. Real Word Recognition

Real Word Recognition: Reaction Time- z-score

Real Word Recognition: Proportion of Looking to Target- Z-scores
Real Word Recognition: First Fixation Duration - z-scores

Real Word Recognition: # Fixations to Target - z-scores

Subject Code

Novel Word Learning: Reaction Time - z-scores

Subject Code

Novel Word Learning: Proportion of Looking to Target - z-scores
Novel Word Learning: # Fixations during Trial - z-scores

Subject Code

z-scores
C.3. Implicit Word Learning

**Implicit Word Learning: Reaction Time - z-scores**

**Implicit Word Learning: Proportion looking to Target - z-scores**
CHAPTER 6: GENERAL DISCUSSION & FUTURE DIRECTIONS

The goal of this dissertation was to complete a unique set of related studies to advance the knowledge of lexical and cognitive processing abilities in late talking and typical infants. The work in this dissertation uses both traditional and novel approaches to study lexical and cognitive processing in infants in an attempt to identify those at risk for SLI. While each of the previous chapters contributes unique pieces of information to the puzzle of late talker research, these promising results encourage additional questions that future LT research should consider. In this final chapter, I consider the results of this dissertation from a dimensional perspective of language delay and discuss both the general and clinical implications for future research.

In the introduction, I provided the background and motivation for the studies in this dissertation. First I laid out the general history of late talker research, then discussed the longitudinal outcomes of previous LT work and the difficulty of predicting long-term outcomes for infants and toddlers at risk for continued language delay. Using previous SLI research as a foundation, I discussed the need to examine lexical and cognitive processing abilities in LTs to identify those infants at the greatest risk for continued language delays. Finally, the studies designed for this dissertation are motivated using an alternative multi-dimensional approach to language delay (Dollaghan, 2004; 2011; 2013; Rescorla, 2009; 2011).

EXPERIMENTAL STUDIES

REAL WORD RECOGNITION

In the first experimental chapter, Chapter 2, two matched groups of 18-month-olds abilities to recognize real words were examined using a different experimental design and method than previous research. First, using eye-tracking methods, we investigated whether LTs would be slower and less accurate recognizing real words as seen in previous work (Fernald & Marchman, 2012). Second, we examined whether differences would emerge when examining additional fine-grained processing measures. Interestingly, in the results we found a different pattern than
previous studies. There were no significant differences between the groups in gross measures of accuracy in our study. However, the accuracy scores for the groups in our study were parallel to accuracy results reported in previous work (Fernald & Marchman, 2012). There were also no significant differences in reaction time between the groups, as seen in other studies. However, when we examine the groups using other time course measures we do see interesting patterns of emerging differences. Specifically, when we examined the time course plots the LT group had a later point of distinction than the typical group between the target and distractor pictures. Each group’s point of distinction mirrored the RT data reported in other work (Fernald & Marchman, 2012). There are also interesting differences emerging, such as the number of times infants looked to the target picture; this was significantly different between groups, with LTs looking more times to target. These qualitative processing measures provide more detailed information about how infants process and understand familiar words in real time. Finally, when we explore qualitative spatial gaze maps we see different patterns of looking between groups. The LT group had a narrowed focus in looking at the pictures compared to the typical group, possibly suggesting they may not fully integrate the picture or possibly have poor representation of the word.

Based on the two groups, these findings suggest that although there were no differences in gross measures of RT and accuracy, there may in fact be different underlying representations of real words for the two groups suggested by different patterns of looking behavior. These data suggest that while accuracy of familiar words are relatively fine, the representation of those words and underlying knowledge may vary on a graded or more detailed level. If we consider the entire sample of 54 infants during the real word recognition task, the data showed no correlations between real word processing variables and vocabulary measures.

The implications of results from the real word studies together suggest that real word recognition may not be the most appropriate task to confidently identify infants at risk for
continued language delay. However, it would be interesting to further unpack the differences in between groups to further examine how LT infants looking patterns for known words compares to their peers.

**Novel Word Learning**

Novel word learning was examined in the two matched groups in Chapter 3. In the novel word-learning task the online processing of learning newly trained novel words was explored using a fixed number of trials during the training phase. As predicted, we found differences between groups on some of the processing measures examined at test. Specifically, the LT group was no different from chance - only 50% accurate during novel test trials - while the typical group was greater than chance at 57% accurate. Similar to results of previous fast mapping tasks (Ellis Weismer & Evans, 2002), the LT group was less accurate at understanding and learning the novel words than they were in recognizing real familiar words (as seen in Chapter 2). When we examined only the accurate trials for each group there were no significant difference between groups in RT of first look (e.g., 1st saccade latency) to the target novel pictures; however, when we look at the time course of processing in more detail we did see there are different points of divergence between groups. Specifically, the LT group did not differentiate between the novel target and distractor pictures, which is not surprising, given their accuracy scores. The typical group did have significant points of divergence beginning at the 1500 ms bin, suggesting they did learn the novel words (as their accuracy scores suggested). The novel word learning study gave us additional insight into how late talking and typical infants learn new words and what processing variables may be useful for teasing apart differences in infants who are at the greatest risk for continued language delay.

When we consider the entire sample of 54 infants during novel word learning and examined the relationship between novel word learning variables and vocabulary, we observe a significant correlation. Specifically, infants with more looks to the novel target during the test
trials also had better vocabulary comprehension and larger productive vocabularies at 18 months. These findings suggest there are interesting differences between how LT and typical infants learn new words. To further examine these differences, future work should consider how infants actually link the new word labels to objects to determine where in the learning process the differences begin.

**Implicit Word Learning**

In Chapter 4, implicit word learning abilities were examined in the same matched groups to investigate whether infants are able to use the underlying statistical properties of the language to learn new words. In this study the LT group was less accurate than the typical group. Although the results found no significant differences in reaction time to the implicit target picture, the data was trending in the expected direction. Further, there were differences in the patterns of time-course for the implicit and non-word conditions when comparing each group’s time-course patterns between conditions. Specifically, the LTs had relatively similar points of divergence between the two conditions. For the implicit word condition, LTs diverged at the 1310 ms bin, while for the non-word condition they diverged at the 1290 ms bin, suggesting they may be using the implicit statistical properties of the language to help them learn words differently than their typical peers. The typical group had an earlier divergent time for the implicit condition (1190 ms bin) than the non-word condition (1800 ms bin), suggesting they may have been using the underlying statistical properties of the language to help them learn the implicitly trained words faster than the trained non-words.

When examining implicit learning abilities and vocabulary a relationship between reaction time to the implicit target picture and productive vocabulary at 18 months was revealed, similar to a finding in older children with SLI (Evans et al., 2009). Overall the results of this study are extremely promising in that we confirmed that implicit learning abilities are useful for learning words for infants. The LT infants may be using the statistical properties of language but
quite possibly in a different way than typical infants. When we consider implicit learning abilities in our sample of 54 infants we see an interesting relationship between proportion of looking to the implicit target and both productive vocabulary and rate of vocabulary growth at 24 months. These findings suggest that implicit learning abilities do in fact play a role in language and word learning in infants. Future research should continue to examine how infants of different abilities use the underlying properties of language to learn words.

The results found in the three experimental chapters of this dissertation proved that lexical and cognitive processing abilities are both accessible and measurable in infants and importantly in the same groups of infants across different studies. These processing abilities are showing emerging differences between groups on more detailed time course measures such as divergence times and first look duration. The results of these studies are encouraging that processing mechanisms in infants may be used as potential factors to identify and predict continued language delay.

**AN ALTERNATIVE APPROACH**

A major goal of this dissertation was to move beyond the traditional group comparisons and to begin to explore language delay based on a multi-dimensional approach. In Chapter 5 lexical and cognitive processing abilities were examined in a large sample of infants to explore whether a subset of infants consistently fell at the tail end of the z-score distributions and whether poor performance may identify later language abilities. It was predicted that the infants who are the greatest risk for continued language delays should fall at the tail end of more processing variables and cluster together more than other infants and that this should occur across conditions.

In Chapter 5 z-score distributions of processing variables were examined across conditions to determine if a subset of infants cluster at the bottom. As a first step to narrow our investigation the z-scores of ten infants who were at the tail end of the distributions for each variable were examined. An interesting pattern in these infants emerged. Specifically, across
tasks and different variables there was a subset of infants who consistently fell at the bottom of
the distributions. This subset of infants are at the greatest risk for continued language delays.
Interestingly, out of the 54 infants in our sample, we identified five infants at the most risk. This
proportion is comparable to rates of children who have been identified with Specific Language
Impairment at kindergarten (Tomblin et al. 1997), and similar to the prevalence rates reported for
children with SLI (Leonard, 1998). Further, this study suggested certain processing tasks may
better identify at risk infants than others. Specifically, the implicit learning task variables
clustered more infants at risk with the slowest rate of vocabulary growth than the other processing
tasks. This pattern implies the implicit learning task may be worth studying in combination with
other predictors to identify later language outcomes. This study, which used a dimensional
approach to analyze a combination of lexical and cognitive processing measures and other
vocabulary variables of interest in the same sample of infants, may provide a useful framework
for developing further studies designed to more accurately identify and predict long-term
outcomes.

**Clinical Implications**

There are many important implications of this research. First, in Chapters 2-4, using the
traditional group comparisons we found both interesting similarities and differences between the
late talking and typical groups in patterns of real word recognition, novel word learning and
implicit word learning. Importantly, in Chapter 2 when examining real word recognition abilities,
we found when LTs are familiar with a word, they are as fast and accurate as typical infants,
however their underlying representations may be less stable than typical infants. The critical
question then is how do we help LTs understand words at a level so they confidently recognize it
as familiar? In Chapter 3, novel word learning was examined and group differences confirmed
previous research that LTs are poor novel word learners. Specifically, the novel word learning
data tell us that for the trials the LTs do get correct, they look as fast as typical infants and evidence a proportion of looking similar to their typical peers.

Chapter 4, describing the implicit learning research, had many important implications as well. If, as the data suggest, infants who are LTs have trouble tracking implicit statistical properties of language like the typical infants then this is critically important information for researchers and clinicians. Specifically, if LT research continues to confirm findings similar to SLI implicit learning research, then late talking infants may benefit from additional exposure to the underlying statistical properties of language before they learn the implicit words. These results are potentially helpful for researchers and clinicians in designing additional inventions that may be appropriate for some LTs.

The final experimental chapter, in which the dimensional approach was utilized to examine lexical and cognitive processing abilities, may have the most important clinical implications. The results identified a subset of infants who consistently fell at the bottom of the distributions of lexical and cognitive processing abilities as well as language measures compared to the entire sample. Although these results are just a first step, if future research continues to find that infants who have the most risk for delay fall at the ends of distributions across variables and across various tasks, then additional identification factors based on lexical and cognitive processing may be able to be used to determine as identifiers of which infants may need intervention. More work needs to be done to determine if these factors actually predict later outcomes as children grow older and enter preschool and kindergarten, but the results are promising.

The last 25 years of research has added an incredible amount of information to the study of LTs. While important advances have been made, collectively we cannot accurately predict long-term outcomes of LTs. This may due to many reasons; however, one factor may be that we have focused on comparing very heterogeneous groups of typical and late talking infants rather
than analyzing individual differences, patterns, clustering and risk factors at an individual level. As stated by Leonard (2013), predicting outcomes of the individual child will be necessary and important for clinicians to understand how new predictive factors may vary for different individual children’s profiles.

While this dissertation has important clinical implications, the results also have potential policy implications that should be considered. Clinicians have large client caseloads and it is imperative that they use the most cost and time effective assessments and interventions available to them. In the future, if we find that it is more effective and practical to determine risk factors for individual infants and toddlers at risk using a dimensional approach (examining processing variables to predict outcomes), then clinicians may be able to identify and treat those infants and toddlers at risk with greater confidence that they are devoting their efforts to those who truly need the intervention.

**FUTURE RESEARCH**

This dissertation is a step in the direction toward better understanding of lexical and cognitive processing abilities in infants using a dimensional approach to language delay. While the results may be an additional important piece of the puzzle, there is still work to be done. Future research should examine how a combination of processing factors in the same sample of infants predicts outcomes over time. Specifically, if useful processing measures are combined with other non-processing factors such as SES or family history of delay, then our predictive power and confidence in early identification may be even stronger. Additionally, if results continue to confirm that infants and toddlers at risk for language delay, like children with SLI, have difficulties learning words, research should focus more acutely on the actual learning phase and the characteristics of words that may influence word learning. As an example, by only examining the final test phase after learning takes place we may have been missing important data. Perhaps we should focus instead on the moment-by-moment processing of online learning in
infants during the precise phases of studies when they actually are faced with the linking of words to referents. Specifically, during training or teaching of new words, researchers should examine if there are differences (e.g., look durations, number of looks, etc.) in how LTs and typical infants actually learn the link between the new word and referent. If in the future we can add the test phase results along with the learning phase data to our predictive factors, we may be able to more finely tune our identification and predictive power, which will positively impact clinical interventions and early intervention policies established for late talkers.
REFERENCES


