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The Relationship Between Working Memory, Procedural Learning, and Declarative Memory in Children with Specific Language Impairment

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THE RELATIONSHIP BETWEEN WORKING MEMORY, PROCEDURAL LEARNING, AND DECLARATIVE MEMORY IN CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT

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ABSTRACT

Background: Children with specific language impairment (SLI) have recently been suggested to have subclinical deficits in executive function skills. The current study seeks to better understand these deficits by exploring the role of nonverbal working memory in word learning and statistical learning in this population. **Method**: Participants included typically developing children along with children with SLI ranging from ages 8-12 years old. Word learning was assessed using a fast-mapping task, statistical learning was measured using a word-segmentation task, and nonverbal working memory was measured using an N-back task. **Results:** A significant difference was found between children's segmentation accuracy scores. Variance in segmentation accuracy scores were predicted by group according to a linear regression model. No significant difference was found in fast-mapping scores or nonverbal working memory scores, although significant correlations were observed between fast-mapping and segmentation accuracy scores, raw receptive vocabulary scores, and CELF-4 receptive language scores. Nonverbal working memory correlated with raw receptive vocabulary scores, expressive language scores, and core language scores. **Discussion:** We caution our readers to interpret our findings carefully, as there are discrepancies from similar studies completed previously. Our results do support the notion that working memory profiles can vary across children, intersecting language skills and modulating performance in word learning. While no association was found between nonverbal working memory and our experimental tasks, a relationship may be observed if a similar study were performed using a verbal working memory task**.**

CHAPTER 1. INTRODUCTION

Specific language impairment (SLI) is characterized by difficulties with language learning in the absence of other conditions that could explain the language learning impairment, such as hearing impairment, intellectual disability, or neurological impairment (Leonard, 2014; Tomblin, Records, Buckwalter, Zhang, Smith, & O'Brien, 1997). Across the literature, a variety of labels have been used to refer to these children. Many researchers have referred to these children as having "specific language impairment" (SLI; Bishop, 2014; Leonard, 2014) while others have labeled this population as having "developmental language disorder" (Bishop, 2017; Reilly et al., 2014). In the current paper, the term specific language impairment is used because we followed the strict SLI inclusionary and exclusionary criteria used in the literature.

According to Tomblin and colleagues, the prevalence of specific language impairment in kindergarten children is 7.42%, using the criteria mentioned previously (Tomblin et al., 1997). Although there is considerable heterogeneity within the linguistic profile of children with SLI, morphosyntactic deficits tend to be the most notable clinical markers (Leonard et al., 1992; Rice, Wexler, & Cleave, 1995). In addition, lexical-semantic deficits have been well-documented in children with SLI (Robert Kail & Leonard, 1986; Kan & Windsor, 2010; Sheng & McGregor, 2010).

While exclusionary criteria have been used historically to diagnose SLI, it is important to note that subclinical deficits in other skills are often observed. For instance, in a longitudinal study, Stark and colleagues (1984) documented that average intelligence quotients for children with SLI are lower than children with typical language, although both groups' scores fell within normal limits. Gallinat and Spaulding (2014) completed a meta-analysis which yielded similar results even after controlling for linguistic deficits affecting IQ score.

In addition, other research has documented differences in cognitive skills including updating working memory, attentional control, and inhibition (Bishop & Norbury, 2005; Im-Bolter, Johnson, & Pascual-Leone, 2006; Mainela-Arnold, Evans, & Coady, 2010a). Although there has been notable variability in the tasks and the task demands that are used to examine executive function abilities, children with SLI frequently perform more poorly than their peers with typical language development (Pauls & Archibald, 2016).

Executive function skills have been suggested to be important for language development (Kaushanskaya, Park, Gangopadhyay, Davidson, & Ellis Weismer, 2017). Executive functions consist of a set of skills that are important for the planning and processing information. Although many executive function (EF) abilities are related to one another, Miyake and colleagues have identified three distinct EF skills: updating working memory, shifting attention, and inhibition (Miyake et al., 2000). These skills play a key role in not only language development, but also daily language use. Therefore, it comes without surprise that skills such as shifting, inhibition, and updating working memory are beginning to be considered when studying causes of language impairment. The current study aimed to examine the contribution of domain-general EF skills on language learning in children with SLI; specifically, we examined updating working memory skills.

Theories of Memory in SLI

Although there are several theories that attempt to explain the language learning difficulties of children with SLI, in the current project we focused on three, the Procedural Deficit Hypothesis (PDH), the Storage-Elaboration Hypothesis (SEH), and the General Slowing Hypothesis (GSH).

Procedural deficit hypothesis

Domain-general accounts of language learning and language disorders suggest that the impairments in SLI span across functions beyond language. One notable domain-general theory is the Procedural Deficit Hypothesis (PDH; Ullman & Pierpont, 2005). Research on procedural memory has informed domain-general language theories such the Declarative/Procedural model (Ullman & Pierpont, 2005). The DP model posits that declarative memory supports word knowledge, while procedural memory is instrumental for extracting patterned information about language, such as morphosyntactic rules. Therefore, the two systems work together to support multiple aspects of language learning. As previously noted, morphosyntactic difficulties serve as the most widely reported clinical marker of SLI. Given this, the PDH proposes that children with SLI have relatively spared declarative memory skills and primary impairments in implicit procedural learning. Thus, the PDH claims that the procedural learning mechanism is responsible for impairments observed in individuals with SLI. Furthermore, the PDH suggests that the declarative memory system may compensate for deficits in procedural learning. Not only is the declarative memory system an inefficient mechanism for learning syntax and some aspects of vocabulary, effective use of this compensation strategy would necessitate a strong declarative memory system.

To support their hypothesis, Ullman and Pierpont (2005) reviewed previous studies investigating individuals with SLI, individuals with other neurological variations, and studies that examine procedural memory and declarative memory. The PDH was supported by studies of neuroanatomical structures, including the caudate nucleus in the basal ganglia and Broca's area. Support was also garnered from an observed shift in the temporo-parietal area during grammatical tasks in children with language impairment, indicating a declarative/lexical shift for the processing of grammatical information (Ullman & Pierpont, 2005). Studies examining declarative learning in children with SLI showed relatively spared skills in terms of verbal long-term memory and episodic memory. Finally, Ullman and Pierpont (2005) supported their hypothesis by pointing to studies showing the comorbidity and subclinical presence of problems with motor function, working memory, and temporal processing. While these nonlinguistic deficits are variable across children with SLI, Ullman and Pierpont (2005) suggested that the PDH served as a sufficient account of language learning difficulties in children with SLI.

Storage-elaboration hypothesis

The storage elaboration hypothesis (SEH) posits that children with SLI have difficulties in storing new lexical content and elaborating semantic knowledge. In other words, children with SLI have trouble encoding new lexical items and have superficial semantic knowledge for the words that they have learned (Robert Kail & Leonard, 1986). Support for this theory has been found in studies such as McGregor, Newman, Reily, and Capone (2002) who found that naming errors were more likely to occur when children have a less rich representation of a word. Additionally, Mainela-Arnold, Evans, and Coady (2010) used a word definition task to investigate word knowledge in children with SLI. Children with SLI were able to define fewer words than their age-matched peers and they produced definitions that were indicative of sparse semantic networks. Additionally, within the receptive domain, Haebig, Kaushanskaya, and Ellis Weismer (2015) examined whether lexical processing was more efficient when listening to words that came from rich semantic neighborhoods relative to words that came from sparse semantic neighborhoods using a lexical decision task. The typically developing group had higher accuracy when judging words from high semantic neighborhoods, but the SLI group did not have significantly higher accuracy for these words. These results indicate that lexical features of words influence lexical processing, but that the influence of semantic neighborhood size may less strongly influence lexical processing in children with SLI, potentially because they may have weaker semantic knowledge (Haebig, Kaushanskaya, & Ellis Weismer, 2015).

Generalized Slowing Hypothesis

Evidence has shown that children with SLI have slower reaction times when compared to their TD peers on linguistic and non-linguistic tasks including mental rotation (Johnston & Weismer, 1983), picture naming (Leonard, Nippold, Kail, & Hale, 1983), grammaticality judgement (Wulfeck, 1993), auditory and visual discrimination (Kohnert Jennifer Windsor, 2004) and digit scanning (Sininger, Klatzky, & Kirchner, 1989). Based on this evidence, Kail posited the generalized slowing hypothesis (GSH) which states that children with SLI have overall slower processing skills than their TD peers (Kail, 1994). In his model, slowing is proportional across processes and results in reaction times that grow at a constant rate depending on what is required for a particular task. Linguistic tasks can be particularly problematic because of the integral role of so many cognitive processes. Slow processing may leave information more vulnerable for decay from memory and therefore less likely to be encoded in long term memory (Leonard, 2017).

Contributing Memory Systems

Declarative memory

Although the PDH considers implicit or procedural learning to be the primary impairment of SLI, some studies have investigated a potential role of declarative memory. For example, Gray (2003) found a significant difference in the number of words learned by children with SLI and children with typical language during both fast mapping tasks and more extended word-learning tasks. Additionally, a meta-analysis investigating novel word learning in children with

SLI and children with typical language development analyzed 28 studies of novel word learning to examine how individual characteristics and the researchers' methods would influence word-learning outcomes (Kan & Windsor, 2010). Overall, the meta-analysis found that children with SLI have significantly poorer word learning performance relative to their chronological age-matched peers. The meta-analysis also found that receptive language skills predict word learning; children with SLI who have greater receptive language deficits have particularly low word-learning performance relative to children with typical language development (Kan & Windsor, 2010). Moreover, studies have identified deficits in both breadth and depth of word knowledge in children with SLI (Mcgregor et al., 2012; Sheng & McGregor, 2010). Nonverbal IQ scores have also been shown to be a predictor of both breadth and depth of vocabulary (Mcgregor, Oleson, Bahnsen, & Duff, 2013.). This relationship raises the question of how nonverbal cognitive functions may be playing a role in language impairment.

Procedural learning

Procedural learning encompasses information that is learned through implicit methods, versus explicit methods, which does not require the individual to be aware of what is being learned (Ullman & Pierpont, 2005). The procedural system refers to the brain structures involved in the learning of information through repeated practice or exposures until the learned information becomes automatic. It is typically associated with the structures of the dorsal stream of the brain and the basal ganglia, which are interconnected subcortical parts such as the putamen and the striatum. These components of the basal ganglia project to cortical parts of the dorsal stream via the thalamus. Particular cortical aspects of the dorsal stream are located in the left hemisphere while most are in the frontal lobe (Ullman & Pierpont, 2005).

Procedural learning has been measured using a variety of tasks including serial reaction time tasks (SRT) and statistical learning tasks (e.g., Hsu, Tomblin, & Christiansen, 2014; Lum, Conti-Ramsden, Morgan, & Ullman, 2014; Lum & Bleses, 2012; Obeid, Brooks, Powers, Gillespie-Lynch, & Lum, 2016). In SRT tasks, an individual is presented with a set of stimuli and is asked to respond to the stimuli in a specific way (e.g., press the stimuli as they appear on the screen). As the task progresses, without the person's knowledge, the complex string of stimuli is repeated. As the individual views the stimuli over time, reaction times for responses decrease, which indicates that the individual is implicitly learning the complex pattern in the task. These tasks have been invaluable in assessing the relationship between procedural learning and language abilities in individuals with various disorders, including individuals with impaired language development. For instance, Lum, Conti-Ramsden, and Page (2012) found that children with SLI have significantly slower reaction times on an SRT task than their typically developing peers. Upon further investigation, grammatical abilities were found to be correlated with SRT performance in children with typical language. In contrast, there was not a correlation between grammatical abilities and SRT performance in the children with SLI (Lum, Conti-Ramsden, Page, & Ullman, 2012). This pattern supports the idea that procedural memory is impaired in children with SLI and aligns with the PDH, suggesting that procedural deficits play a key role in the language learning difficulties that children with SLI experience. It has also been suggested, because of these procedural deficits, that children with SLI may use different (less efficient) strategies when learning language.

One hypothesis of the relationship between procedural learning and word learning is that children with SLI present impaired statistical learning skills. Statistical learning falls under the category of procedural learning and specifically refers to the learner's ability to implicitly track patterns in input, such as sound patterns of words within a language. Infants and young children have been shown to have high sensitivity to probabilistic properties of language, and statistical learning has been to shown to play a role in vocabulary knowledge, grammatical knowledge, as well as phonological knowledge (Gerken, Wilson, & Lewis, 2005; Mainela-Arnold & Evans, 2014; Richardson, Harris, Plante, & Gerken, 2007; Romberg & Saffran, 2010; Saffran, Aslin, & Newport, 1996). In a statistical learning task, Evans and colleagues (2009) showed that children with SLI required more listening time than their TD peers to recognize statistical properties of language. Additionally, Haebig (2017) showed that children with SLI have poorer statistical learning abilities when compared to their peers with typical language as well as peers with autism spectrum disorder. Finally, Hsu and Bishop (2014) tested statistical learning abilities in children with SLI on verbal and motoric tasks. When stimuli had underlying statistical properties, unbeknownst to the participant, children with SLI performed significantly worse than their age-matched peers and more similarly to grammar-matched peers. However, when there was no statistical relationship to aid in learning, children with SLI performed similarly to age-matched peers and better than grammar-matched peers.

Working memory

Working memory has been posited to have different parts including verbal, visuospatial, and phonological (Baddeley, 2003). In his model, Baddeley describes working memory as having four parts, the phonological loop, visuospatial sketch pad, the central executive, and the episodic buffer. The phonological loop processes auditory information while the visuospatial sketch pad is responsible for tasks including visuospatial stimuli. The central executive is where information from both the phonological loop and visuospatial sketch pad are combined, manipulated, and then encoded in long-term memory. Additionally, the episodic buffer has been inserted more recently as a mechanism that oversees each of these processes.

Beyond the documented procedural learning deficits, children with SLI also have been found to have other cognitive weaknesses, often manifesting subclinically. A significant amount of work has specifically examined working memory skills in children with SLI to better explain language processing and learning difficulties. For instance, Archibald and Gathercole (2006) have documented impaired working memory skills in the verbal and visuospatial domains, and reduced processing capacities in children with SLI. A meta-analysis on SLI and TD nonword repetition performance revealed studies with large effect sizes across different tasks and measures (Graf Estes, Evans, & Else-Quest, 2007). These large effect sizes indicate a significant difference in phonological working memory capabilities in children with SLI relative to typically developing children. Deficits in these nonword repetition tasks mimic deficits that exist in language learning for children with SLI. When difficulties are present with phonological working memory, children will have trouble maintaining and manipulating phonological information long enough to encode it (Graf Estes, Evans, & Else-Quest, 2007).

Leonard, Ellis Weismer, Miller, Francis, Tomblin, and Kail (2007) investigated how working memory and processing speed influence linguistic performance in children with SLI. They found that working memory and processing speed are independent factors in predicting linguistic knowledge. In their models, verbal working memory and processing speed served as the strongest predictors of the children's linguistic knowledge, with verbal working memory explaining the largest amount of variance (Leonard et al., 2007). Furthermore, their models demonstrated a distinction in verbal and nonverbal working memory. Although a great deal of previous work has identified significant deficits in phonological working memory in children with SLI, other studies have found deficits in nonverbal working memory (i.e., visual-spatial working memory) (see Table 1). In fact, a meta-analysis suggested that children with SLI have deficits in visual-spatial working memory (Vugs, Cuperus, Hendriks, & Verhoeven, 2013). However, some studies have failed to find nonverbal working memory deficits or found that only some children with SLI have visuo-spatial working memory deficits (Archibald & Gathercole, 2006a; Ellis Weismer et al., 2017). Gray and her colleagues (2019) further examined working memory profiles of children with SLI. Using a battery of verbal and nonverbal working memory tasks, Gray et al. (2019) demonstrated that children with SLI, typically developing children, and children with dyslexia all have substantial variability in working memory skills. Working memory profiles were distributed across groups. This indicates that rather than working memory deficits cooccurring with language impairment predominantly, working memory skills can intersect with language skills across the language endowment spectrum.

Working memory has been investigated using a variety of tasks that tap into different working memory components. One task is the N-Back task, wherein individuals are instructed to indicate if a stimulus is the same or different as a stimulus seen previously. Depending on the stimuli used, this task can test verbal and nonverbal working memory because it requires the individual to hold information (e.g., an non-namable shape or an image that can be read or labeled) seen previously in their working memory and then determine if subsequent stimuli are the same or different (Haebig, Kaushanskaya, & Ellis Weismer, 2015; Ellis Weismer et al., 2018). Another working memory task is the size judgement task, where individuals are presented with a list of nouns and then instructed to list the nouns back in the order of smallest to largest. Size judgement tasks measure verbal working memory skills (McDonald, 2008). Also, the corsi block task has been used to explore visuospatial working memory. It requires individuals to watch an examiner point to blocks or a computer program to highlight blocks on a screen and then the individual must select the blocks in the same order (Kaushanskaya, Park, Gangopadhyay, Davidson, & Ellis Weismer, 2017). Lastly, nonword repetition has been used as a measure of phonological working memory. As the name of the task suggests, individuals are given a list of nonwords and then asked to repeat them back (Mainela-Arnold et al., 2010; Montgomery, Magimairaj, & Finney, 2010). In addition to these experimental tasks, standardized measures have been used to measure working memory capabilities (Archibald & Gathercole, 2006a). Table 1 gives examples of tasks used to measure working memory, along with a brief description of each task and examples of studies that did or did not identify group differences in performance on such tasks.

Table 1. Working Memory Tasks

Task	Aspect of Working Memory Measured	Description	Outcomes
Size Judgement Task	Verbal Working Memory	Participants are given a list of words and instructed to recall the list from smallest to largest.	SLI group responded similarly to TD controls (Donlan, Bishop, Hitch, 1998)
Non-word Repetition	Phonological Working Memory	Participants given non-word stimuli and asked to recall.	Children with SLI have been shown to perform significantly poorer and TD children (Baird, Dworzynski, Slonims, & Simonoff, 2010)
N-Back	Varies depending on stimuli	Participants given a stream of stimuli and asked to determine if each stimulus is the same as the target (0-back), the stimulus seen just before (1-back), or the stimulus seen two images prior (2-back).	Performance of children with SLI has varied on N-back tasks. Some studies report significantly poorer performances (Ladani & Lukacs, 2019), while others do not (Haebig, Kaushanskaya, & Ellis Weismer, 2015)

(table cont.)

Task	Aspect of Working Memory Measured	Description	Outcomes
Corsi Blocks	Visuo-spatial Working Memory	Participant instructed to touch blocks in the same order as the examiner in increasing lengths.	SLI group was significantly less accurate than TD peers (Bavin, Wilson, Maruff, & Sleeman, 2005)
Backward Digit Span	Verbal Working Memory	Participant instructed to count backwards in certain intervals (e.g. count backwards from 100 in intervals of 7)	Mixed results: some studies have indicated children with SLI perform significantly poorer than TD peers (Archibald & Gathercole, 2006a; Ladani & Lukacs, 2019) while others have shown no significant groups between SLI and TD groups (Petruccelli, Bavin, & Bretherton, 2012)

Nuanced view on the relationship between procedural, declarative, and working memory

Lum, Ullman, and Conti-Ramsden (2015) investigated the relationship between procedural and declarative memory. In their study, children with SLI were sub-classified as having either average phonological working memory skills or low phonological working memory skills using a norm-referenced test battery, the Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001), which included a backward digit recall sub-task, digit recall task, word list matching task, word list recall task, and nonword list recall task in order to assess verbal working memory. Declarative memory was assessed through a word list-learning task. In this task, the children were auditorily presented with a list of words four times. Across the four presentations, the children were asked to recall the words in the list. In addition, they were asked to recall the words in the list immediately after listening to a second set of distractor words, and to recall the words after a 15-minute delay. In addition to the recall measures, the children participated in a delayed recognition task, in which they were asked to identify the target words from a larger set of words. Lum et al. (2015) found that verbal working memory skills predicted performance on their declarative memory task. Working memory scores were stronger predictors of declarative memory scores than group was. These findings partially support the PDH by demonstrating an intact declarative memory system in the presence of an intact working memory system. These findings align with the belief that multiple memory systems play a role in lexical-semantic development (Lum & Conti-Ramsden, 2013; Lum, Ullman, & Conti-Ramsden, 2015). Lum and colleagues propose that deficits in declarative memory in individuals with SLI would be associated with working memory impairments.

Methods of evaluation can produce very different findings depending on the part of working memory investigated. Across the literature, variability of tasks chosen to investigate working memory in children with SLI and children with typical language development has resulted in mixed findings. Some studies have found differences between the groups (Vugs et al., 2013; Vugs, Hendriks, Cuperus, & Verhoeven, 2014); while others have shown similar visual-spatial working memory capabilities between children with SLI and TD (Archibald & Alloway, 2008; Baird et al., 2010).

Due to the large variety of tasks used, the current study investigated nonverbal working memory specifically, using an N-back task, and its relation with procedural and declarative memory in school-age children with SLI and children with typical language development. We have extended a study conducted by Haebig, Saffran, and Ellis Weismer (2017), which examined word learning, using a fast-mapping task, and statistical learning, using a word segmentation task. Haebig et al. found that children with SLI had significantly poorer performances on the word segmentation task than peers with typical language. These findings align with another study that found poor word segmentation performance in school-age children with SLI (Evans et al., 2009). Additionally, Haebig and colleagues (2017) found that children with SLI had poorer performance on their fast mapping novel word learning task. Importantly, Haebig et al. (2017) did not examine the association between working memory and procedural or declarative learning. The current study aims to expand Lum and colleagues' (2012) interpretation of the PDH by examining the relationship between working memory, declarative memory, and implicit learning in both children with typical language and children with SLI.

Therefore, the research questions are:

1) Is there a relationship between statistical learning and nonverbal working memory in children with SLI and children with TD and does this relationship differ according to group?

2) Is there a relationship between fast-mapping and nonverbal working memory in children with SLI and children with TD and does this relationship differ by group?

If nonverbal working memory supports language development, we hypothesize that working memory performance will correlate with performance on the statistical learning and fast mapping performance; however, this association may be stronger for the typically developing children. Additionally, if nonverbal working memory serves as an underlying mechanism in word learning, we hypothesize that children with SLI who have poor nonverbal working memory skills will have significantly poorer fast-mapping abilities relative to children with SLI who have stronger nonverbal working memory skills.

CHAPTER 2. METHODS

Participants

A total of 51 children between the ages of 8 and 12 years old were included in the study. Within this sample, 28 children had typical language development (TD) and 23 children had SLI. The majority of the participants were initially recruited from a larger two-year longitudinal study of executive functions and language at the University of Wisconsin-Madison. Forty-seven children lived in the greater Madison metropolitan area (Wisconsin, USA) and four children lived in the greater Baton Rouge metropolitan area (Louisiana, USA). See Table 2 for participant characteristics. Two participants with typical language development from the original Haebig et al. (2017) sample were removed in the current data analysis in order to better match the TD and SLI groups on nonverbal cognitive skills.

During the first year of the larger study, standardized assessments were administered to measure the participants' language and cognitive skills. The Perceptual Reasoning Index of the Wechsler Intelligence Scale for Children - IV edition (WISC-IV; Wechsler, 2003) assessed children's nonverbal cognitive abilities. Participants' receptive vocabulary abilities were measured using the Peabody Picture Vocabulary Test - 4th edition (PPVT; Dunn & Dunn, 2007). Receptive and expressive lexical and grammatical skills were measured using the Clinical Evaluation of Language Fundamentals – 4th edition (CELF-4; Semel, Wiig, & Secord, 2003). The same standardized measures were administered to children in Louisiana, during their first or second visit in the study. All of the children had WISC-IV standard scores above 85 and passed a pure-tone hearing screening. Children were identified as TD if that had no history of special education services and achieved a standard score that was within or above the normal range on the CELF-4. Children with SLI had scores at least 1.25 standard deviations below the mean on one or more composite measures of the CELF-4 or had at least a 14-point gap between CELF-4 scores and the WISC-IV and had a history of or were currently receiving language therapy. Participants in both groups were required to score below the core autism cutoff score on the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003) to rule out the presence of autism spectrum disorder. Inclusion in the study required participants to complete at least three of the experimental tasks as well as meet the criteria listed above. Children were matched on chronological age ($t(51) = -0.32$, $p = .753$) and cognition scores ($t(49) = 0.56$, $p = .581$), measured by the WISC-IV standard score. Participant characteristics can be seen in Table 2.

Table 2. Participant characteristics

	TD (*n* = 28; 18 females)			SLI (*n* = 23; 12 females)			Group Comparisons
	M	SD	Range	M	SD	Range	
Chronological Age	10.17	1.26	8.1-12.8	10.28	1.18	8.1-11.7	TD = SLI, $p = .753$
Maternal Years of Education	16.46	2.77	12-22	15.45	4.23	11-26	TD = SLI, $p = .314$
Cognition[a]	103.82	8.04	88-119	102.35	10.88	86-129	TD = SLI, $p = .581$
Receptive Vocabulary[b]	109.07	16.76	85-142	94.22	13.77	74-121	TD > SLI, $p = .001$
Language[c]	102.74	11.94	91-134	81.91	14.23	67-114	TD > SLI, $p < .001$

Note. [a]Cognition measured using WISC-4, [b]Receptive vocabulary measured using the PPVT-4, [c]Language measured using the CELF-4 core language score

Experimental Procedures

Standardized and experimental tasks were administered in a counterbalanced schedule. Participants completed each N-Back task, the segmentation task, and either the PPVT-4 and the CELF-4 or the WISC-4 on one day. On a separate day, participants completed the fast mapping task and either the PPVT-4 and the CELF-4 or the WISC-4. The set of tests administered to each child was balanced so that order of administration would not affect performance.

Nonverbal working memory

The participants' working memory (WM) skills were assessed using a visual N-back task. The task requires children to look at images and to press one of two buttons to categorize each image according to the specific N-back rule. Images used were abstract shapes with no clear verbal label. The task was programmed using E-Prime Studio 2 (Schneider, Eschman, & Zuccolotto, 2002). Participants completed three conditions of the task including 0-back, 1-back, and 2-back. The 0-back condition required children to press a green button when the pre-defined target image appeared on the screen and press the red button when the image was different from the target. The other two conditions required children to press the green button when the image on the screen matched the target image from one (1-back) or two (2-back) trials before and press the red button if the image differed from the image that appeared on the previous or two previous trials (see Figure 1). Five practice trials were included in the 0-back and 1-back condition and eight practice trials were included in the 2-back condition. Each stimulus was presented for 1500 ms, with an inter-stimulus interval (ISI) of 500 ms, across all three conditions. Each condition consisted of 40 total trials with 30 "misses" (non-target image) and 10 "hits" (target-image items). A fixed pseudorandom presentation of the stimuli was used so that in the 0-back condition at least two intervening trials were presented between target the target image presentation. In order to maintain consistency with previously published manuscripts with overlapping participant samples, overall accuracy across the 0-back, 1-back, and 2-back conditions was used as the index of WM (Ellis Weismer et al., 2017; Haebig et al., 2015). Haebig (2017) did not present information about working memory abilities in their sample.

Word segmentation task

To assess statistical learning capabilities, children completed a word segmentation task using an artificial language. Two artificial languages from Graf Estes et al. (2009) were used; children were assigned to one of the two languages. Each artificial languages consisted of four disyllabic novel words (Language A: /time/, /mɑno/, /dobu/, /pigɑ/; Language B: /nome/, /mɑti/, /gɑbu/, /pido/). These words were repeated in pseudorandom order with no pauses or acoustic cues to word boundaries. The stimuli were recorded by a Mainstream American English-speaking female. Transitional probability (TP) refers to the statistical likelihood of the co-occurrence of sounds within a language; specifically, it is the probability of stimulus Y given stimulus X, as a function of the frequency of the co-occurrence of XY (i.e., frequency of XY | frequency of X [Saffran, Aslin, & Newport, 1996]). Individuals are more likely to put together, or segment, sounds with high TP than low TP. When listening to an artificial language, individuals must rely on the statistical structure rather than pauses or prosodic cues to successfully segment words. Within the artificial language that was used for this study, syllables that made up words in the artificial language had high within-word transitional probability (within-word transitional probability = 1.0, across word transitional probability = 0.33; Graf Estes, Evans, Alibali, & Saffran, 2007).

Children were instructed to sit and listen to a "Martian language" while watching a nature scene video; the exposure phase of the word segmentation task lasted 4.5 minutes. After being exposed to the artificial language, children completed a practice task where they chose between commonly known disyllabic English words and disyllabic nonwords following American English phonotactics. Next, the children completed a 32-item two-alternative forced choice (2AFC; word vs. nonword) test. The 2AFC test consisted on one word and one nonword from the artificial language. Nonwords consisted of a pair of syllables from the artificial language that never occurred together in the artificial language (TP = 0.0). Words from Language A were nonwords for Language B, and vice versa. During testing, the first stimulus played auditorily as the number 1 appeared on the left side of the screen, the second stimulus was then played auditorily as the number 2 appeared on the right side of the screen. Children were then prompted by a question mark in the center of the screen to select the stimulus that sounded like the 'Martian language'. Children pressed the button-box key with either the number 1 or 2 labeled above it to submit their response (Haebig, Saffran, & Ellis Weismer, 2017).

Fast mapping

Word learning was assessed using a fast-mapping task. Four novel words (/timo/, /bole/, /deno/, /pɑdu/) paired with four different novel objects were used in the task. The objects were two-dimensional and of solid color (see Figure 2). Although there was overlap in phonemes that were present in the artificial language that was used in the word segmentation task and the novel words that were used in the fast-mapping task, there was no overlap in syllables. During the teaching phase, each novel object was displayed on a large-screen TV with its novel word label presented auditorily. Each pair was presented individually three times in a nonsequential pseudorandomized order. A test phase followed, where two of the objects were shown on opposite sides of a screen. The child's attention was directed to one of the objects with an auditory cue (e.g. 'Find the _____.' or 'Where's the ___?'). A total of 16 test trials were administered consisting of four test trials for each object-label pair. The task was 4.5 minutes in length. In the initial study, video recordings were made of the child's face to collect eye-gaze data for the children in the first data set. These data were derived and examined by trained coders who performed their analysis offline using Looking-While-Listening (LWL) coding procedures

(Fernald, Zangl, & Marchman, 2008). A second test phase was performed after the eye-gaze test phase. In this phase, the child was shown a piece of paper with each of the four objects in each corner. The examiner asked the child to point to each of the object after she listed each label (e.g. 'Find the _.' Where's the _?'). Each child's pointing responses were recorded in writing (Haebig et al., 2017). For the purposes of the current study, only pointing data will be analyzed.

CHAPTER 3. RESULTS

Group Comparisons

Before answering the research questions, we compared the children's performance across the three tasks to identify any group differences. First, we compared group performance on the statistical learning task. There was a significant group difference ($t(49) = 2.15$, $p = .038$), with higher word segmentation scores for the TD group ($M = 61.7$, $SD = 14.59$) than the SLI group ($M = 53.6$, $SD = 11.56$). To see the distribution of segmenting scores, see figures 3 and 4. The difference in fast-mapping was not found to be significantly different between the TD group ($M = 63.4$, $SD = 36.9$) and the SLI group ($M = 48.9$, $SD = 24.4$; $t(49) = 1.61$, $p = .113$). The distribution of fast-mapping scores are displayed in figures 5 and 6. Finally, no significant group difference was found between nonverbal working memory overall accuracy scores for the groups ($t(49) = 1.55$, $p = .128$; see Figures 8 and 9). The TD group had a mean proportion of overall accuracy score on the N-back task of 0.851 ($SD = 0.066$) and the mean performance for the SLI group was 0.809 ($SD = 0.12$).

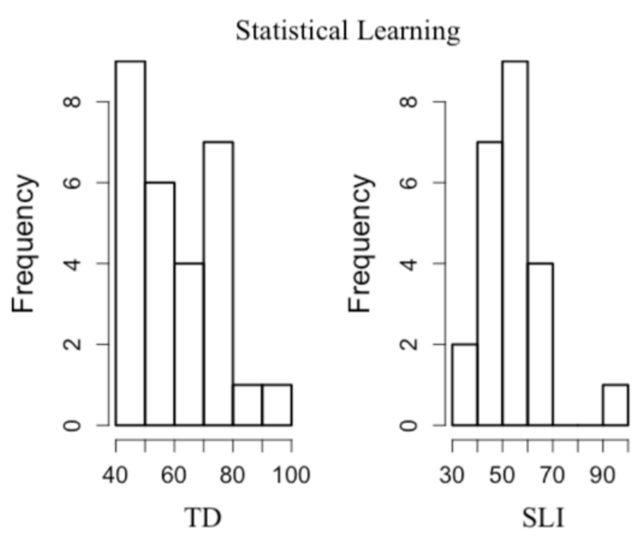


Figure 3. Segmenting Accuracy Scores for TD Children and Children with SLI

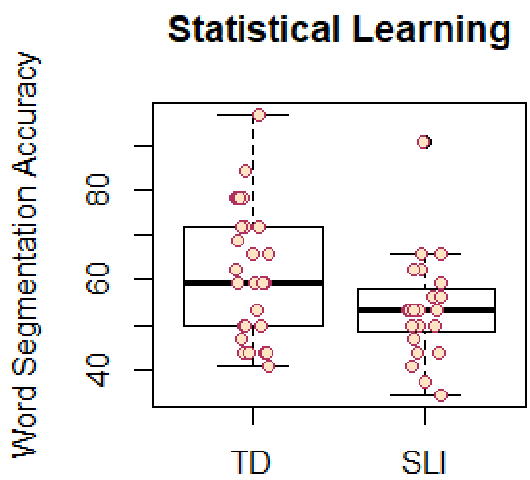


Figure 4. Segmenting Accuracy Scores for TD Children and Children with SLI

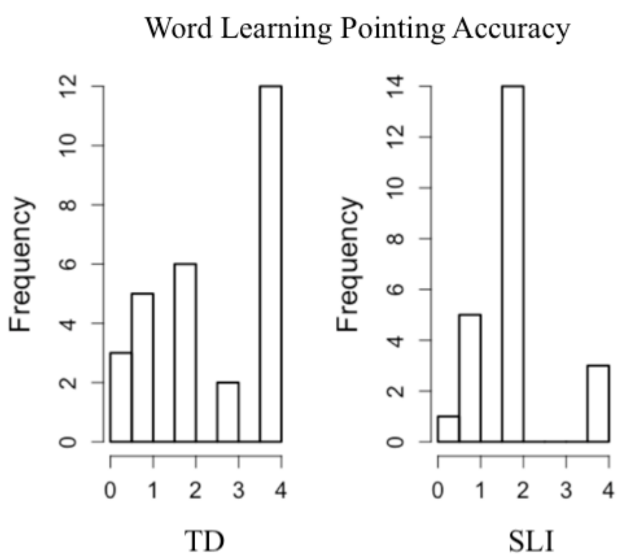


Figure 5. Distribution of Fast-Mapping Accuracy Scores in Each Group

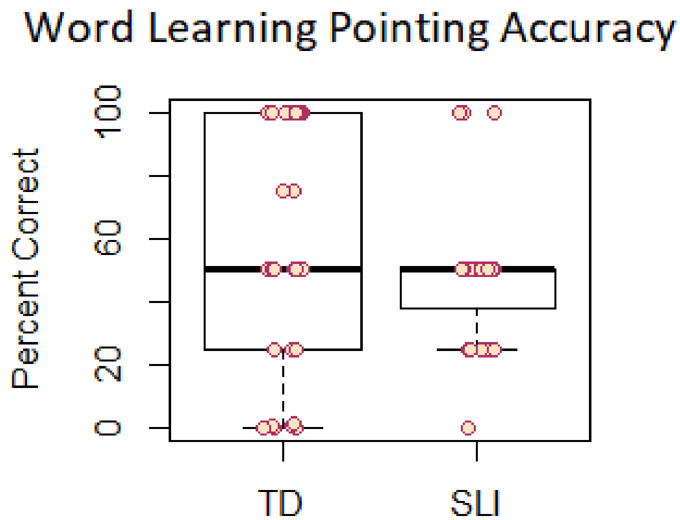


Figure 6. Fast-Mapping Accuracy Scores for SLI and TD Groups

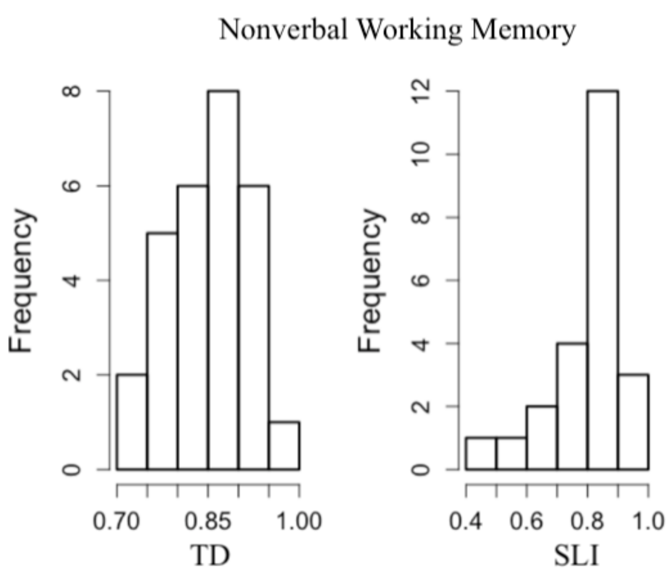


Figure 7. Distribution of Working Memory Accuracy Scores in Each Group

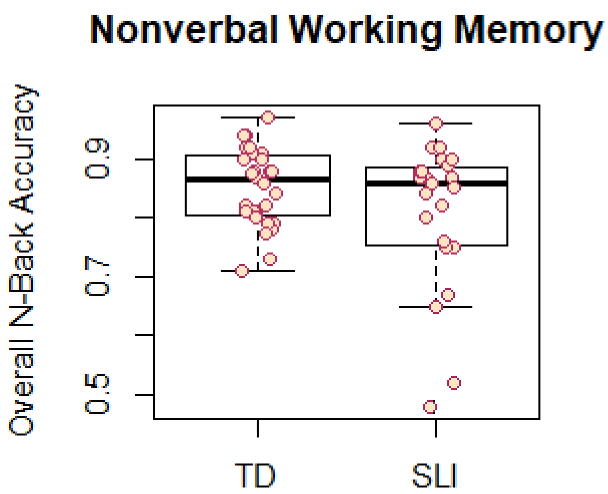


Figure 8. Working Memory Overall Accuracy Scores for SLI and TD groups

Working Memory and Language Associations

As a first step of addressing the research questions, we conducted bivariate correlations. We examined associations between working memory, statistical learning, fast mapping, and other child characteristics to investigate the relationships between each variable. Significant correlations in only the combined groups were found between working memory and expressive language, measured using the Expressive Language composite standard score from the CELF-4, (r = .340 , p = 0.071) and working memory and overall language scores, measured using the Core Language composite standard score from the CELF-4, (r = .364, p = 0.01). Working memory also correlated with raw receptive vocabulary scores in groups combined (r = .379, p = .006). A marginal correlation was also observed in the SLI group (r = .413, p = .050) but not in the TD group alone. Additionally, receptive language scores, measured using the Receptive Language composite standard score from the CELF-4, were significantly correlated to fast mapping scores only when both groups were combined and not in each individual group (r = .283, p = .04). Fast-mapping also correlated with raw receptive vocabulary scores in both groups combined (*r* = .325, *p* = .02). This correlation remained significant for the SLI (*r* = .489, *p* = 0.02) group but not the TD group (*r* = .087, *p* = .66) when associations were examined within each group. Additionally, fast-mapping accuracy scores correlated with segmentation accuracy scores for both groups combined (*r* = .417, *p* = .01).

Table 3. Bivariant Correlations

	Receptive Vocabulary (PPVT-4)		Language Scores (CELF-4)			Segmentation	Fast-Mapping	Working Memory
	Raw	SS	RL	EL	CLS			
Groups Combined								
Segmentation	0.164	0.140	0.253	0.185	0.208	-	0.417*	0.040
Fast Mapping	0.325*	0.191	0.283*	0.101	0.193	0.417*	-	0.237
Working Memory	0.379*	0.151	0.257	0.340*	0.364*	0.040	0.237	-
TD								
Segmentation	0.036	0.069	0.007	-0.111	-0.114	-	0.478*	0.073
Fast-Mapping	0.215	0.087	0.092	-0.097	-0.042	0.478*	-	0.279
Working Memory	0.227	0.062	0.104	0.187	0.216	0.073	0.279	-
SLI								
Segmentation	0.097	0.170	0.262	0.062	0.165	-	0.204	-0.109
Fast-Mapping	0.489*	0.302	0.504*	0.127	0.378	0.204	-	0.220
Working Memory	0.413	0.077	0.203	0.309	0.342	-0.109	0.220	-

Note. [a]Standard Score, [b]Receptive Language, [c]Expressive Language, [d]Core Language Score, *$p < .01$, ** $p < .001$

Research Question 1: Relationship Between Working Memory, Statistical Learning, and Group

The first research question asked whether there is a relationship between statistical learning and nonverbal working memory in children with SLI and TD children. To assess the associations among working memory, word segmentation, and group, we used a linear regression model with working memory scores, group, and an interaction between working memory and group as the independent variables. Group membership accounted for unique variance in word segmentation performance; however, working memory did not. Additionally, there was no significant interaction between working memory and group (See Table 3).

Additionally, a mean-split was performed in which each group was divided into a high or low working memory group based on the respective mean N-back overall accuracy score. Descriptively, in the TD group, children with high working memory had higher average word segmentation scores (*M* = 63.54, *SD* = 16.27) than their TD peers with low working memory (*M* = 59.62, *SD* = 12.72). Conversely, children with SLI and high working memory (*M* = 51.46, *SD* = 10.01) and children with SLI and low working memory (*M* = 57.81, *SD* = 13.77) performed relatively similarly.

Table 3. Linear Regression Model: Word Segmentation Regressed on Working Memory and Group

	B	***t*-value**	***p*-value**
Group	7.98	2.03	.048
Working Memory	-10.08	-0.44	.665
Group x Working Memory	26.26	0.57	.569

Research Question 2: Relationship between Working Memory, Fast Mapping, and Group

The second research question investigated the relationship between fast mapping and working memory in TD children and children with SLI. Pointing data from the fast mapping task yielded mean accuracy scores of 63.3 % (*SD* = 36.9) for the TD group and 48.9 % (*SD* = 24.3) for the SLI group. A linear regression model with fast-mapping scores as the dependent variable and working memory, group, and an interaction between group and working memory as independent variables. There were no unique predictors of fast mapping performance (see Table 4).

We also explored the outcomes of a mean-split based on average overall N-back accuracy scores in each group. Descriptively, in the TD group, children with high working memory had higher fast-mapping accuracy scores (*M* = 75.00, *SD* = 31.34) than TD children with low working memory scores (*M* = 50, *SD* = 39.53). In contrast, children with SLI and high working memory (*M* = 48.33, *SD* = 25.82) performed similarly to the children with SLI and low working memory scores (*M* = 50, *SD* = 23.15).

Table 4. Linear Regression Model: Fast-Mapping Regressed on Working Memory and Group

	B	***t*-value**	***p*-value**
Group	10.35	1.14	.260
Working Memory	42.94	0.80	.426
Group x Working Memory	121.82	1.15	.255

CHAPTER 4. DISCUSSION

Statistical Learning and Nonverbal Working Memory

We first asked if a relationship exists between statistical learning and nonverbal working memory for children with SLI and typically developing children. Children with SLI were found to perform significantly worse than their TD peers on the statistical learning task. A linear regression model indicated that group membership explained a significant amount of variance while working memory scores did not. These findings align with previous work that has indicated mixed working memory profiles across different language profiles, including SLI (Gray et al., 2019). Statistical learning is one skill, albeit a very important skill, in processing and learning language. Surprisingly though, our findings do not indicate a relationship between standardized measures of language and statistical learning. However, statistical learning did correlate with fast-mapping outcomes which suggests a relationship between the ability to learn words and the ability to recognize probabilistic properties of auditory input. While it is odd that the same significant correlations were not observed between the statistical learning task and standardized measures of language it could be due to the nature of each measure. In other words, the fast-mapping task measured the amount of words learned after a short teaching period, much like a dynamic assessment. Both standardized measures employed for this study were static assessments, measuring each child’s existing language skills. Maybe these data highlight the importance of statistical learning in examining the learning process rather than overall existing language skills.

When low and high working memory subgroup means were examined, children in the TD group with low working memory performed similarly to the low and high working memory SLI subgroups. Children with typical language and high working memory scores had higher fast-mapping outcomes than the other three subgroups. It was particularly notable that the working memory subgroups (mean-split high and low subgroups) within the SLI group performed very similarly on the fast-mapping task. This finding challenges previous claims that working memory is associated with word learning which led us to believe an association may exist between working memory and word segmentation (Lum et al., 2015). Rather, scores of children with both linguistic profiles acted independently of working memory scores. It should be noted that sample sizes when participants were split into four groups rather than two were small and not ideal for examining the role of working memory on word learning. Additionally, and as mentioned previously, many cognitive processes are involved in language learning and it is possible that working memory doesn't play the largest role in this one aspect of language development.

Additionally, statistical learning could possibly rely on other cognitive skills such as attention (Baker, Olson, & Behrmann, 2004; Toro, Sinnett, & Soto-Faraco, 2005). It has been observed that attention can affect infants' abilities to learn word-referent pairs based on statistical properties (Smith & Yu, 2012; Thiessen, Hill, & Saffran, 2005). Adults have also been shown to increase statistical learning when their attention is directed to target stimuli (Baker et al., 2004). While it is likely that working memory supports aspects of language learning, statistical learning may not rely on working memory as heavily as other language learning skills do. Alternatively, given that our working memory task was nonverbal, it is possible that a working memory task that engaged linguistic or phonological processing would reveal a different relationship with a statistical learning word segmentation task. Significant correlations were observed between working memory and receptive vocabulary raw scores, expressive language scores, and core language scores in both groups combined. These data indicate some involvement of nonverbal working memory in language learning and further investigation could parse which mechanisms are most supported.

Fast-mapping and Nonverbal Working Memory

Our second research question investigated the relationship of fast-mapping and nonverbal working memory in children with SLI and typically developing children. No significant difference was found in fast-mapping scores between children with SLI and TD children. This finding contradicts a previous study that used mostly overlapping data that was used in the current study (Haebig et al., 2017). In the previous study, eye gaze data were analyzed in order to understand fast mapping (Haebig et al., 2017); however, pointing data replicated their eye gaze findings. In the current study, only pointing data were used. It is possible that the small changes in participants in the TD group led to small differences in group fast mapping performance. In the previous study, the TD group had an average pointing accuracy of 70% (Haebig et al., 2017). In the current study, the TD participants differed slightly; TD fast mapping pointing accuracies were lower, leading to an overall average of 62%. It is possible that if eye gaze data were available, an interpretation of looks to the target versus the distractor would reveal more subtle differences in fast mapping between the two groups that were not demonstrated in the pointing data. Previous studies have demonstrated that eye gaze behavior often reveal subtle processing abilities that are not readily observable when examining more explicit measures of learning and knowledge (e.g., Venker, Haebig, Edwards, Saffran, & Ellis Weismer, 2016).

An interesting pattern was observed when a mean-split was used to examine the association between working memory scores and word learning scores. Working memory appeared to play a relatively larger role in fast-mapping for children with typical language than the children with SLI. The fast-mapping means of children with typical language and high working memory were higher than children with typical language and low working memory while both groups within the SLI group had similar fast-mapping averages. This contradicts what Lum (2015) and his colleagues posited which would have led us to expect working memory to play a larger role in the word learning skills of children with SLI. It is difficult to determine why our results stray from what other studies have found but the difference in how word learning was assessed could be playing a role as well as the fact that the working memory task used in the current study was nonverbal. Additionally, because pointing data were used in our analyses scores ranged from 0-100 and increased in intervals of 25. This does not leave much variety in scores and makes subtle differences in performance more difficult to recognize.

Fast-mapping scores did not correlate with nonverbal working memory. This lack of association between working memory and fast-mapping is contradictory of Lum and colleagues' findings (2015), who found an association with working memory and declarative learning. Notably though, in the Lum et al. study, working memory was measured using a verbal working memory task and the declarative learning task required the children to memorize a list of known words. The current study utilized a nonverbal working memory task and a fast mapping task that measured novel fast mapping. An important future study would be to examine verbal working memory with fast mapping in children with SLI.

It is also notable that the matching criteria in the current study differed from previous studies of children with SLI. Previous studies have matched on grammar-abilities, age, or standardized language test scores (Archibald & Gathercole, 2006b; Gray et al., 2019; Lum et al., 2015). The current study matched for cognitive skills using nonverbal IQ, based on other studies investigating statistical learning (e.g., Evans et al., 2009).

Additionally, the difference found in receptive vocabulary scores supports previous findings which indicated poor lexical-semantic skills in children with SLI. Kan and Windsor (2010) demonstrated across 28 novel word learning studies that children with SLI show difficulties associating word labels to their referents when compared to children with typically developing language. The fact that a significant difference in receptive vocabulary scores was found between children with SLI and children with typical language indicates a break down in word learning abilities for children with SLI. Additionally, a significant correlation was observed between fast-mapping and receptive vocabulary raw scores, measured by the PPVT-4, in both groups combined. This supports the notion that stronger word learning skills are related to the size of a child's lexicon (Gray & Brinkley, 2011). The correlation continued to hold significance in the children with SLI, however the same relationship was not observed in the TD group. While it would seem that fast-mapping would continue to relate to vocabulary size across development, these data could be interpreted as an indication that children are less dependent on fast-mapping as their vocabulary matures. Past studies have demonstrated that children with SLI perform more similarly to grammar-matched, younger children rather than age-matched peers on a word-referent associative learning task (Bishop & Hsu, 2015). The association of fast-mapping and receptive vocabulary outcomes could be another example of an immature word-learning mechanism in children with SLI. Therefore, while the current data did not show a significant difference in fast-mapping scores between groups, we caution readers to interpret the findings carefully given the extensive literature on word learning weaknesses in children with SLI and the current group difference in PPVT-4 scores.

Theoretical Implications

When considering other theoretical perspectives which guided the current study, the results support the PDH and partially support the SEH, however more evidence is necessary to explore the General Slowing Hypothesis (R. Kail, 1994; R Kail & Leonard, 1986; Ullman & Pierpont, 2005). We observed a significant difference between groups for statistical learning scores which adds evidence that children with SLI have a poorer ability to recognize statistical patterns in input as the PDH suggests. Although the groups did not differ significantly in fast-mapping scores, children with SLI did demonstrate smaller receptive vocabularies as measured by the PPVT-4, supporting the SEH's claim that children with SLI have weaker abilities to learn. A task involving use of words learned would be beneficial in exploring the elaboration component of the SEH further. Finally, the fact that children with SLI did not recognize patterns in input in the statistical learning task as well as their TD peers suggests some level of processing deficits. However, there were no group differences in processing the visual information that was presented in the N-back task. It is difficult to make claims about the General Slowing Hypothesis. Additional data that would include a measure of reaction time on each task may help to support or refute this hypothesis. Future studies may compare processing speed in TD children and children with SLI when processing different types of information for children with SLI and TD.

Variation from Motivating Studies

The current study was motivated by two previous studies conducted by Haebig et al. (2017) and Lum et al. (2015). While the data from Haebig et al. (2017) and the current study contained overlapping data, there were notable differences. First, different examiners administered standardized and experimental measures with participants. Additionally, the recruitment process differed for each study. During data collection at the University of Wisconsin – Madison, participants were recruited from a database of individuals generally interested in participating in university research studies. At Louisiana State University, participants were recruited from the community and had not previously participated in research studies. It could be speculated that the pool of participants from the University of Wisconsin – Madison had more intrinsic motivation to participate in a research study than the participants at Louisiana State University.

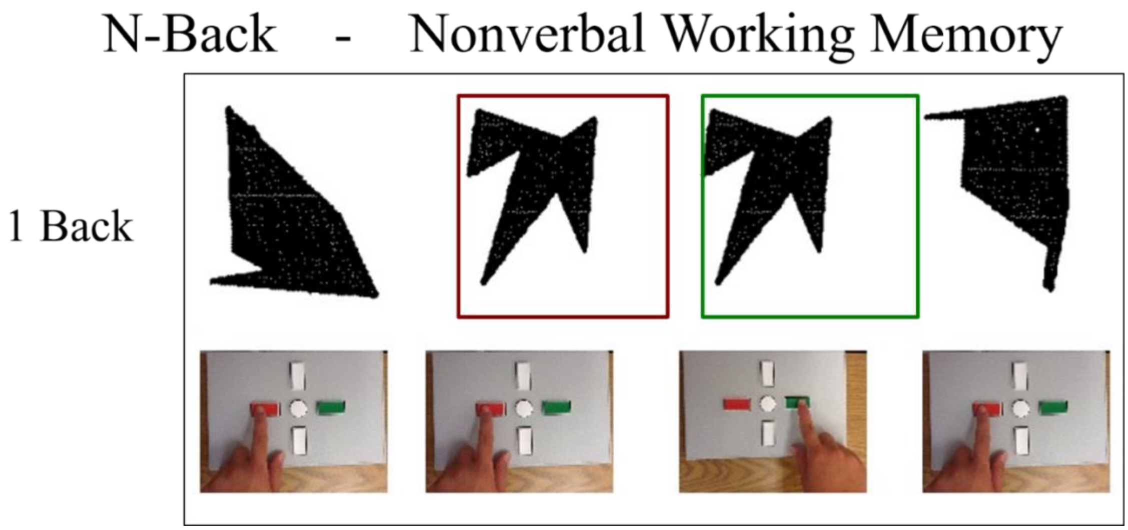
Another strong motivator for the current study was Lum and colleague's suggestion of an association between verbal declarative memory and working memory in children with SLI (Lum et al., 2015). Children with SLI who also showed impaired verbal working memory were observed to perform more poorly on a word recall and recognition task than peers with normal verbal working memory capabilities. We sought to explore if an association could also be seen between nonverbal working memory and word learning. An association was not found between working memory the fast-mapping task in the current study. This finding contradicts the idea of an association between working memory and word learning in both children with SLI and children with typically developing language. As mentioned previously, the current study differs from Lum's study in that the working memory measure was nonverbal and the measure of word learning involved fast-mapping and only required children to complete a recognition task immediately following exposure to stimuli.

The lack of a group difference in nonverbal working memory performance supports the notion that deficits in working memory skills in children with SLI could be due to verbal components of the measures used rather than deficits in working memory alone (Alloway, Rajendran, & Archibald, 2009). We have demonstrated that when working memory measures are nonverbal, children with SLI can perform similarly to their TD peers.

Limitations

The current study's limitations include differences from the design of Haebig (2017) which used mostly overlapping data. The sample collected at LSU was small compared to the number of participants from the University of Wisconsin – Madison (n = 74). Also, only typically developing children were included at the second point of data collection. With data being collected from two different regions, it may have been more beneficial to include the same number of children across the two diagnostic groups. Second, our study was limited in that it did not analyze both eye-gaze data and pointing data for the fast mapping task, as was previously done in the original study (Haebig et al., 2017). The current study used only pointing data, likely not picking up on more subtle differences between the two groups. Also, as mentioned previously, matching criteria for the current study differed from other studies investigating SLI word learning profiles which have used age, language measures, and grammar measures (Archibald & Gathercole, 2006b; Gray et al., 2019; Lum et al., 2015). For the current study, matching was modeled after other studies that investigated statistical learning which used cognitive skills (Evans et al., 2009).

APPENDIX A. NONVERBAL WORKING MEMORY TASK EXAMPLE



APPENDIX B. FAST MAPPING TASK REFERENT IMAGES




APPENDIX C. IRB APPROVAL FORM

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu
lsu.edu/research

TO: Eileen Haebig
Communication Sciences and Disorders

FROM: Dennis Landin
Kinesiology

DATE: June 11, 2019

RE: **IRB#** 4239

TITLE: The Relationship Between Working Memory, Procedural Learning, and Declarative Memory in Children with Specific Language Impairment

New Protocol/Modification/Continuation: New Protocol

Review type: Full ____ Expedited _X_ **Review date:** 5/23/2019

Risk Factor: Minimal ___X___ Uncertain ______ Greater Than Minimal______

Approved_____X_____ **Disapproved**__________

Approval Date: 6/11/2019 **Approval Expiration Date:** 6/10/2020

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 20

LSU Proposal Number (if applicable)**:**

By: Dennis Landin, Chairman DLandin

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: When emailing more than one recipient, make sure you use bcc.**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

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