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Phonological working memory impairments in children with specific language impairment: where does the problem lie?

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Abstract

Purpose—The purpose of this study was to determine which factors contribute to the lexical learning deficits of children with Specific Language Impairment (SLI).

Method—Participants included 40 7-8-year old participants, half of whom were diagnosed with SLI and half of whom had normal language skills. We tested hypotheses about the contributions to word learning of the initial encoding of phonological information and the link to long-term memory. Children took part in a computer-based fast-mapping task which manipulated word length and phonotactic probability to address the hypotheses. The task had a recognition and a production component. Data were analyzed using mixed ANOVAs with post-hoc testing.

Results—Results indicate that the main problem for children with SLI is with initial encoding, with implications for limited capacity. There was not strong evidence for specific deficits in the link to long term memory.

Conclusions—We were able to ascertain which aspects of lexical learning are most problematic for children with SLI in terms of fast-mapping. These findings may allow clinicians to focus intervention on known areas of weakness. Future directions include extending these findings to slow mapping scenarios.

1. Introduction

1.1Purpose

The purpose of this study was to try to determine, or rule out, possible sources for the word learning problems that characterize children with specific language impairment (SLI). Although it is well known that children with SLI have difficulty learning novel lexical labels (e.g. Alt & Plante, 2006), there are several possible sources for this problem. Different causes may require different types of intervention. Without knowing the source of the problem, it is difficult to use a focused intervention approach. Also, it is possible that an intervention that is based on an incorrect assumption of where the deficit lies will be ineffectual or even counterproductive. Therefore, two possible sources of lexical learning problems were examined: problems encoding information into the phonological loop and problems accessing information from long term memory.

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These two possible sources of word learning problems were drawn from Baddeley's (2003) model of working memory, specifically the phonological loop. This psychological construct is thought to be the place where people encode and rehearse novel phonological information before committing the information to long term memory. The purpose of this study is not to prove or disprove Baddeley's model, but rather to use a theoretical model to shed some light on the interplay between components of working memory and word learning.

1.2 Why look at working memory as related to word learning?

Although Baddeley's model was not created to explain word learning, there are components of it that have been implicated as possible sources of word learning deficits for children with language impairment, and Baddeley himself suggested the phonological loop as a means to learn language (Baddeley, Gathercole, & Papagno, 1998). Certainly, there are other models of working memory that exist (e.g. Cowan et al., 2005), but Baddeley's model allows for direct testing of at least two components of working memory that may be directly implicated in word learning. We can also use a formal model of the interaction between working memory and word learning (Gupta & MacWhinney, 1997) to help explain how the components of working memory we will examine in Baddeley's model (i.e. initial encoding into the phonological loop and link to long term memory) may relate to the task of word learning.

Working memory has often been suggested as a significant contributing factor in the process of word learning (e.g. Ellis & Sinclair, 1996; Martin & Gupta, 2004). Recent work has provided evidence for links between children's performance on language tasks and tasks involving working memory (see van Daal, Verhoeven, van Leeuwe, & van Balkom, 2008 for a brief review). In a review of the literature on working memory and specific language impairment, Montgomery, Magimairaj and Finney (2010) conclude that working memory should be considered as a potential influence in the language learning of this population. In terms of word learning, the authors note that there has been evidence of “robust associations” between phonological short term memory and word learning in children up to age 8 that weaken slightly, but remain important into adulthood (p. 80).

1.3 How might this association work?

It is important to be able to explain how this association might work. One model of the link between short-term memory and word learning comes from Gupta and MacWhinney (1997) who suggest that these two processes are related in that they share a cognitive and neural system. They propose that both short-term memory and word learning rely upon “core phonological processing mechanisms” and are both involved in rehearsal and chunking of incoming information (p.325). In this model, novel information triggers the creation of new ‘chunk nodes’, which then trigger learning and allow for the encoding of individual phonemes, then syllables. Representations become strengthened through either rehearsal or additional presentations of the novel word. In order to produce a word, the learner has to activate a chunk node, which Gupta and MacWhinney say can occur through the use of semantic information. The activated layer will then provide the information in sequential order for the individual phonemes that need to be produced.

Gupta and MacWhinney (1997) are careful to state that verbal short-term memory does not play a causal role in word learning; they only specify the shared underlying neural and cognitive processes. On the other hand, Gathercole and Baddeley (1990) suggest that phonological working memory deficits may play a causal role in language development. The present study is not designed to prove either case. Instead, both these models – one of working memory, and one of working memory and word learning- provide an important starting point to test word learning. The point of commonality is that of the central role of phonological processing.

1.4 Problem Source 1: Initial encoding of phonological information

When a child is exposed to a novel word, he or she must first encode that word into the phonological loop, if one uses Baddeley's model, or create a new chunk node, if one uses the Gupta and MacWhinney model. In either case, a child needs to encode phonological input into a short-term memory system before that word can be learned, and committed to long term memory. A problem with that initial input into working memory would likely be problematic for word learning, with several scenarios possible.

In the first scenario, children with SLI might not be able to encode a sufficient amount of information due to problems with perception. If the problem is with perception, or is specifically phonological, we would expect to see poor performance on words of any length. This poor performance might manifest as an incorrectly learned word, a word with partial phonological representations, or a word that is not learned at all. In terms of word recognition, a child's performance would depend upon the nature of the word recognition task. For example, if a child has a partial representation of a word, that might be enough to help him or her recognize the word in the future. However, if a task demanded specific, detailed metalinguistic decisions about the novel word, the outcome would likely be poor. In terms of production, poor input could lead to poor output and reflect the quality of the initial phonological input.

This type of finding – poor word learning due to problems with initial phonological encoding - would be predicted by theories that posit perceptual processing problems for children with SLI, such as the rate-processing constraint hypothesis (c.f. Tallal & Gaab, 2006). This theory in particular might predict that phonological encoding problems might only ensue when stimuli were presented at a rapid rate. There are studies that suggest problems with phonological representation such as Criddle and Durkin's (2001) finding that children with SLI were not as good as peers at noticing phonemic changes in novel morphemes. Also, Nash and Donaldson (2005) found that children with SLI exhibited deficits in phonology during word learning tasks compared to peers, even with up to 12 exposures to real, but low frequency words.

Alternatively, children with SLI could have adequate abilities to perceive the phonology of a novel word, but only be able to encode a limited amount of phonological information. The underlying problem would not be one of perception, but rather one of capacity. Phonological encoding (either into the phonological loop, or activation of a novel chunk, and subsequent weighting of phonemes) would be appropriate, but only for a limited number of phonemes. In such a scenario, a child would show intact representations for shorter words compared to longer words, relative to their peers.

Children with SLI have been found to have problems with phonological working memory, specifically when measured through nonword repetition tasks (e.g. Bishop, 2002; Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000; Gathercole, 1995; Girbau & Schwartz, 2007). Recent work has suggested that specific problems with phonological memory may only exist for those children who have comorbid SLI and dyslexia (Catts, Hogan, Adlof, & Ellis Weismer, 2005). However, if the problem is not specifically phonological, but secondary to a limited capacity for language due to working memory constraints (e.g. Just & Carpenter, 1992), we might only see problems emerge in longer words. Specifically, children with SLI might have poorer resource allocation resulting in processing inefficiencies. Alternatively, they might simply have a smaller total capacity for cognitive and linguistic processing. Therefore, we might expect children with SLI to have representations for longer words that were less precise. Whether the problem is with perception or capacity, there are certainly several situations in which difficulty encoding phonological information, a working memory issue, could result in a variety of word learning problems.

1.5 Problem Source 2: Link to long term memory

When a new word is being learned, the processing of the incoming phonological information does not happen in a vacuum, even though the particular arrangement of phonemes is novel. For example, although the phonological loop was originally conceived as a stand-alone component of the working memory model, Baddeley (2003) has acknowledged that, even within the rehearsal component of the phonological loop, learners have access to information about language from long term memory. Specifically, there is evidence of effects of neighborhood density, phonotactic probability, and wordlikeness on tasks thought to tap the phonological loop, such as word learning tasks (e.g. Storkel, Armbruster & Hogan, 2006) and word recognition tasks (e.g. Frisch, Large, & Pisoni, 2000). Thorn, Gathercole, and Frankish (2005) suggest that other findings such as lexicality effects, semantic similarity effects, and imageability effects also contribute to the evidence that information in long term memory influences performance on short term memory tasks. Effects such as those found for phonotactic probability could only come into play if learners had access to the statistical probabilities of their native language. These statistical probabilities are part of long-term memory, and thus there must be a link to long-term memory, even before a novel word is committed to long term memory.

Information about a language's statistical probabilities should be helpful for learners by allowing them to process words in a way that gives them context. Specifically, when a learner is trying to recall a newer memory, he or she can rely on information from long term memory in order to ‘fill-in-the-blanks’ in terms of components of the new memory that are underspecified. This process is often referred to as redintegration (e.g. Thorn et al., 2005). There are competing theories for how, specifically, redintegration works (for a review, see Thorn et al., 2005), but the key factor in all theories is that long term memory, in some way, influences short term performance.

If a child with SLI has a weak link to long term memory, this can result in a breakdown in word learning. The child might not have the benefits of redintegration. Gupta and MacWhinney's (1997) model acknowledges the role of long term knowledge in their model in the way in which they posit the chunk layers are organized. Specifically, they note that chunk layers, which are at the level of the word form, are organized in a way that mirrors the phenomenon of phonological similarity. That is, words with similar phonological forms will have similar representations in their model. This type of organizational system would represent the learner's more general long-term lexicon.

Performance on word production tasks would be predicted to be poor if a child had a weak link to long term memory. A lack of contextualization from associations with long-term memory could lead to poor phonological specification, and therefore less precise output. For word recognition, the nature of the task would dictate the outcome. Partial representations might be adequate for one type of task, and inadequate for a task demanding more detailed knowledge.

There is evidence that children with SLI do not process information such as phonotactic probability in the same way as their peers (Alt & Plante, 2006; Munson, Kurtz, & Windsor, 2005). Specifically, Munson and colleagues found that in a nonword repetition task, phonotactic probability had a stronger effect on school-aged children with SLI than it did on typically-developing age-matched peers. The performance of the children with SLI was similar to the performance of younger, typically-developing children. They thought that this was most likely related to the children's vocabulary level. Alt and Plante (2006) found that, in a word learning task, preschoolers with SLI did not map as many semantic attribute of novel objects as typically-developing peers when the objects' lexical labels were phonotactically infrequent. This suggests that phonological processing differences between impaired and unimpaired children can have an effect that extends beyond the realm of phonology and taps into lexical and semantic development as well. The pattern seems to be that children with SLI show stronger effects of phonotactic probability than their age-matched peers, and when a condition related to phonotactic probability makes a task more difficult for all children, the task may be markedly more difficult for children with SLI.

Therefore, one possible explanation for word learning problems is that children with SLI have access to the information about the general lexical characteristics of their native language in long term memory, but are unable to utilize that information as efficiently as peers. They may be trying to learn novel words without adequate reference points, thus impairing their ability to process the new information, categorize the information, or both. A model for this type of processing problem comes from Ahissar's (2007) anchoring deficit hypothesis. This hypothesis was created to explain numerous deficits reported in people with dyslexia. Ahissar proposed that people with dyslexia are less likely to form perceptual anchors of specific stimuli, which would allow them to more easily interpret new or incoming information. An anchor, or recognition that a stimulus is familiar, allows a person to treat the stimuli as part of a category or organized system. Without an anchor, each piece of information is treated as novel, decontextualized, and thus takes more effort to process. A similar problem could exist for children with SLI, particularly given that many of the teenaged and adult participants who demonstrated anchoring deficits in the studies Ahissar (2007) reports also had mild language impairments.

1.6 Fast Mapping

In terms of word learning, fast-mapping is when someone is asked to learn a word with fewer than 3 exposures to the stimuli (Carey & Bartlett, 1978). Fast mapping has the advantage of being able to provide insight into the initial processes or patterns a learner uses when he or she encounters a novel word. What happens during slow mapping, when a learner has had repeated exposures to stimuli, may reflect an individual's compensations as he or she tries to learn. These may differ from, or mask, the actual source of the word learning problem. It is important to find the source of word learning problems. Treatments designed to address problems with a link to long-term memory might not only look different from treatments designed to address problems with initial encoding, but might not help the learner at all.

1.7 The Current Study

In order to determine which of these suggested problems might be the sources for word learning difficulties in children with SLI, we asked school-age children with and without SLI to learn nonword labels for novel dinosaurs. We manipulated word length and phonotactic probability in order to test both of the proposed word learning problem sources. Children were asked to complete word recognition and word production tasks to allow for varying levels of task difficulty. It is possible that several problems related to phonological working memory might underlie the lexical learning problems of children with SLI. Given the complex nature of language and word learning, it is likely that these sources may interact with one another. Therefore, our specific hypotheses were:

1. If a problem with initial encoding into the phonological loop reflects an underlying frank phonological processing deficit, then children with SLI will perform worse than unimpaired peers on all nonwords.

2. If the problem is with limited capacity for phonological information, then children with SLI will perform worse than unimpaired peers on long nonwords compared to short nonwords.
3. If the problem is with ability to efficiently use information in long term memory, then children with SLI will perform worse than peers with typical development (TD) for nonwords with low phonotactic probability.
4. There will be interactions between the possible sources of the word learning problem such that the potentially more difficult conditions (longer nonwords, lower phonotactic probability) will combine to create the most difficulty for learners.

2. Methods

2.1 Participants

Participants included 40 7- and 8-year old children: half with SLI and half with typical language skills (TD). Children were matched individually for age and sex and by group for maternal level of education. Mothers of children in the SLI group had an average of 1 year of college, while mothers of children in the TD group had an average of 2 years of college. There was no significant difference between groups on age (p=.16) or maternal level of education (p=.18) (See Table 1). All students were monolingual English-speakers per parent report. Information on race and ethnicity can be found in Table 2. (See Table 2.)

Children were recruited through local school districts and summer programs. Children were labeled as SLI based on a current diagnosis of SLI plus a Clinical Evaluation of Language Fundamentals-IV (CELF-IV) (Semel, Wiig, & Secord, 2003) core language composite score of less than 85, or no previous diagnosis of SLI plus a CELF-IV score of less than 85 and a clinical judgment of impaired language skills based on informal interactions with a certified speech language pathologist. At a cut-off of 1 standard deviation below the mean, this test has a sensitivity of 100% and a specificity of 82% (Semel et al. 2003). Exclusionary criteria included a nonverbal intelligence score of less than 75 on the Kaufman Assessment Battery for Children-II (KABC-II) (Kaufman & Kaufman, 2006), failure on a hearing screening, a performance on the Goldman Fristoe Test of Articulation (GFTA-2) (Goldman & Fristoe, 2000) revealing significant phonological pattern usage that would prevent standard scoring of the production task, or parental report of other impairments (cognitive, social, or motor). No specific cut-off score was used for the GFTA-2, but errors children exhibited needed to be judged articulatory rather than phonological in nature. Specifically, children needed to demonstrate only distortions rather than substitution or deletions. Descriptive measures included scores on the Peabody Picture Vocabulary Test-IV (PPVT-IV) (Dunn & Dunn, 2007), a test of receptive vocabulary, and scores on the Test of Word Reading Efficiency (TOWRE) (Torgesen, Wagner, & Rashotte, 1999), a reading test. The PPVT-IV was used to describe the general word learning skills of the participants, given that this is a word learning task. The TOWRE was used to estimate the number of children enrolled who were not likely to have co-morbid reading problems. Children were described as having difficulty with reading when their TOWRE scores were lower than 85, given that the TOWRE manual described the mean score of their normative Learning Disabled group as roughly one standard deviation below the mean (Torgesen et al., 1999).

To be included in the study children with typical language needed to pass the hearing screening, have parental report of no impairments, and receive scores above the cut-offs specified for the children with SLI. Summary measures appear in Table 1.

2.2 Experimental task

In order to test the hypotheses, an experimental fast mapping task was created, in which children heard each nonword two times. The task was designed to come across as a game to participants. The experiment had a story line to let the participants know why their help in answering questions was needed. Children were asked to help a paleontologist and his assistant track never-before-seen dinosaurs. The paleontologist would spy a dinosaur in his binoculars and label it. The child then watched the dinosaur walk across the screen and eat something. The paleontologist would label it (auditorily) a second time. Then, then child was asked to help the assistant catalogue the dinosaur. Once the dinosaur was labeled, its picture flew into a book. (See Figure 1.)

There were two portions of the task used to track how children fast mapped the novel word: recognition and production. The recognition portion of the task required participants to make a lexical decision about the name of the dinosaur. Participants were presented with the name of the dinosaur, along with three phonological foils. These four labels were presented in random order. When each label was presented, the participant needed to decide if it was the real label for the dinosaur or not. They made this decision for each of the four choices, and did not receive feedback on their response, so as not to influence future decisions. Each choice was scored individually, so there were a total of four possible points for each dinosaur on the recognition portion of the task. Children made their choice (correct/incorrect label) by pressing a button on a button box. The response was recorded and scored by the computer. The recognition portion of the task always preceded the production portion of the task. While both tasks have the potential to influence one another, pragmatically it makes less sense to continue to ask a child about a word if they have already named it.

The production portion of the task required participants to recall and produce the name of the dinosaur. Children also did not receive feedback about the nature of their production. Responses were transcribed online, audio recorded, and later double-scored for percent consonants correct. All of the productions were double-scored. When there was a disagreement, a third listener was brought in to make the final decision.

2.2.1 Training—Before beginning the experimental task, children completed a training component. In the training component, participants were exposed to the characters in the experimental game. Dr. Bones was a paleontologist, and Joe was his hapless assistant who sometimes forgets his own name. The eventual task structure was modeled, but with familiar objects, to ensure children understood the task. Children were required to fast map a label onto an object. This was followed by a recognition component where the child had to make lexical decisions about the real label and three phonological foils, followed by an expressive component where the child needed to name the object. In the training, the child first practiced with a common object (e.g. “dog”) and then moved on to real dinosaurs (e.g. “tyrannosaurus”, “triceratops”). As the children worked their way through the training, they were given explicit directions about what they should do, and given explicit feedback about what they had done. On the last of the three practice trials, they did not receive feedback, in order to mimic the tasks to come. If children could not complete the training correctly, they were not allowed to proceed to the experimental task. All children passed the training. At no time during the training or the task were children given explicit instructions to practice or rehearse the names of the dinosaurs, nor were they explicitly reinforced or punished for doing so.

2.2.2 Experimental Task Design—The purpose of the task was to examine the effects of initial phonological encoding and links to long-term memory on word learning. In order to tap into these measures, we created a fast-mapping task that asked children to learn the names for 24 novel dinosaurs. The names were orthogonally varied by length (2- versus 4-syllables) and phonotactic probability (high versus low probability) such that there were 6 novel nonwords in each condition. (See nonwords in appendix A).

2.3 Stimuli construction

2.3.1The task—The task was designed using animations created in Adobe Flash, which were changed to movie files and presented in the game format using DirectRT (Jarvis, 2006). Dinosaurs were randomly matched with their labels for each child. Half the children had the "correct" button on the left side of their button box, while the other half had the "correct" button on the right side of the button box.

2.3.2 The Dinosaurs—The dinosaurs were constructed so as not to closely resemble any real dinosaurs or other animals. Dinosaurs were pilot tested with typically-developing 7-and 8-year-old children, who were also asked to name the dinosaurs. Dinosaurs that were easily nameable, or had readily identifiable features were eliminated from the study. We created a total of 24 novel dinosaurs. Features of the dinosaurs including their size, color, and pattern were randomly varied. (See appendix B for an example of the dinosaurs). They were presented in five different backgrounds and ate one of a variety of plants or animals. During the animation, children also heard dinosaurs' footsteps and chewing sounds. These sounds were never presented during a labeling portion in order to eliminate interference.

2.3.3. Nonword construction—There were three phonological and lexical characteristics of nonwords of interest: length, phonotactic probability, and stress. Nonword length varied so that shorter nonwords were 2 syllables (CV-CVC) and longer nonwords were 4 syllables (CV-CV-CV-CVC). This distinction is based on evidence showing that children with SLI tend to be discriminated from children with TD when nonwords are 3 syllables in length (e.g. Alt, Plante, & Creusere, 2004). Nonword phonotactic probability was calculated using the Phonotactic Probability Calculator (Vitevitch & Luce, 2004), which was designed for such purposes. This calculator "...yields a token-based estimate of position-specific biphone probability" (Vitevitch & Luce, 2004, p.482). Phonotactic probability for nonwords was calculated based on the summed biphone probability of all biphones within a nonword. Distinctions between high and low probability words was based on those words that fall above and below the median level of probability for a set of words. The differences between the average probabilities of the groups were statistically significant (t (df, 22)=7.07, $p<.001$). Stress for all nonwords was produced with typical English stress patterns (trochaic for the 2-syllable set and stress on the first and third syllables for the 4-syllable set.) Neighborhood density is a factor that can influence word learning, but was controlled for in this experiment. Neighborhood density, in this case, defined as the number of real word neighbors a nonword would have based on the addition, deletion, or substitution of a phoneme, was a non-issue due to word length. Neighborhood density decreases dramatically in English with increasing syllable length of words. In other words, all of the nonwords were constructed so that they were from low density neighborhoods. Some of the nonwords used in these experiments were part of the stimuli set for the Munson et al. (2005) study.

2.3.4 Foils—For the recognition portion of the task, participants needed to make a decision about the accuracy of the real label and three foils. Each label had the same type of foils: one that was different in the initial syllable of the word (e.g. target: /bedæg/, foil: /bledæg/), one that differed in the final syllable of the word (e.g. target: /bedæg/, foil: /bedæ/), and one that had one fewer syllable than the target (e.g. target: /bedæg/, foil: /dæg/). Foils were constructed this way to replicate the work of Maillart, Schelstraete, and Hupet (2004), who found that children with SLI had underspecified phonological representations, and were less able than peers with TD to reject pseudowords that had slight modifications at either the beginning or end of the word.

2.4 Procedures

Recruiting began after receiving approval from the University of Arizona Institutional Review Board for the procedures in this study. After receiving parental consent, participants were scheduled for their first testing session. During the first session, we secured participant assent and performed a hearing screening. Participants were seen for between two and four sessions, depending upon the time they had available and their motivation. The other exclusionary measures, descriptive tasks, and experimental task were divided quasi-randomly between the remaining sessions. All children were able to complete and attend to the experimental task. Exclusionary measures were administered by a certified speech language pathologist. Other measures were administered by trained research assistants. At least 20% of all standardized tests were double-scored. Interrater reliability averaged 97.71% with a minimum of 90% agreement and a maximum of 100% agreement. Scoring for the production portion of the task was based on percent consonants correct-adjusted, in which correctly articulated sounds and common clinical distortions are scored as correct (Shriberg, Austin, Lewis, McSweeny, & Wilson, 1997). This measure was used due to the higher agreement that typically comes from transcribing consonants as opposed to vowels.

3. Results

3.1 Word Length and Phonotactic Probability

To determine the effect of word length and phonotactic probability, a mixed ANOVA was run with classification (SLI, TD) as the between-group factors and length (Short, Long) and phonotactic probability (High, Low) as the within group factors. Post-hoc effects were tested using a Bonferroni test for between group differences and planned comparisons for within group differences. A separate ANOVA was run for the recognition and the production component of the task. There was no significant difference between children who had the “yes” response button on the right and those who had it on the left, so data were collapsed across those conditions.

3.1.1Recognition—In terms of main effects, there were, as predicted, significant effects for both classification and word length. The highest possible score on this task was 96. For classification, the SLI group's mean of 73.95 (SD 8.38) was significantly lower than the TD group's mean of 83.95 (SD 6.00) (F (1, 38) =18.79, p<.001, η_{pp}^2 = .33). For word length, the maximum score was 48. All participants were more accurate on shorter words (x=41.02, SD=3.99) than on longer words (x=37.92, SD=5.47) (F (1, 38) = 96.10, p<.001, η_p^2 =.417). There were no significant effects for phonotactic probability (F (1, 38) =.75, p<.39, η_p^2 =. 019).

However, there were no significant effects for the predicted interactions. Neither length × classification (F (1, 38) = 2.046, p<.16, η_p^2 =.05), phonotactic frequency × classification (F (1, 38) =.33, p<.56, η_p^2 =.008), nor length × phonotactic frequency × classification were significant (F (1, 38) = 1.17, p<.28, η_p^2 =.03). (See Figure 2.)

3.1.2. Production—The production task allowed us to determine the effect of word length and phonotactic probability on nonword production. For the production portion of the task, data from only 38 of the original 40 participants were included due to equipment failure for two of the participants with SLI. Therefore, unequal N post hoc tests were used instead of the Bonferroni test when between group measures were tested. There were significant main effects for classification, word length and phonotactic probability. These scores were calculated as percent consonant correct, with a maximum score of 100%. The TD group (x=73.95%, SD=8.4%) performed significantly better than the SLI group (x=62.39%, SD=9.5%) (F (1, 36) =15.62, p<.0003, η_p^2 =.302). For word length, all participants were more accurate on shorter words (x=80.00%, SD=10.37%) than on longer words (x=67.91%, SD=10.64%) (F (1, 36) = 92.63, p<.0000, η_p^2 =.72). For phonotactic probability, all participants were more accurate on higher probability words (x=80.72%, SD=10.1%) than on lower probability words (x=67.19%, SD=9.5%) (F (1, 36) = 107.996, p<.0000, η_p^2 = .749).

There was also a significant length × classification interaction (F (1, 36) =8.68, p<.005, η_p^2 =.194) such that the SLI group's performance was only worse than the TD group's on longer words (F (1, 36)=21.99, p<.001) not on shorter words (F (1, 36)=3.64, p=.064). There was a significant length × probability interaction (F (1, 36) =16.22, p<.0002, η_p^2 = .31). The main effects were amplified such that short length and high probability combined to produce the best performance (F (1, 36)=19.91, p<.001) and long length and low probability combined to produce the worst performance (F (1, 36)=91.5, p<.001). (See Figure 3).

4. Discussion

4.1 Evidence for problems with initial encoding

There was evidence for problems with initial encoding. Participants with SLI were notably worse than peers with TD at encoding words on all but one comparison. They performed equivalently to their peers on the production of short words. This finding shows that the problem with initial encoding cannot be fully ascribed to a frank phonological deficit. If children with SLI simply could not efficiently encode incoming phonological stimuli, then there would be no condition where they performed as well as their peers. The fact that, even in a fast-mapping condition, they are able to produce short nonwords as well as peers, but not long nonwords indicates that this is likely a problem with limited capacity.

It is interesting to note that this finding was not consistent across the different task components. All children performed better on the recognition task than on the production task. One reason for this may be that the recognition task provided choices (yes/no) which allowed for some guessing, whereas the production task did not. This may have enabled children to achieve higher scores overall. The finding that children with SLI showed more of a boost for short nonwords in the production component of the tasks compared to the recognition component of the tasks could reflect the different task demands. While production might require more fine-grained knowledge of the phonemic structure of the nonwords, the recognition task required meta-linguistic reflection on the nature of the nonwords. Children had to make decisions about somewhat subtle phonemic changes to the nonwords. If children were not particularly good at using meta-linguistic skills, word length might not matter. However, word length became more important when children had to produce the words without being provided with choice. The different task demand led to different profiles of performance.

The SLI group's ability to perform as well as peers on production of short nonwords suggests that theirs is not a problem only with phonology. More likely, it points to problems with the different task demands (recognition that may involve phonological manipulations or meta-linguistic abilities versus production). The differential difficulty with longer nonwords supports a limited capacity hypothesis. Ramus and Szenkovits (2008) propose that the phonological deficit found in people with dyslexia is really a deficit that emerges as a function of task demands, specifically when short-term memory is involved. Specifically, they propose that the underlying phonological representations of their adult subjects are intact. The deficit in processing phonology only happens when these subjects are asked to

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process phonological information in ways that load heavily on short-term memory, require metalinguistic awareness, or require processing to happen quickly. The current study was not designed to manipulate the rate at which stimuli were presented. The tasks did require participants to learn words with varying phonological working memory demands and the word recognition task did require some metalinguistic processing. The children with SLI were as accurate as their peers in the least taxing condition (short words that did not require metalinguistic processing). Therefore, Ramus and Szenkovits's (2008) explanation for phonological deficits in adults with dyslexia may also fit for the reported phonological working memory deficits seen in some children with SLI.

Some might argue that poor performance on longer words would be viewed as a problem with decay, or forgetting. While word length effects have often been viewed in this light, Lewandowsky and Oberauer (2008) point out the many confounds that occur in experiments examining the word length effect. Use of Bayseian reasoning led them to conclude that the word length effect "...tells us nothing about whether time-based decay causes short-term forgetting" (p.886).

4.2 Evidence for problems with effective use of information in long term memory

There was no evidence for children with SLI not being able to effectively use information from long term memory. In this case, that information was specific to phonotactic probability. If we define redintegration as the use of information in long term memory to shore up unclear, newer memory traces, then we do not have evidence for a specific problem with redintegration in children with SLI. We used the influence of phonotactics as our metric of access to information from long term memory. When phonotactics did play a role in word learning, children with SLI followed the same patterns of usage as typically developing peers, as was found in previous studies. Use of phonotactic probability for both groups appears to be influenced by task demands. The production portion of the task was more demanding than the recognition portion of the task and it was only on the production portion of the task that there was a main effect for phonotactic probability. The fact that the children with SLI performed in the same manner as their peers is evidence that they have the potential to benefit from statistical learning like same-aged peers.

Although we expected children with SLI to show similar patterns of usage to unimpaired peers, we also expected to find decrements in performance compared to peers, specifically when conditions were difficult. In this case, difficulty would mean low phonotactic probability words. There was no support for this hypothesis. This finding is in contrast to that of Alt and Plante (2006), in which children with SLI showed significantly worse performance than their peers in the low phonotactic probability condition. In both experiments, the low probability condition was the more difficult one. However, in the current study, there was no classification × phonotactic probability interaction. There are several possible reasons for the different findings in this case. First, there are task differences to take into account. Although these were both word learning studies, the current study did not include a semantic features component. It is possible that the increased task demands of the semantic task in Alt and Plante (2006) led to the difference in groups. However, the difference might also be attributed to age. The children in the current study were school-aged, compared to the preschoolers in the 2006 study. It may be that children with SLI simply take longer than peers to reap the benefits of the statistical properties of their native language. As Munson et al. (2005) pointed out, the effects of phonotactic probability becomes less strong with age in typically-developing children. If the children with TD are showing less of an effect, and the children with SLI are starting to take advantage of these effects, between group differences would be less apparent. However, Munson et al. (2005) also found vocabulary size predicted the effect size of phonotactic probability. Their school-age children with SLI showed a stronger effect of phonotactic probability than did the same-age children with NL. Although our SLI group had significantly lower vocabulary scores than the TD group, there were no differences in how each group reacted to differences in phonotactic probability of the stimuli. This does not mean that vocabulary is not important. One must once again consider task differences. Munson and colleagues measured nonword repetition, not word learning. The differential task demands could explain the difference in findings.

4.3 SLI and Reading Deficits

Catts and colleagues (2005) showed that the proposed phonological working memory problems posited to be central to the deficit profile of children with SLI was actually related to comorbidity with dyslexia. Their study examined performance on phonological awareness tasks and nonword repetition tasks for children who had SLI only, had dyslexia only, or had both disorders. Most of the problems with phonological processing came from children with a label of dyslexia, not SLI only. Given this finding, it is important to evaluate the reading status of participants in studies that examine phonological processing. Approximately 70% of our sample did not show evidence of word reading problems through use of the TOWRE. Granted, the TOWRE is not a comprehensive evaluation of reading. Rather, it functioned more as a screening instrument. Nevertheless, the finding that children with SLI in the current study showed problems on tasks involving phonological working memory is unlikely to be due to a preponderance of undiagnosed dyslexia among participants.

However, this does not mean that children with SLI have a *specific* problem with phonological working memory. Rather, they may have a problem with more general processing capacity. In this experiment, the information they were asked to process involved phonological working memory. Also, the tasks children were asked to perform here were not the same as the tasks in Catts et al. (2005). This was a word learning task which has additional demands. If it is indeed the case that children with SLI have more generalized processing deficits, we should be able to show evidence for the deficits in tasks that involve processing other types of information.

4.4 Clinical Implications

There are two main points that follow from the results of this study: 1) school-age children with SLI continue to have difficulty with the initial phase of word learning compared to their peers 2) strategies that assume that the only problem children with SLI face during learning is phonological may not be successful. Clearly, these points need to be taken in the context in which they were derived – an experimental fast-mapping study. It is noteworthy that children with SLI performed poorly on the recognition portion of the task, as well as on the expressive portion (for longer words). School age children may be able to repeat words, but that does not mean they will have a clearly specified phonological representation for the word. The fact that they can say new words may make educators overlook the fact that these students may not really have a solid grasp of the word. For example, a school-aged child may not initially perceive the difference between new academic vocabulary terms like ‘ectoplasm’ and ‘endoplasm’, especially if the child is not being asked to repeat the words. A lack of phonological specification could logically have a cascading effect on poor semantic encoding of novel words if, in the example above, a child starts to conflate characteristics of two opposite concepts. We have much to learn about how school-age children learn words, given the complex nature of the task (McGregor, Sheng & Ball, 2007). While toddlers and preschoolers are learning everyday vocabulary, school-age children are more likely to be learning academic vocabulary. Academic vocabulary is more likely to contain longer words, lower probability words, and to be encountered differently than words that are part of a child's everyday experience.

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Especially when learning these new types of words, it is important to know what parts of word learning are difficult for children with SLI. It is possible that children with SLI could be taught strategies to help them boost the knowledge of words they have begun to learn. Primarily, their problems appear to be related to encoding; one cannot recall what has not been encoded. Instead, educators may want to focus on their selection of vocabulary words (e.g. choosing shorter words) to help scaffold children into a concept. When working on longer words, educators might focus more on activities that require encoding, such as providing multiple exemplars. Helping children fine-tune their phonological representations by contrasting similar-sounding words might also encourage better word learning. Please remember that these suggestions are based on the idea that what we see in fast-mapping will translate to slow-mapping, an idea which has yet to be proven.

4.5 Future Directions

Although there are distinct benefits to using a fast-mapping paradigm, namely that it lets one see how people with impairment interact with novel stimuli free from the use of compensatory behaviors, there are limits to the technique. Trends that are present in fast-mapping may change given more exposure to stimuli, and therefore limit the generalizability of these findings. The possible clinical implications described above need to be looked at in this light. Future work needs to examine how these patterns may change in a slow-mapping context.

This study has ruled out problems with access to long term memory and use of information in long-term memory for children with SLI. However, we can only be confident of this finding for the impact that phonotactic probability has on nonword learning. There are certainly other sources of long-term memory that may support word learning and short term memory that were not directly investigated in this study that deserve examination in the future.

This study provides evidence that children with SLI may have a limited capacity for word learning, but only when words are longer. This helps us to clarify the nature of the word learning problems children with SLI have. However, this study was not designed to test the possible mechanisms by which a problem with limited capacity might manifest (e.g. problems with processing speed, limited cognitive resources, shorter overall memory span). Future work that better defines the nature of the capacity limitations would be an important contribution to the literature.

4.6 Summary

Baddeley's (2003) model of working memory was chosen as a template for this experiment for two reasons. First, it is likely that working memory influences word learning. Second, its modular approach allows for a systematic examination of components of word learning that might be problematic for children with language impairment. The findings from this study support the idea that the main problem for children with SLI during word learning in the fast-mapping stage is a problem with initial encoding into the phonological loop, particularly for longer words. This problem happens regardless of word length when children have to make meta-linguistic judgments about words, but is not a frank phonological memory problem. The fact that children with SLI can learn short (2-syllable) nonwords as well as peers, but not longer nonwords, points to a limited capacity problem. It is possible that this limited capacity is not just limited to the realm of phonological working memory, but may affect other domains of processing as well. Children with SLI are clearly tuned into the implicit phonological patterns of English, but this does not make their overall learning performance equivalent to peers.

Acknowledgments

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Appendix A

Task 1 Stimuli

Short Length High Probability	Short Length Low Probability	Long Length High Probability	Long Length Low Probability
/ˈnok^{ɛ}n/	/ˈvugim/	/ˈkisɝˌtaləm/	/ˈz□fe, ^{t}□oth^{ɛ}d/
/ˈb^{I}kuf/	/ˈn^fæm/	/ˈmoni, t^kif/	/ˈvufæ, ^{t}□az^{ə}□/
/ˈmæb^{ɛ}p/	/ˈkefu□/	/ˈwæke, t^{I}s^{I}t/	/ˈde^{d}□□, kivan/
/ˈt^{ɛ}k^{ɛ}t/	/ˈtedaum/	/ˈkefɝˌmæsən/	/ˈg^{ɛ}□e, toinen/
/ˈsæs^{I}n/	/ˈbedæg/	/voin^{ə}, fesæt/	/ˈnikoi, gefip/
/ˈtan^{ə}g/	/ˈpaug^{ə}b/	/k^{I}s^{ə}, sa□^{ə}m/	/ˈjoiw^{ɛ}, □a□oik/

Appendix B

Examples of some novel dinosaurs

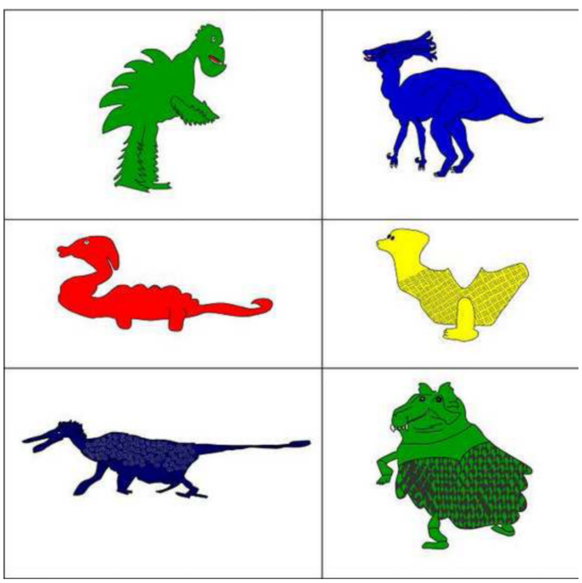

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Figure 1.
Stills from experimental task 1

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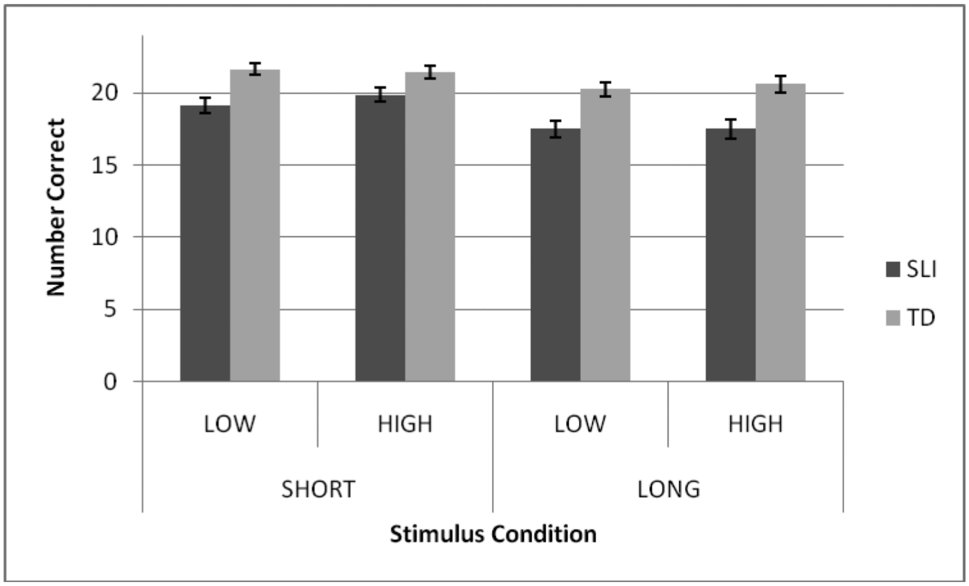

Figure 2.
Performance on recognition component

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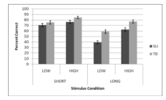

Figure 3.
Performance on production component

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Table 1

Participants' Demographic Features and Means and Standard Deviations on Standardized Tests

	SLI		TD	
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**
Age in months	91.25	5.50	93.95	6.45
Maternal Level of Education	13.26	2.15	14.15	1.89
*CELF-IV	72.35	12.49	105.15	8.49
*PPVT-IV	88.45	8.27	108.70	15.31
*TOWRE	89.50	14.15	103.05	10.84
*GFTA-II	97.20	11.94	105.05	3.36
K-ABC-II	95.35	13.34	103.80	13.74

Note: CELF-IV= Clinical Evaluation of Language Fundamentals-4th edition, PPVT-IV= Peabody Picture Vocabulary Test- 4th edition, TOWRE=Test of Word Reading Efficiency, GFTA-II=Goldman Fristoe Test of Articulation, 2nd edition, K-ABC-II= Kaufman Assessment Battery for Children- 2nd edition.

*significantly different at p<.007

Table 2

Reporting of Race and Ethnicity by Group

	Race			Ethnicity		
	White	**Multi-Racial**	**Not Reported**	**Hispanic**	**Not-Hispanic**	**Not-Reported**
SLI	6	4	10	14	2	4
NL	16	2	2	5	11	4