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Phonological and Lexical Effects in Verbal Recall by Children with Specific Language Impairments

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Abstract

Background & Aims—The present study examined how phonological and lexical knowledge influences memory in children with specific language impairments (SLI). Previous work showed recall advantages for typical adults and children due to word frequency and phonotactic pattern frequency and a recall disadvantage due to phonological similarity among words. While children with SLI have well documented memory difficulties, it is not clear whether these language knowledge factors also influence recall in this population.

Methods & Procedures—16 children with SLI (mean age 10;2) and CAM controls recalled lists of words differing in phonological similarity, word frequency, and phonotactic pattern frequency. While previous studies used a small set of words appearing in multiple word lists, the current study used a larger set of words, without replacement, so that children could not gain practice with individual test items.

Outcomes & Results—All main effects were significant. Interactions revealed that children with SLI were affected by similarity, but less so than their peers, comparably affected by word frequency, and unaffected by phonotactic pattern frequency.

Conclusions—Results due to phonological similarity suggest that children with SLI use less efficient encoding, while results due to word frequency and phonotactic pattern frequency were mixed. Children with SLI used coarse-grained language knowledge (word frequency) comparably to peers, but were less able to use fine-grained knowledge (phonotactic pattern frequency). Paired with phonological similarity results, this suggests that children with SLI have difficulty establishing robust phonological knowledge for use in language tasks.

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Keywords

verbal memory; specific language impairment; phonological similarity; word frequency; phonotactic pattern frequency

Specific language impairments, or SLI, refers to a developmental disorder primarily affecting language. Children with SLI have nonverbal intelligence, hearing, neurological function, oral structure and function, and social/emotional development all within normal limits. Even so, they experience difficulty acquiring and using language. Current estimates place the incidence of SLI at approximately 7.4 percent, or one in 13.5 children (Tomblin, Records, Buckwalter, Zhang, Smith and O'Brien, 1997). For perspective, current CDC estimates on the prevalence of Autism Spectrum Disorders, or ASD, in the U.S. place its prevalence at 1.14 percent, or one in 88 children (Centers for Disease Control and Prevention, 2012). The prevalence of ASD along with the social and potential language and cognitive deficits it causes makes it a serious health crisis. Accordingly, the prevalence of SLI, along with the language and academic risks it causes makes it just as serious a public health crisis.

One of the defining features of this population of children is a deficit in verbal recall. For example, the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition* (DSM-IV) describes "Expressive Language Disorder" and "Mixed Receptive-Expressive Language Disorder", essentially the two subtypes of SLI, which may be manifest clinically by symptoms including difficulty recalling words (American Psychiatric Association, 2000). Indeed, there is a long history of studies demonstrating poor verbal recall by children with SLI, both for strings of digits and for meaningful sentences (Ceci, Ringstrom and Lea, 1981; Graham, 1980; Kail, Hale, Leonard and Nippold, 1984; Menyuk, 1964, 1969; Menyuk and Looney, 1972; Stark, Poppen and May, 1967; Wiig and Semel, 1976, 1980). Researchers have documented poor verbal memory capacity in this population, along with deficits in memory processes, including the ability to maintain and regenerate items in verbal memory (Kirchner and Klatzky, 1985) and in the time required to scan verbal memory (Sininger, Klatzky and Kirchner, 1989).

Based on these findings, Gathercole and Baddeley (1990) suggested that verbal memory deficits might be the underlying impairment in SLI. To test this theory, they had a group of children with SLI and verbal and nonverbal control groups participate in memory tasks using single nonwords. In order to preclude any potential group differences in language knowledge, children repeated nonwords instead of real words. That is, because children with SLI have primary language deficits, there can be no reasonable assumption that real words are equally familiar to them. Therefore, Gathercole and Baddeley used nonwords that were equally unfamiliar to all children. Their results revealed that children with SLI repeated nonwords less accurately than age-matched children developing language typically, but also less accurately than younger, language-matched controls. Further, group differences were most evident as nonword length increased. They concluded that these children's memory deficits are more severe than would be predicted based on their language abilities, which may be the factor that limits their language abilities.

While memory deficits are ubiquitous in this population, it is not at all clear that they are disproportionate to language deficits. Van der Lely and Howard (1993) measured verbal span in six children with SLI, a control group matched on receptive vocabulary, a second group matched on expressive vocabulary, and a third matched on expressive grammar. Across three recall tasks (semantically related vs. unrelated words, real words vs. nonwords, and phonologically similar vs. dissimilar words) and two response conditions (verbal response vs. picture pointing response), van der Lely and Howard reported no group effects or interactions after language scores were covaried out of analyses. That is, the memory performance of children with SLI was almost perfectly predicted by their language skills, suggesting that these children's language impairment cannot be caused by a primary memory deficit.

An interesting implication from these disparate results is that language abilities might actually determine memory abilities. While children with SLI may be more impaired than their language-age peers on measures of nonword repetition, they perform comparably to language-age peers on measures of real-word recall. This raises the question of how language knowledge interacts with verbal recall. Some current models of memory suggest that memory performance is determined by the rememberer's facility with the objects of recall (Jones, Gobet and Pine, 2008; MacDonald and Christiansen, 2002). For example, Miller and Isard (1963) reported that adult recall of meaningful sentences was better than recall of those same words presented in random order. Similarly, DeGroot (1965) reported that chess masters were better able than novices to reconstruct a configuration of chess pieces when that configuration arose from a series of legal moves. However, there were no group differences when chess pieces were arranged randomly. The implication for children with SLI is that poorer recall for real words results from the words themselves being less robustly stored, while poorer nonword repetition would result from the phonemes being less robustly represented (Bishop, 2000; Coady, Kluender and Evans, 2005; Mainela-Arnold, Evans and Coady, 2008).

Phonological Similarity Effects in Verbal Recall

One factor affecting recall is structural similarity among list items. People typically recall a greater number of phonologically dissimilar words, and fewer phonologically similar words. Baddeley (1986) argued that this happens because phonological traces of similar items interfere with one another, and so are recalled less well. The difference in recall for phonologically dissimilar vs. phonologically similar lists can be considered the "phonological similarity effect". Montgomery (1995) argued that this similarity effect results from difficulty establishing a phonological representation of input in working memory. Alternatively, Gathercole and Baddeley (1990) argued that it results from difficulty with trace discrimination at recall. Whether it is an input phenomenon, an output phenomenon, or both, the phonological similarity effect is ubiquitous, with consistent effects across studies (e.g., Conrad and Hull, 1964; Mueller, Seymour, Kieras and Meyer, 2003).

Because the phonological similarity effect is so robust, researchers examined whether it might be used to measure the efficiency of phonological encoding in disordered populations. "Phonological encoding" refers to the process by which the phonetic form of an utterance is spelled out, but has also been used to refer to the reciprocal process in which a word is broken down into its component parts. Liberman and colleagues (Liberman, Shankweiler, Liberman, Fowler and Fischer, 1977) used the phonological similarity effect to show that poor readers use less efficient phonological encoding strategies. Skilled readers show expected similarity effects when recalling lists of rhyming vs. nonrhyming letters (B D P vs. H K L), but less skilled readers showed a smaller similarity effect. Gathercole and Baddeley (1990) were the first to extend this methodology to children with SLI. As part of their test battery, they measured serial recall of lists of phonologically similar vs. dissimilar words using a paradigm in which children pointed at pictures of named objects. They used six phonologically similar words and six phonologically dissimilar words, which they combined into lists from two to six items in length. While they did not examine effects due to list length directly, Gathercole and Baddeley reported that children with SLI exhibited expected phonological similarity effects for shorter lists of words, but reduced similarity effects for longer lists. They interpreted this finding as evidence that children with SLI used inefficient phonological encoding strategies, at least when phonological capacity was exceeded.

Attempts to replicate these findings have raised a number of questions. Van der Lely and Howard (1993) conducted their own examination of the phonological similarity effect using a larger pool of words—four sets of seven dissimilar words (28 total) and four sets of five similar words (20 total). They conducted an omnibus analysis and found a significant main effect of similarity, but no main effect of group or group by similarity interaction. Based on the absence of group differences, they reached the opposite conclusion, that children with SLI use efficient phonological encoding strategies. James, Van Steenbrugge and Chiveralls (1994) replicated Gathercole and Baddeley's (1990) similarity study in a group of children with SLI with central auditory processing difficulties (CAP) and age- and language-matched control groups. They also used a set of six similar and six dissimilar words that were recombined into lists ranging in length from two to six items and measured serial recall via a picture pointing paradigm. They reported significant main effects for group and similarity and a significant interaction between the two. When they examined effects for each list length, they found significant group by similarity interactions for four- and six-item lists, where the children with SLI showed a reduced similarity effect relative to language-matched children for four-item lists and relative to age-matched children for six-item lists. Because children with SLI/CAP showed a similarity effect, albeit reduced, and because they showed a reduced phonological memory capacity, James and colleagues disregarded significant interactions and concluded that children with SLI/CAP were able to use efficient phonological encoding in working memory. Finally, Montgomery (1995) examined the similarity effect in a group of children with SLI and a group of language-matched controls. Like Gathercole and Baddeley (1990), he recombined a set of six similar and a set of six dissimilar words into lists ranging from two to six items in length, and had children recall words by pointing to pictures in order. He examined effects due to group and similarity, but did not consider list length effects. He reported significant main effects of group and similarity, but no group by similarity interaction, and so concluded intact phonological encoding abilities.

In summary, the results from these studies do not converge on whether children with SLI make efficient use of phonological encoding in phonological working memory. Children with SLI are affected by similarity, but less so for longer lists. As Snowling, Chiat and Hulme (1991) pointed out, having to recall longer nonwords or longer lists of real words taxes not only memory capacity, but also auxiliary processes that support memory, including phonological encoding. However, none of these encoding studies included list length as an independent variable, so inefficient phonological encoding is a tenuous conclusion at best. These studies are further complicated because they all used a small set of words that were recombined to create many different word lists. Because each word appeared in multiple lists, children likely gained practice with individual test items (Gupta, Lipinski and Aktunc, 2005).

Long-Term Language Knowledge Effects in Verbal Recall

Two long-term language knowledge factors known to affect verbal recall are word frequency, or how frequently a word occurs in the language environment (henceforth “frequency”), and phonotactic pattern frequency, or how frequently a word’s phonological pattern occurs in the language environment (henceforth “probability”). Hulme and colleagues (Hulme, Roodenrys, Schweickert, Brown, Martin and Stuart, 1997) compared adult recall of high- vs. low-frequency words and reported an advantage for high-frequency words. Similar findings have also been reported for children developing language typically (Henry and Millar, 1991; Majerus and Van der Linden, 2003). Hulme and colleagues (1997) suggested that high-frequency words are either more accessible or more robustly specified, and so support redintegration more effectively. Redintegration is the hypothesized process in which decaying memory traces are reconstructed from long-term language knowledge. As Schweickert (1993) originally described it, redintegration occurs when a rememberer uses long-term lexical (and/or phonological) knowledge to reconstruct rapidly decaying phonological traces.

There is some controversy about the nature of redintegration processes. Schweickert (1993) originally proposed redintegration as a secondary process. When attempting to retrieve words corresponding to rapidly decaying traces, the rememberer’s primary process involves retrieving words directly from the phonological store while the secondary process uses long-term lexical and/or phonological knowledge to reconstruct decaying traces. More recent models of working memory have explained these language effects in terms of a single system (Buchsbaum and D’Esposito, 2008; Jacquemot and Scott, 2006; MacDonald and Christiansen, 2002). These models argue that maintenance of phonological materials in working memory is subserved by the same processes involved in speech perception and production. Because both speech perception and production depend on word frequency and phonotactic pattern frequency [a high-WF advantage in perception (Connine, Titone and Wang, 1993) and production (Jescheniak and Levelt, 1994) and a high-PPF advantage in perception (Newman, Sawusch and Luce, 1997) and production (Vitevitch, Armbrüster and Chu, 2004)] then performance on memory tasks will also necessarily reflect these WF and PPF effects. A secondary process such as redintegration thus becomes extraneous.

The other language factor affecting verbal recall is phonotactic pattern frequency, or the frequency of a word’s phonological pattern. Traditionally, these effects have been separated into phonotactic probability effects and neighborhood density effects. Phonotactic probability refers to the frequency with which a word's constituent phonemes occur and co-occur in the language environment. Its effects are typically facilitatory, where performance is quicker and more accurate for items with frequently occurring sound patterns. Neighborhood density refers to the number and frequency of words that share considerable phonemic overlap with a target word (Luce and Pisoni, 1998). These two factors, the number and frequency of similar sounding neighbors, are meant to provide an index of lexical competition. These effects are typically inhibitory, with slower and less accurate processing of words with many neighbors.

Phonotactic probability and neighborhood density are related theoretically in that words that sound like many other words (high density) have high-frequency phonotactic patterns, and vice versa. Even so, researchers have maintained a distinction between them for a number of reasons (Vitevitch and Luce, 1998, 1999; Vitevitch, Luce, Pisoni and Auer, 1999), including directionality of the effects (phonotactic probability is facilitatory; neighborhood density is inhibitory), hypothesized source of the effects (phonotactic probability is sublexical; neighborhood density is lexical), and types of stimuli involved (phonotactic probability dominates processing of nonwords; neighborhood density dominates processing of real words). Recent findings, however, suggest that this distinction between phonotactic and density effects is not so clearcut. Vitevitch and Luce (1999) reported that tasks can be manipulated to enhance non-dominant effects in the processing of both words and nonwords. That is, tasks can be constructed to make the word level the most predictive for processing nonwords (as in a lexical decision task) or to make the phoneme level most predictive for processing real words (as in a phoneme monitoring task). Indeed, listeners can and do show inhibitory, lexical-level effects in the processing of nonwords (Storkel, Armbrüster and Hogan, 2006; Storkel and Hoover, 2010), and facilitatory, sublexical-level effects in the processing of real words (Roodenrys, Hulme, Lethbridge, Hinton and Nimmo, 2002; Yates, Friend and Ploetz, 2008).

No studies to date have examined the role of probability in real-word recall, but some studies have reported a neighborhood density advantage. Both adults (Roodenrys et al., 2002) and children developing language typically (Thomson, Richardson and Goswami, 2005) recall a greater number of words from denser and higher-frequency phonological neighborhoods, even though density typically exerts an inhibitory effect. Phonotactic probability is known to exert a facilitatory influence on nonword recall (nonword repetition; for a review, see Coady and Evans, 2008), and so it is reasonable to expect that this factor will also facilitate real-word recall. That is, both phonotactic probability and neighborhood density are hypothesized to exert a facilitatory influence on real-word recall. Because both tasks exert a positive influence, it is not necessary to differentiate them for this particular task.

While probability and density influences on memory tasks have been well documented in adults and typically developing children, it is unclear to what extent language knowledge influences recall by children with SLI. There is clear evidence that they are sensitive to word frequency. For example, children with SLI are more likely to add correct morphological markers to frequent vs. infrequent words in a verb-tense marking task (Marchman, Wulfeck and Ellis Weismer, 1999) and in a plural marking task (Oetting and Rice, 1993). Further, their sensitivity is similar to that of children developing language typically. There is also evidence that children with SLI are sensitive to phonotactic pattern frequency in nonword repetition tasks (for a review, see Coady and Evans, 2008), but to date, no studies have examined whether they use this source of information in real-word recall.

The purposes of the present study were (1) to examine the efficiency of phonological encoding in children with SLI, and (2) to examine the degree to which verbal recall is affected by long-term language knowledge (frequency and probability) in children with SLI. To this end, children with SLI and children with typical language development recalled lists of words two to six items in length. Word lists varied along three orthogonal dimensions—phonological similarity, word frequency, and phonotactic pattern frequency. The specific questions to be answered are: (1) Do children with SLI encode phonological materials as efficiently as their unimpaired peers? Children with SLI are expected to show a similarity effect, but a significant interaction would reveal a smaller effect for children with SLI, indicating less efficient phonological processing. Alternatively, a nonsignificant interaction would suggest intact phonological encoding. Also, if there is a similarity interaction, is it mediated by list length? Is inefficient encoding simply a consequence of overloaded memory capacity? (2) Are children with SLI affected by word frequency in a recall task? If so, are they as affected as their unimpaired peers? Again, assuming that they do utilize this source of information in recall, then potential interactions would reveal whether they use it to the same degree as typically developing children. (3) Are children with SLI affected by phonotactic pattern frequency? If so, are they affected to the same degree as children developing language typically?

Method

Participants

A total of 32 monolingual English-speaking children participated, 16 children with specific language impairment, or SLI (9 females, 7 males), mean age 10;2 (range 8;7 – 11;9) and 16 children developing language typically (8 females, 8 males), mean age 10;2 (range 8;5 – 12;3). Groups were matched for chronological age, with no age difference between groups, $t(30) = 0.09$, *n.s.*, $\eta^2_p = 0$, power = .05. Children were drawn from a larger sample of children in public schools. All children met exclusion criteria for SLI (Leonard, 1998), having no frank neurological impairments, no evidence of oral-motor disabilities, normal hearing sensitivity, and no social or emotional difficulties, based on parent report. Nonverbal IQs were at or above 85 (one standard deviation below the mean or higher) as measured by the Leiter International Performance Scale—Revised (Leiter-R; Roid and Miller, 1997). To control for possible confounding effects of articulation impairments, only children without articulation deficits were included. Speech intelligibility during spontaneous production was at or above 98 percent for all children, as determined by a certified speech-language pathologist. Also, all children had normal range hearing sensitivity on the day of testing as indexed by audiometric puretone screening at 20 dB HL for 500-, 1000-, 2000-, and 4000-Hz. tones.

The language assessment measure was the Clinical Evaluation of Language Fundamentals—Third Edition (CELF-III; Semel, Wiig and Secord, 1995). Children with SLI received the full expressive and receptive language batteries of the CELF-III, and composite expressive (ELS) and receptive (RLS) language scores were calculated. Chronological age-matched typically developing children (CAM) received the full expressive battery, but their receptive abilities were only screened with the Concepts and Directions subtest of the receptive language battery. Two additional descriptive language measures were collected but not used for diagnosis. The Peabody Picture Vocabulary Test—Third Edition (PPVT-III; Dunn and Dunn, 1997) and the Expressive Vocabulary Test (EVT; Williams, 1997) were collected as measures of receptive and expressive vocabulary, respectively.

The language criterion for children with SLI was ELS at least one standard deviation below the mean (<85). The group of children with SLI included two children with only expressive language impairments (E-SLI; RLS ≥ 85) and fourteen with both expressive and receptive language impairments (ER-SLI; RLS < 85). Language criteria for the age-matched control group were ELS above 85 and standard score on the Concepts and Directions subtest at or above 8. Group summary statistics are provided in Table 1. Children with SLI scored significantly below CAM children on all language measures: CELF-III ELS, $t(30) = 9.16$, $p < .0001$, $\eta^2_p = .736$, power = 1; PPVT-III, $t(30) = 4.77$, $p < .0001$, $\eta^2_p = .431$, power = .99; and EVT, $t(30) = 4.82$, $p < .0001$, $\eta^2_p = .436$, power = .99. However, there were no group differences in nonverbal IQ, $t(30) = 1.31$, $p = .20$, $\eta^2_p = .054$, power = .25.

Stimuli

Lists of consonant-vowel-consonant (CVC) words ranging in length from two to six items were created. Two lists at each length varied along three orthogonal dimensions—frequency, probability, and similarity. Ultimately, 80 different word lists contained a total of 320 words, with each word occurring in only a single list.

CVC words were taken from the Hoosier Mental Lexicon (Nusbaum, Pisoni and Davis, 1984). All words receiving an adult familiarity rating of 4 or higher (indicating “know it’s a word, not sure of its meaning”) were included as potential stimulus words. Some words actually attested in children’s speech in the Brown corpus (1973) did not receive familiarity ratings, but were also included as stimulus items. These words were *name*, *year*, *jack*, and *jeep*. Frequency counts were taken from the Kučera and Francis corpus (1967). The 1099 English CVC words meeting the familiarity threshhold (Nusbaum et al., 1984) were separated into high- and low-frequency groups by a median split. Probability was estimated from the Brown corpus (Brown, 1973), as described in Coady and Aslin (2004). The same 1099 CVC words were separated into high- and low-probability groups by a second median split. Because of the positive correlation between phonotactic probability and neighborhood density, and because both of these variables facilitate real-word recall (Roodenrys et al., 2002; Thomson et al., 2005), no attempt was made to control for neighborhood density. Thus, there were four groups of words: (1) high frequency, high probability; (2) high frequency, low probability; (3) low frequency, high probability; and (4) low frequency, low probability.

Words from each of the four groups were combined into 20 lists, or four lists at each of five lengths (two – six items). Two lists at each length contained similar words, and two contained dissimilar words. Similarity was determined separately for each syllable position

—onset, nucleus, and coda, and was based on shared phonetic features or on perceptual confusability, using confusion matrices for consonants (Miller and Nicely, 1955) and for vowels (Peterson and Barney, 1952). Words were judged to be similar if they contained either phonemes in common (as in rhyming *muck* and *buck*) or perceptually confusable phonemes in the same syllable position (as in non-rhyming *neck* and *map*, in which onset consonants, vowels, and coda consonants are all different, but share phonetic features and so consequently are confusable). Words in similar lists contained identical or confusable phonemes in at least two of three syllable positions. Due to the difficulty of finding words sharing no phonetic overlap, some dissimilar word lists contain minimally confusable phonemes, notably /f/ and /s/. The decision to include words containing /f/ and /s/ in the same syllable position in dissimilar word lists was based on two factors. First, phonological similarity was always carried by at least two of the three phonemes. Lists containing /f/ and /s/ in similar lists also contained confusable phonemes in other positions, as in *fit* and *sick*, while those containing the same consonants in dissimilar lists did not share any additional overlap, as in *file* and *south*. Second, the inclusion of these minimally confusable phonemes within a dissimilar word list should actually interfere with recall, thereby reducing the phonological similarity effect. As the results will show, this effect was so robust that this turned out to not be a problem.

Information about the stimulus words is provided in Table 2. In order to insure that the dimensions were truly orthogonal, lists were compared in terms of log frequency, log phonotactic probability, log frequency weighted neighborhood density (calculation described in Coady and Aslin, 2003), and stimulus duration. The high- and low-frequency words differed in log frequency, $t(318) = 25.422$, $p < .0001$, $\eta^2_p = .67$, power = 1, but not in log probabilily, $t(318) = 1.517$, *n.s.*, $\eta^2_p = .007$, power = .33, density, $t(318) = -0.274$, *n.s.*, $\eta^2_p = 0$, power = .06, or duration, $t(318) = 0.525$, *n.s.*, $\eta^2_p = .001$, power = .08. High- and low-probability words differed in log probability, $t(318) = 22.506$, $p < .0001$, $\eta^2_p = .614$, power = 1, and in density, $t(318) = 8.785$, $p < .001$, $\eta^2_p = .195$, power = 1, but not in log frequency, $t(318) = 1.708$, *n.s.*, $\eta^2_p = .009$, power = .40, or duration, $t(318) = -1.435$, *n.s.*, $\eta^2_p = .006$, power = .30. Phonologically similar and dissimilar words did not differ in log frequency, $t(318) = -0.044$, *n.s.*, $\eta^2_p = 0$, power = .05, log probability, $t(318) = 0.714$, *n.s.*, $\eta^2_p = .002$, power = .11, or duration, $t(318) = 1.416$, *n.s.*, $\eta^2_p = .006$, power = .29. However, there was a small yet significant effect of density, $t(318) = -2.868$, $p < .01$, $\eta^2_p = .025$, power = .82, in which words in similar lists came from denser lexical neighborhoods than words in dissimilar lists. Density is hypothesized to facilitate recall, while similarity should reduce recall. Accordingly, density should actually reduce the similarity effect. However, as the results will show, this effect was so robust that density effects were negligible.

A master list of all 320 words was compiled. A female speaker of the local dialect, blind to the purpose of the study, read words in citation form directly onto a Windows-based waveform analysis program at a 44.1 kHz.-sampling rate with 16-bit resolution. Each individual word was excised, normalized for volume, and saved as its own soundfile. Words were then concatenated into lists with a one-second interstimulus interval. The time interval between lists was five seconds for two-item lists, and increased with list length. Lists were arranged in a fixed random order in blocks of ascending size. Digitized lists were transferred to compact disc for presentation.

Procedure

Previous studies were limited to picturable words so that children could respond by pointing to pictures, thereby avoiding possible output difficulties. However, van der Lely and Howard (1993) reported similar results for children with SLI (with no articulation difficulties) in conditions requiring a verbal response and conditions requiring a picture-pointing response. Because children in this study had articulation within the normal range, a verbal response paradigm was determined to be feasible, which expanded the pool of potential stimulus words. Also, a free recall task was used instead of a serial recall task. Similarity effects are typically reported for serial recall, which requires simultaneous retrieval of phonological information and order information (e.g., Mueller et al., 2003). While serial recall should be preferred to examine similarity effects, Turner, Henry and Smith (2000) reported that language-knowledge effects were evident in children in a free recall task, but not in a serial recall task. Further, Fournet, Juphard, Monnier and Roulin (2003) reported similarity effects in both serial and free recall conditions. Therefore, a free recall task was used to examine lexical and phonological effects in working memory.

Children participated in the recall task as part of a larger experimental protocol. Listeners were tested individually in a quiet room. Lists were presented over headphones at a comfortable listening level. Word lists were blocked by list length, but mixed across all other factors. The task was presented in blocks of ascending size. At the start, children were told that they would be hearing lists of two words, and their job was to listen and then repeat the words back in any order. If a child did not respond after hearing a list, the experimenter paused the CD and prompted the child for a response. Once the child indicated that they had remembered all they could, stimulus presentation resumed. After an entire block of lists was presented, children took a short rest, and then were told that they'd be hearing lists one item longer. This continued until children had completed six-item lists. For all children, this recall task was the second task in the experimental battery, occurring after a measure of verbal working memory (Mainela-Arnold, Evans and Coady, 2010). It started approximately 10–15 minutes into the session and lasted approximately 15–20 minutes, with longer breaks before and after. Sessions were recorded for subsequent transcription.

Scoring

The first author transcribed children's responses from recordings of the experimental sessions. Whole words were transcribed using English orthography. CVC words were scored in a binary fashion as either correct or incorrect (1 or 0). Because stimulus items were real words, in many cases differing by a single phonetic feature, and because none of the children had articulation difficulties, cases in which a child missed a single segment were counted as errors. Interscorer reliability was calculated after a second listener unfamiliar with the task re-transcribed sessions for two randomly chosen children from each group (12.5 percent of the data). This transcriber was given the target word lists, but was blind to children's language status, and blind to the purpose of the study. Interscorer reliability for the two children with SLI was $r = .87$ (93.3% agreement), and for the two age-matched controls was $r = .88$ (94.5% agreement).

Results

Recall was calculated as the percentage of words correctly recalled in each of the eight cells at each of the five list lengths, with results collapsed across the two lists in each cell. As an example, consider the child who heard two different lists of similar, high-frequency, high-probability words four items in length. The child recalled two words from the first list and one from the second. That child recalled three of eight words in that condition, so recall for this cell was 37.5%. Raw accuracy scores were analyzed with a mixed model factorial analysis of variance (ANOVA), with list length, similarity, frequency, and probability as within subjects factors, and group as the between subjects factor. For the sake of simplicity, results are presented for each factor separately.

In a second analysis, vocabulary scores were covaried out. Current models suggest that memory is a function of one's facility with the items to be remembered (Jones et al., 2008; MacDonald and Christiansen, 2002). According to these models, performance in this memory task using real words can be explained in terms of children's vocabulary knowledge. To test this possibility, the role of children's vocabulary knowledge in recall was examined directly. A composite vocabulary score was calculated as the sum of raw expressive (EVT; Williams, 1997) and receptive (PPVT-III; Dunn and Dunn, 1997) vocabulary scores, and this composite score was entered into the analysis as a covariate.

Group

Collapsed across different levels of list length, similarity, frequency, and probility, children with SLI recalled 54.8 percent of all words, while typically developing CAM controls recalled 71.1 percent of all words, a significant group difference, $F(1,30) = 43.917$, $p < .0001$, $\eta^2_p = .594$, power = 1. This group difference held even after the composite vocabulary score was covaried out, $F(1,29) = 12.30$, $p = .001$, $\eta^2_p = .298$, power = .92.

List Length

Results for list length for both groups, collapsed across similarity, frequency, and probability are shown in Figure 1. There was a significant main effect of list length, $F(1,30) = 1624.374$, $p < .0001$, $\eta^2_p = .982$, power = 1, with recall falling as list length increased. The group by length interaction was significant, $F(1,30) = 14.923$, $p < .001$, $\eta^2_p = .332$, power = .96, with significant effects for both groups, although the effect was larger for children with SLI, $F(1,15) = 1577.826$, $p < .0001$, $\eta^2_p = .991$, power = 1, than for CAM controls, $F(1,15) = 480.484$, $p < .0001$, $\eta^2_p = .970$, power =1. With vocabulary scores covaried out, effects due to list length were attenuated, but still significant, $F(4,116) = 7.81$, $p < .001$, $\eta^2_p = .212$, power = .997, and this effect still differed for the two groups, as indicated by a significant length by group interaction, $F(4,116) = 3.02$, $p < .05$, $\eta^2_p = .094$, power = .79. As in the previous analysis, the effect of length was greater for children with SLI, $F(1,14) = 11.19$, $p = .005$, $\eta^2_p = .44$, power = .88, and smaller though still significant for CAM children, $F(1,14) = 10.35$, $p < .01$, $\eta^2_p = .43$, power = .85.

Phonological Similarity

Similarity results for both groups, collapsed across list length, frequency and probability are provided in Figure 2. For all children, the similarity effect was significant, with better recall of dissimilar word lists, $F(1,30) = 255.547$, $p < .0001$, $\eta^2_p = .895$, power = 1. The group by similarity interaction was also significant, $F(1,30) = 3.974$, $p = .05$, $\eta^2_p = .117$, power = .49. Examination of this interaction revealed that children with SLI were affected by similarity, $F(1,15) = 111.283$, $p < .0001$, $\eta^2_p = .881$, power = 1, but less so than CAM typically developing children, $F(1,15) = 144.268$, $p < .0001$, $\eta^2_p = .906$, power = 1. The main effect of similarity was not mediated by list length, as indicated by a nonsignificant two-way interaction, $F(1,30) = 1.544$, *n.s.*, $\eta^2_p = .049$, power = .23. However, the similarity by group interaction was mediated by list length, i.e., a significant three-way interaction as shown in Figure 3, $F(1,30) = 41.534$, $p < .0001$, $\eta^2_p = .581$, power = 1. Based on the significant three-way interaction, as well as on Gathercole and Baddeley's (1990) finding that children with SLI show reduced similarity effects for longer lists, group by similarity interactions were examined for each list length.

For two-item lists, both groups showed a comparable similarity effect as indicated by a nonsignificant interaction, $F(1,30) = 2.412$, *n.s.*, $\eta^2_p = .074$, power = .32. For three-item lists, the group by similarity interaction was significant, $F(1,30) = 4.182$, $p = .05$, $\eta^2_p = .122$, power = .51, with a larger effect for children with SLI, $F(1,15) = 51.724$, $p < .0001$, $\eta^2_p = .775$, power = 1, and a smaller but still significant effect for age-matched controls, $F(1,15) = 27.332$, $p < .0001$, $\eta^2_p = .646$, power = .99. For four-item lists, this pattern reversed. The group by similarity interaction was significant, $F(1,30) = 4.88$, $p < .05$, $\eta^2_p = .140$, power = .57, but with a smaller similarity effect for children with SLI, $F(1,15) = 58.476$, $p < .0001$, $\eta^2_p = .796$, power = 1 relative to CA-matched controls, $F(1,15) = 78.387$, $p < .0001$, $\eta^2_p = .839$, power = 1. For five-item lists, the group by similarity interaction was significant, $F(1,30) = 25.707$, $p < .0001$, $\eta^2_p = .463$, power = .99, with significant similarity effects for children developing language typically, $F(1,15) = 41.901$, $p < .0001$, $\eta^2_p = .736$, power = 1, but not for children with SLI, $F(1,15) = 0.172$, *n.s.*, $\eta^2_p = .011$, power = .07. This pattern was repeated for six-item lists: interaction, $F(1,30) = 19.934$, $p < .0001$, $\eta^2_p = .612$, power = 1, children with SLI, $F(1,15) = 3.545$, *n.s.*, $\eta^2_p = .191$, power = .42, and CA-matched controls, $F(1,15) = 54.873$, $p < .0001$, $\eta^2_p = .785$, power = 1.

After vocabulary knowledge was statistically removed from the analysis, the main effect of similarity remained significant, $F(1,29) = 5.98$, $p < .05$, $\eta^2_p = .171$, power = .66, along with the similarity by group interaction, $F(1,29) = 4.12$, $p = .05$, $\eta^2_p = .124$, power = .50. Children with SLI showed no effect due to similarity, $F(1,14) < 1$, $p = .997$, $\eta^2_p = 0$, power = .05, while CAM children still showed significantly better recall for phonologically dissimilar words, $F(1,14) = 10.71$, $p < .01$, $\eta^2_p = .43$, power = .86.

Word Frequency

Frequency results for both groups, collapsed across probability, similarity, and list length are provided in Figure 4. All children recalled high-frequency words more accurately than low-frequency words, $F(1,30) = 117.947$, $p < .0001$, $\eta^2_p = .797$, power = 1. This effect was similar for both groups, as indicated by a nonsignificant group by frequency interaction,

$F(1,30) = 0.994$, *n.s.*, $\eta^2_p = .032$, power = .16. The two-way interaction between frequency and similarity was not significant, $F(1,30) = 0.016$, *n.s.*, $\eta^2_p = .001$, power = .05, but the three-way frequency by similarity by list length interaction was significant, $F(1,30) = 45.335$, $p < .0001$, $\eta^2_p = .602$, power = 1. This interaction is shown in Figure 5. Examination of this interaction revealed that the similarity by length interaction was greater for high-frequency words, $F(1,30) = 32.841$, $p < .0001$, $\eta^2_p = .523$, power = 1, than for low-frequency words, $F(1,30) = 11.416$, $p < .01$, $\eta^2_p = .276$, power = .91.

For shorter lists, from two to four items in length, the similarity effect was greater for low-frequency words: two-item lists, high-frequency, $F(1,30) = 0.130$, *n.s.*, $\eta^2_p = .004$, power = .06; low-frequency, $F(1,30) = 11.824$, $p < .01$, $\eta^2_p = .283$, power = .91; three-item lists, high-frequency, $F(1,30) = 25.826$, $p < .0001$, $\eta^2_p = .463$, power = .99; low-frequency, $F(1,30) = 50.209$, $p < .0001$, $\eta^2_p = .626$, power = 1; four-item lists, high-frequency, $F(1,30) = 26.976$, $p < .0001$, $\eta^2_p = .473$, power = .99; low-frequency, $F(1,30) = 71.544$, $p < .0001$, $\eta^2_p = .705$, power = 1. For longer lists five to six items in length, the similarity effect was greater for high-frequency words: five-item lists, high-frequency, $F(1,30) = 24.609$, $p < .0001$, $\eta^2_p = .451$, power = .99; low-frequency, $F(1,30) = 10.156$, $p < .01$, $\eta^2_p = .253$, power = .87; six-item lists, high-frequency, $F(1,30) = 83.986$, $p < .0001$, $\eta^2_p = .737$, power = 1; low-frequency, $F(1,30) = 4.363$, $p < .05$, $\eta^2_p = .127$, power = .53.

While main effects due to group, list length, and similarity remained significant in the analysis of covariance, the main effect due to the lexical variable frequency was attenuated. After vocabulary scores were covaried out, there was no main effect due to frequency, $F(1,29) = 1.72$, $p = .20$, $\eta^2_p = .06$, power = .92, and the frequency by group interaction remained nonsignificant, $F(1,29) = 0.77$, $p = .39$, $\eta^2_p = .03$, power = .14.

Phonotactic Pattern Frequency

Probability results for both groups, collapsed across frequency, similarity, and list length are shown in Figure 6. The main effect of probability approached but did not reach statistical significance, $F(1,30) = 3.643$, $p = .066$, $\eta^2_p = .108$, power = .46. However, there was a significant group by probability interaction, $F(1,30) = 4.127$, $p = .05$, $\eta^2_p = .121$, power = .50. Examination of this interaction revealed that children with SLI were not affected by probability in the free recall task, $F(1,15) = 0.008$, *n.s.*, $\eta^2_p = .001$, power = .05, while age-matched controls recalled high-probability words more accurately than low-probability words, $F(1,15) = 7.561$, $p = .015$, $\eta^2_p = .335$, power = .73. Neither the probability by list length interaction, $F(1,30) = 2.639$, *n.s.*, $\eta^2_p = .081$, power = .35, nor the probability by list length by group interaction, $F(1,30) = 0.091$, *n.s.*, $\eta^2_p = .003$, power = .06, was significant. However, the main effect of probability was mediated by frequency, $F(1,30) = 16.137$, $p < .001$, $\eta^2_p = .35$, power = .97. This interaction, shown in Figure 7, revealed probability effects for high-frequency words, $F(1,30) = 14.825$, $p < .001$, $\eta^2_p = .331$, power = .96, but not for low-frequency words, $F(1,30) = 1.98$, *n.s.*, $\eta^2_p = .062$, power = .28. The three-way interaction with group was not significant, $F(1,30) = 0.389$, *n.s.*, $\eta^2_p = .013$, power = .09.

Like frequency, effects due to probability were attenuated when vocabulary scores were statistically removed from the analysis. The probability effect was no longer significant, $F(1,29) = .30$, $p = .59$, $\eta^2_p = .01$, power = .08, and effects due to probability did not differ by group, as indicated by a nonsignificant group by probability interaction, $F(1,29) = 2.86$, $p = .102$, $\eta^2_p = .09$, power = .37.

To summarize, children with SLI recalled fewer words overall than children with typical language development. All children recalled fewer words as list length increased, but this effect was larger for children with SLI. There was a significant main effect of similarity, but an interaction with group revealed that this effect was smaller for the children with SLI. This interaction also varied by list length. Children with SLI were affected by similarity at shorter, but not longer list lengths, while controls were affected at all list lengths. All children recalled more high-frequency words, and the magnitude of this effect was comparable for both groups. There was a marginally significant effect due to probability, but the interaction revealed that this was limited to age-matched controls. Children with SLI showed no such effect. Entering vocabulary scores as a covariate did not affect group differences, list length effects, or similarity effects. However, it did eliminate effects due to both frequency and probability.

Discussion

The purpose of the present experiment was to examine language effects in verbal recall by children with specific language impairments, or SLI. Specifically, the experiment was designed to measure (1) whether children with SLI encode phonological materials as efficiently as chronological age-matched typically developing children, (2) whether children with SLI exploit lexical and/or sublexical knowledge to facilitate verbal recall, and (3) whether these potential language knowledge effects are comparable for children with SLI and CAM typically developing peers. To answer these questions, children with SLI and CAM typically developing controls recalled lists of words varying in phonological similarity, word frequency, and phonotactic pattern frequency.

Previous studies have examined the efficiency of phonological encoding in this population (Gathercole and Baddeley, 1990; James et al., 1994; Montgomery, 1995; van der Lely and Howard, 1993). However, these studies have not reached a consensus as to whether children with SLI encode phonological materials as efficiently as typically developing children. Gathercole and Baddeley (1990) and James and colleagues (1994) reported group differences in the phonological similarity effect for longer word lists, but van der Lely and Howard (1993) and Montgomery (1995) reported no such group differences. A potential problem with all of these studies is that they used a small set of words, each of which appeared in multiple lists. The rationale for using a small set of words was well-founded—children with SLI are more likely to have greater difficulty in tasks requiring verbal output, and so these studies used small sets of picturable words that children could point to. But recombining a small set of words likely reduced the strength of the phonological similarity effect because children gained practice with individual test items (Gupta et al., 2005). Because van der Lely and Howard reported similar results in conditions requiring a pointing response and conditions requiring a verbal response for children with SLI with no articulation difficulties, the current study measured recall via verbal response to a larger set of words.

Consistent with all previous studies, a robust main effect of similarity was shown, in which recall of dissimilar words was greater than recall for phonologically similar words. The group by similarity interaction was significant, and revealed a smaller similarity effect for children with SLI. Children with SLI were less affected by similarity among test items to be recalled, suggesting that they encode phonological materials less efficiently than typically developing children. The three-way group by similarity by length interaction was also significant, revealing that children with SLI were affected by similarity for shorter word lists (two-four items), but unaffected by similarity for longer word lists (five-six items). Age-matched controls were unaffected for the two-item lists, likely due to ceiling effects, but showed expected similarity effects for longer lists, three to six items in length. These results replicate earlier findings reported by Gathercole and Baddeley (1990) and James and colleagues (1994). These groups noted that children with SLI use less efficient phonological encoding strategies when memory resources are exceeded. By using a larger set of words, thereby precluding potential practice effects, the current result show that the deficit in phonological encoding is not limited to just those conditions where memory resources are exceeded. The significant three-way group by similarity by list length interaction revealed that the deficit experienced by children with SLI in phonological encoding is most pronounced for longer word lists. But the significant two-way group by similarity interaction revealed general group differences in the efficiency of phonological encoding strategies.

The role of long-term language knowledge in word recall has been examined in children with typical language abilities, but very little work has examined these effects for children with SLI. Both Henry and Millar (1991) and Majerus and Van der Linden (2003) have reported that typically developing children recall a greater number of high-frequency words. Mainela-Arnold and colleagues (2010) have examined frequency effects in recall in children with SLI using dual processing tasks. In these tasks, children hear a list of short sentences, judge their veracity, and then recall the last word from each sentence. Their study used a set of sentences in which the final words varied in frequency and in neighborhood density. Results revealed significant main effects of group and frequency, but no interaction. Children with SLI and CAM peers were similarly affected by frequency in this recall task. The results of the current study replicate this second result using a different experimental paradigm—one that did not require competing language processing. All children recalled high-frequency words more accurately than low-frequency words, and the effect was similar for children with SLI and CAM typically developing controls. This replicates other findings that children with SLI respond to differences in word frequency much like typically developing children (Mainela-Arnold et al., 2008; Marchman et al., 1999; Oetting and Rice, 1993).

Just like lexical knowledge, phonological knowledge affected recall in children developing language typically. Children recalled words from dense neighborhoods more accurately than words from sparse neighborhoods (Thomson et al., 2005). Because words from dense neighborhoods necessarily sound like many other words, i.e., they contain frequent phonotactic patterns, these neighborhood density effects can be interpreted as probability effects. In the current study, this result was replicated for the children with typical language development, but not for children with SLI. Typically developing children recalled a greater number of high-probability words, but children with SLI showed no evidence of any such sensitivity. This pattern of results suggests that the lexical representations of children with SLI are intact, but their sublexical representations are somehow deficient.

A potential explanation is that the phonological representations of children with SLI are less robustly specified than those of children developing language typically. If children with SLI have difficulty establishing robust phonological knowledge from words in their lexicons, then they will be less able to use knowledge of phonotactic frequency patterns to facilitate recall. In the case of real words, there is another source of knowledge—that of word frequency—that they can use. Indeed, children with SLI showed very robust frequency effects in free recall. In the case of nonwords, however, there is no other source of language knowledge to apply to the task. In this case, children with SLI will be forced to use their fragile knowledge of phonotactic patterns to facilitate repetition. This explanation gains some support from the significant frequency by probability interaction. For high-frequency words, there was a significant probability effect, with better recall for high-probability words. For low-frequency words, on the other hand, there was no effect due to probability. Generally speaking, the phonological forms of high-frequency words are assumed to be robustly represented in the mental lexicon, while low-frequency words are characterized by less specified phonological representations (e.g., Metsala and Walley, 1998). For the entire group of children in the current study, there was a probability effect for robustly represented high-frequency words, but no effect for less robustly represented low-frequency words. So children were able to use phonological knowledge to support recall of words with robust phonological representations, but not words characterized by fragile underlying representations.

The same argument can be made about the three-way interaction between similarity, frequency, and list length. For high-frequency words, there was a robust effect due to similarity. However, for low-frequency words, the similarity effect was greatly reduced for longer word lists. Again, if low-frequency words are less robustly specified, then it is reasonable to expect that they will be encoded less efficiently. Thus, the efficiency of phonological encoding processes and the use of knowledge of phonotactic patterns both appear to rely on the robustness of underlying phonological representations. It is not surprising, then, that children with SLI experienced difficulty with both of these phonological factors. A number of recent studies have suggested that children with SLI have difficulty establishing mature lexical representations, which might be the primary cause of the language impairment (Bishop, 2000; Coady et al., 2005; Mainela-Arnold et al., 2008).

While fragile phonological representations can explain the reduced effect for recall of high- vs. low-probability words by children with SLI, they are more likely to be a consequence of a phonological encoding deficit rather than a causal factor. In order to establish robust representations, children must have intact phonological encoding skills that allow them to break words down into their constituent phonemes. Children who are less able to break words down will be at a disadvantage for building robust representations. The group by similarity interaction and the group by probability interaction both point to a phonological deficit. However, the two interactions suggest different deficits. The reduced similarity effect has been interpreted as evidence for a phonological encoding deficit (Liberman et al., 1977). Children who are less able to break words down into their component phonemes are less likely to receive interference from other phonologically similar words. An encoding deficit makes it difficult for the affected individual to focus on individual phonemes, consequently limiting the acquisition of robust representations.

These findings of less efficient phonological processing and less robust phonological representations lend support to the alternative account of nonword repetition. Nonword repetition tasks have gained wide acceptance in recent years because of the transparent relationship between repetition accuracy and vocabulary, and because it is sensitive to a wide variety of language disorders (for a review, see Coady and Evans, 2008). The generally accepted explanation of this finding is phonological memory capacity as a third variable in correlation analyses. According to this account, nonword repetition accuracy and vocabulary are correlated because both rely on phonological memory capacity. Presumably, children with SLI experience difficulty in both nonword repetition and vocabulary growth because both are limited by reduced phonological memory capacity (Gathercole and Baddeley, 1990). An alternative account argues that deficits in the ability to repeat nonwords actually arise from deficits either in the initial encoding of phonological materials or in the nature of the materials to be remembered (Edwards and Lahey, 1998; Snowling et al., 1991). Archibald and Gathercole (2007) have acknowledged that a phonological memory deficit alone is insufficient for explaining the linguistic deficits experienced by children with SLI. Further, recent computer simulations suggest that developmental changes in nonword repetition accuracy result from changes in long-term language knowledge, while changes in working memory capacity have no effect (Jones et al., 2008). The results of the current study suggest that children with SLI do indeed experience deficits in verbal recall, but also a deficit in the efficiency with which phonological materials are encoded. This is suggestive of a deficit in the robustness of underlying linguistic representations. However, the current study revealed no deficit in these children’s ability to use lexical knowledge in the form of word frequency to facilitate recall. These results suggest that memory deficits can be explained in terms of phonological deficits.

Group memory differences persisted even after effects due to vocabulary knowledge were covaried out of the analysis. This finding suggests that group differences in vocabulary cannot fully explain group differences in memory. That is, standardized measures of vocabulary knowledge might not be the best index for the robustness with which the acoustic forms of words are stored. Children with SLI appear to have a relative strength in vocabulary compared to more pronounced deficits in other linguistic domains (Gray, Plante, Vance and Henrichsen, 1999). It seems reasonable that these children’s language and memory abilities are more severely affected than their vocabulary scores would indicate. Effects due to list length and similarity also remained significant in the analysis of covariance. Children with SLI were still more affected by increasing list length, as indicated by a significant group by length interaction. However, a group by similarity interaction revealed no effect of similarity for children with SLI, at least with vocabulary covaried out, but a significant effect for age-matched peers. This finding that children with SLI encode phonological materials less efficiently than their unimpaired peers replicates a number of previous studies reporting difficulty establishing robust phonological representations (Bishop, 2000; Coady et al., 2005; Mainela-Arnold et al., 2008). While effects due to group, list length and phonological similarity could not be reduced to vocabulary knowledge, effects due to frequency and probability were eliminated when vocabulary was covaried out. This suggests that better recall for frequently occurring words and for words with frequently occurring phonotactic patterns is a function of one's vocabulary. It is worth noting that this finding shows that frequency, probability, and even neighborhood density are not functions of the individual words. Instead, those factors are a part of the knowledge a language user learns about those words, just like meaning and pronunciation.

The results of the current study provide additional evidence that children with SLI have a deficit in verbal recall, replicating many other studies (Ceci et al., 1981; Gathercole and Baddeley, 1990; Graham, 1980; James et al., 1994; Kail et al., 1984; Kirchner and Klatzky, 1985; Mainela-Arnold et al., 2010; Menyuk, 1964, 1969; Menyuk and Looney, 1972; Montgomery, 1995; Sininger et al., 1989; Stark et al., 1967; van der Lely and Howard, 1993; Wiig and Semel, 1976, 1980). However, they also provide evidence for a phonological deficit. To date, the primary evidence for this deficit has been from nonword repetition tasks, in which semantic and syntactic demands are eliminated. The current study replicates this finding using real words. The similarity results show that children with SLI encode phonological materials (spoken real words in this case) less efficiently than their unimpaired peers. The probability results show that children with SLI are unable to use the frequency of words' phonological patterns to facilitate real-word recall. Both of these results are in contrast with the frequency results, in which children with SLI showed comparable sensitivity to typically developing peers (see also Mainela-Arnold et al., 2008; Marchman et al., 1999; Oetting and Rice, 1993). Together, these results suggest that children with SLI have difficulty with both the storage and processing of phonological materials.

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Appendix. Word lists used in the free recall task

Sim hi-freq hi-prob	**Dis hi-freq hi-prob**	**Sim hi-freq lo-prob**	**Dis hi-freq lo-prob**	**Sim lo-freq hi-prob**	**Dis lo-freq hi-prob**	**Sim lo-freq lo-prob**	**Dis lo-freq lo-prob**
fill *sell*	*wise* *meat*	*neck* *map*	*sauce* *rule*	*bait* *cake*	*might* *lair*	*deb* *dip*	*comb* *hug*
car *gear*	*bone* *fat*	*wrap* *lack*	*race* *beef*	*muck* *buck*	*din* *pat*	*jeep* *cheat*	*yoke* *bib*
gun *come* *hung*	*down* *chair* *like*	*dash* *boss* *gas*	*sad* *nerve* *lip*	*jot* *chat* *jut*	*kit* *mar* *ban*	*lash* *lush* *rash*	*cage* *shed* *veer*
base *does* *guess*	*noise* *deep* *roar*	*shell* *feel* *chill*	*cape* *loose* *foam*	*wane* *weed* *whale*	*hiss* *mat* *dell*	*shod* *sob* *shag*	*hoop* *sire* *toad*
man *not* *more* *none*	*shake* *rose* *good* *win*	*dive* *tire* *dine* *time*	*verse* *type* *mood* *lodge*	*booze* *fuzz* *wheeze* *buzz*	*shone* *par* *mouse* *yak*	*batch* *gash* *ditch* *birch*	*dial* *goose* *van* *woke*
war *burn* *pair* *four*	*bell* *nine* *route* *cook*	*shore* *church* *sheer* *chore*	*moon* *rock* *peace* *third*	*hick* *seep* *hop* *suck*	*dad* *hum* *lure* *mike*	*tab* *peg* *tag* *cab*	*zip* *couch* *dire* *wove*
fit *sick* *sheet* *thick* *feet*	*yes* *been* *cup* *mate* *role*	*year* *learn* *nurse* *search* *near*	*root* *match* *gaze* *file* *south*	*writ* *lick* *rut* *rake* *lit*	*tot* *bun* *jar* *lace* *heave*	*rip* *limb* *reek* *rib* *leak*	*chop* *mug* *hive* *sash* *curl*
pull *core* *tour* *could* *pour*	*mile* *scene* *dirt* *wave* *use (v)*	*code* *tube* *cope* *cool* *pope*	*young* *vote* *size* *dull* *rage*	*gnome* *mum* *noun* *moan* *numb*	*tame* *bide* *lore* *fawn* *wick*	*mash* *niece* *moss* *gnash* *mesh*	*sod* *foul* *boom* *coke* *hash*
back *debt* *kick* *get* *deck* *bit*	*give* *worse* *yell* *ride* *phone* *make*	*check* *jet* *shop* *cheek* *shock* *jack*	*mouth* *chain* *loop* *wish* *dog* *five*	*dole* *bull* *gale* *dill* *bail* *gall*	*goat* *hatch* *rum* *sieve* *tease* *whirl*	*dub* *bug* *dove* *buff* *dug* *bud*	*cheese* *vine* *ledge* *hook* *raid* *whiff*
rice *light* *wine* *rain* *line* *wait*	*bird* *these* *look* *half* *name* *goal*	*peak* *tip* *cheap* *pitch* *keep* *chip*	*theme* *toss* *wife* *nail* *rich* *joke*	*pun* *tin* *keen* *ping* *kin* *pine*	*deed* *hip* *wool* *chess* *fern* *cave*	*jug* *chick* *jerk* *chug* *jig* *chuck*	*zoom* *peach* *knack* *lull* *thief* *tide*

What this paper adds

What is already known

For typical adults and children, the frequencies with which words occur in the language environment and the frequencies with which words' phonological patterns occur both affect memory performance, with an advantage for more frequently occurring items. In addition, memory performance is typically reduced for lists of structurally similar words, which is taken as evidence for the efficiency of phonological processing. However, it is not clear to what extent these factors affect recall in children with Specific Language Impairments, or SLI. One of the defining features of this population is a deficit in verbal recall. This paper attempts to explore how language knowledge influences real-word recall in children with SLI.

What this study adds

Consistent with previous studies, children with SLI do indeed recall fewer words than age-matched, typically developing children. However, relative to their typically developing peers, children with SLI are more affected by increasing list length, comparably affected by word frequency, less affected by phonological similarity, and completely unaffected by the frequency of words' phonological patterns. These results suggest that children with SLI process phonological materials less efficiently than their peers, and that they have difficulty either extracting or using phonological regularities from their language input.

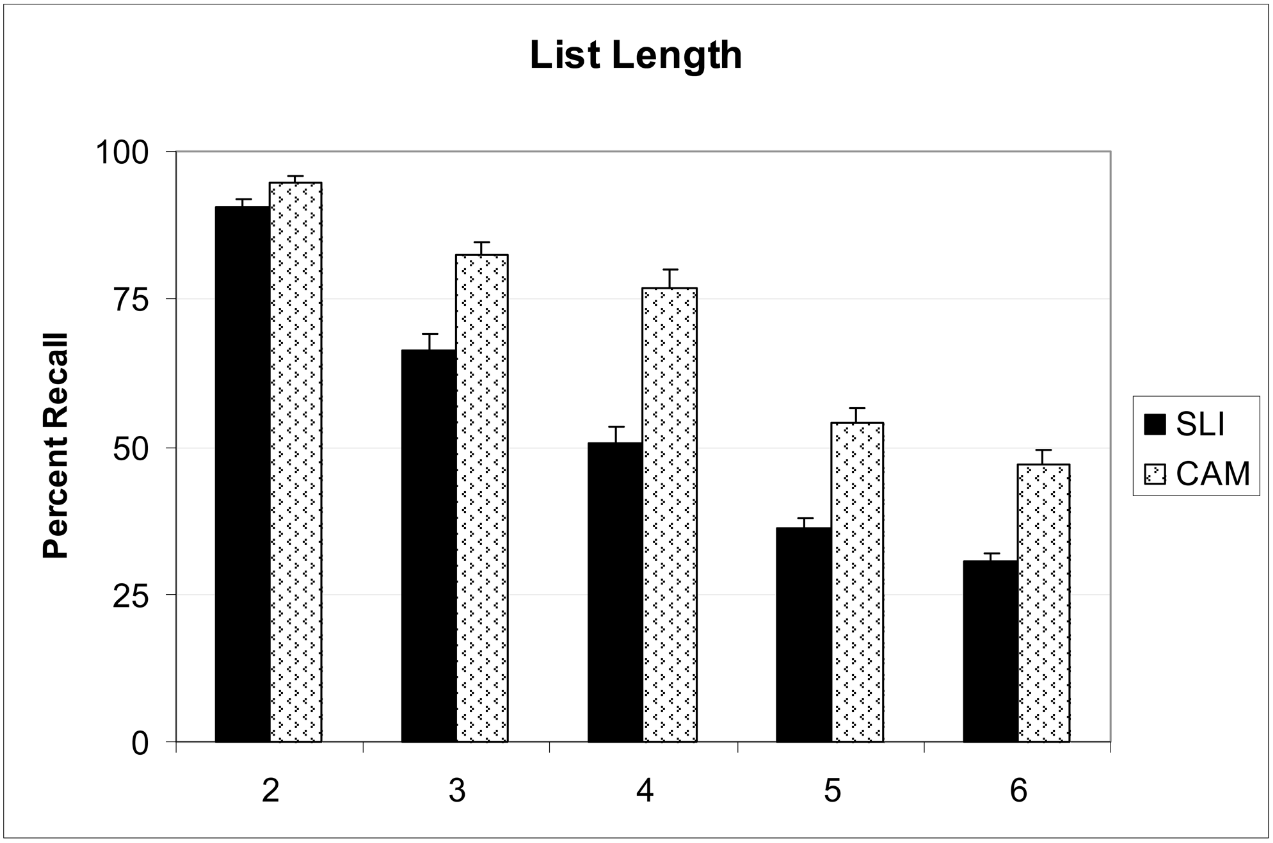

Figure 1.
Percentage of words recalled, including standard error bars, as a function of list length, for children with SLI (black bars) and for CAM typically developing children (hatched bars). Results are collapsed across phonological similarity, word frequency and phonotactic pattern frequency.

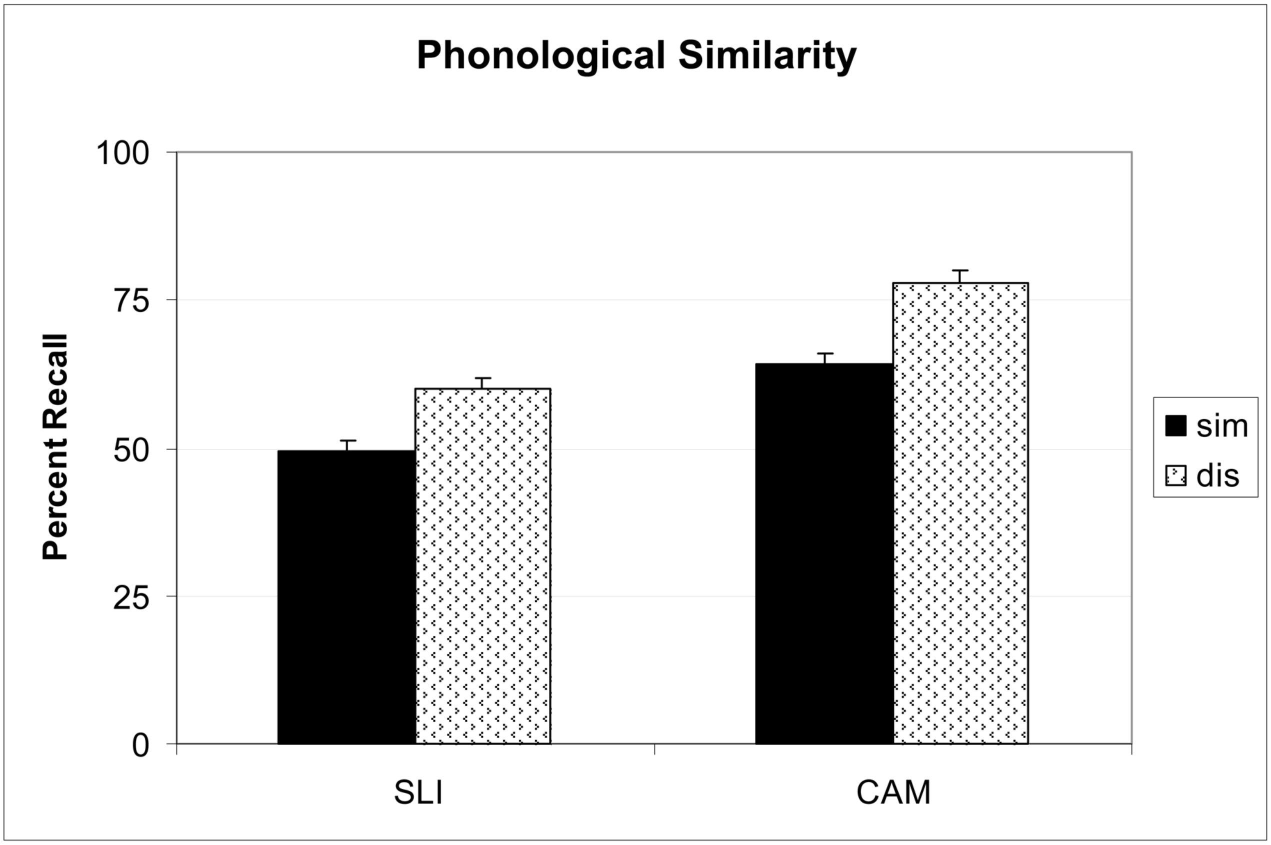

Figure 2.
Percentage of phonologically similar and dissimilar words recalled and standard error bars for children with SLI (left) and CAM controls (right). Results are collapsed across list length, word frequency and phonotactic pattern frequency.

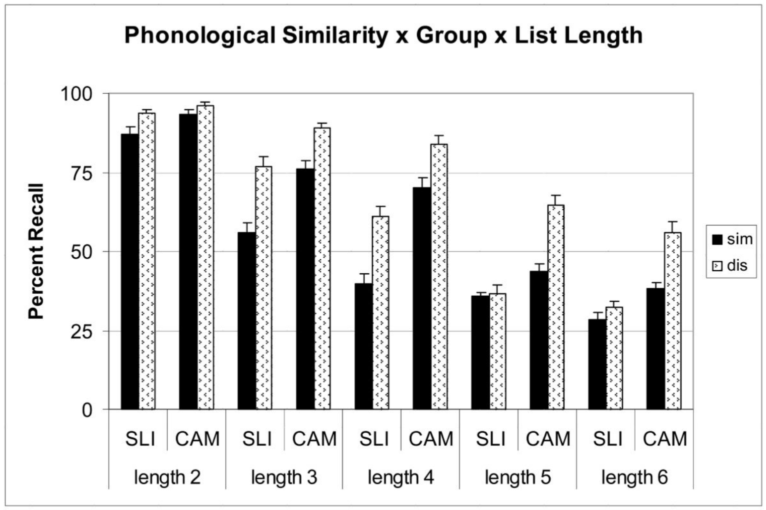

Figure 3.

Percentage of phonologically similar and dissimilar words recalled and standard error bars as a function of group (SLI vs. CAM) and list length. Results are collapsed across word frequency and phonotactic pattern frequency.

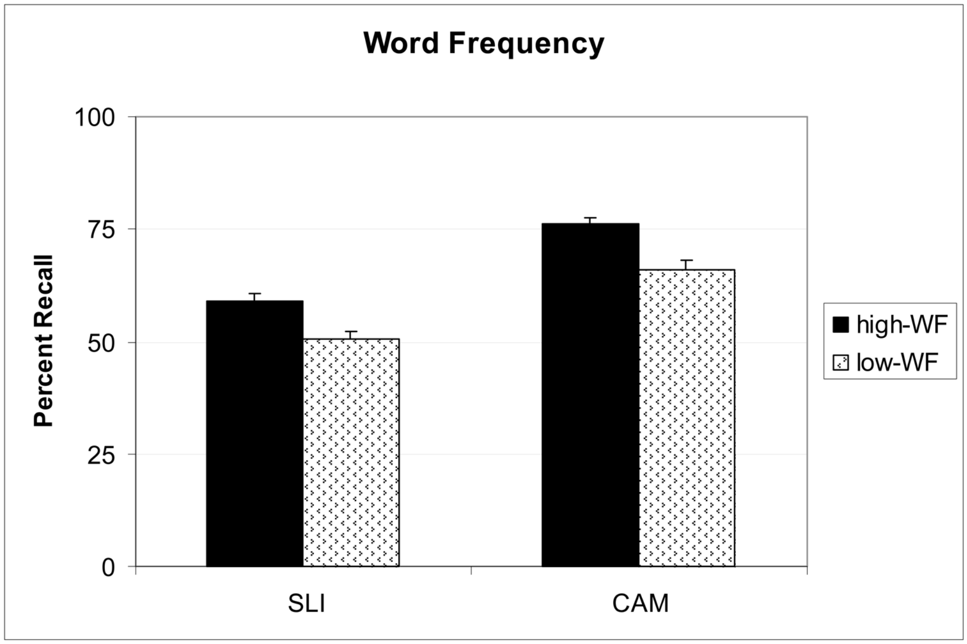

Figure 4.
Percentage of high- and low-frequency words recalled and standard error bars for children with SLI and CAM controls. Results are collapsed across list length, phonological similarity and phonotactic pattern frequency.

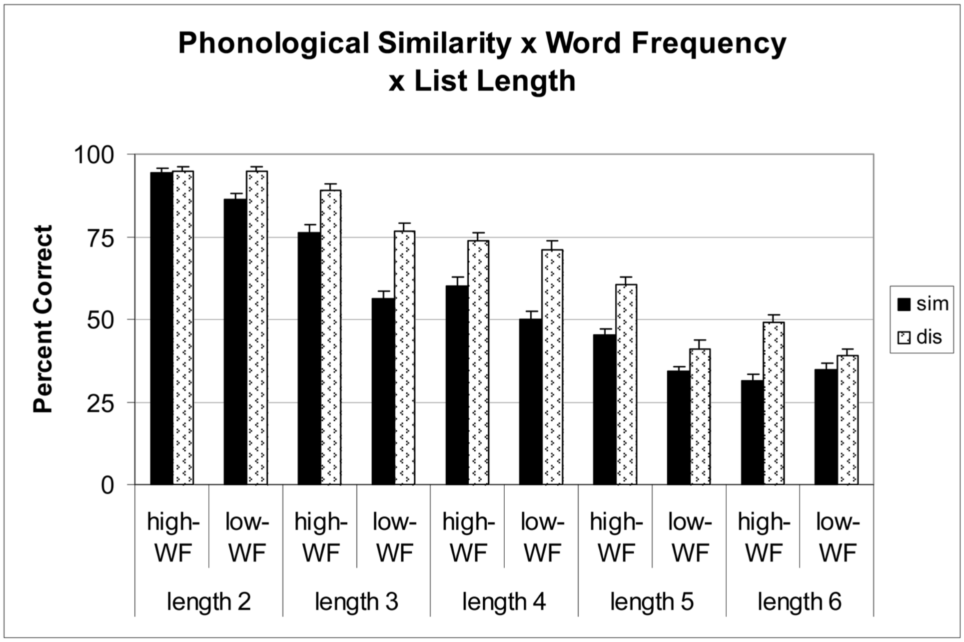

Figure 5.

Percentage of phonologically similar and dissimilar words recalled and standard error bars as a function of word frequency (high vs. low) and list length. Results are collapsed across group and phonotactic pattern frequency.

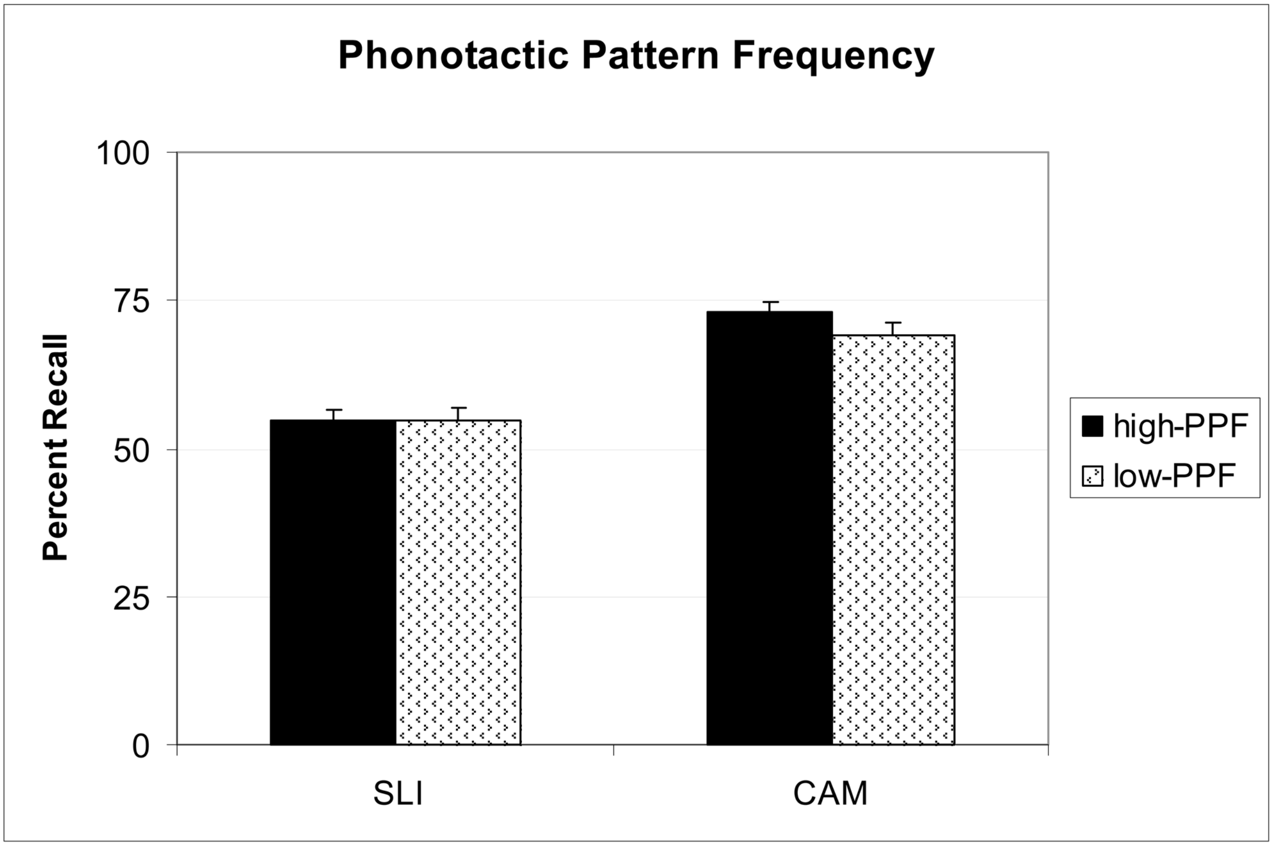

Figure 6.

Percentage of high- and low-phonotactic pattern frequency words recalled and standard error bars for children with SLI and CAM controls. Results are collapsed across list length, phonological similarity and word frequency.

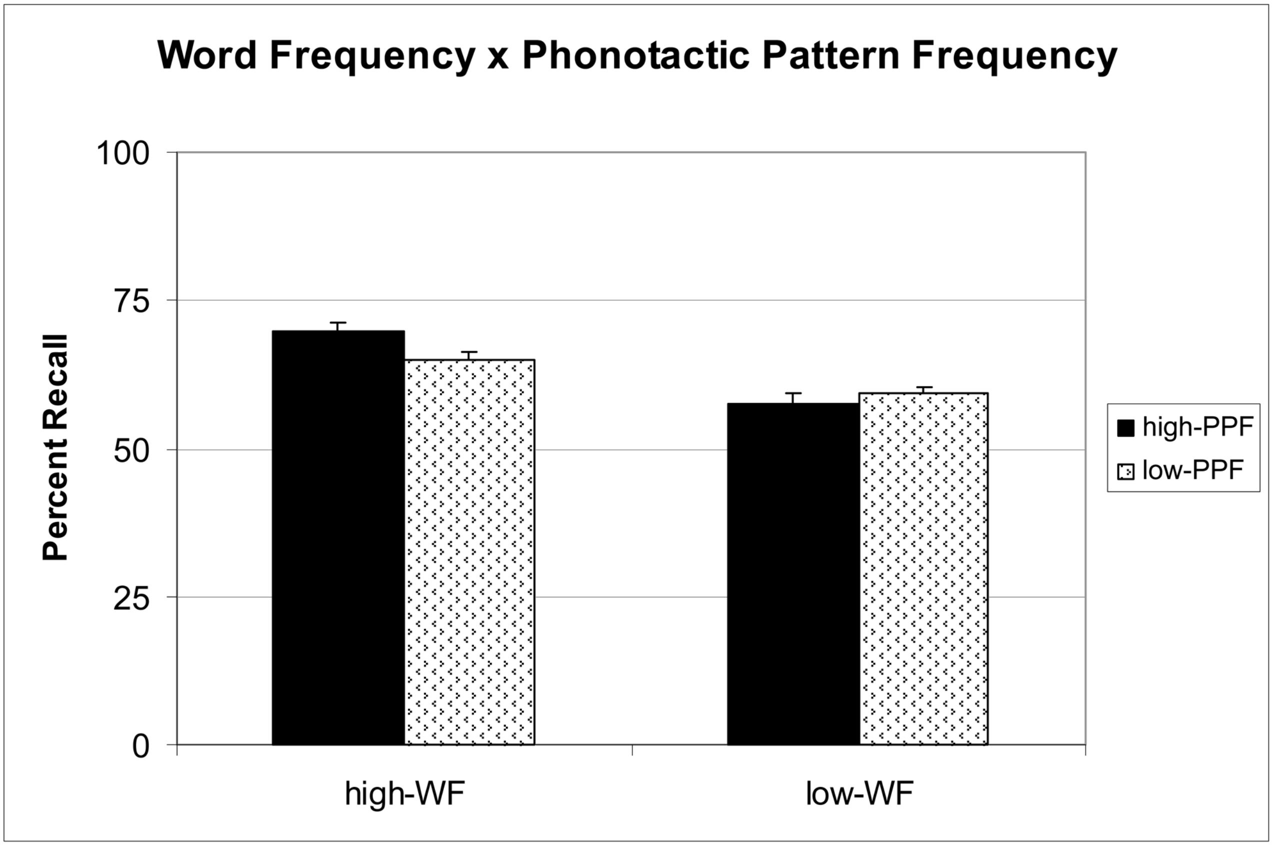

Figure 7.
Percentage of high- and low-phonotactic pattern frequency words recalled and standard error bars as a function of word frequency. Results are collapsed across group, list length, and phonological similarity.

Table 1

Group summary statistics for children with SLI and chronological age-matched (CAM) typically developing children. Means (and standard deviations) are presented for chronological age (years;months), maternal education (years), standard NVIQ scores[a], composite Expressive (ELS) and Receptive (RLS) Language Scores from the CELF-III[b], standard scores on the PPVT-III[c], the EVT[d], and standard scores from the Word Identification and Word Attack subtests of the WJ-III[e].

	Children with SLI	**CAM Typically Developing Children**
Age	10;2 (1;0)	10;2 (1;2)
Maternal Education	13.6 (1.5)	16.3 (3.1)
NVIQ	99.4 (8.6)	103.1 (7.3)
CELF-III ELS	72.4 (11.0)	110.7 (12.6)
CELF-III RLS	68.7 (13.2)	--
PPVT-III	91.3 (10.3)	107.1 (8.5)
EVT	81.9 (6.7)	98.3 (11.9)
Word ID	92.0 (9.6)	106.1 (9.9)
Word Attack	93.1 (9.6)	105.0 (6.2)

[a]Leiter International Performance Scale—Revised (Roid and Miller, 1997)

[b]Clinical Evaluation of Language Fundamentals—Third Edition (Semel et al., 1995)

[c]Peabody Picture Vocabulary Test—Third Edition (Dunn and Dunn, 1997)

[d]Expressive Vocabulary Test (Williams, 1997)

[e]Woodcock-Johnson III Tests of Achievement (Woodcock, McGrew and Mather, 2001)

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Table 2

Summary statistics for stimulus words. Means (and standard deviations) are provided for word familiarity ratings from the Hoosier Mental Lexicon (Nusbaum, Pisoni and Davis, 1984) or the MRC Psycholinguistic Database (Colthart, 1981), log word frequency (Kučera and Francis, 1967), log phonotactic probability (Coady and Aslin, 2004), log-frequency weighted neighborhood density (LFWND; Coady and Aslin, 2003), and age of acquisition ratings (Cortese and Khanna, 2008).

	Familiarity	Log Frequency	Log Probability	LFWND	AOA
Sim high-freq high-prob	6.97 (0.13)	2.28 (0.58)	−4.15 (0.48)	79.99 (26.7)	3.20 (0.63)
Dis high-freq high-prob	6.95 (0.16)	2.21 (0.56)	−4.30 (0.45)	62.24 (27.2)	3.02 (0.66)
Sim high-freq low-prob	6.97 (0.06)	1.87 (0.48)	−5.72 (0.60)	57.88 (21.4)	3.58 (0.57)
Dis high-freq low-prob	6.95 (0.10)	1.90 (0.38)	−5.80 (0.66)	45.40 (21.9)	3.50 (0.72)
Sim low-freq high-prob	6.47 (0.77)	0.67 (0.44)	−4.33 (0.40)	78.34 (28.2)	4.51 (1.08)
Dis low-freq high-prob	6.46 (0.82)	0.72 (0.43)	−4.17 (0.49)	74.96 (28.6)	4.40 (1.12)
Sim low-freq low-prob	6.53 (0.71)	0.76 (0.36)	−6.31 (1.10)	48.35 (18.1)	4.26 (0.88)
Dis low-freq low-prob	6.74 (0.40)	0.74 (0.38)	−5.90 (0.78)	47.22 (17.5)	4.03 (1.06)