Beyond Capacity Limitations: Determinants of Word Recall Performance on Verbal Working Memory Span Tasks in Children With SLI

RESEARCH NOTE

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Reduced verbal working memory capacity has been proposed as a possible account of language impairments in specific language impairment (SLI). Studies have shown, however, that differences in strength of linguistic representations in the form of word frequency affect list recall and performance on verbal working memory tasks. This suggests that verbal memory capacity and long-term linguistic knowledge may not be distinct constructs. It has been suggested that linguistic representations in SLI are weak in ways that result in a breakdown in language processing on tasks that require manipulation of unfamiliar material. In this study, the effects of word frequency, long-term linguistic knowledge, and serial order position on recall performance in the competing language processing task (CLPT) were investigated in 10 children with SLI and 10 age-matched peers (age 8 years 6 months to 12 years 4 months). The children with SLI recalled significantly fewer target words on the CLPT as compared with their age-matched controls. The SLI group did not differ, however, in their ability to recall target words having high word frequency but were significantly poorer in their ability to recall words on the CLPT having low word frequency. Differences in receptive and expressive language abilities also appeared closely related to performance on the CLPT, suggesting that working memory capacity is not distinct from language knowledge and that degraded linguistic representations may have an effect on performance on verbal working memory span tasks in children with SLI.

KEY WORDS: specific language impairment, working memory, word frequency, serial order, linguistic representation

The purpose of this study was to investigate the extent to which processing capacity is or is not distinct from language knowledge in children with specific language impairment (SLI). Specifically, the goal of this study was to investigate factors that potentially affect the retention and recall of the target words on the competing language processing task (CLPT) in children with SLI. Children with SLI have difficulty acquiring language in the absence of frank neurological, hearing, emotional, or intellectual impairments. Despite having normal nonverbal intelligence, these children exhibit a range of linguistic and nonlinguistic processing deficits (Leonard, 1998). A substantial body of research links poor performance on working memory tasks with language impairments in these children (e.g., Dollaghan & Campbell, 1998; Ellis Weismer, Evans, & Hesketh, 1999; Ellis Weismer et al., 2000; Montgomery, 2000). These limited processing capacity accounts include but are not limited to reduced size of working memory (Ellis Weismer et al., 1999), reduced processing speed (e.g., Kail & Salthouse, 1994; Leonard, 1998; Miller, Kail, Leonard, & Tomblin, 2001), reduced speed of processing across modalities (Fazio, 1998), or reduced computational energy or efficiency (e.g., Bishop, 1997).

There is, however, debate regarding the extent to which processing deficits are the underlying cause of language impairments in SLI (e.g., van der Lely & Howard, 1993). Based on findings in typical adult sentence processing (Pearlmutter & MacDonald, 1995) and connectionist computer modeling (MacDonald & Christiansen, 2002), it has been suggested that the nature of human language architecture is such that long-term linguistic knowledge and processing capacity are primitives that cannot vary independently. There is also a parallel debate among the investigators of SLI regarding the nature of the trade-off relationship between storage and processing for children with SLI (Ellis Weismer et al., 1999; Gillam, Cowan, & Marler, 1998; Montgomery, 2002). For example, Montgomery has argued that slower speed of lexical processing affects both the processing and storage components of working memory tasks in children with SLI, resulting in a trade-off relationship between storage and processing that differs fundamentally from that of typically developing children. Finally, Ellis Weismer et al. (1999) have proposed that reduced long-term language knowledge may result in poor working memory capacity, suggesting a bidirectional relationship between long-term language knowledge and working memory capacity in children with SLI. If one assumes, in keeping with connectionist computer modeling (MacDonald & Christiansen, 2002), a language architecture in which processing capacity is not distinct from language knowledge, then differences in the representational strength of long-term linguistic knowledge may result in the appearance of reduced verbal working memory capacity in children with SLI. It appears that before reduced recall of target words on working memory tasks in children with SLI can be interpreted as evidence of reduced working memory capacity, factors affecting the recall of the target words need to be directly investigated.

Two models of working memory, with focuses on phonological and verbal aspects of working memory, have particularly influenced investigations of processing deficits in SLI. These are Baddeley and colleagues' three-part model of working memory span (Baddeley, 1992; Gathercole & Baddeley, 1990) and Just, Carpenter, and colleagues' model of verbal working memory (Daneman & Carpenter, 1980; Just & Carpenter, 1992). In Baddeley and colleagues' model, working memory comprises three components: the central executive, the visuospatial sketch pad, and the articulatory loop. The central executive is the attentional controller, responsible for coordinating information from the articulatory loop and the visuospatial sketch pad. The articulatory loop is the system responsible for maintaining and manipulating phonological information (e.g., Baddeley, 1992; Gathercole & Baddeley, 1990). Functionally, this temporary storage and processing of novel phonological information have been referred to as *phonological working memory*. The focus of Baddeley and colleagues' model is the role that phonological working memory plays in language acquisition and language impairments (e.g., Baddeley, 1992; Gathercole & Baddeley, 1990). According to the model, impairments in the ability to temporarily store phonological information in working memory result in the language impairments in SLI (e.g., Gathercole & Baddeley, 1990).

In the most recent instantiation, Baddeley (2003) has added "crystallized" systems to the model, one of which is long-term language knowledge. This system accounts for the impact of language regularity or language knowledge on working memory tasks, for example, the finding that nonwords of any given length that resemble English words are more easily repeated by English speakers than words that do not resemble English words (Gathercole, 1995). Baddeley argues, however, that architecturally, the human language processing system has separable systems for long-term language knowledge and short-term processing (Baddeley & Logie, 1999).

Just, Carpenter, and colleagues' model of verbal working memory focuses on the trade-off between storage and linguistic comprehension processes during language processing (e.g., Daneman & Carpenter, 1980; Just & Carpenter, 1992). In their model, verbal working memory functions as a short-term storage for the intermediate and final products of the listener's verbal computations and is roughly equivalent to the central executive component of Gathercole and Baddeley's phonological working memory model (Just & Carpenter, 1992). Verbal working memory span consists of a fixed "pool of operational resources that perform the symbolic computations" (Just & Carpenter, 1992, p. 122). Verbal working memory span, according to Just and Carpenter (1992), consists of a fixed "pool of operational resources that perform the symbolic computations" (p. 122), and limitations in verbal capacity constrain language processing so that individual differences in verbal working memory capacity account for differences in language comprehension. Just and Carpenter (1992) have defined "differences in total capacity"

(p. 145) in their model as overall amount of activation that can be allocated for language processing and "processing efficiency" (p. 145) linguistic knowledge as the ease by which individuals execute linguistic operations, such as accessing lexical items. While they argue that their model does not attempt to differentiate between total capacity limitations and limitations in the way long-term linguistic knowledge is processed, they acknowledge that individual differences in verbal working memory span may be due to the differences in either total capacity or the efficiency with which long-term linguistic knowledge is processed.

There is evidence to suggest that linguistic knowledge does affect verbal working memory capacity. In particular, studies have shown a direct relationship between language abilities and an individual's efficiency and accuracy on immediate recall tasks (e.g., Engle, Nations, & Cantor, 1990; Gathercole, 1995). These findings are consistent with recent connectionist modeling work by McDonald and colleagues (e.g., MacDonald & Christiansen, 2002; Seidenberg & MacDonald, 1999). This work suggests that processing capacity emerges from an interaction between features inherent in the language input (e.g., frequency and regularity of patterns in the language) and innate biological–architectural factors of the individual speaker. For example, MacDonald and Christiansen have shown that individual differences in language processing abilities may be the result of not differences in working memory capacity, as traditionally interpreted, but the representational strength of the long-term linguistic knowledge being manipulated. From this perspective, the strength of these representations is directly dependent on frequency from language input where high-frequency information is processed more rapidly and efficiently than low-frequency information.

The effects of cumulative long-term language knowledge on language processing, in the form of word frequency, neighborhood density, and phonotactic probability, have been the subject of extensive investigations in both adults and children (e.g., Gathercole, Frankish, Pickering, & Peaker, 1999; Luce & Pisoni, 1998; Munson, 2001; Roodenrys, Hulme, Lethbridge, Hinton, & Nimmo, 2002; Storkel & Rogers, 2000; Van Overschelde, 2002). *Word frequency* refers to the frequency with which lexical items occur in a language. Neighborhood structure is usually considered to comprise two factors: (a) the number of words in the neighborhood *(neighborhood density)* and (b) the frequencies of the neighbors (*neighborhood frequency;* Luce & Pisoni, 1998). *Phonotactic probability* refers to the frequency of certain sound sequences appearing in words in a particular language. Studies investigating individuals' processing of real words, as opposed to nonwords, indicate that the best single factor affecting the ability to recognize and recall lexical items is word frequency (e.g., Luce & Pisoni, 1998; Roodenrys et al., 2002).

The paradigm typically used to assess verbal working memory span in the Just and Carpenter model is a task designed to jointly assess storage and processing functions that operate simultaneously (e.g., Daneman & Carpenter, 1980). In this task, individuals read or listen to lists of unrelated sentences (varying in number of sentences) and judge their truthfulness while attempting to remember the last words of each sentence in a given list. After each list of sentences, individuals are asked to recall the final words of each sentence in the list (e.g., "Babies drive *trucks,* Milk is *white,* Lions have *tails*"; Gaulin & Campbell, 1994). Carpenter and Just have argued that the processing component of working memory is tapped as individuals determine the truth value of each sentence, while the storage component is tapped by having to retain and recall the final words in each of the sentences in a given set. Based on this model, an individual's verbal working memory capacity is defined as the maximum number of sentences an individual can correctly comprehend while simultaneously maintaining the correct recall of the final words of the sentences in the list.

On Just and Carpenter–type verbal span tasks modified for use with children (CLPT; Gaulin & Campbell, 1994), children with SLI recall significantly fewer words than their typically developing peers (Ellis Weismer et al., 1999). Ellis Weismer and Thordardottir (2002) have argued that this poor word recall on the CLPT for children with SLI is evidence of a functionally smaller temporary storage space (e.g., reduced verbal working memory capacity) relative to unimpaired peers. In particular, Ellis Weismer et al. have suggested that as children with SLI are required to allocate more of their verbal working memory resources to the comprehension of a greater number of sentences or longer sentences in the task, they are left with fewer resources for storage of verbal material (Ellis Weismer et al., 1999).

While children with SLI recall fewer words on the CLPT as compared with their typically developing peers, it is not clear if this is a result of inefficient processing of long-term linguistic knowledge or reduced storage capacity (Ellis Weismer et al., 1999). Specifically, if children with SLI are working with poor long-term language knowledge that results in slow, inefficient processing of lexical items, then target words recalled for children with SLI and chronological-age-matched (CA) peers should be differentially affected by word frequency and long-term language knowledge. Furthermore, Gillam et al. (1998) have shown than children with SLI evidence reduced serial order effects in serial recall tasks, a difficulty that also could result in poorer retention of target words in each of the sentence lists.

The purpose of this study therefore was to investigate factors potentially affecting the retention and recall of the target words on the CLPT in children with SLI. These included frequency of words recalled on the CLPT, the serial position of target words in sentence list (e.g., first, middle, last sentence), and long-term language knowledge assessed by standardized language measures. The following research questions were posed:

1. Would children with SLI differ from CA peers in their ability to correctly answer the "yes/no" sentences on the CLPT?
2. Would children with SLI differ from their CA peers in the percentage of target words recalled?
3. Would children with SLI differ from their CA peers in the number of high-frequency versus low-frequency target words recalled?
4. Would children with SLI differ from their peers in the number of target words recalled in different serial positions in the lists (e.g., first, middle, last)?
5. Is processing capacity, defined by target words recalled on the CLPT, distinct from language knowledge, as assessed by expressive and receptive standardized language measures?

Method

Participants

Originally, 24 children, 12 children with SLI and 12 CA peers were identified from a larger study investigating gesture and cognitive processing. For each child with SLI, a matching criterion of ±6 months was used for the CA control. To allow for the investigation of the effects of frequency and serial order on the recall of target words on the CLPT for the two groups of children, only children who were able to recall the target words of the sentences were included in the analysis for this research note. The criterion for inclusion was the ability to recall six or more of the target words correctly. Two children with SLI failed to meet these criteria (e.g., recalling whole sentences instead), resulting in a total of 20 children, 10 children with SLI (age 8 years 2 months to 12 years 4 months) and their 10 CA-matched controls (age 8 years 4 months to 12 years 2 months). The children were primarily from the majority culture; in the SLI group, 7 were White and 3 were African American, and in the CA group, 9 were White and 1 was Hispanic. All children completed individual testing sessions in the Child Language and Cognitive Processes Laboratory at the University of Wisconsin—Madison, Waisman Research Center.

All participants met the following inclusion criteria: (a) nonverbal intelligence at or above 85, as measured by either the Leiter International Performance Scale (Roid & Miller, 1997) or the Columbia Mental Maturity Scale (Burgemeister, Blum, & Lorge, 1972), (b) passing a pure-tone audiometric screening at 20 dB HL at 500, 1000, 2000, and 4000 Hz, (c) absence of oral and speech motor disabilities, and (d) monolingual, English-speaking homes. Children were excluded if they had any of the following conditions based on parent report: cognitive delay, emotional or behavioral disturbances, motor deficits, or frank neurological signs including seizure disorders or use of medication to control seizures.

Receptive and expressive language skills of the children were assessed using the Clinical Evaluation of Language Fundamentals—Revised (CELF–R; Semel, Wiig, & Secord, 1987). Children with SLI had both expressive and receptive deficits, as measured by the Expressive Language score (ELS) and Receptive Language score (RLS) on the CELF–R, with both the ELS and RLS scores being 1.00 standard deviation or more below the mean. While the children with SLI were administered all six subtests of the CELF–R, the children in the CA group were administered the three expressive subtests, to assess expressive language skills, and one receptive subtest, the Oral Directions (OD) subtest, to screen receptive language skills. Children in the CA group were required to have a composite ELS of 85 or greater and standard scores on the OD receptive subtest of the CELF–R of 8 or greater. The two groups did not differ significantly in nonverbal intelligence, $t(18) = -1.69$, $p > .05$; however, both ELSs, $t(18) = -9.27$, $p < .05$, and OD scores, $t(18) = -6.62$, $p < .05$, were significantly different for the two groups. The results of standardized testing for these 20 children are shown in Table 1.

Experimental Task

In addition to standardized testing, all of the children completed the CLPT (Gaulin & Campbell, 1994). As described earlier, in the CLPT, children listen to lists of short sentences (from one to six sentences in length) while attempting to retain the last word of each sentence. They are presented all of the sentences in a given list and asked to respond "yes" or "no" to each sentence individually. After children have heard all the sentences in a list, they are asked to recall the last word in each of the sentences in the list. At each of the six list lengths, children hear two lists of sentences.

Table 1. Standard scores of Expressive and Receptive Language, Oral Directions, and nonverbal IQ for the SLI and the CA groups.

	SLI (n = 10)			CA (n = 10)		
Standard score	*M*	Range	*SD*	*M*	Range	*SD*
Age in months	126.00	102–148	16.59	124.70	104–146	14.28
ELS	66.00*	54–76	7.48	100.40*	88–112	9.03
RLS	68.80	54–83	12.13	—	—	—
OD	4.56*	3–8	1.46	10.70*	8–15	2.36
IQ	101.20	89–117	8.39	107.10	98–115	7.16

Note. SLI = specific language impairment; CA = chronological-age-matched control; ELS = Expressive Language score; RLS = Receptive Language score; OD = Oral Directions. Dashes indicate that data were not available. Standard scores for ELS, RLS, and IQ have a normed mean of 100 (*SD* = 15); standard scores for the OD have a normed mean of 10 (*SD* = 3). All standard scores are from the Clinical Evaluation of Language Fundamentals—Revised (normed *M* = 100, *SD* = 15) except for IQ, which is from the Columbia Mental Maturity Scale or the Leiter International Brief IQ Scale.

*$p < .05$.

The sentences on the CLPT are simple, three-word constructions, such as "Sheep eat lions," of the formats, subject–verb–object, subject–verb–modifier, and subject–auxiliary–main verb. At each length level, half of the sentences are true, and half are false.

A copy of the original audiotape used in Gaulin and Campbell (1994) was presented to the children via headphones and a Sony minidisc player. On the recording, a female voice reads the instructions, the 4 practice sentences, and the 42 experimental sentences. The duration of each sentence is approximately 2 s, followed by a 4-s pause for the children to answer "yes" or "no." At the end of each list of sentences, children hear the prompt, "What was the last word of each sentence?" Children were given only the pause time on the tape to recall the last words of each sentence in the list. Children's responses were recorded on a Sony minidisc recorder using an external Lavalier microphone.

Practice. All of the children completed the two practice sentence lists on the tape and were able to answer the "yes/no" portion of the practice sentences correctly. If a child was unable to repeat the target words of the practice sentences, he or she was first asked if he or she remembered what the lady on the tape said. If the child did not remember, the practice sentences were repeated one by one by the examiner. After each practice sentence, the child was again asked to repeat the last word of the sentence. All children were able to correctly recall at least one target word during the second practice list of sentences, and all of the children showed evidence of understanding the task.

Coding target words. The CLPT target words to be recalled were coded for serial order position in the sentence list and word frequency. Serial order position of a target word was determined to be (a) first, if it appeared in the first sentence of the sentence list; (b) middle, if it appeared in the middle sentences of the sentence list; or (c) last, if it appeared in the last sentence of the sentence list. The serial order positions of the target words are presented in Table 2.

Frequency for the target words in each of the sentences was calculated from the spoken word counts of 7-year-olds published by Moe, Hopkins, and Rush (1982). The Moe et al. database includes frequency counts for 6,412 words. Individual word frequencies in the database were calculated out of the 286,108 words produced by the children during interview and play sessions in their school. Word frequencies in the Moe et al. database range from that for words such as *and,* which has the highest count of 19,376, to that for words such as *auction,* which has a count of 1.

For the target words on the CLPT, individual word frequencies range from 0 to 287, as shown in Table 2. As can be seen in Table 2, words having high and low frequencies are not distributed equally throughout the CLPT. Specifically, as seen in Table 2, many of the target words having higher word frequencies occur in sentences in list length 6 (e.g., *run* = 287; *candy* = 140). In contrast, more of the target words having lower word frequency occur in short sentence lists such as list length 3, (e.g., *tails* = 5; *dry* = 8).

To investigate the effect of word frequency on recall of target words in the children with SLI and their CA peers, pairs of high- and low-frequency words were identified on the CLPT that were matched as closely as possible for serial position in the list and length of sentence list. Three criteria were used: (a) A word was defined as low frequency if it had a frequency of 11 or lower and was defined as high frequency if it had a frequency of 61 or higher. According to this

Table 2. Word frequency, serial order position for target last words, and sentence list length for Sentence Lists A and B for the CLPT.

List A				List B			
Word	WF	SOP	SLL	Word	WF	SOP	SLL
Leaves	70		1	Fly	50		1
Purple	14	First	2	Eat	220	First	2
Wheels	23	Last	2	Blue	127	Last	2
Dance	5	First	3	Jokes	11	First	3
Dry	8	Middle	3	Tails	5	Middle	3
Sweet	11	Last	3	White	132	Last	3
Tickle	14	First	4	Shells	4	First	4
Trucks	16	Middle	4	Cake	30	Middle	4
Fly	50	Middle	4	Small	32	Middle	4
Bridges	3	Last	4	Float	13	Last	4
Ear(s)[a]	6	First	5	Feet	77	First	5
Paper	61	Middle	5	Whistle	9	Middle	5
Worms	10	Middle	5	Wagons	1	Middle	5
Race	38	Middle	5	Thorns	3	Middle	5
Bark	3	Last	5	Talk	76	Last	5
Square	28	First	6	Swim	45	First	6
Books	45	Middle	6	Slippers	0	Middle	6
Jump	131	Middle	6	Lions	39	Middle	6
Candy	140	Middle	6	Eyes	92	Middle	6
Fly	50	Middle	6	Run	287	Middle	6
Round	42	Last	6	Yellow	95	Last	6

Note. CLPT = competing language processing task; WF = word frequency; SOP = serial order position; SLL = serial list length.

[a]Because the word *Ears* was not in the database, the frequency count for the singular form *Ear* was used instead.

criterion, the words falling within the high-frequency category accounted for 77% of all the spoken words in the samples, and the low-frequency words accounted for 16% of the spoken words in the samples. (b) Pairs of low- and high-frequency words were matched for length of sentence list (e.g., both words occurred in list length 6) and serial order positions (e.g., both words occurred in the first sentence of the list). (c) Pairs were chosen to have the largest possible difference in frequency. Because the CLPT was not originally designed to investigate the question of the effects of frequency, the criteria were designed to allow for the identification of words that are truly high and low frequency and that differed maximally in overall frequency while maintaining comparable list length and similar serial order positions but having a sufficiently large enough number of pairs to analyze.

Using these criteria, five high-frequency and five low-frequency target words having the same sentence list length and similar serial position were identified from the CLPT. These pairs are shown in Table 3. They include a pair of high- and low-frequency target words from sentences appearing in list-initial position of list length 5, two pairs of high- and low-frequency target words from sentences in the middle of the sentence lists of list lengths 5 and 6, and one pair of high- and low-frequency words from list-final position of list length 3. The percentage of high- and low-frequency word recall was calculated for each child.

Reliability. A total of 10% of the children's responses on the CLPT were recoded by an independent coder. Point-to-point agreement was high, with 100% agreement for the "yes/no" answers and 99.87% agreement for target last words recalled.

Results

"Yes/No" Answers

The mean percentage correct answers to the "yes/no" portion of the CLPT for the SLI group was 94.1% (SD = 7.05) and 99% for the CA group (SD = 1.7). For this analysis, all the sentences in the CLPT were used. A t test assuming unequal variances revealed that

Table 3. The sentence list length, serial order position, and word frequency for the high- and low-frequency target last word pairs used in the frequency analysis.

	High frequency				Low frequency			
Pair	Word	SSL	SOP	WF	Word	SSL	SOP	WF
1	Feet	5	First	77	Ears	5	First	6
2	Paper	5	Middle	61	Wagons	5	Middle	1
3	Run	6	Middle	287	Slippers	6	Middle	0
4	White	3	Last	132	Sweet	3	Last	11
5	Talk	5	Last	76	Bark	5	Last	3

the SLI and the CA groups did not differ significantly in the percentage correct "yes/no" responses, $t(10.04) = -2.06$, $p > .05$, $\eta^2 = .19$, *power* = .50. Observed power was computed on SPSS using .05 alpha levels.

Target Words Recalled

The mean percentage target words recalled for the SLI group was 36.4% ($SD = 14.14$) and for the CA group was 63.32% ($SD = 12.06$). For this analysis, all the target words to be recalled in the CLPT were used. A *t* test, with equal variances assumed, indicated that the children with SLI recalled significantly fewer target words than the CA group, $t(18) = -4.33$, $p < .05$, $\eta^2 = .54$, *power* = 1.0.

To investigate whether verbal working memory capacity is distinct from receptive long-term language knowledge, we performed an analysis of covariance (ANCOVA) using the standard scores from the OD subtest of the CELF–R as a covariate. The SLI and CA groups were no longer significantly different in the percentage of target words recalled, $F(1, 19) = 1.83$, $p = .19$, $\eta^2 = .10$, *power* = .24, suggesting that group differences in working memory capacity, defined as percentage of words recalled, are not distinct from differences in receptive language knowledge.

We performed an ANCOVA with the ELS of the CELF–R as a covariate, to investigate whether verbal working memory capacity is distinct from expressive long-term language knowledge. With the ELS as a covariate, the SLI and CA groups were no longer significantly different in the percentage of target words recalled, $F(1, 19) = 0.00$, $p = .95$, $\eta^2 = .00$, *power* = .05, indicating that group differences in verbal working memory capacity, defined as CLPT percentage of words recalled, are not distinct from differences in expressive language knowledge. Taken together, these findings suggest that working memory capacity is not distinct from long-term expressive or receptive language knowledge.

Word Frequency of Target Words

To investigate whether the SLI and CA groups differed in terms of their ability to recall the pairs of high- and low-frequency target words listed in Table 3, we performed a Group × (Frequency × Participant) analysis of variance (ANOVA). The frequency factor has only two levels, therefore, the sphericity assumption of the repeated measures ANOVA was fulfilled, and no adjustments were necessary. The descriptive analysis indicated that while the percentage of recall of low-frequency words appears different for the SLI ($M = 36.67$, $SD = 21.08$) and CA ($M = 66.67$, $SD = 20.79$) groups, the percentage of recall of high-frequency words was similar for the SLI ($M = 43.30$, $SD = 21.08$) and CA ($M = 50.00$, $SD = 17.67$) groups. The percentages of high- and low-frequency words recalled are presented in Table 4. The ANOVA yielded a significant main effect of group, $F(1, 18) = 5.92$, $p < .05$, $\eta^2 = .25$, *power* .63, indicating that overall, children with SLI recalled a smaller percentage of the words used in this analysis as compared with their CA peers. More interestingly, there was a significant Group × Frequency interaction, $F(1, 18) = 6.68$, $p < .05$, $\eta^2 = .27$, *power* = .69, indicating that the SLI group and the CA groups were differentially affected by the frequency of the words to be recalled.

Post hoc comparisons with Holm adjustment were used to control the Type I error (Seaman, Levin, & Serlin, 1991). The sequentially rejective Holm procedure was designed to control the Type I error while maintaining maximal power for each comparison. In this procedure, the contrasts are ordered from largest to smallest in terms of the absolute value of the test statistic. The largest contrast is tested with the alpha level set at alpha divided by number of comparisons. If the planned contrast is not significant, the testing is stopped. If the contrast is significant, the next largest contrast is tested at α divided by number of contrasts minus 1. The procedure is continued in this manner until a nonsignificant contrast is reached.

Table 4. The percentage of high-frequency and low-frequency words recalled for the SLI and CA groups.

	SLI		CA	
	M	*SD*	*M*	*SD*
High	43.33	21.08	50.00	17.67
Low	36.67	18.92	66.67	20.79

The results of this analysis indicated that the SLI group recalled significantly fewer low-frequency target words as compared with the CA group, $F(1, 18) = 11.39$, $p < .025$, but did not differ significantly from the CA group in the percentage of high-frequency target words recalled, $F(1, 18) = 0.59$, $p > .05$. The findings from this analysis indicate that children with SLI appear to be differentially affected by the overall word frequency of the target words, with lower frequency words being disproportionately harder for children with SLI to recall as compared with their CA peers.

To investigate the relationship between long-term receptive language knowledge and word frequency effects, an ANCOVA with the OD subtest standard score from the CELF–R battery as a covariate was performed. The Frequency × Group interaction was no longer significant, $F(1, 17) = 1.043$ $p = .32$, $\eta^2 = .06$, *power* = .17; and neither was the main effect of group, $F(1, 17) = 1.0$, $p = .76$, $\eta^2 = .10$, *power* = .06. This suggests that the difference in the ability to recall words of different frequency between the two groups appears to be related to differences in receptive language knowledge.

We performed an ANCOVA with ELS from the CELF–R battery as a covariate to investigate the potential relationship between long-term expressive language skills and the word frequency effects. The main effect of group, $F(1, 17) = .00$, $p = .98$, $\eta^2 = .00$, *power* = .05, was no longer significant. However, the Frequency × Group interaction still remained significant, $F(1, 17) = 5.76$, $p = .03$, $\eta^2 = .25$, *power* = .62. This suggests that while the overall group differences in CLPT target word recall appear to be influenced by long-term expressive language skills, the group difference in the ability to recall high- and low-frequency words does not appear to be related to expressive language skills.

Table 5. The percentage of words recalled in list-initial, list-middle, and list-final serial positions for children with SLI and CA controls.

	SLI		CA	
Position	*M*	*SD*	*M*	*SD*
First	17.65	18.92	52.75	30.42
Middle	15.50	13.63	52.00	13.95
Last	82.70	20.43	89.95	12.93

Serial Order Position of the Target Words

To investigate whether the SLI and the CA groups differentially recalled target words in different serial positions in the sentence lists, the recall performance of the target words on the CLPT for list lengths 3 through 6 was analyzed. This resulted in an analysis of 8 words in sentences in the beginning of the list, 20 words in sentences occurring in the middle, and 8 words in sentences occurring at the end of the list. The percentage of words recalled in each of the different positions (first, middle, and last) was calculated for each child. The mean percentage of first target words recalled was 17.65 ($SD = 18.92$) for the SLI group and 52.75 ($SD = 30.42$) for the CA group, the mean percentage of middle target words recalled was 15.50 ($SD = 13.63$) for the SLI group and 52.0 ($SD = 13.95$) for the CA group, and the mean percentage of last target words recalled was 82.70 ($SD = 20.43$) for the SLI group and 89.95 ($SD = 12.93$) for the CA group. The percentages of words recalled in different serial order positions are presented in Table 5. A Group × (Serial Position × Participant) repeated measures ANOVA was performed. These data violated the sphericity assumption of repeated measures ANOVA, and therefore, Huynh–Feldt adjustments were used. The main effect of group was significant, $F(1, 18) = 13.58$, $p < .05$, $\eta^2 = .43$, *power* = .94, indicating that overall, children with SLI recalled a smaller percentage of the target words; and the main effect of serial position was significant, $F(2, 32) = 97.15$, $p < .05$, $\eta^2 = .84$, *power* = 1.0, indicating that both groups recalled words better in certain positions. A significant Serial Position × Group interaction, $F(2, 32) = 7.2$ $p < .05$, $\eta^2 = .29$, *power* = .88, was also observed, indicating that the groups were recalling words in different serial positions in a differential manner.

To further investigate the interaction term, simple effects of serial position were investigated for the two groups. The simple effects of serial position were significant for both groups—the SLI group, $F(2, 18) = 114.89$, $p < .05$, $\eta^2 = .93$, *power* = 1.0, and the CA group, $F(1, 12) = 19.56$, $p < .05$, $\eta^2 = .69.$, *power* = .99—suggesting that the recall performance of both groups was influenced by the serial position of the target words in the sentence lists. Post hoc comparisons with a Holm correction for Type I error were used again to investigate how the children were influenced by the serial position. The results of this analysis suggested that the SLI group recalled a significantly higher percentage of words in the final position when compared with words in the middle position, $F(1, 9) = 160.80$, $p < .025$. The children with SLI did not, however, differ in recalling words in first versus middle serial list positions, $F(1, 9) = 0.32$, $p > .05$. A similar pattern was found for the CA group: Words in list-final positions were recalled significantly better than words in the middle position, $F(1, 9) = 118.14$, $p < .025$, but words in list-initial positions were recalled as well as words in the middle of the list, $F(1, 9) = .03$, $p > .05$.

The results of this analysis indicate that all of the children were using the same strategy, where they recalled the most recently heard target word in the list more frequently than words in other positions in the lists. The first words were not recalled any more often than the middle words in either group. Interestingly, this absence of a primacy effect (better recall of first words as compared with middle words) for either group suggests that the children were not using a rehearsal strategy in recalling the target words. The significant Group × Serial Position interaction term must have then been driven by the magnitude differences in the recency effect (better recall of last words as compared with middle words) for the two groups. This notion was supported by the larger effect size of .93 in the simple effect of serial position for the SLI group as compared with the effect size of .69 for the CA group. Further, post hoc comparison with a Holm correction for Type I error suggested that while the two groups were significantly different in recalling words in the middle, $F(1, 18) = 9.60$, $p < .025$, and initial positions, $F(1, 18) = 34.06$, $p < .017$, the two groups did not differ in the percentage words recalled in the last serial order position, $F(1, 18) = .90$, $p > .05$. Taken together, the results indicate that while both groups evidenced a recency effect and a lack of primacy effect, the recency effect appeared greater in the SLI group as compared to the CA group.

Discussion

The purpose of this study was to investigate factors potentially affecting the retention and recall of the target words on the CLPT in children with SLI. Specifically, the goal of this study was to investigate the extent to which word frequency of target words recalled, the serial position of target words in sentence list (e.g., first, middle, or last sentence), and long-term language knowledge assessed by standardized language measures affect word recall performance for children with SLI on the CLPT. In keeping with Ellis Weismer et al. (1999), the children with SLI did not differ from the CA peers in their ability to accurately answer the "yes/no" portion of the task. The two groups, again consistent with Ellis Weismer et al. (1999), did differ, however, in the target words recalled, with the SLI group recalling significantly fewer target words than their peers.

To investigate the effect of word frequency on target word recall performance, overall word frequency was calculated using the Moe et al. (1982) database for each of the target words on the CLPT, and five pairs of high- and low-frequency words were identified that occurred in the same list length and had a similar position in each list. Results of the word frequency analysis revealed that the children with SLI did not differ from their CA peers in their ability to recall high-frequency words but were significantly poorer in their ability to recall low-frequency words.

With respect to the serial order position, the two groups did not differ in the pattern of words recalled in different positions on the lists. Both groups recalled significantly more words that occurred in sentences at the end of the lists, as compared with words occurring in sentences at the beginning or middle of the lists. However, while both groups evidenced a recency effect and a lack of primacy effect, the recency effect appeared somewhat heightened in the SLI group as compared with the CA group. This finding is the opposite of that found by Gillam et al. (1998), who reported a reduced effect of recency in the SLI group as compared with their peers. There are multiple differences between the studies. The task in Gillam et al. was a simple list recall task, whereas the task in this study was a sentence span task. In addition, the lists in the Gillam et al. study were presented to each child at their span level, whereas the list lengths in this study were increasing and beyond the children's spans. Both of these differences made the task in this study more demanding regarding both storage and processing. It is possible that the more demanding task caused the heightened recency effects in this study. Perhaps when faced with such a demanding task, the children referred to a strategy where they mostly repeated target words presented in list-final positions. Note also that in this study, unlike the Gillam and colleagues' study, due to the increasing numbers of sentences in the lists on the CLPT, the number of words appearing in the middle position was greater than the number of words appearing in the initial and final positions. Because the counts for each child were calculated as a percentage of words recalled out of all the words in the specific order position, counts were comparable across the serial positions. However, the power to detect differences between the different serial order positions may have been uneven. Consequently, the primacy and recency profiles of individual children were inspected. While all of the children with SLI and 7 CA controls evidenced a recency effect and a lack of primacy effect, only 3 children in the CA group evidenced a recency effect and a defined primacy effect, suggesting that the statistical analysis was not greatly biased. Overall, the results suggest that while both groups of children may have shared the type of strategy they used to recall each of the target words appearing in the sentence lists, the children with SLI were disproportionately more affected by the overall frequency of the target words to be recalled.

The ANCOVA of CLPT target word recall and long-term language abilities, as measured by CELF–R scores, revealed that group differences in the percentage of CLPT target words recalled were not distinct from differences in the CELF–R receptive OD subtest and ELS. This finding supports the notion that long-term language knowledge and processing capacity may be inseparable entities. Interestingly, while the OD subtest scores did appear to be related to the differential effects word frequency had on target word recall in the SLI and CA groups, the ELSs did not appear to be related to the differential group effects of frequency. This suggests that whereas receptive language knowledge may play a role in the better recall of low-frequency words in the CA group as compared with the SLI group, expressive language skills may not.

Implicit in the current limited capacity accounts is the assumption that working memory capacity and linguistic knowledge are separate entities that may be impaired independently of each other. Models of adult language processing, based on parallel distributed processing (PDP) connectionist computer models, have suggested, however, that this separation between working memory capacity and linguistic knowledge is artificial (MacDonald & Christiansen, 2002; Seidenberg & MacDonald, 1999). These PDP accounts have directly challenged the claim that symbolic linguistic knowledge and working memory capacity are distinct separable entities. Instead, these accounts argue that linguistic knowledge and working memory capacity are primitives that cannot vary independently but rather both emerge from the interaction between features inherent in the language input (e.g., frequency and regularity of patterns in the language) and innate biological–architectural factors of the individual speaker (MacDonald & Christiansen, 2002).

According to these accounts, language knowledge is not represented in a symbolic rule form but as patterns of activation in a distributed network (McClelland, 1995). Information processing is seen as activation of a network of neuronlike units that are connected to each other through *hidden units*. In general, the network learns from a mismatch between an internal representation stored in its hidden unit connections and the input it receives. Over the course of the training (feeding the network input), the network gradually readjusts the connection weights and in this way begins to represent the information internally in its connections in a probabilistic manner. In this way, language knowledge is stored in the network connections and the same network functions as the information-processing mechanism. Because these distributed connectionist-based language representations are essentially frequency distributions, MacDonald and Christiansen (2002) argue that the strength of the knowledge representations is directly dependent on input frequencies. Thus, greater experience leads to stronger mappings between input and output, so that high-frequency information is processed more rapidly and accurately than low-frequency information. Moreover, due to the nature of this network architecture, MacDonald and Christiansen argue that this framework is better equipped to explain the effects of language knowledge on processing capacity when compared with the competing limited processing accounts. They suggest that language-processing differences traditionally associated with working memory are due to representational strength.

If one assumes a language architecture where processing capacity is not distinct from the language representation, then deficits in the representational strength of linguistic information may result in the appearance of limited verbal working memory span in children with SLI. While current capacity limitation accounts of children with SLI have focused predominantly on the nature of the restrictions in computational work space (for detailed discussion, see Leonard, 1998), it has been suggested that aspects of language in children with SLI are poorly represented (Bishop, 2000; Dollaghan, 1998; Evans, 2002). Bishop (2000) has argued that the nature of linguistic representations may differ in children with SLI in ways that may result in a breakdown in language processing on tasks that require manipulation of novel materials. The results of this study are consistent with this view. Interestingly, if the processing capacity of children with SLI is directly affected by their long-term linguistic knowledge, this has direct implications on language intervention. According to this framework, processing capacity of a child is not seen as a fixed entity, but as being determined by the interaction of the computational properties of the child's neural network and experience. If this account is true, the processing capacity of a child with language impairment can be directly improved by increasing language input (Evans, 2001).

This study has specific limitations that are related to the design of the CLPT and the CELF–R. First, one of the weaknesses in this study was that the CLPT was not designed to investigate the effects of frequency, and the effects of frequency are confounded in the effects of list length and the effects of serial list position. Therefore, a quite drastic word selection was performed, and it is possible that the observed effects of frequency are specific only to the words used in this study. Consequently, the effects of frequency should be further investigated in a modified sentence span task, where the effects of frequency are carefully controlled.

A second weakness of this study has to do with the nature of the CELF–R. The CELF–R OD subtest was used as a measure of receptive language knowledge, and the CELF–R ELS as a measure of expressive language knowledge, because of the conventional idea that static language measures such as standardized language tests measure context-independent language knowledge and processing measures such as CLPT measure processing capacity. One might argue, however, that many of the CELF–R subtests include a memory component and that it is not surprising that these memory-dependent language measures are related to CLPT performance. For example, the OD subtest involves processing of the lexical items, syntactical analysis of the sentence constructs, and temporary storage of the parts of increasingly longer sentences. This argument highlights the intertwined nature of processing capacity and long-term language knowledge at a practical level. Many of the current standardized language tests appear memory dependent, and the working memory measures appear language dependent, as they do use words and sentences as items to be processed. Further, the composite CELF–R RLS would have been a more ideal measure of receptive language knowledge than the OD subtest alone. Unfortunately, due to the preliminary nature of this study, the whole RLSs were not available for the typically developing children. While this study gives us reasons to suspect that something in the linguistic representation of children with SLI may account for their poor performance in verbal working memory tasks as compared with their peers, further research needs to use language tasks that pose minimized memory demands and specify exactly what component of the linguistic representation might lead into poor performance in working memory tasks. There is evidence to suggest that the lexical representations of children with SLI are perhaps degraded in that their phonological representations are holistic or less precise (Dollaghan, 1998) and their semantic representations for the lexical items are fewer and less detailed (McGregor & Appel, 2002; McGregor, Newman, Reilly, & Capone, 2002). For example, the forward-gating task, in which children hear progressively larger proportions of words, has been used to investigate the preciseness of lexical representations in children with SLI (Dollaghan, 1998; Montgomery, 1999) and poses minimal memory demands on the children. It has been shown that children with SLI do not differ from their age-matched peers in their ability to recognize highly familiar lexical items (Dollaghan, 1998; Montgomery, 1999). In contrast, Dollaghan observed that children with SLI required significantly more acoustic–phonetic information (e.g., gating duration) to recognize newly taught words as compared with their typically developing peers, suggesting less precise lexical representations in children with SLI as compared with their peers. Further studies should investigate if the gating performances of the SLI and CA groups are differentially affected by word frequency and phonological frequency measures, such as neighborhood density, further reflecting less specified phonological representations. Further research should also examine if the lexical preciseness, as measured by the gating durations, accounts for whether the particular words are recalled in a sentence span task.

Acknowledgments

This research was supported by three grants: two from the National Institute on Deafness and Other Communication Disorders (R01 DC 5650-01, Julia Evans, principal investigator, and F31 DC 6536-01, Elina Mainela-Arnold, principal investigator) and one from the Spencer Foundation (S133-DK59, Julia Evans, principal investigator). We thank Lisbeth Simon, Kristin Ryan, Jeffry Coady, Miggie Manhei Shum, and Adria Leno for their assistance at different stages of this study; Martha Alibali, Maryellen MacDonald, and Jeffry Coady for helpful discussions; and children and parents in the greater Madison metropolitan area for their time and effort in participating in the study.

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Received March 26, 2004

Revision received August 6, 2004

Accepted November 30, 2004

DOI: 10.1044/1092-4388(2005/062)

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