Published in final edited form as:
J Speech Lang Hear Res. 2010 December ; 53(6): 1656–1672. doi:10.1044/1092-4388(2010/08-0240).

Beyond capacity limitations II: Effects of lexical processes on word recall in verbal working memory tasks in children with and without specific language impairment

Elina Mainela-Arnold[1], **Julia L. Evans**[2,3,4], and **Jeffry Coady**[5]
[1]Pennsylvania State University, State College, PA
[2]Speech Language & Hearing Sciences, San Diego State University, San Diego, CA
[3]Research Scholar, Center for Language, University of California San Diego
[4]Faculty, Joint Doctoral Program in Language and Communication Disorders, SDSU/ICSD
[5]Boston University, Boston, MA

Abstract

Purpose—This study investigated the impact of lexical processes on target word recall in sentence span tasks in children with and without specific language impairment (SLI).

Method—Participants were 42 children (ages 8;2–12;3), 21 with SLI and 21 typically developing peers matched on age and nonverbal IQ. Children completed a sentence span task where target words to be recalled varied in word frequency and neighborhood density. Two measures of lexical processes were examined, the number of non-target competitor words activated during a gating task (lexical cohort competition) and word definitions.

Results—Neighborhood density had no effect on word recall for either group. However, both groups recalled significantly more high than low frequency words. Lexical cohort competition and specificity of semantic representations accounted for unique variance in the number of target word recalled in the SLI and CA groups combined.

Conclusions—Performance on verbal working memory span tasks for both SLI and CA children is influenced by word frequency, lexical cohorts, and semantic representations. Future studies need to examine the extent to which verbal working memory capacity is a cognitive construct independent of extant language knowledge representations.

Keywords

SLI; verbal working memory; lexical processing; word frequency; neighborhood density

Introduction

Sentence Span in SLI

Specific language impairment (SLI) refers to a developmental disability in which children exhibit difficulty learning language in the absence of hearing loss or other emotional and neurodevelopmental disorders, such as autism or intellectual disability (Leonard, 1998, pg.

Contact information: Elina Mainela-Arnold, Department of Communication Sciences and Disorders, Pennsylvania State University, 308 Ford Building, University Park, PA 16802-3100, ezm3@psu.edu, 1-814-863-6248.

423; Tomblin et al., 1997). These children present delayed onset and slower acquisition of lexical and grammatical forms, smaller lexicons, and particular difficulty with inflectional morphology and complex sentence structures (Leonard, 1998).

Although the underlying cause of SLI is still unknown, various theoretical accounts of the deficits seen in SLI have been proposed. A few of these accounts postulate that certain features in the child's abstract grammatical system may either be absent or impaired (e.g. Gopnik & Crago, 1991; Rice & Wexler, 1996; Rice et al., 1998). Alternatively, a substantial body of evidence now indicates a direct relationship between working memory capacity and slower speed of processing and language abilities in SLI (Leonard et al., 2007; Johnston, 1994; Montgomery, 1995; Montgomery & Evans, 2009). For example, in a recently completed large scale study, Leonard and colleagues (2007) examined (1) if processing measures "predict children's performance on measures that presumably reflect language knowledge" (pg. 412), (2) if the processing measures consist of "conceptually and methodologically distinct processes of speed and working memory" (pg. 412), and (3) if "processing limitations extend to nonverbal areas" as well (pg. 412). This study is a culmination of nearly three decades of research investigating verbal and nonverbal speed of processing (e.g. Miller et al., 2001), verbal working memory capacity (e.g. Ellis Weismer et al., 1999; Montgomery, 1995) and overall processing capacity (e.g. Johnston, 1994) in children with SLI. Working memory is generally believed to have limited capacity where there are trade-offs between the resources required to maintain information in memory and the speed with which information can be processed.

Inherent in studies investigating the cognitive processing factors outside the language system is an assumption that "speed" and "working memory capacity" are constructs that reside outside of the language system, and that children with SLI have particular limitations in the computational resources available for language processing (e.g. Ellis Weismer et al. 1999; Montgomery, 1995; Johnston; 1994). With this constraint, processing and storage of information will be degraded when computational demands exceed available resources (e.g. Just & Carpenter, 1992; Shiffrin & Schneider, 1977). If children with SLI come to the language learning situation with fewer working memory resources or slower processing speed, they may need to encounter words and structures more times than usual in order to develop a mature linguistic system (Leonard et al., 2007). The results of Leonard and colleagues' study showed that composite measures of speed and working memory capacity made unique contributions to language abilities in children with SLI, with nonverbal cognitive speed of processing and verbal working memory factors emerging as the latent variables that accounted for the largest amount of the variance in language abilities in the children.

Various theoretical accounts of working memory have been used in studying working memory limitations in SLI (For review, see Leonard et al., 2007). One these models is Just and Carpenter's (1992) model. This model postulates that verbal working memory functions as short-term storage for the intermediate and final products of the listener's verbal computations. Just and Carpenter argue that limitations in global linguistic processing capacity constrain language processing ability, and that individual differences in verbal working memory capacity explain differences in language ability. Individuals with low verbal working memory spans are less skilled in language than individuals with high verbal working memory spans.

A paradigm typically used to assess verbal working memory capacity is the sentence span task (Daneman & Carpenter, 1980). The traditional version of this task involves reading lists of sentences and recalling the last words. According to Just and Carpenter (1992), an individual's verbal working memory capacity or "span" is the number of sentences in a list for which the individual can correctly recall all the target words. Gaulin and Campbell (1994) developed an auditory version of the Daneman and Carpenter sentence span task to assess verbal working memory capacity in children. In the Competing Language Processing Task (CLPT), children listen to lists of short sentences and judge their veracity while simultaneously retaining the target last words of each sentence. Children are presented lists of one to six sentences and asked to respond yes or no to each of them individually. After the children have heard all the sentences in a given list, they are asked to recall the target last words in each of the sentences in the list. Gaulin and Cambell reported that four age groups of typically developing children (6, 8, 10 and 12 year olds) significantly differed in percent target words recalled. This indicates significant developmental changes in the ability to recall target words in the CLPT. They also report a strong correlation between CLPT percentage target words recalled and the Peabody Picture Vocabulary Test- Revised, suggesting that receptive vocabulary and verbal working memory as measured by the sentence span task are related skills.

The CLPT has been used to investigate working memory deficits in children with SLI (Ellis Weismer et al., 1999; Ellis Weismer & Thordardottir, 2002; Leonard et al., 2007; Rodekohr & Haynes, 2001). These studies have established that both children with SLI and typically developing peers exhibit near ceiling level performance in the yes/no answer portion of the task. However, children with SLI recall significantly fewer target words compared to typically developing peers. Ellis Weismer and Thordardottir (2002) compared these children's performance on the CLPT and nonword repetition, a task which is thought to measure phonological working memory. Traditionally, while the CLPT is thought to measure both short-term storage and processing of verbal information (Ellis Weismer et al., 1999), nonword repetition is thought to measure primarily short-term storage only (Gathercole & Alloway, 2006). Ellis Weismer and Thordardottir (2002) observed that while performance on nonword repetition accounted for a portion of the language performance in standardized language testing in children with SLI, CLPT percentage target words recalled accounted for a significantly greater proportion of the variance in language abilities in children with SLI. As Ellis Weismer and colleagues (2000) reported for the nonword repetition task, Rodekohr and Haynes (2001) reported that the CLPT is not biased against African American English dialect users, unlike traditional knowledge-based standardized language measures. They report that CLPT successfully separated typically developing African American English dialect users from African American English users with SLI. In the culminating work by Leonard and colleagues (2007) investigating capacity limitations as the underlying deficit in SLI, two of the verbal working memory tasks were span tasks, namely the original CLPT and a modified listening span task involving grammatical judgment.

Limitations in Total Capacity or Efficiency of Linguistic Processing?

While poor recall of target words in auditory sentence span tasks in children with SLI is a robust finding, it is still unclear why this is the case. One possibility is that these children "have" the necessary language skills to access words and parse the simple sentences, but their capacity for maintaining information in short-term memory is compromised by the need to simultaneously process sentences (Ellis Weismer et al., 1999). In other words, children with SLI would have limitations in total capacity available for linguistic and lexical processing. A second possibility is that group differences in the efficiency with which children execute linguistic processes may account for the differences. According to Just and Carpenter (1992), individual differences in sentence span tasks may be due to efficiency of linguistic processing, such as lexical access. Critical to investigations of SLI, this working memory model does not attempt to differentiate effects due to individual differences in total capacity from effects due to individual differences in the efficiency of linguistic processing

(Just & Carpenter, 1992). Individual differences in verbal working memory span may be due to either or both of these factors. By differences in total capacity Just and Carpenter refer to overall amount of activation that can be allocated for language processing. By efficiency of linguistic processing they refer to efficiency with which individuals execute linguistic operations, such as lexical access.

Recent attempts to model human language processing in parallel distributed processing (PDP) connectionist computer models pose theoretical reasons to question whether limited processing capacity accounts can sufficiently explain individual differences in language ability and language difficulties seen in SLI. These models have lead investigators to propose that the separation between working memory capacity and linguistic knowledge is an artificial one (Seidenberg & MacDonald, 1999; MacDonald & Christiansen, 2002). These neural-network architectures assume that language is processed and represented by a single underlying neural network. Architecturally, this means that working memory is not separate from linguistic knowledge. Consequently, language knowledge or representation and language processing may not be impaired separate from one another. These investigators have proposed that individual differences in both processing capacity and linguistic knowledge emerge from the interaction between features inherent in the language input and innate biological neural-architectural factors of the individual speaker (MacDonald & Christiansen, 2002). Thus, if biological factors are identical, individuals having greater experience with language will have greater working memory capacity. Importantly, if biological factors are not identical, individuals who have the same language experience but differing abilities to extract language regularities (e.g., strengthen the network of connections) will differ in both working memory and language capacities.

Leonard and colleagues (2007) acknowledged the possibility of bidirectional effects between processing capacity and language ability. However, their statistical model addressed only whether capacity limitations underlie language difficulties in children with SLI. A model with the opposite causal direction remains to be considered. The extent to which efficiency of linguistic processing impacts performance on sentence span tasks needs to be investigated. Theories differ regarding whether the cognitive constructs of working memory capacity and speed of processing are distinct cognitive constructs independent of long-term memory and knowledge (Baddeley, 2003) or whether representations activated in working memory are merely a subset of the same representations in long-term memory (Cowan, 2005). Making this distinction is critical to studies investigating the underlying impairment in SLI. If the capacity limitations seen in SLI are due to restrictions in total processing capacity available for language processing, then we would be closer to drawing a causal link between total capacity limitation and language impairments in SLI. However, if linguistic processing, such as efficiency of lexical access, accounts for poor word recall in sentence span tasks in children with SLI, then the limited capacity accounts have less to say about the causes of SLI. In the latter case, we would simply have linguistic processing correlating with linguistic processing.

Evidence from several experiments suggests that efficiency of linguistic operations and linguistic knowledge do impact working memory performance in typically developing individuals. Dixon, LeFevre, and Twilley’s (1988) structural modeling showed that performance on sentence span tasks was explained by both short-term storage capacity as measured by simple digit recall, and vocabulary knowledge in typically developing adults. Further, bilingual individuals have been shown to perform better when serial recall tasks were presented in their first language as opposed to their second language (Thorn et al., 2002). Pearlmutter and MacDonald (1995) reported a study that suggested that speed of sentence comprehension in typical adults is constrained by their knowledge of syntactic regularities rather than overall capacity allocated to the linguistic processing. They presented two groups of typical adults differing in sentence span with sentences that were either syntactically ambiguous or unambiguous. Reading times for words appearing at the ambiguous points of the sentences were measured. The two groups differed in their reading times in that the high-span individuals' reading times at the ambiguous points were *longer* than reading times for the unambiguous points. Such a difference was not found for the low-span individuals. Pealmutter and MacDonald further showed that these individual differences were attributable to differential linguistic knowledge of possible alternatives at the ambiguous points.

Further support for the notion that linguistic knowledge impacts on working memory performance comes from studies showing that *distributional lexical regularity* influences list recall performance. Distributional regularity in the form of word frequency has been shown to influence word recall in simple list recall. Typical adults recall more high than low frequency words (Roodenrys et al., 2002; Van Overschelde, 2002). Distributional regularity in the form of phonological neighborhood structure also impacts word list recall. Phonological neighborhood structure is usually conceived as of two factors: (1) neighborhood density, the number of similar sounding words in the neighborhood, and (2) neighborhood frequency, the frequencies of the neighbors in a particular neighborhood (Luce & Pisoni, 1998). Typical adults (Roodenrys et al., 2002) and children (9-yr-olds, Thomson et al., 2005) recall more words that come from dense as opposed to sparse neighborhoods, and more words that have high as opposed to low frequency neighbors.

Finally, Mainela-Arnold and Evans (2005) found preliminary evidence suggesting that children's linguistic skills at least partly contribute to the SLI vs. peer group differences in CLPT word recall performance. Performance on the CLPT was analyzed to determine if the frequency of target words influences recall differently in children with SLI and CA controls. Results of the word frequency analysis revealed that the children with SLI did not differ from their peers in their ability to recall high frequency words, but were significantly poorer in their ability to recall low frequency words. Thus, it appeared that the children with SLI were disproportionately affected by the overall frequency of the target words to be recalled when compared to their peers. Secondary analysis of the influence of receptive language abilities (as measured by Clinical Evaluation of Language Fundamentals, Oral Directions subtest) on CLPT word recall revealed that for both total words recalled, as well as word frequency, the differences between the two groups were accounted for by differences in oral language comprehension abilities. Both analyses suggest that the group differences in CLPT word recall are at least in part due to group differences in linguistic abilities. However, the CLPT was not designed to investigate the effects of frequency, and the effects of frequency were not balanced across target words in different list positions. Therefore, the findings of this study are preliminary in nature. Further investigation is needed using a task design that would directly examine the effects of word frequency on target word recall in tasks like the CLPT.

Lexical Processes

If human language architecture is such that processing capacity is not distinct from lexical and linguistic knowledge, then the manner in which words are stored in children's lexicons is relevant for processing capacity. Specifically, if long-term storage of words in the lexicons of children with SLI is degraded, inefficient lexical processing may interfere with performance on verbal working memory tasks like the CLPT and create performance that appears like limited working memory capacity.

Apart from list recall, both word recognition and production are influenced by distributional language regularity. Adults are faster at recognizing high frequency words and slower at recognizing low frequency words as evidenced by perceptual identification of words in noise (Luce & Pisoni, 1998), auditory lexical decisions, (Luce & Pisoni, 1998), repeating words (Luce & Pisoni, 1998) and in gating tasks (Grosjean, 1980; Metsala, 1997; Walley et al., 1995). Children show these effects as well. Children's word recognition in gating tasks is facilitated by high as opposed to low word frequency (Mainela-Arnold et al., 2008; Metsala, 1997; Walley et al., 1995). While word frequency facilitates word recognition, neighborhood density exerts an inhibitory effect (Garlock et al., 2001; Luce & Pisoni, 1998; Vitevitch & Luce, 1998; 1999). Adults are faster and more accurate at recognizing words that have few similar sounding neighbors and slower and less accurate at recognizing words that have many similar sounding neighbors. These inhibitory effects of neighborhood density on word recognition are emergent in children. Older children (first and second graders) exhibit neighborhood density effects similar to those found in adults (Garlock et al., 2001; Mainela-Arnold et al., 2008; Metsala, 1997), but these effects are smaller when compared to adults (Metsala, 1997). Furthermore, younger children (preschoolers) do not show effects of neighborhood density on gating durations (Garlock et al., 2001).

Word production is influenced by word frequency and neighborhood density as well. High frequency words are produced more easily than low frequency words as evidenced by faster naming of high as compared to low frequency words (Spieler & Balota, 2000), fewer natural and elicited speech errors associated with high frequency words as compared to low frequency words (Harley & MacAndrew, 1995), and fewer tip-of-the-tongue states associated with retrieving high frequency words versus low frequency words (Harley & Bown, 1998; Vitevitch & Sommers, 2003). Words with more neighbors are also named more quickly and are less likely to contain speech errors (Vitevitch, 2002), and they are less likely to elicit tip-of-the-tongue states (Vitevitch & Sommers, 2003).

Among other linguistic impairments, lexical learning in children with specific language impairment (SLI) differs from age expectations. Delayed onset of lexical acquisition may be the first clinical indication of SLI, and children with SLI can be differentiated from typically developing peers based on estimates of vocabulary size, standardized vocabulary tests, and lexical measures in spontaneous language samples (Watkins et al., 1995; Bishop, 1997). Children with SLI exhibit slower speed of naming (Lahey & Edwards, 1996; Leonard et al., 1983) and slower reaction times in word recognition experiments (Lahey & Edwards, 1996). Children with SLI make naming errors, both phonological errors (Lahey & Edwards, 1999) and semantic errors (McGregor & Appel, 2002; McGregor et al., 2002) at higher rates than their peers. Several studies have shown that in novel word learning tasks, children with SLI exhibit poorer performance when compared to peers (Dollaghan, 1987; Ellis Weismer & Hesketh, 1996; Ellis Weismer & Hesketh, 1993; Rice et al., 1994; Oetting et al., 1995).

Recent studies have pinpointed two specific deficits in lexical processes in children with SLI, utilizing tasks with minimal external working memory demands. First, Mainela-Arnold, Evans and Coady (2008) reported that lexical access of children with SLI is characterized by difficulty inhibiting non-target competitor words in the context of the forward gating task. In gating tasks, children hear acoustic chunks (i.e., gates) of words, starting from the beginning and increasing in length. Children are asked to guess the word after each gate. Mainela-Arnold and colleagues found that children with SLI did not differ from their peers in the ability to perceive initial sounds and activate the target words in their lexicons, as evidenced by comparable amounts of acoustic information needed to first activate the target words. However, group differences were evident in the ability to commit to correctly identified target words. Children with SLI were more likely to change their word guesses when they heard larger acoustic chunks of the words, and they produced significantly more non-target competitors. These results suggest that children with SLI have difficulty with inhibiting non-target competitor words during lexical access, but not with initially activating words in their lexicons. Thus, performance on the gating task provides us a window onto these children's

NIH-PA Author Manuscript

NIH-PA Author Manuscript

lexical access beyond "having" and "not having" particular words in their vocabularies, providing a more gradient measure of lexical access. Consider a hypothetical child, who is asked to recall the target words "shells, cake, small, float" during the CLPT recall. If this child has lingering activation of competitor words for each these target words to be recalled, it is conceivable that this competitor activation results in reduced word recall.

Secondly, children with SLI have also been reported to exhibit word definitions that are indicative of sparser semantic representations when compared to peers (Marinellie & Johnson, 2002; McGregor et al., 2002; Mainela-Arnold et al., under review). In all three of these studies, children with SLI produced word definitions that contained fewer content details than those produced by typically developing children. Mainela-Arnold and colleagues reported that children with SLI often produced word definitions that were indicative of some semantic knowledge of the words to be defined, but failed to produce the wealth of precise detail that their typically developing peers did. Again, consider the hypothetical child having to recall the word "shells" during the CLPT recall. It is conceivable that recalling "shells" would be easier if the child had a detailed mental image of a shell than if the child had a vague recollection of something that had to do with snails.

Leonard and colleagues (2007) acknowledged that their processing measures, although representative, may not have covered all of the relevant processing operations involved in acquiring language or in responding to items on language tests. Given that performance in sentence span tasks might be explained by the efficiency of linguistic processing, and given that children with SLI exhibit unique lexical deficits, i.e. difficulties inhibiting lexical competitors and sparse semantic representations, it is possible that poor word recall in sentence span tasks can be explained by these two types of lexical processing deficits: (1) difficulty inhibiting competitor words during lexical access, and (2) the sparseness of lexical semantic representations activated during sentence span tasks.

Current Study

Traditionally, reduced target word recall in sentence span tasks by children with and without SLI has been interpreted as evidence of reduced working memory capacity. However, before we can draw such conclusions, we need to investigate lexical factors affecting the retention and recall. Specifically, the way in which target word recall is influenced by factors such as lexical access and distributional regularity need to be investigated. If inefficient lexical access explains poor word recall in sentence span tasks, we should observe two things. First, word recall in a sentence span task should differentially affected by lexical factors known to influence lexical processing (i.e. word frequency and neighborhood density) in children with SLI when compared to chronological age matched (CA) peers. Specifically we would expect children with SLI to receive greater facilitation by high word frequency and high neighborhood density than CA peers. Second, the ability to inhibit competitor words and/or the richness of word definitions should predict how many words children with and without SLI are able to recall in a sentence span task.

Method

Participants

A total of 42 children (ages 8;2–12;3), 21 with SLI and 21 typically developing, chronological age and performance IQ matched peers (CA) participated in the studies. A group wise matching criterion of +/−6 months and +/− 6 IQ points was used. All children met the following inclusion criteria: (1) Performance Intelligence Quotient above 85 as measured by Leiter International Performance Scale (Roid & Miller, 1997; LIPS) (2) normal hearing based upon ASHA guidelines for hearing screening, (3) normal oral and speech motor abilities as observed by a certified speech language pathologist and (4) a monolingual English speaking home environment.

Children were not eligible to participate if they had any of the following conditions based upon parent report: (1) any neurodevelopmental disorders besides SLI (2) emotional or behavioral disturbances, (3) motor deficits or frank neurological signs, (4) seizure disorders or use of medication to control seizures.

All children completed a series of standardized language testing. Receptive and expressive language skills were assessed using the Clinical Evaluation of Language Fundamentals 3 (Semel et al., 1995; CELF 3). Receptive vocabulary was assessed using the Peabody Picture Vocabulary Test (Dunn & Dunn, 1997; PPTV) and expressive vocabulary using the Expressive Vocabulary Test (Williams, 1997; EVT).

The language testing criterion for inclusion in the SLI group was a score of 81 (1.25 SD below the mean) or lower in one or more of the following indexes: CELF 3 Expressive Language Score, CELF 3 Receptive Language Score, or EVT expressive vocabulary Standard Score. The language testing criteria for inclusion in the CA group was a score of 85 (1.00 SD below the mean) or higher in all of the following indexes: CELF 3 Expressive Language Score, and EVT expressive vocabulary Standard Score. Typically developing children's overall receptive language abilities were also screened using the Concepts and Directions subtest of CELF 3 receptive battery. None of the children in the typically developing group received a standard score below 1 SD in the Oral Directions subtest. Furthermore, all of the children in the SLI group had a history of speech/language services. None of the children in the CA group had received speech/language services.

As can be seen in Table 1, the SLI and CA groups differed significantly on all language measures. The groups differed significantly on CELF 3 Expressive Language Scale, $t(40) = 10.84$, $p < .05$, CELF 3 Concepts and Directions receptive subtest scores, $t(40) = 9.67$, $p < .05$, PPTV standard scores, $t(40) = 4.75$, $p < .05$, EVT standard scores, $t(35.51) = 6.40$, $p < .05$, *unequal variances assumed*. Children in the SLI and CA groups did not differ significantly on nonverbal IQ as measured by LIPS performance IQ, $t(40) = .90$, $p > .05$, or age, $t(40) = .28$, $p > .05$. The SLI group consisted of 14 White, five African-American, and two biracial children. The CA group consisted of 18 White and three African-American children.

Stimuli

A new version of the CLPT, a frequency manipulated sentence span task (FMSS), was created so that the target final words to be recalled could be carefully controlled for word frequency and phonological neighborhood density, while word frequency of the rest of the words in the sentences could be controlled.

Target words to be recalled—A set of 48 monosyllabic target words were chosen based on word frequency, neighborhood density and initial sounds. Word frequency counts were taken from Moe et al. (1982), based on speech produced by seven-year-olds, and neighborhood density counts from the Washington University in St. Louis Speech and Hearing Laboratory neighborhood density calculator available online at http://128.252.27.56/neighborhood/Home.asp. The counts for the calculator are based on the Hoosier Mental Lexicon (Nusbaum et al., 1984). Four frequency categories were created, with 12 words in each category: (1) high word frequency (WF), high neighborhood density (ND); (2) high WF, low ND, (3) low WF, high ND and (4) low WF, low ND. The words, their frequency counts and the balancing of the frequency counts were described in detail in a previous study (Mainela-Arnold et al., 2008). The words and their word frequency and neighborhood density counts are listed in Appendix A.

Sentence lists—As in the original version of the CLPT, sentence lists for the tasks contained an increasing number of sentences per list, starting from three sentence lists (level 3 list) and increasing to five sentence lists (level 5 list). There were four lists of sentences at each level (3–5), one list of sentences ending with target words from each of the four frequency categories (1) high word frequency (WF), high neighborhood density (ND); (2) high WF, low ND, (3) low WF, high ND or (4) low WF, low ND. Equal numbers of true and false sentences were created for each of the four frequency categories. None of the target words to be recalled within a list shared phonemic overlap. All sentences contained high frequency verbs (*is*, *are*, *have*, or *can*). The first words in the sentences were controlled for word frequency, but not for neighborhood density. FMSS stimulus sentences are listed in Appendix B. Consistent with Gaulin and Campbell's (1994) original auditory sentence span task study, a 4 second pause was inserted for yes/no responses after the sentences. A 10 second pause was inserted for recalling target words from three sentence lists, a 13 second pause for four sentence lists and a 16 second pause for five sentence lists. Two recordings, FMSS 1 and FMSS 2, with the four types of sentence lists mixed in two different ways were created. Each child was randomly assigned to one of the recordings, counterbalancing over the two groups so that an equal number of children in the two groups were presented with FMSS 1 and FMSS 2.

A female speaker with an upper Midwestern accent read the stimuli in a soundproof chamber. Sentences were recorded directly to a Windows based wave form program at a 44.1-kHz. sampling rate with 16-bit resolution.

Procedure

All children completed the FMSS task. As in the original Competing Language Processing Task (CLPT), children listened to lists of simple, three-word sentences and determined if each sentence was true or false. After hearing all of the sentences in a given list, children were asked to repeat the target word from each sentence in the list. The children were given the following instructions: "Now you will play a memory game. You will hear some true and false sentences. After each one, I want you to say "yes" or "no". After you have done a group of sentences, the lady on the tape will say: "Tell me the last words" and then your job will be to repeat the last words of the sentences in that group. Don't worry about getting them in the right order. As you will go on, the groups will have more sentences. It will be hard, it will go fast and you won't be able to ask any questions, because I'm not allowed to stop the tape, but I want you to keep trying to do the best you can. Remember to say "yes" or "no" after each sentence, then you will be asked to say the last words of the sentences you just heard. Let's practice." Two practice lists of two sentences each were played to each child. All children learned to respond appropriately, correctly responding "yes" or "no" after the sentences and recalling at least one of the target words correctly.

Sentences were presented to the children via headphones as a computer .wav file at a sound level reported as comfortable by the child. Children's responses were recorded using a Sony minidisc recorder using an external Lavalier microphone and simultaneously hand written on a coding-sheet.

Coding

Children's responses were transcribed orthographically from the audiotapes. Two counts were determined for each child: (1) number of correct yes/no responses and (2) number of target words recalled. When determining whether a word was recalled or not, we allowed minor articulatory errors, the criterion being whether the coder could be correctly identify the word. Further, addition or deletion of grammatical morphemes was not considered an error, e.g. “played” was considered correct for the word “play” and “heel” was considered correct for “heels”.

Reliability

Reliability of the coding was established by having a second person code 15% of the children’s answers from the audio tapes. Point-to point reliability for the variables was high: 98% for yes/no answers and 97% for words recalled.

Gating Competition Scores

Children completed a forward gating task that was used as a measure of lexical processing, specifically, a measure of non-target word activations during lexical access. On the gating task, each of the 48 test words, which were also the target words to be recalled on the FMSS task, were presented to the children in ten gates. Each of the gates included an increasingly larger chunk of acoustic information: 120, 180, 240, 300, 360, 420, 480, 540, 600, and 660 milliseconds starting from the beginning of the words. For the presentation of the words, a duration blocked format was followed, i.e. the particular gate durations for all words were presented temporally adjacent. For example, we presented all 120 ms gates for several words before moving to 180 ms gates. The stimuli were presented to the children in a sound-attenuated chamber at 75 dB HL with the speaker positioned approximately two feet in front of the child. Children’s responses were recorded using a Sony minidisc recorder and an external Lavalier microphone and simultaneously hand written on an answer-sheet. Children made an attempt at guessing the words after each chunk. This unique procedure gave us a window into the non-target words children activated during the lexical access. Consider the hypothetical example of the child hearing progressively larger portions of the word “big” by responding (1) “will”, (2)“bear”, (3)“big”, (4)“bee”, (5)“bit”, (6)“big”, (7)“big”, (8)“big”, (9)“big”, and (10)“big”. The non-target competitor activations for this example are “will”, “bear”, “bee” and ”bit”. The Gating Competition scores consisted of the mean number of non-target words children produced for each gated word. More details of the forward gating task procedure and stimuli can be found in Mainela-Arnold et al. (2008).

Semantic Scores

Children completed a word definition task that was used as a measure of the richness of lexical semantic representations. Children were asked to define each of the stimulus words, which were the same as the target words for the FMSS and gating tasks. The stimulus words were presented to the children in a carrier sentence “What does ___ing mean?”, What is _____?” or “What does_____ mean?” depending on word class. Children’s responses were recorded using a Sony minidisc recorder and an external Lavalier microphone and transcribed orthographically from the audiotapes. Five raters scored the definitions for richness of children’s understanding of the content of the words. The raters used a scale of 0 to 4, a rating system adapted from Astell and Harley (2002). Raters were blind to both group assignment and hypotheses. Details of the word definition task procedure and stimuli can be found in Mainela-Arnold et al. (under review).

Results

Number of correct yes/no answers and target word recalled

Group differences in children’s ability to correctly answer the yes/no sentences were investigated first. Children with SLI did not significantly differ from the children in CA group in the number of correct yes/no responses, $F(1, 40) = 1.21$, $p = .28$, *partial* $\eta^2 = .03$, SLI $M = 43.14$, $SD = 4.70$; CA $M = 44.67$, $SD = 4.28$.

We then confirmed that we are replicating the previous finding of fewer target words recalled in the SLI group than in CA group. This was the case, children with SLI significantly differed from the children in CA group in the number target words recalled, $F(1, 40) = 26.54$, $p < .05$, *partial* $\eta^2 = .40$, SLI $M = 21.81$, $SD = 5.36$; CA $M = 31.86$, $SD = 7.15$.

Effects of distributional regularity

The next analysis focused on the impact of word frequency and neighborhood density on target word recall in the SLI and CA groups. Table 2 presents the means and standard deviations for these data. Inspection of the means suggested a facilitative effect of high word frequency on recalling words.

A mixed-design ANOVA was conducted with FMSS target words recalled as the dependent variable. Group was the between-subjects factor, and Word Frequency and Neighborhood Density were the within-subjects factors. Two significant main effects were found. The main effect of Group was significant, $F(1, 40) = 26.54$, $p < .05$, *partial*$\eta^2 = .40$, indicating that children with SLI recalled fewer target words than their CA peers. The main effect of Word Frequency also reached significance, $F(1, 40) = 6.19$, $p < .05$, *partial* $\eta^2 = .13$, indicating that all children recalled more high frequency words. However, the interactions with the Group did not reach significance, Group × Word Frequency, $F(1, 40) = .15$, $p = .70$, *partial* $\eta^2 < .00$, Group × Neighborhood Density $F(1, 40) = .09$, $p = .77$, *partial* $\eta^2 < .00$, Group × Word Frequency × Neighborhood Density, $F(1, 40) = .35$, $p = .66$, *partial* $\eta^2 = .01$, suggesting that the two groups were not differently impacted by distributional regularity of the words to be recalled.

The main effect of Neighborhood Density did not reach significance, $F(1, 40) = 1.84$, $p = .18$, *partial* $\eta^2 = .04$, nor did the Word Frequency × Neighborhood Density interaction, $F(1, 40) = .00$, $p = .77$, *partial* $\eta^2 < .00$, suggesting that Neighborhood Density did not have a significant impact on children's word recall.

Lexical predictors of word recall

A subset of the children, 16 children with SLI and 16 CA matches, completed the two lexical measures, Gating Competition and Semantic Scores. These groups did not differ significantly on nonverbal IQ as measured by LIPS performance IQ, $t(30) = 1.83$, $p > .05$, but did significantly differ on CELF 3 Expressive Language Scale, $t(30) = 8.97$, $p <.05$, CELF 3 Concepts and Directions receptive subtest scores, $t(30) = 8.00$, $p < .05$, PPTV standard scores, $t(30) = 4.65$, $p < .05$, EVT standard scores, $t(30) = 5.43$, $p < .05$.

Two measures of lexical richness and processing were considered as possible predictors of FMSS target word recall: Gating Competition and Semantic Scores. As was reported previously (Mainela-Arnold et al., 2008; under review), children with SLI activated more competitor words on the gating task, i.e. produced more non-target words (Gating Competition), SLI $M = 4.30$, $SD = .68$, *range* = 3.21–5.88; CA $M = 3.46$, $SD = .77$, *range* = 1.92–4.54; $F(1, 30) = 10.5$, $p <.05$, *partial* $\eta^2 = .26$ and defined words with fewer semantic details (Semantic Scores) compared to CA peers, SLI $M = 2.38$, $SD = .56$, *range* = 1.07–3.19; CA $M = 3.01$, $SD = .31$, *range* = 2.42–3.59; $F(1, 30) = 15.26$, $p < .05$, *partial* $\eta^2 = .34$. Table 3 presents the correlations between the predictor variables and the FMSS word recall for the two groups combined and Figures 1 and 2 present scatter plots for these data. Both of the predictors, Gating Competition, $r = -.42$, $p < .05$, and Semantic Scores, $r = .54$, $p <.05$, correlated significantly with children's FMSS word recall.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Multiple Regression—A multiple regression analysis was completed to investigate if children's ability to recall words in the FMSS task was predicted by their ability to inhibit non-target competitor words in the gating task and/or semantic richness of their knowledge of the words to be defined. Because the distribution of the FMSS target words recalled for the two groups combined was bimodal, a log transformation was conducted. Histograms and normal P-P plots of residuals were inspected to ensure that the following analyses met the assumptions of the regression analysis. To control for the effects of age, Age was entered in Step 1. Gating Competition was entered in Step 2 and Definition Scores were entered in Step 3. An initial analysis with all three independent variables (Age, Gating Competition and Definition Scores) force entered accounted 55% of the variance in FMSS word recall. Table 3 presents partial and semi-partial correlations between the variables, and Table 4 shows the results of the multiple regression analysis.

The first step was a significant fit for the data, $F(1, 30) = 7.26$, $p <.05$. Age was a significant predictor of children's FMSS word recall, $\beta = .44$, $t = 2.70$, $p < .05$, accounting for 20 percent of the variance in FMSS word recall. The second step was also a significant fit for the data, $F(2, 29) = 9.70$, $p < .05$. The R^2 change from Step 1 to Step 2 was significant at F change = 9.96, $p < .05$, with Gating Competition accounting for an additional 20 percent of the variance in FMSS recall independent from Age. The third step was also a significant fit for the data, $F(3, 28) = 11.43$, $p <.05$. The R^2 change from Step 2 to Step 3 was significant at F change = 9.32, $p < .05$, with Definition Scores accounting for an additional 15 percent of the variance in FMSS recall independent from Age and Gating Competition.

The β- coefficients also suggested that both Gating Competition, $\beta = -.38$, $t = -2.92$, $p < .05$, and Definition Scores were significant predictors of FMSS word recall, $\beta = .40$, $t = 3.05$, $p < .05$. The fewer non-target competitors children activated in the gating task, the better their ability to recall the same words in the FMSS task was. Also, the fewer semantic details their word definitions contained, the fewer words they recalled in the FMSS task.

For the sake of completeness, a second model with Age in the first step, Definition Scores in the second step, and Gating Competition in the third step was run. For this model, the second step was also a significant fit for the data, $F(2, 29) = 10.23$, $p < .05$. The R^2 change from Step 1 to Step 2 was significant at F change = 10.83, $p < .05$, with Definition Scores accounting for 21 percent of the variance in FMSS recall independent from Age. The third step was also a significant fit for the data, $F(3, 28) = 11.43$, $p < .05$. The R^2 change from Step 2 to Step 3 was significant at F change = 8.51, $p < .05$, with Gating Scores accounting for 14 percent of the variance in FMSS recall independent from Age and Definition Scores.

Discussion

This study investigated the possibility that reduced recall of target words on sentence span tasks in children with and without SLI reflects lexical factors rather than reduced overall working memory capacity. The way in which target word recall in sentence span tasks is influenced by lexical processes was examined directly. The hypothesis was that if the efficiency of lexical access, rather than overall capacity limitations, explains poor recall in sentence span tasks, then (1) word recall ability in a sentence span task should be differentially affected by word frequency and neighborhood density in children with SLI when compared to chronological age matched (CA) peers and (2) the ability to inhibit competitor words and/or the richness of word definitions in low memory load tasks predict how many words children with and without SLI are able to recall in a sentence span task

Let us consider the effects of *word frequency* first. Both children with SLI and typically developing peers were equally affected by word frequency. Children recalled more high than low frequency words, but high word frequency did not facilitate word recall in the SLI group any more than it did in the CA group. The facilitative effect of word frequency is consistent with the idea of inseparable processing capacity and linguistic representations in children in general. This supports the idea that at least part of the variance in children's sentence span can be explained by efficiency of lexical processing. This also supports the idea of inseparable effects of processing capacity and linguistic representations suggested by MacDonald and Christiansen (2002). However, the lack of disproportionate effects of word frequency for the two groups was inconsistent with our hypothesis and preliminary study (Mainela-Arnold & Evans, 2005). The prediction was that children with SLI should show evidence of a larger effect due to word frequency if group differences in lexical knowledge and organization account for group differences in word recall in FMSS. One possible interpretation for this null finding is that children's performance on sentence span tasks is influenced by lexical knowledge, but the group differences between children with SLI and typically developing peers are not explained by lexical knowledge, but rather a third variable such as a limitation in total processing capacity. Another possible explanation has to do with the fact that the word frequency differences between the high and low frequency words were less extreme in this study than in the preliminary study. The current study attempted to control for the effects of neighborhood density separate from word frequency. Since word frequency and neighborhood density are correlated, this manipulation resulted in the high frequency words that were much lower in frequency than high frequency words in the preliminary study.

Let us now consider the effects of *neighborhood density*. There were no significant effects of neighborhood density on word recall in sentence span tasks for the children overall. An explanation similar to what was discussed for word frequency may explain this. The manipulation for word frequency reduces the difference between high and low density neighborhoods, making it more difficult to detect these effects. Another possible explanation has to do with the sentence span task. The literature reports effects of neighborhood density on simple list recall in typical adults (Roodenrys et al., 2002) and children (Thomson et al., 2005), but we are not aware of studies reporting effects of neighborhood density on a sentence span task that involve processing of sentences in addition to list recall. It is possible these effects may be hampered by the sentence processing component of the task. Future studies should address this issue.

Two lexical predictors were considered, measures from tasks that have recently been shown to pose difficulties for children with SLI. These predictors were Gating Competition, i.e. the number of non-target competitors produced in a gating task (Mainela-Arnold et al., 2008), and Semantic Scores, i.e. richness of children's semantic representations as measured by word definitions (Mainela-Arnold et al., under review). The lexical predictors Gating Competition and Semantic Scores were significant predictors of children's word recall on a sentence span task, together accounting 35% of variance in word recall, with Gating Competition accounting for 14% and Semantic Scores accounting for 15% of unique variance in word recall in children with and without SLI. This suggests that the ability to inhibit competing lexical representations and the richness of semantic knowledge are associated with word recall in sentence span tasks. At least part of the variance in children's sentence spans can be explained by these lexical processing measures. This further supports the idea of inseparable effects of processing capacity and linguistic representations suggested by MacDonald and Christiansen (2002).

The regression analysis had limitations related to the sample size. First, the overall sample size of 32 was small for multiple regression analyses. Furthermore, the two groups, SLI and CA, were combined to increase power for these analyses. It may be argued the association between the lexical measures and sentence span recall was an artifact of the two groups of children differing for all three variables, rather than the variables being associated. In Table 3, we have presented correlations, and in Figures 1 and 2, FMSS by Gating Competition and FMSS by Semantic Score scatter plots for the two groups separately. As can be seen from the correlations and scatter plots, the associations that were significant for the two groups combined, the associations between FMSS and Gating Competition (SLI $r = -.20$, CA $r = .01$) and the associations between FMSS and Definition Scores (SLI $r = .34$, CA $r = .17$), did not reach significance for the SLI and CA groups separately. Therefore, as is the case for any correlation analyses, it is possible that the associations were mediated by a third variable-the relationship between semantic abilities and FMSS, and lexical competition and FMSS may be mediated by third variable along which the two groups differ. A future study should investigate these associations in a larger group of children with SLI and typically developing children separately.

A possible interpretation for the results in this study as a whole is that attention plays a role in both the lexical tasks and word recall in sentence span tasks (Leonard et al., 2007), i.e. that some of the shared variance between the lexical measures and the sentence span task may be due to by individual differences in attentional control and inhibition. In the context of connectionist models and advances in neuroscience, what has been traditionally viewed as working memory capacity may consist of global competition of activation in large scale neural networks with a top-down attentional bias from prefrontal cortex circuits (for review see Maia & Cleeremans, 2005). Therefore, the shared variance between target word recall in the sentence span task and the lexical measures may be accounted for by at least two potential explanations that are not mutually exclusive. Sentence span task may involve both bottom-up competition from words and sentences activated during the task, and a biasing activation modulated by top- down attention.

This study highlights the complex interactive relationship between lexical variables such as lexical activation, lexical maintenance, and semantic representation and the construct of working memory capacity. The results from this study clearly show that lexical variables such as word frequency, lexical cohort competition and the richness of the semantic network linked to a given word form influence the ability to hold a given lexical item in memory during sentence span tasks. This suggests that future studies designed to assess working memory capacity need to start from the assumption that working memory as a construct does not tap into isolated brain functions, but is instead a dynamic interaction within and between distributed neural networks. Recent fMRI studies show that the neuroanatomical architecture of working memory taps into different networks of various brain regions supporting different functional subcomponents functioning as a distributed network (Gruber et al., 2007; Gruber & von Cramon, 2003).

The sentence span task used in the this study as well as the Leonard and colleague’s study (2007) clearly rely on a set of cognitive processing components that require at least: (1) recognition of input stimuli as a “word”, (2) the activation of meaning representations stored with the lexical form, (3) the ability to maintain the lexical form in memory for a sufficient length of time to repeat it and, (4) the ability to “filter” or ignore competing information. Clearly, there is a relationship between poor performance on working memory tasks such as the one used in this study and in prior studies and language abilities. However, the results of this study highlight the open question as to whether poor performance on language assessment measures is due to deficits in the those cortical structures that support performance on working memory tasks (e.g., poor performance on working memory capacity tasks), or if poor language abilities *and* poor performance on working memory capacity tasks are both due to impaired cortical networks that support performance on both tasks.

In sum, the results of this study suggest that there is an influence of lexical representations on the performance of working memory tasks. The findings contribute to the now substantial body of work clearly showing that there is a relationship between poor performance on working memory capacity measures and language abilities in children with SLI. However, the results from this study, taken together with our understanding of the cortical networks that support lexical processing and working memory capacity suggest that our processing accounts of SLI need to become more formalized. Future studies need to begin to carefully deconstruct the components of cognitive processing and link them to recent advances in our understanding of the cortical dynamics of language processing.

Acknowledgments

We thank Lisbeth Heilmann for her assistance in collecting the data and Matthew Keeler for assistance in coding the data. We also thank Maryellen MacDonald, Martha Alibali, Susan Ellis Weismer, and Lynn Turkstra for their helpful comments at early stages of this research. We thank Bruce Tomblin and Laurence Leonard for discussions on the topic of the premises of working memory theories of SLI, and Carol Miller for comments on the manuscript. Finally, we are most grateful to the parents and children who participated in the study. Parts of this research were reported in the first author's doctoral dissertation at the University of Wisconsin-Madison. This research was supported by two grants from the National Institute on Deafness and Other Communication Disorders (F31 DC 6536, Elina Mainela-Arnold, Principal Investigator, and R01 DC 5650-01, Julia Evans, Principal Investigator).

Reference List

Astell AJ, Harley TA. Accessing semantic knowledge in dementia: evidence from a word definition task. Brain and Language 2002;82:312–326. [PubMed: 12160527]

Baddeley AD. Working memory and language: An overview. Journal of Communication Disorders 2003;36:189–208. [PubMed: 12742667]

Bishop, DVM. Uncommon Understanding: Development and Disorder in Language Comprehension in Children. UK: Psychology Press Publishers; 1997.

Cowan, N. Working memory capacity. New York, NY: Taylor & Francis Group; 2005.

Daneman M, Carpenter P. Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behavior 1980;19:466.

Dixon P, LeFevre J, Twilley LC. Word knowledge and working memory as predictors of reading skill. Journal of Educational Psychology 1988;80:472.

Dollaghan CA. Fast mapping in normal and language-impaired children. Journal of Speech and Hearing Disorders 1987;52:218–222. [PubMed: 3455444]

Dunn, L.; Dunn, L. Peabody Picture Vocabulary Test. 3 ed.. Circle Pines, MN: American Guidance Service; 1997.

Ellis Weismer S, Evans J, Hesketh LJ. An examination of verbal working memory capacity in children with specific language impairment. Journal of Speech Language and Hearing Research 1999;42:1249–1260.

Ellis Weismer S, Hesketh LJ. The influence of prosodic and gestural cues on novel word acquisition by children with specific language impairment. Journal of Speech and Hearing Research 1993;36:1013–1025. [PubMed: 8246467]

Ellis Weismer S, Hesketh LJ. Lexical learning by children with specific language impairment: Effects of linguistic input presented at varying speaking rates. Journal of Speech and Hearing Research 1996;39:177–190. [PubMed: 8820709]

Ellis Weismer, S.; Thordardottir, ET. Cognition and Language. In: Accardo, P.; Capute, A.; Rogers, B., editors. Disorders of Language Development. Timonium, MD: New York Press, Inc; 2002. p. 21-37.

Ellis Weismer S, Tomblin JB, Zhang XY, Buckwalter P, Chynoweth JG, Jones M. Nonword repetition performance in school-age children with and without language impairment. Journal of Speech Language and Hearing Research 2000;43:865–878.

Garlock VM, Walley AC, Metsala JL. Age-of-acquisition, word frequency, and neighborhood density effects on spoken word recognition by children and adults. Journal of Memory and Language 2001;45:468–492.

Gathercole SE, Alloway TP. Short-term and working memory impairments in neurodevelopmental disorders: Diagnosis and remedial support. Journal of Child Psychology and Psychiatry 2006;47:4–15. [PubMed: 16405635]

Gaulin C, Campbell T. Procedure for assessing verbal working memory in normal school-age children. Perceptual and Motor Skills 1994;79:55–64. [PubMed: 7991333]

Gopnik M, Crago MB. Familial Aggregation of A Developmental Language Disorder. Cognition 1991;39:1–50. [PubMed: 1934976]

Grosjean F. Spoken word recognition processes and the gating paradigm. Perception and Psychophysics 1980;28:267–282. [PubMed: 7465310]

Gruber O, Muller T, Falkai P. Dynamic interactions between neural systems underlying different components of verbal working memory. Journal of Neural Transmission 2007;114:1047–1050. [PubMed: 17318301]

Gruber O, von Cramon DY. The functional neuroanatomy of human working memory revisited. Evidence from 3-T fMRI studies using classical domain-specific interference tasks. Neuroimage 2003;19:797–809. [PubMed: 12880808]

Harley TA, Bown HE. What causes a tip-of-the-tongue state? Evidence for lexical neighborhood effects in speech production. British Journal of Psychology. 1998 -151.

Harley, TA.; MacAndrew, SB. Interactive models of lexicalization: Some constrains from speech error, picture naming, and neuropsychological data. In: Levy, J.; Bairaktraris, D.; Bullinaria, J.; Cairns, D., editors. Connectionist Models of Memory and Language. London, England: UCL press; 1995. p. 311-331.

Johnston, JR. Cognitive abilities of children with language impairment. In: Watkins, R.; Rice, M., editors. Specific Language Impairment in Children. Toronto, Canada: Decker; 1994. p. 685-715.

Just M, Carpenter P. A capacity theory of comprehension: Individual differences in working memory. Psychological Review 1992;99:122–149. [PubMed: 1546114]

Lahey M, Edwards J. Why do children with specific language impairment name pictures more slowly than their peers? Journal of Speech and Hearing Research 1996;39:1081–1098. [PubMed: 8898260]

Lahey M, Edwards J. Naming errors of children with specific language impairment. Journal of Speech Language and Hearing Research 1999;42:195–205.

Leonard, LB. Children with Specific Language Impairment. Cambridge, MA: The MIT Press; 1998.

Leonard LB, Ellis WS, Miller CA, Francis DJ, Tomblin JB, Kail RV. Speed of processing, working memory, and language impairment in children. Journal of Speech, Language, and Hearing Research 2007;50:408–428.

Leonard LB, Nippold MA, Kail R, Hale CA. Picture naming in language-impaired children. Journal of Speech and Hearing Research 1983;26:609–615. [PubMed: 6668948]

Luce PA, Pisoni DB. Recognizing spoken words: The neighborhood activation model. Ear and Hearing 1998;19:1–36. [PubMed: 9504270]

MacDonald MC, Christiansen MH. Reassessing working memory: comment on Just and Carpenter (1992) and Waters and Caplan (1996). Pyschological Review 2002;109:35–54.

Maia TV, Cleeremans A. Consciousness: converging insights from connectionist modeling and neuroscience. Trends Cognitive Science 2005;9:397–404.

Mainela-Arnold E, Evans JE, Coady JA. Explaining lexical semantic deficits in specific language impairment: The role of phonological similarity, phonological working memory, and lexical competition. Journal of Speech, Language, and Hearing Research. (in press).

Mainela-Arnold E, Evans JL. Beyond capacity limitations: Determinants of word recall performance on verbal working memory span tasks in children with SLI. Journal of Speech Language and Hearing Research 2005;48:897–909.

Mainela-Arnold E, Evans JL, Coady JA. Lexical representations in children with SLI: evidence from a frequency-manipulated gating task. Journal of Speech, Language and Hearing Research 2008;51:381–393.

Marinellie SA, Johnson CJ. Definitional skill in school-age children with specific language impairment. Journal of Communication Disorders 2002;35:241–259. [PubMed: 12064786]

McGregor KK, Newman RM, Reilly RM, Capone NC. Semantic representation and naming in children with specific language impairment. Journal of Speech, Language, and Hearing Research 2002;45:998–1014.

McGregor KK, Appel A. On the relation between mental representation and naming in a child with specific language impairment. Clinical Linguistics and Phonetics 2002;16:1–20. [PubMed: 11913029]

Metsala JL. An examination of word frequency and neighborhood density in the development of spoken-word recognition. Memory & Cognition 1997;25:47–56.

Miller CA, Kail R, Leonard LB, Tomblin JB. Speed of processing in children with specific language impairment. Journal of Speech Language and Hearing Research 2001;44:416–433.

Montgomery JW. Examination of phonological working memory in specifically language-impaired children. Applied Psycholinguistics 1995;16:355–378.

Montgomery JW, Evans JL. Complex sentence comprehension and working memory in children with specific language impairment. Journal of Speech, Language, and Hearing Research 2009;52:269–288.

Nusbaum, HC.; Pisoni, DB.; Davis, CK. Sizing up the Hoosier mental lexicon: Measuring the familiarity of 20,000 words. Bloomington, IN: Speech Research Laboratory, Department of Psychology, Indiana University; 1984.

Oetting JB, Rice ML, Swank LK. Quick incidental-learning (QUIL) of words by school-age-children with and without SLI. Journal of Speech and Hearing Research 1995;38:434–445. [PubMed: 7596109]

Pearlmutter NJ, MacDonald MC. Individual differences and probabilistic constrains in syntactic ambiguity resolution. Journal of Memory and Language 1995;34:521–542.

Rice ML, Oetting JB, Marquis J, Bode J, Pae SY. Frequency of input effects on word comprehension of children with specific language impairment. Journal of Speech and Hearing Research 1994;37:106–122. [PubMed: 8170118]

Rice ML, Wexler K. Toward tense as a clinical marker of specific language impairment in English-speaking children. Journal of Speech and Hearing Research 1996;39:1239–1257. [PubMed: 8959609]

Rice ML, Wexler K, Hershberger S. Tense over time: The longitudinal course of tense acquisition in children with specific language impairment. Journal of Speech Language and Hearing Research 1998;41:1412–1431.

Rodekohr RK, Haynes WO. Differentiating dialect from disorder: A comparison of two processing tasks and a standardized language test. Journal of Communication Disorders 2001;34:255–272. [PubMed: 11409607]

Roid, M.; Miller, L. Leiter International Performance Scale, Revised. Dale Wood, IL: Stoelting; 1997.

Roodenrys S, Hulme C, Lethbridge A, Hinton M, Nimmo LM. Word-frequency and phonological neighborhood effects on verbal short-term memory. Journal of Experimental Psychology. 2002 -1019.

Seidenberg M, MacDonald M. A probabilistic constrains approach to language acquisition and processing. Cognitive Science 1999;23:569–588.

Semel, E.; Wiig, E.; Secord, W. Clinical Evaluation of Language Fundamentals-3 (CELF-3). San Antonio, TX: Psychological Corporation; 1995.

Shiffrin R, Schneider W. Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. Psychological Review 1977;84:127–190.

Spieler DH, Balota DA. Factors influencing word naming in younger and older adults. Psychology and Aging 2000;15:225–231. [PubMed: 10879577]

Thomson JM, Richardson U, Goswami U. Phonological similarity neighborhoods and children's short-term memory: Typcial development and dyslexia. Memory & Cognition 2005;33:1210–1219.

Thorn ASC, Gathercole SE, Frankish CR. Language familiarity effects in short-term memory: The role of input delay and long-term knowledge. The Quarterly Journal of Experimental Psychology 2002;55:1363–1383. [PubMed: 12420999]

Tomblin JB, Records NL, Buckwalter P, Zhang XY, Smith E, O'Brien M. Prevalence of specific language impairment in kindergarten children. Journal of Speech Language and Hearing Research 1997;40:1245–1260.

Van Overschelde JP. The influence of word frequency on recency effects in directed free recall. Journal of Experimental Psychology: Learning, Memory, and Cognition 2002;28:611–615.

Vitevitch MS, Luce PA. When words compete: Levels of processing in perception of spoken words. Psychological Science 1998;9:325–329.

Vitevitch MS, Luce PA. Probabilistic phonotactics and neighborhood activation in spoken word recognition. Journal of Memory and Language 1999;40:374–408.

Vitevitch MS, Sommers MS. The facilitative influence of phonological similarity and neighborhood frequency in speech production in younger and older adults. Memory & Cognition 2003;31:491–504.

Walley AC, Michela VL, Wood DR. The Gating Paradigm-Effects of Presentation Format on Spoken Word Recognition by Children and Adults. Perception & Psychophysics 1995;57:343–351. [PubMed: 7770325]

Watkins RV, Kelly DJ, Harbers HM, Hollis W. Measuring children's lexical diversity: Differentiating typical and impaired language learners. Journal of Speech and Hearing Research 1995;38:1349–1355. [PubMed: 8747826]

Williams, KT. Expressive Vocabulary Test. Circle Pines, MN: American Guidance Services, Inc; 1997.

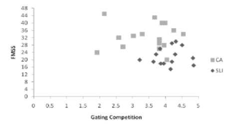

Figure 1.
FMSS by Gating Competition scatter plot for the SLI and CA groups

NIH-PA Author Manuscript

NIH-PA Author Manuscript

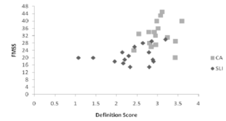

Figure 2.
FMSS by Definition Scores scatter plot for the SLI and CA groups

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 1

Age ranges in months, and standardized test scores for the SLI and CA groups

Group	Age in months	LIPS[a]	ELS[b]	CD[c]	RLS[d]	PPTV[e]	EVT[f]
SLI							
Mean	120.00	99.05	71.50*	5.38*	66.28	91.66*	81.67*
SD	12.30	8.47	11.62	2.15	13.65	10.70	7.40
Range	101–141	89–119	50–84	3–10	50–86	69–112	64–93
CA							
Mean	119.76	101.57	108.90*	12.48*	Na	106.76*	98.57*
SD	13.11	8.80	12.26	2.58	Na	9.87	9.97
Range	98–147	87–119	86–131	8–17	Na	93–119	86–124

*p < .05, two tailed t-test, equal variances assumed

[a] Leiter International Performance IQ: Standard Score (mean of 100, standard deviation of 15)

[b] Clinical Evaluation of Language Fundamentals: Expressive Language Score (mean of 100, standard deviation of 15)

[c] Clinical Evaluation of Language Fundamentals: Concepts and Directions receptive standard Subtest Score (mean of 10, standard deviation of 3)

[d] Clinical Evaluation of Language Fundamentals: Receptive Language Score (mean of 100, standard deviation of 15)

[e] Peabody Picture Vocabulary Test: Standard Score (mean of 100, standard deviation of 15)

[f] Expressive Vocabulary Test: Standard Score (mean of 100, standard deviation of 15)

Table 2

The means and standard deviations (SD) for the number target words recalled for the four frequency categories, (1) high word frequency (WF), high neighborhood density (ND), (2) high WF, low ND, (3) low WF, high ND, (4) low WF, low ND, for the SLI and CA groups.

	High WF High ND	**High WF Low ND**	**Low WF High ND**	**Low WF Low ND**
SLI				
Mean	5.62	5.86	4.95	5.38
SD	1.80	2.06	1.47	1.80
Range	2–9	2–10	3–8	3–10
CA				
Mean	8.19	8.52	7.53	7.62
SD	2.16	2.33	2.1	2.20
Range	3–12	4–13	4–12	4–12

Table 3

Correlations between children's FMSS word recall, the control variable Age, and the two predictor variables Semantic Scores and Gating Competition

Pearson's correlations				
	FMSS	**Age**	**Semantic Score**	**Gating Competition**
FMSS	1.00			
Age	.44*	1.00		
Semantic Score	.54*	.18	1.00	
Gating Competition	−.42*	.078	−.18	1.00

Partial correlations at regression analysis Model 1 Step 3.		**Semi-partial (part) correlations at regression analysis Model 1 Step 3.**	
	FMSS		*FMSS*
Age	.50	*Age*	.39
Semantic Score	.50	*Semantic Score*	.39
Gating Competition	−.48	*Gating Competition*	−.37

Pearson's correlations SLI group		*Pearson's correlations CA group*	
	FMSS		*FMSS*
Semantic Score	.34	*Semantic Score*	.17
Gating Competition	−.20	*Gating Competition*	.01

* $p < .05$

Table 4

Multiple regressions.

	β-*coefficient*	R^2	F	R^2 change	F change
Model 1					
Step 1, Age	.44*	.20	7.25*		
Step 2, Gating Competition	-.46*	.41	9.70*	.21	9.96*
Step 3, Semantic Score	.40*	.55	11.43*	.15	9.32*
Model 2					
Step 1, Age	.44 *	.20	7.25*		
Step 2, Semantic Score	.48*	.41	10.23*	.22	10.83*
Step 3, Gating Competition	-.38*	.55	11.43*	.14	8.51*

* $p < .05$

NIH-PA Author Manuscript
NIH-PA Author Manuscript

APPENDIX A

Log word frequency (WF) and neighborhood density (ND; number of neighbors) for four categories of target words, (1) High WF, high ND, (2) High WF, ND, (3) Low WF, high ND, (4) Low WF, low ND.

(1) High WF, high ND			**(2) High WF, low ND**		
Word	**WF**	**ND**	**Word**	**WF**	**ND**
Big	6.54	20	Black	5.00	1
Bike	4.62	19	Blue	4.84	12
Call	4.41	25	Cold	4.45	11
Cut	4.14	25	Count	3.91	7
Fight	4.20	24	Fish	4.91	13
Hard	5.20	18	High	4.29	9
Hot	5.15	28	House	4.76	5
Leaf	4.25	19	Lunch	3.99	7
Name	3.71	16	Move	4.50	8
Pick	4.92	34	Play	6.66	3
Sit	4.65	36	Soft	4.34	5
Work	4.56	20	Watch	5.69	5
Mean	4.70	*23.70*	*Mean*	4.82	*7.17*
(3) Low WF, high ND			*(4) Low WF, low ND*		
Word	*WF*	*ND*	*Word*	*WF*	*ND*
Bath	0	17	Beard	0	6
Boil	0	15	Blame	0	7
Cash	0	26	Cough	0	11
Comb	0	24	Cure	0	1
Fur	1.39	20	Fetch	0	8
Heel	0.69	29	Hire	0	5
Hum	1.39	25	Huge	1.79	2
Lock	0.69	32	Lamp	1.39	11
Nest	0	15	Nurse	0	10

(1) High WF, high ND			(2) High WF, low ND		
Word	**WF**	**ND**	**Word**	**WF**	**ND**
Poke	0.69	27	Plant	1.10	8
Sore	1.61	32	Search	0	11
Wit	0	31	Wound	0	10
Mean	0.54	*24.40*	*Mean*	0.36	*7.50*

When defining neighbors for the words, words with an addition, a deletion or a substitution of one sound were included in the neighborhood. When using the neighborhood calculator, a familiarity criterion of 6 was applied to exclude words with low familiarity ratings from the neighborhoods. Since word frequency and neighborhood density are correlated (e.g., many high frequency words are also high in neighborhood density), the words were chosen so that the effects of word frequency and neighborhood density can be separated. This was done by making word choices that maintained the following significant and non-significant differences:

(1) Word frequency for the high WF, high ND words (mean WF = 4.70) and the high WF, low ND (mean WF = 4.82) did not significantly differ, $t(df=23) = .40$, $p > .05$.

(2) Word frequency for the low WF, high ND words (mean WF = .54) and low WF, low ND words (mean WF = .36) did not significantly differ, $t(df=23) = .80$, $p > .05$.

(3) Neighborhood density for the high WF, high ND words (mean ND = 23.7) and low WF, high ND words (mean ND = 24.4) did not significantly differ, $t(df=23) = .3$, $p > .05$.

(4) Neighborhood density for the high WF, low ND words (mean ND = 7.2) and the low WF, low ND words (mean ND = 7.5) did not significantly differ, $t(df=23) = .23$, $p > .05$.

APPENDIX B

Sentences in the Frequency Manipulated Sentence Span (FMSS) contained target words that were (1) high word frequency (WF), high neighborhood density (ND), (2) high WF, low ND, (3) low WF, high ND, (4) low WF, low ND.

FMSS practice			
Doors can think	No	Wolves can eat	Yes
Birds have eyes	Yes	Ghosts are real	No
FMSS sentences			
	Level 3		
High WF, high ND		*High WF, low ND*	
Boys can bike	Yes	Ducks can move	Yes
Rooms can cut	No	Bears are blue	No
Streets have names	Yes	Cats are soft	Yes
Low WF, high ND		*Low WF, low ND*	
Jars have wit	No	Vets can cure	Yes
Hawks have nests	Yes	Gardens have plants	Yes
Boots can hum	No	Caves have lamps	No
	Level 4		
High WF, high ND		*High WF, low ND*	
Brothers can fight	Yes	Pools are high	No
Schools can sit	No	Kids can watch	Yes
Rocks are hard	Yes	Books can play	No
Beds can pick	No	Moms can count	Yes
Low WF, high ND		*Low WF, low ND*	
Bruises are sore	Yes	Brides have beards	No
Parents have baths	Yes	Clinics have nurses	Yes
Bathrooms have locks	Yes	Bosses can hire	Yes
Cows can comb	No	Humans can cough	Yes
	Level 5		
High WF, high ND		*High WF, low ND*	
Pigs have leaves	No	Girls have lunch	Yes
Friends can call	Yes	Fire is cold	No
People can work	Yes	Babies can fish	No
Bugs are big	No	Ice is black	No
Snow is hot	No	Dads have houses	Yes
Low WF, high ND		*Low WF, low ND*	
Spikes can poke	Yes	Sleds have wounds	No
Logs have fur	No	Moose can blame	No
Tea can boil	Yes	Fleas are huge	No
Pans have cash	No	Cops can search	Yes
Sharks have heels	No	Rugs can fetch	No