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Complex Sentence Comprehension and Working Memory in Children With Specific Language Impairment

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Abstract

Purpose—This study investigated the association of 2 mechanisms of working memory (phonological short-term memory [PSTM], attentional resource capacity/allocation) with the sentence comprehension of school-age children with specific language impairment (SLI) and 2 groups of control children.

Method—Twenty-four children with SLI, 18 age-matched (CA) children, and 16 language- and memory-matched (LMM) children completed a nonword repetition task (PSTM), the competing language processing task (CLPT; resource capacity/allocation), and a sentence comprehension task comprising complex and simple sentences.

Results—(1) The SLI group performed worse than the CA group on each memory task; (2) all 3 groups showed comparable simple sentence comprehension, but for complex sentences, the SLI and LMM groups performed worse than the CA group; (3) for the SLI group, (a) CLPT correlated with complex sentence comprehension, and (b) nonword repetition correlated with simple sentence comprehension; (4) for CA children, neither memory variable correlated with either sentence type; and (5) for LMM children, only CLPT correlated with complex sentences.

Conclusions—Comprehension of both complex and simple grammar by school-age children with SLI is a mentally demanding activity, requiring significant working memory resources.

Keywords

children; specific language impairment (SLI); working memory; sentence comprehension

A hallmark comprehension deficit of children with specific language impairment (SLI) is their understanding of complex grammar (Bishop, Bright, James, Bishop, & van der Lely, 2000; Norbury, Bishop, & Briscoe, 2002; van der Lely, 1996, 1998, 2005; van der Lely & Harris, 1990; van der Lely & Stollwerck, 1997). Many of these same children also exhibit various concomitant processing limitations, chief among them inferior working memory (Archibald & Gathercole, 2006; Ellis Weismer, Evans, & Hesketh, 1999; Gathercole & Baddeley, 1990; Marton & Schwartz, 2003; Montgomery, 1995, 2000a). *Working memory*

refers to the ability to engage in simultaneous information processing and storage. It is unclear, however, to what extent these children's complex sentence comprehension problems relate to their working memory limitations. The present work investigated the association of two core components/mechanisms of working memory (phonological short-term memory [PSTM] storage and attentional resource capacity/allocation) on the comprehension of complex sentences by children with SLI.

Working Memory in SLI

Developmental memory researchers (e.g., Bayliss, Jarrold, Baddeley, & Gunn, 2005; Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2005; Conlin, Gathercole, & Adams, 2005; Gathercole, 1999; Gathercole, Pickering, Ambridge, & Wearing, 2004; Towse, Hitch, & Hutton, 2002) conceptualize working memory as a multidimensional system comprising several separable yet interactive components/mechanisms. Two of these are the PSTM storage buffer and an attentional resource capacity/allocation function. Attentional resource capacity/allocation is considered part of the central executive component of working memory by some investigators (e.g., Baddeley, 1996, 1998). A robust body of evidence supports the existence of each of these (e.g., Barrouillet & Camos, 2001; Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2005; Conlin et al., 2005; Gathercole et al., 2004; Gavens & Barrouillet, 2004).

PSTM

PSTM is a capacity-limited storage buffer responsible for momentarily storing speech input while some kind of cognitive task (e.g., comprehension) takes place (Baddeley, 1998, 2003). Speech enters PSTM automatically but will fade quickly if it is not immediately processed in some fashion. For example, temporarily holding speech in PSTM presumably enables a listener to invoke the language system to immediately process that material (Baddeley, 1998). Baddeley (1998) has further suggested that PSTM serves as a mnemonic window in which sequences of incoming words are held.

Developmental research suggests that PSTM capacity develops with age and asymptotes by about age 8 years or so (e.g., Gathercole, 1999). PSTM capacity of school-age children is measured using a variety of tasks, including digit span, word span, and nonword repetition (NWR; e.g., Archibald & Gathercole, 2006; Gathercole, 1999). The NWR task in which children are asked to repeat nonwords varying in length has been used in many studies. It has been argued that NWR is a robust and sensitive index of PSTM capacity because successful repetition requires children to use a variety of phonological and memory-related processes (perception, encoding, storage, retrieval, production), presumably independent of lexical knowledge (e.g., Gathercole, 2006; Gathercole, Willis, Emslie, & Baddeley, 1992). This is especially the case when the stimuli do not closely resemble real words in a constituent syllable structure/stress pattern (Dollaghan, Biber, & Campbell, 1993; Gathercole et al., 1992). Typically developing children usually show highly accurate repetition of one-, two-, and three-syllable items, with decreasing accuracy for four-syllable items. Such a performance pattern has been interpreted to reflect the limited capacity nature of PSTM (e.g., Baddeley, 2003; Gathercole, 1999, 2006).

Children with SLI, compared with age-matched (CA) peers, exhibit marked limitations in PSTM capacity (e.g., Archibald & Gathercole, 2006; Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000; Gathercole & Baddeley, 1990; Montgomery, 1995). Most SLI studies have used the NWR task. The now consistent pattern across these studies is that these children have significant trouble repeating longer nonwords than shorter nonwords, even when “wordlikeness” has been controlled (e.g., Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000; Montgomery, 1995). Some researchers caution that the poor repetition of children with SLI may be due to basic phonological processing problems (Snowling, Chiat, & Hulme, 1991) or more general processing capacity limitations (Edwards & Lahey, 1998). Others interpret such findings as evidence of reduced PSTM capacity (Gathercole, 2006; Gathercole & Baddeley, 1990). It is important to note here that the issue of whether NWR is facilitated by language knowledge or whether it represents an independent predictor of language performance in children remains unclear (e.g., Edwards, Beckman, & Munson, 2004; Munson, Kurtz, & Windsor, 2005).

Attentional Resource Capacity/Allocation

Developmental research also suggests that children’s attentional resource capacity and/or ability to effectively allocate these resources improves through adolescence (e.g., Barrouillet & Camos, 2001; Gathercole, 1999; Gathercole et al., 2004; Gaulin & Campbell, 1994; Gavens & Barrouillet, 2004; Johnson, 1997). *Resource capacity* refers to the amount of cognitive/mental capacity (i.e., mental energy) available to an individual to perform a cognitive task. *Resource allocation* refers to a person’s ability to divide his/her attentional resources between two or more different concurrent mental activities.

Resource capacity/allocation abilities are assessed using complex memory tasks in which the listener is asked to engage in concurrent information processing and storage, such as a listening span task (Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2005; Gaulin & Campbell, 1994) or an operational (math procedures) span task (Kane, Bleckley, Conway, & Engle, 2001). Gaulin and Campbell (1994), in their competing language processing task (CLPT), presented 6- to 12-year-old children with sets of short (three-word) simple sentences (e.g., *Pumpkins are purple*, *Fish can swim*) and asked them to comprehend each sentence (i.e., answer yes/no question) followed by recalling as many sentence-final words as possible from each set. Such a task invites children to devote their attentional resources between language processing (i.e., comprehend each sentence) and verbal storage (i.e., retain increasingly longer sets of sentence-final words). Gaulin and Campbell reported that whereas the children demonstrated high sentence comprehension across the age span (i.e., 93%), word recall steadily improved with age. Whether improved complex memory performance is due to increases in capacity or allocation skills remains open, but some have argued that an increase in capacity is a primary driving force (e.g., Barrouillet & Camos, 2001; Gavens & Barrouillet, 2004).

The SLI literature suggests that children with SLI have the ability to allocate their attentional resources simultaneously to verbal processing and storage during complex memory tasks but, relative to control children, have fewer resources to commit (Archibald & Gathercole, 2006; Ellis Weismer et al., 1999; Im-Bolter, Johnson, & Pascual-Leone, 2006;

Mainela-Arnold & Evans, 2005; Marton & Schwartz, 2003; Montgomery, 2000a, 2000b). Ellis Weismer et al. (1999) assessed the attentional resource capacity/allocation of a group of school-age children with SLI and a CA group of control children using the CLPT. Whereas both groups showed similar sentence comprehension (>96% correct), the children with SLI yielded significantly poorer word recall (40% accuracy) than the typically developing children (60% accuracy). Similar findings have been reported by Archibald and Gathercole (2006) and Mainela-Arnold and Evans (2005). Overall, such results suggest that, relative to typically developing children, children with SLI have an overall smaller supply of attentional resources that limit their ability to store as much verbal material while maintaining accurate comprehension.

Complex Sentence Comprehension in SLI

The complex sentence comprehension abilities of children with SLI have, curiously, received relatively little research attention. Much of the extant research has been carried out by van der Lely and colleagues (Marinis & van der Lely, 2007; Marshall & van der Lely, 2006; van der Lely, 1996, 1998, 2005; van der Lely & Harris, 1990; van der Lely, Rosen, & Adlard, 2004; van der Lely & Stollwerck, 1997). The work of van der Lely and colleagues has been motivated to answer the question of whether children with SLI suffer from a deficit in their syntactic system.

To account for the difficulties children with SLI have comprehending complex sentences, van der Lely and colleagues have proposed the deficit in computational grammatical complexity (CGC) hypothesis (e.g., Marshall & van der Lely, 2006; van der Lely, 2005), a descendent of the earlier representational deficit for dependent relationships (RDDR) hypothesis (e.g., van der Lely, 1998). At the heart of the CGC (RDDR) hypothesis is the claim that the core deficit of children with SLI is in the representation and/or mechanisms responsible for building hierarchical grammatical structures. Specifically, their syntactic deficit is characterized as a difficulty in computing nonlocal syntactic dependencies between different sentence constituents. Difficulty establishing syntactic relationships, in turn, gives rise to inconsistent comprehension of a range of structures. These same children, however, have little trouble understanding subject–verb–object sentences (e.g., *The cat scratched the dog*) because such sentences can be processed using a simple left to right (canonical word order) strategy, that is, assign the first encountered noun phrase (NP) the agent role and so on. Finally, the CGC (RDDR) hypothesis assumes that general processing capacity deficits (e.g., working memory, processing speed) play no significant role in the comprehension difficulties of children with SLI.

In the present study, we focus on two types of complex sentences that van der Lely and colleagues have used to test the CGC (RDDR) hypothesis: (a) verbal *be* reversible passives and (b) pronominal sentences involving pronouns and reflexives. Both types of sentences involve creating nonlocal syntactic dependencies, with reversible passives involving movement and pronominal sentences involving anaphoric binding (Chomsky, 1995).

Passive sentences (e.g., *The boy was kissed by the girl*) violate the canonical word order of English (e.g., *The boy kissed the girl*). In the verbal *be* passive, children cannot rely on

typical word order to help them interpret who does what to whom (e.g., NP1 is the agent, and NP2 is the patient). Rather, the child must come to realize that the argument representing the patient is the grammatical subject, and the argument representing the agent is expressed in the prepositional phrase (PP) appearing later in the sentence. Using current linguistic theory (e.g., Manzini & Roussou, 2000), it is assumed that for the sentence above, NP1 (*the boy*) originally is the complement of the verb *kissed* but gets moved to the specifier position of the tense phrase through a process referred to as *argument movement*. The relationship between *the boy* and its original position in the sentence (marked as *t* for trace) is specified through a process of co-indexing (_i). The second NP (*the girl*) appears in an adjunct prepositional *by*-phrase (*by the girl*) with the agent role getting transmitted from the passive morpheme (*-ed*) to the NP in the *by*-phrase (Guasti, 2002). Because the passive morpheme receives the thematic role of the external argument, the thematic role cannot be assigned to another NP; therefore, it gets expressed in an adjunct PP headed by the preposition *by*. This transmission operation is expressed by co-indexing the passive morpheme and the *by*-phrase (Guasti, 2002). Verb tense appears in tense and occurs through movement of the auxiliary *was* from the verb position. Finally, the passive participle *kissed* maintains its verb position.

Although children with SLI demonstrate difficulty comprehending verbal *be* passives, they evidence no problem comprehending other passive forms (e.g., Bishop et al., 2000; Norbury et al., 2002; van der Lely, 1996, 1998; van der Lely & Dewart, 1986; van der Lely & Harris, 1990; van der Lely & Stollwerck, 1997). For instance, they have little trouble with nonreversible passives, such as *The milk was spilled by the boy* (van der Lely, 1996; van der Lely & Dewart, 1986), because the thematic role of agent is assigned to an animate NP. That is, pragmatic (real-world) cues facilitate comprehension. Similarly, when hearing truncated passives, such as *The fish was eaten*, children with SLI and control children demonstrate equally good comprehension. Even though short passives can be regarded as being a complex structure with a noncanonical word order (Bishop et al., 2000; van der Lely, 1996), they pose no special problem for children with SLI. The reason appears to be that the children adopt an adjectival interpretation such that in the sentence above, *eaten* is interpreted as a stative verb (i.e., an adjective) rather than a passive participle. Thus, *The fish was eaten* is interpreted to mean the fish is in a state of having been eaten. Short passives pose little difficulty for children with SLI because they represent (relative to verbal *be* passives) a syntactically simpler structure requiring fewer move operations and the assignment of just one thematic role (see Borer & Wexler, 1987, for a more complete discussion of adjectival passive interpretation by young typically developing children).

A second aspect of syntax examined by van der Lely and colleagues (van der Lely, 1998; van der Lely & Stollwerck, 1997) has been binding principles (Chomsky, 1995), which determine pronominal reference. According to binding theory, there are two principles that guide the interpretation of sentences containing reflexives or pronouns. Principle A states that a reflexive (e.g., *Daffy Duck says Bugs Bunny is tickling himself*) must be bound in its governing category, in which “bound” means co-indexed/locally bound to an antecedent, that is, the anaphor must refer to the noun within the same clause. This allows the listener to build a short-distance syntactic dependency between the anaphor and its antecedent. In the

sentence above, a listener interprets the reflexive *himself* as referring to the local (closest) antecedent, *Bugs Bunny*. Principle B states that a pronoun (e.g., *Daffy Duck says Bugs Bunny is tickling him*) must be free in its governing category such that the pronoun may only refer to a nonlocal antecedent, that is, the anaphor cannot refer to a noun in the same clause. A listener in this case must build a long-distance syntactic relationship. In the example given, a listener would interpret the anaphor *him* to refer to the distant antecedent, *Daffy Duck*.

Results from a number of studies reveal that, relative to CA children, children with SLI are significantly less consistent comprehending passive and pronominal sentences (Bishop et al., 2000; Norbury et al., 2002; van der Lely, 1996, 1998; van der Lely & Stollwerck, 1997). Even relative to language-CA controls, children with SLI show poorer performance for passive sentences (van der Lely, 1998). However, it is important to note that in van der Lely and Harris's (1990) study, the SLI and language control groups were matched only on single word receptive vocabulary knowledge and not on working memory skills, as is the case in the present study. Viewed within the CGC (RDDR) framework, the problems children with SLI have comprehending these structures rest at the doorstep of a faulty syntactic computational system. Specifically, the children have trouble building nonlocal syntactic dependencies. In the case of passives, their difficulty relates to their failure to consistently invoke the movement operation as described earlier because they treat movement as optional rather than obligatory (van der Lely, 1998). Their inconsistent comprehension of pronominal sentences centers on their difficulty with anaphoric binding because they are presumably free to choose to bind the anaphor to either a local or a nonlocal antecedent.

Building nonlocal syntactic dependencies has also been the focus of much research attention in the adult language processing literature. Noncanonical word order sentences containing object relative clauses (*The girl [_i] that the boy kissed [_{t_i]} was smiling*) especially have been found to be harder to process than canonical word order sentences. The reason appears to relate to the complexity of assigning thematic roles to the NP arguments that have moved. For the above example, NP1 (*The girl*) must be understood to be the object of the verb *kissed* even though it occupies the typical agent position. According to generative linguistic theory (Chomsky, 1995), and as described earlier, the movement of an NP leaves a phonologically empty NP (placeholder) at the position of the gap referred to as a trace (indicated by [_{t_i]} in the example). It is further assumed that the trace is linked to the antecedent (indexed by _i) such that *The girl* receives the thematic role of object via its link to the trace. During processing of such sentences, the gap site (trace) is the cue that triggers the antecedent (NP) to be reactivated from working memory, thus allowing the proper thematic role assignments to be made and the syntactic dependency to be built.

There also appears to be a memory-based account for explaining why such sentences are more difficult to process than canonical sentences. The difficulty apparently owes to the fact that two NPs must be stored in working memory before either of them can be syntactically and semantically integrated with the following verb phrase (VP; e.g., Gibson, 1998; Gordon, Hendrick, & Johnson, 2004; Gordon, Hendrick, Johnson, & Yoonhyoung, 2006). In fact, Lewis (1996) has argued that listeners are only able to keep track of two (maybe three) syntactic dependencies at the same time during processing. Evidence for the contribution of

working memory to complex sentence processing comes from, for example, the fact that high working memory span listeners are more reliable to comprehend such sentences than low working memory span listeners (e.g., Chen, Gibson, & Wolf, 2005; Gibson, 1998; Just & Carpenter, 1992; King & Just, 1991).

Relation of Working Memory to SLI Sentence Comprehension

Relatively few studies have examined the intersection of working memory and sentence comprehension in children with SLI (e.g., Ellis Weismer & Thordardottir, 2002; Montgomery, 1995, 2000a, 2000b, 2004), with fewer still having explored the influence of working memory on their comprehension of complex grammar (e.g., Joannisse & Seidenberg, 1998; Norbury et al., 2002). Some of the first studies to experimentally examine the association between working memory and sentence comprehension were conducted by Montgomery (1995, 2000a, 2000b). The association between PSTM and sentence comprehension was examined in Montgomery (1995), and attentional resource capacity/allocation and comprehension were examined in Montgomery (2000a, 2000b). In both studies, children with SLI and typically developing control children listened to simple sentences (e.g., *The dirty little boy climbed the big tall tree*), semantically reversible complex sentences with a single embedded relative clause (e.g., *The girl who is laughing is touching the boy*), and sentences with a double embedded relative clause (e.g., *The little boy who is standing is hugging the little girl who is sitting*). Both the simple and complex sentences appeared in short and long versions of each other, as the aim of the studies was to assess sentence length on children's comprehension. Findings from each of the studies showed that the children with SLI had significantly greater trouble comprehending the long sentences than the short sentences, relative to the typically developing children and relative to themselves. In Montgomery (1995), a correlation analysis (combining groups for long sentences only) showed a significant association between PSTM and sentence comprehension. Results from Montgomery (2000a, 2000b) show no correlation between resource capacity/allocation and sentence comprehension. However, given the aim of these studies, analyses to assess the influence of memory on complex sentence comprehension separate from simple sentence comprehension were not carried out.

A study by Norbury et al. (2002) is one of the few that has explicitly examined the influence of memory (i.e., PSTM capacity) on the complex grammar comprehension of children with SLI. A group of children with SLI and a control group of children (as well as a group of children with hearing impairment) were tested. Although the main aim of their study was to determine whether the overall syntactic comprehension profile of the children with SLI was consistent with van der Lely's (1998) RDDR hypothesis, the authors also assessed the association between PSTM (indexed by NWR) and complex sentence comprehension. The complex sentences were the same ones used in the studies of van der Lely and colleagues (van der Lely, 1996, 1998; van der Lely & Stollwerck, 1997). Predictably, relative to the typically developing children, the children with SLI performed significantly worse at comprehending the complex sentences and on the NWR task. The correlation between NWR and performance on at least the passives for the SLI group was also significant, albeit weak ($r = .34$). Additionally, the authors found that only a small percentage of the children in the SLI group showed a comprehension profile of syntactic deficits (markers) consistent with a

“pure” grammatical deficit. Norbury et al. took these results to indicate that children with SLI do not suffer from a modular deficit in the syntactic computational system. Bishop et al. (2000), conducting a similar study, reported comparable results and put forth a similar conclusion.

Aim and Predictions of the Present Study

Research exploring the relationship between the complex sentence comprehension deficits and working memory limitations of children with SLI is sparse. The aim of the present work was to expand the work of Norbury et al. (2002). Accordingly, we examined the association of two components/mechanisms of working memory (PSTM capacity and attentional resource capacity/allocation) with complex sentence comprehension in a group of children with SLI and two groups of typically developing children, one matched on age and the other on receptive language and working memory.

We reasoned that accurate complex sentence comprehension should entail the children completing the following processes in a timely manner: allocate sufficient attentional resources to (a) the PSTM buffer to keep each new incoming sequence of words in an active state long enough for it to be processed (e.g., Norbury et al., 2002), (b) the language system to retrieve appropriate linguistic properties of all the input words and appropriate syntactic computational processing schemes to build the appropriate syntactic dependency, and (c) reactivation (retrieval) processes responsible for reactivating those representations from prior processing (McElree, Foraker, & Dyer, 2003) that are being temporarily stored in working memory (e.g., Daneman & Carpenter, 1980, 1983; Just & Carpenter, 1992; King & Just, 1991).

If the poor comprehension of the children with SLI is related to their working memory limitations, then they should show poorer comprehension compared with their CA peers but comparable comprehension with their language- and memory-matched (LMM) peers. More important, we might expect significant correlations to emerge for the children with SLI (e.g., Norbury et al., 2002) between complex sentence comprehension and at least attentional resource capacity/allocation because the complex sentences should exceed their resource capacities. For the CA children, we would expect to find no significant correlations because all the sentences should be well within the bounds of their linguistic competence (e.g., Booth, MacWhinney, & Harasaki, 2000; Dick, Wulfeck, Krupa-Kwiatkowski, & Bates, 2004; Maratsos, 1974) and attentional resource capacities. For the younger LMM children, we would hypothesize that they should show an overall similar correlation pattern to the children with SLI given their similar linguistic-conceptual knowledge and memory capacities.

Method

Participants

Twenty-four children with SLI between the ages of 6 and 12 years ($Age_M = 9;1$ [years;months]), 18 typically developing children matched on age ($Age_M = 9;1$), and 16 younger typically developing children ($Age_M = 6;3$) matched on receptive language

participated. The SLI group was matched on a group-wise basis with the children in the CA group. The groups were comparable in age, $F(1, 40) = -0.069, p = .95, \eta^2 = .001$. Similarly, the children with SLI were group-wise matched with the younger children on the basis of the raw score on the Linguistic Concepts subtest of the Clinical Evaluation of Language Fundamentals, Third Edition (CELF-3; Semel, Wiig, & Secord, 2003), $F(1, 38) = 1.73, p = .49, \eta^2 = .02$. This subtest assesses children's knowledge of various concepts (e.g., temporal, spatial) embedded in short commands. On a measure of children's single word receptive vocabulary knowledge—the Peabody Picture Vocabulary Test—III (Dunn & Dunn, 1997)—the SLI group attained a significantly higher raw score than the group of younger children, $F(1, 38) = 5.96, p = .02, \eta^2 = .17$. The SLI and younger groups were also closely matched (group-wise) on the two memory variables. The groups yielded comparable percentage correct on the NWR task, $F(1, 38) = 0.238, p = .62, \eta^2 = .014$, and the CLPT (i.e., mean dual span that reflected the number of sentences for which the child comprehended the sentence and recalled the last words correctly), $F(1, 38) = 1.72, p = .19, \eta^2 = .04$. The younger group hereafter is referred to as the LMM group.

The SLI group attained an overall Receptive Language standard score and an overall Expressive Language standard score of -1.25 standard deviations or more below the mean on the CELF-3. The CA and LMM groups attained a standard score that was within the normal range (i.e., a score at or above a standard score of 85) on each of the language measures administered. In addition to the CELF-3 and the Peabody Picture Vocabulary Test—III being administered, the Expressive Vocabulary Test (Williams, 1997) was also administered as a measure of children's single word expressive vocabulary.

All of the children (a) demonstrated at least normal-range nonverbal IQ (≥ 85) on the Leiter International Performance Scale (Roid & Miller, 1997); (b) demonstrated normal-range hearing sensitivity as determined by audiometric pure-tone screening at 20 dB HL at 500, 1000, 2000, and 4000 Hz (American Speech-Language-Hearing Association, 1990) at time of testing; and (c) came from monolingual English-speaking homes. Children were excluded if they (a) had a history of frank neurological impairment, psychological/emotional disturbance, or attention deficit disorder, or (b) used medications to control seizures (on the basis of parent report). The SLI group differed in IQ relative to both the CA group, $F(1, 40) = 3.08, p = .001, \eta^2 = .11$, and the LMM group, $F(1, 38) = 42.6, p = .001, \eta^2 = .35$. Within the SLI group, 11 children were African American, and 1 was of Asian descent. In the CA and LMM groups combined, 5 children were African American, and 2 were of Hispanic descent. Table 1 displays descriptive summary data for each group.

PSTM Task

This study used Dollaghan and Campbell's (1998) NWR task as the index of PSTM capacity. Norbury et al. (2002) observed that limitations in PSTM, as measured by the Children's Test of Nonword Repetition (CNRep; Gathercole & Baddeley, 1996), were related to syntactic deficits in SLI. Meta-analysis of CNRep and the NWR (Dollaghan & Campbell, 1998) indicates, however, which words in the CNRep and NWR differ significantly in the magnitude of the estimate they provide for the NWR deficit of children with SLI (Graf Estes, Evans, & Else-Quest, 2007). One important difference between the

CNRep and the NWR is the wordlikeness of the items. Gathercole and Baddeley (1990) have argued that low-wordlike nonwords tap “pure” phonological storage more directly, with less influence from lexical knowledge than high-wordlike items. The CNRep, however, contains items that have both high and low wordlikeness on the basis of measures of phonotactic probability (Vitevitch, Luce, Charles-Luce, & Kemmer, 1997). The CNRep also includes several low-wordlike nonwords that contain real English syllable or word content, as in *perplisteronk*. In contrast, the items on the NWR were designed to minimize wordlikeness by excluding real words and using consonants in nontypical positions for English. Thus, the NWR provides a cleaner measure of PSTM capacity that is less confounded by an individual’s extant lexical knowledge.

Task design and stimuli—The task consists of a set of 16 nonsense words that increases from one to four syllables in length. The phonemes that make up the consonants are early developing sounds that are acoustically salient and have low wordlikeness. Furthermore, none of the syllables that constitute the words correspond to English lexical items. The nonwords contain only tense vowels and therefore contain no weak syllables. The original NWR stimuli from Dollaghan and Campbell (1998) were digitized and stored in MP3 format.

Task procedures—The NWR task was presented under headphones to children at a comfortable listening level as determined by the child. Children’s responses were recorded via digital recorder and stored on a G4 Mac (Apple, Cupertino, CA) for later transcription and analysis. Prior to the presentation of the task, children heard the taped instructions, “Now I will say some made-up words. Say them after me exactly the way that I say them.” Only one presentation of each word was provided on the tape, and no words were replayed for the child.

Scoring and interrater agreement—The same scoring procedures used by Dollaghan and Campbell (1998) were employed in this study. Phonemes within the nonwords were scored as correct/incorrect relative to each target phoneme (substitutions or omissions were counted as errors). Distortions of phonemes were not scored as errors. Phoneme additions were noted and tallied, but they were not counted as errors because they are not indicative of loss of information about the target phonemes per se. In instances in which the syllable structure of the nonword was not maintained (adding or omitting syllables), an anchoring procedure was first used to align syllable sequences as closely as possible to the target syllable prior to individual phoneme scoring. All audio-taped responses were independently transcribed by trained judges until 100% agreement was reached for each consonant, vowel, and phoneme for all the nonwords.

Attentional Resource Capacity/Allocation Task

The CLPT (Gaulin & Campbell, 1994) was used as the index of attentional resource capacity/allocation. The CLPT is an adaptation of a listening span task developed by Daneman and Carpenter (1980) to assess adults’ complex verbal memory span. Three reasons motivated our use of the CLPT. First, similar to the view of Kane and colleagues (Kane et al., 2001; Kane, Conway, & Engle, 1999), we regard this task to reflect children’s

domain-general use of controlled and flexible attentional abilities (i.e., allocation of attentional resources to the language processing system and PSTM buffer). Second, because the task includes sentences that are well within the linguistic grasp of all the children, any difference between the SLI and the CA groups can be interpreted to be attributable to group differences in resource capacity/allocation, not linguistic knowledge. Third, performance on similar listening span tasks has been shown to correlate with complex sentence comprehension in adults (e.g., Daneman & Carpenter, 1983; Just & Carpenter, 1992; Roberts & Gibson, 2002). Finally, some researchers (e.g., Christiansen & MacDonald, 1999) might argue that such a measure is not appropriate to use in language processing studies because a correlation between performance on such a task and sentence comprehension is inevitable, rendering the interpretation of such a relation theoretically vacuous. This concern is greatly diminished, however, given that both verbally based tasks (listening span) and math-based tasks (operational span) significantly correlate with a variety of cognitive performances (e.g., Conway & Engle, 1996; Daneman & Merikle, 1996; Kane et al., 2001).

Task design and stimuli—The sentences on the CLPT consist of 42 simple three-word sentences, such as *Sheep eat lions*, and are comprised of subject–verb–object, subject–verb–modifier, and subject–auxiliary–main verb constructions. Sentence length, grammatical complexity, and vocabulary level are constant across the 42 sentences. Children listen to each sentence while simultaneously attempting to retain the last word of each sentence. After each sentence, they are asked to respond to the truth value of the sentence by responding “yes” or “no.” The CLPT contains four practice items in addition to the 42 test sentences. The sentences are arranged in two groups at six different levels. For Level 1, children are required to comprehend only one sentence and to recall the last word of that sentence. Each group increases by one sentence at each level from one to six. Thus, Level 6 contains six sentences that the children must comprehend individually while simultaneously retaining the last word of each previously presented sentence. In the same manner as the listening span task by Daneman and Carpenter (1983), the yes/no portion of the CLPT was designed to prevent children from focusing solely on the word-recall portion of the task. A copy of the original recording used by Gaulin and Campbell (1994) was obtained and digitized for this study.

Task procedures—The CLPT was presented to the children under high-quality headphones at a comfortable listening level (as determined by each child) via a Sony minidisc player. On the recording, a female voice read the instructions, the four practice sentences, and the 42 experimental sentences. The duration of each sentence was approximately 2 s, followed by a 4-s pause for the children to answer “yes” or “no.” At the end of each group of sentences, children heard a prompt “What was the last word of each sentence?” Children were given only the 4-s 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. Prior to the presentation of the task, the children heard the following taped instructions:

I’m going read you some true and false sentences. After each one I want you to say “yes” or “no.” After we have done a group of sentences I will ask you to tell me the last word of each sentence in that group. Don’t worry about getting them in the

right order. As we go on, the groups will have more sentences. It will get hard and you won't be able to ask any questions, but I want you to keep trying to do the best you can. Remember to say "yes" or "no" after each sentence. Then, when I ask you, please say the last word of each sentence you just heard. Do you understand? Let's try some.

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/she was first asked whether he/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 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.

Scoring and interrater agreement—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.

Sentence Comprehension Task

Task design and sentence stimuli—The comprehension task was modeled after the sentences used by van der Lely and colleagues (Bishop et al., 2000; van der Lely, 1996, 1998; van der Lely & Stollwerck, 1997). The task included 48 experimental sentences, 36 complex sentences, and 12 simple sentences. The complex sentences included 12 semantically reversible verbal *be* passives (e.g., *The woman is kissed by the baby*), 12 pronominals (e.g., *Bugs Bunny says Daffy Duck is hugging **him***), and 12 reflexives (e.g., *Daffy Duck says Bugs Bunny is hugging **himself***). The complex sentences were regarded as complex because they required children to compute a nonlocal dependency (e.g., Marinis & van der Lely, 2007; van der Lely, 1998). The 12 simple active sentences (e.g., *The clown is hugging the tiny white elephant*), despite their containing elaborated NPs and/or VPs (i.e., inclusion of adjectives or adverbs), were considered simple because they conformed to canonical word order and could be processed using a simple left to right processing strategy (i.e., entailed no computation of a nonlocal dependency).

All of the complex sentences and nearly all of the simple sentences contained two-argument predicates; sentence types did not differ in number of predicates taking two arguments, $t(47) = -1.21, p = .56$. The mean length was 7.5 words for the complex sentences and 8.1 words for the simple sentences, a difference that was significant, $t(47) = 3.26, p = .002$. In addition, all the sentences contained names of highly familiar cartoon characters as well as nouns, verbs, adverbs, and adjectives familiar to children between 6 and 12 years of age (Moe, Hopkins, & Rush, 1982). Example experimental sentences are displayed in the Appendix.

The complex sentences were identical or very similar to those used by van der Lely and colleagues (Bishop et al., 2000; van der Lely, 1996, 1998; van der Lely & Stollwerck, 1997). A few of the original sentences by van der Lely and colleagues were modified for

vocabulary to ensure that all the sentences contained words familiar to U.S. children. It should be noted that with respect to the passive sentences, only “full progressive” (verbal *be*) passives (*The boy is kissed by the girl*) were used. We did not include all the passive constructions used by van der Lely and colleagues. Because one of the aims of the earlier studies by van der Lely (1996) was to examine the nature of comprehension errors of children with SLI, her studies included other passives—such as short ambiguous passives (e.g., *The fish is eaten*)—along with full progressives. Because the aim of the present study was on exploring the nature of the relationship between working memory and complex sentence comprehension, only the verbal *be* passive was included.

Picture stimuli—For each sentence, three high-quality color illustrations were prepared by a professional illustrator, one matching the sentence and two foils. For the passives, one foil involved a picture that depicted the correct agent, patient, and action but showed the patient performing the action on the agent (theta role reversal; van der Lely, 1996). The second foil differed from the sentence in terms of “tense” in that whereas each test sentence (and its target picture) reflected a present tense action, the foil depicted the proper agent and patient roles but a past tense action. That is, the action performed by the agent was clearly depicted as already having taken place. The pronominal and reflexive sentences included one foil picture that depicted the correct agent performing the right action but on the wrong patient (van der Lely, 1996). The other foil involved the wrong character carrying out the correct action (van der Lely, 1996). For the simple sentences, each foil differed from the sentence in terms of one key semantic feature (e.g., size or color of agent or patient). Across the 48 experimental sentences, the location of the target picture appeared equally often at the top, middle, or bottom of the array.

Stimulus generation procedures—Procedures for recording, generating, and editing the sentence comprehension task were as follows. A male speaker with a neutral midwest dialect sat in an isolated acoustic booth and read the stimuli using a high-quality microphone connected to a Dell PC. Sentences were read at a normal rate (~4.4 syllables per second; Ellis Weismer & Hesketh, 1993) and with normal prosodic variation. Sentences were digitized at 22.5 kHz, low-pass filtered (10 kHz), and normalized for intensity using CoolEdit Pro-2 software. Each wave file was then edited to eliminate any noise at the beginning or end of the file.

Task procedures—Prior to the experiment proper, children completed a brief pretest to assess their familiarity with the various cartoon characters used in the sentences and pictures. The examiner showed the child a stimulus booklet containing pages that included two or three cartoon characters. The examiner asked the child “show me X (character name).” All the children achieved 100% recognition accuracy. In the experiment proper, the child was asked to listen carefully to a man saying some sentences. The child was told that after each sentence, three pictures would appear on the computer touch screen. The pictures appeared just after the stimulus sentence (100 ms) because we wished to prevent possible immediate interference between verbal and visual input processing. Thus, by design, children needed first to construct and retain a representation of the input sentence before scanning and interpreting each of the pictures and selecting the correct picture. Each

sentence was presented just once. Sentences and their corresponding pictures were output from the computer in a predetermined random order (controlled by E-Prime; Schneider, Eschman, & Zuccolott, 2002). The child heard two demonstrations and completed three practice trials. The child's response was automatically recorded by and stored on the computer by a custom-written E-Prime program. The dependent variable was percentage of sentences comprehended correctly.

General Testing Procedures

Each child was tested individually in a quiet lab. All testing (including initial participant qualification testing) was completed as part of a larger experimental protocol and occurred over three sessions, with each session lasting approximately 2 hr. Children were given frequent breaks during testing. All auditory stimuli were delivered binaurally over high-quality headphones at a comfortable listening level as determined by each child. Because this study was part of a larger research program, the memory and sentence comprehension tasks were each administered on different days, with children's participation in the comprehension and memory tasks each being separated by a minimum of 1 week.

Data Preparation Procedures

Prior to the analyses, each group's task performances were evaluated to determine whether the scores were normally distributed. For the NWR task, the SLI and LMM groups yielded normally distributed scores (Shapiro-Wilk test = .988, $p > .05$), but the CA group yielded a nonnormal distribution (WS = .839, $p < .05$). Therefore, these children's scores were transformed into a log transform score, with the results yielding a normal distribution (WS = .923, $p > .05$). For the CLPT, three scores were examined: percentage of correct sentence comprehension, percentage of correct word recall, and mean combined span score reflecting the mean sentence set length (e.g., two-sentence sets, three-sentence sets) for which children correctly comprehended the sentence and recalled the last word. For comprehension accuracy, each group yielded a nonnormal distribution ($p < .01$). Thus, each group's scores were transformed into a log transform score, which yielded normal distributions ($p > .05$). For percentage of word recall, each group produced a normal distribution ($p > .05$). Finally, children's comprehension of simple and complex sentences was examined. For the simple sentences, the SLI group yielded nonnormal scores (WS = .842, $p < .01$), as did the CA group (WS = .862, $p < .01$), but the LMM group yielded a normal distribution. After log transformation, both the SLI and CA groups' distribution was normal ($p > .05$). For the complex sentences, each group produced a normal distribution ($p > .05$).

Results

Children's Performance on the Experimental Tasks

Working Memory

NWR task: The SLI group's performance on the NWR task was compared with the CA group's performance using an analysis of covariance (ANCOVA), with score on the Leiter International Performance Scale serving as the covariate given that the SLI group attained a significantly lower IQ score than the CA children. Preliminary analyses showed no group

differences in homogeneity of variance. Results of the ANCOVA show that the children with SLI repeated significantly fewer nonwords than the CA children, $F(1, 39) = 17.57, p = .001, \eta^2 = .31$.

CLPT: Group comparisons were made on three dependent variables: percentage of sentence comprehension accuracy, total percentage of words recalled correctly, and mean dual span reflecting the mean number of sentences for which the child comprehended the sentence and recalled the last words correctly. This span score reflected children's ability to successfully allocate their attention simultaneously to information processing and information storage. Such a combined score has been argued to be a more robust estimate of resource capacity/allocation (i.e., complex memory span) than the traditional measure of percentage of sentence-final words recalled because the combined score is a direct reflection of dual-task performance, whereas percentage of words recalled is not (e.g., Cowan et al., 2005).

The SLI and CA groups were first compared. Tests of homogeneity of variance were run for each dependent variable and revealed that the groups showed comparable variances for the first two scores but not the third. Thus, for the third score, a two-sample t test with a Satterthwaite adjustment to the degrees of freedom was performed. For sentence comprehension accuracy, no group difference occurred, $F(1, 39) = 0.061, p = .81, \eta^2 = .002$. For percentage of words recalled, the SLI group recalled significantly fewer words than the CA group, $F(1, 39) = 6.14, p = .01, \eta^2 = .14$. For the dual span score, the children with SLI again scored significantly worse than the CA children, $t(39) = -3.24, p = .002$.

The SLI and LMM groups were compared on comprehension accuracy and percentage of words recalled. Recall that the groups were already matched on the dual span score. Tests of homogeneity of variance were first run on each of the two dependent variables, with the results showing that the groups yielded comparable variances for each. Results of the ANCOVA reveal comparable group performance for comprehension accuracy, $F(1, 37) = 0.080, p = .78, \eta^2 = .002$, as well as percentage of words recalled, $F(1, 37) = 0.802, p = .37, \eta^2 = .02$. A descriptive summary for each group on both the memory tasks is displayed in Table 2.

Sentence Comprehension—The dependent variable for the simple sentences was percentage of sentences correctly comprehended. For the complex sentences, the dependent variable was a composite score reflecting mean percentage correct across the passive, pronominal, and reflexive sentences (Bishop et al., 2000; Norbury et al., 2002; van der Lely, 1996, 1998; van der Lely & Stollwerck, 1997). Tests of homogeneity of variance were first run to determine whether the groups demonstrated similar variances for each sentence type. The SLI and CA groups showed comparable variances for the simple sentences, but for the complex sentences, the groups yielded significantly different variances. The SLI and LMM groups showed comparable variances for both sentence types. The CA and LMM groups yielded comparable variances for the simple sentences but different variances for the complex sentences. When there were differences in variances between the groups (e.g., for complex sentences), an independent samples t test with a Satterthwaite adjustment to the degrees of freedom was performed.

For *simple sentences*, the SLI group showed comparable comprehension with both the CA group, $F(1, 39) = 0.603$, $p = .44$, $\eta^2 = .02$, and the LMM group, $F(1, 37) = 0.137$, $p = .71$, $\eta^2 = .004$. For *complex sentences*, the SLI group performed significantly worse than the CA group, $t(32) = -3.97$, $p < .0001$, but comparably with the LMM group, $F(1, 37) = 0.194$, $p = .66$, $\eta^2 = .005$. Finally, the CA and LMM groups demonstrated comparable comprehension of simple sentences, $F(1, 32) = 2.95$, $p = .09$, $\eta^2 = .09$, but for the complex sentences, the CA group yielded higher comprehension, $t(19) = 2.79$, $p = .01$. Table 3 displays the descriptive statistics for each group on the comprehension task.

Within-group analyses were run to examine the pattern of comprehension between the sentence types within each group. The expectation was that the SLI group should comprehend fewer of the complex sentences than simple sentences, whereas the CA and LMM groups should show no difference between sentence types. The children with SLI indeed comprehended significantly fewer complex sentences than simple sentences, $t(23) = -4.47$, $p = .001$. The CA children and LMM children showed no difference between sentence types: CA, $t(17) = -0.303$, $p = .76$; LMM, $t(15) = 1.24$, $p = .23$.

Correlation Analyses

SLI Group—The correlation and partial correlation matrices for the children with SLI are shown in Table 4. The partial correlations were computed to reveal associations between/ among the different variables that are independent of age. First, it can be seen that age correlated with both of the working memory scores as well as with both simple sentence comprehension and complex sentence comprehension. It can also be seen that NWR significantly correlated with CLPT dual span. However, the partial correlation was not significant. Thus, covariation with age accounted for the association between NWR and CLPT.

Table 4 also indicates that whereas complex sentence comprehension correlated with CLPT dual span, it did not correlate with NWR. The correlation between the CLPT and comprehension remained significant even after covarying for the effects of age. For the simple sentences, the reverse was true in that NWR correlated with comprehension, but no correlation occurred with the CLPT. Even after partialing out the effects of age, NWR remained significantly correlated.

CA Group—Table 5 displays both raw and partial correlations. Age did not correlate with NWR, but it did correlate with CLPT. Also, age did not correlate with either simple or complex sentence comprehension. The NWR and CLPT performances were also significantly correlated, but when the effects of age were removed, the correlation did not remain significant. Thus, similar to the SLI group, covariation with age accounted for the association between NWR and CLPT. With respect to sentence comprehension, neither of the memory variables correlated with simple sentence comprehension or with complex sentence comprehension.

LMM Group—Table 6 presents the raw and partial correlations. Unlike the SLI and CA groups, age failed to correlate with either memory variable or with either simple or complex sentence comprehension. In addition, no significant correlation emerged between NWR and

CLPT. Regarding comprehension, neither memory variable correlated with simple sentence comprehension. However, CLPT correlated with complex sentence comprehension, with the partial correlation remaining significant. NWR did not correlate with complex sentence comprehension. All significant correlations reported were medium (.3) to large (.5 or larger) correlations (Cohen, 1983).

Discussion

The aim of the present work was to test the hypothesis that limitations in two core mechanisms of working memory—PSTM capacity and attentional resource capacity/allocation—in children with SLI are significantly associated with their difficulty understanding complex grammar. We begin with a brief discussion of the groups' performances on each of the experimental tasks and then move on to a discussion of the relationship between the children's working memory and sentence comprehension abilities.

Describing Children's Performance on the Experimental Tasks

Working memory—On the NWR task, the children with SLI, predictably, performed significantly worse than the CA children. By design, the SLI and LMM groups performed similarly. The poorer performance of the SLI group compared with the CA group is in keeping with the extensive SLI literature (e.g., Archibald & Gathercole, 2006; Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000; Gathercole & Baddeley, 1990; Montgomery, 1995, 2004). The poorer NWR performance of the children with SLI is also in keeping with the interpretation that these children have more limited PSTM capacity than their age peers (e.g., Ellis Weismer et al., 2000; Gathercole, 2006; Montgomery, 2004). However, an important and new finding from this study is that age was found to correlate with NWR in the children with SLI. This finding is important because it indicates that PSTM capacity increases in children with SLI during the early school-age years, as it does in CA children (e.g., Alloway, Gathercole, & Pickering, 2006; Gathercole, 1999). Although age did not correlate with NWR in the CA children, in the present study this is likely due to the fact that the children performed very well on the task. Age did not correlate with NWR in the youngest (LMM) children as well. This finding is perhaps not surprising given the restricted age range of the children and/or the small sample size.

The children with SLI were also found to perform more poorly than the CA children on two of the three measures related to the CLPT. Whereas the SLI and CA groups showed comparable sentence comprehension accuracy, the children with SLI recalled significantly fewer sentence-final words than the CA children. These results are in keeping with previous reports (e.g., Archibald & Gathercole, 2006; Ellis Weismer et al., 2000; Mainela-Arnold & Evans, 2005). We also calculated a dual span score reflecting the mean sentence set length for which the children were able to correctly comprehend the sentences and recall the sentence-final words. This score provided a co-index of children's ability to simultaneously achieve both accurate verbal processing and verbal storage. Predictably, the SLI group was outperformed by the CA children. In line with conventional notions of complex memory span (e.g., Just & Carpenter, 1992; King & Just, 1991), the lower dual span score and lower word recall of the children with SLI suggest that, relative to age peers, children with SLI

have less overall attentional resources to support simultaneous verbal processing and storage. Finally, age was found to correlate significantly with CLPT performance (i.e., combined score) for both the SLI and CA groups. Importantly, this finding shows that, similar to their age peers, the attentional resource capacity/allocation mechanism of working memory in children with SLI improves during the early school-age years. In the case of the LMM children, however, age did not correlate with CLPT dual span. Again, the lack of correlation is probably due to the restricted age range of the children and/or the small sample size.

Sentence comprehension—Our results replicate those of van der Lely and colleagues (Bishop et al., 2000; van der Lely, 1996, 1998; van der Lely & Harris, 1990; van der Lely & Stollwerck, 1997) and Norbury et al. (2002). On the simple sentences, the children with SLI and the CA children, as expected, performed similarly. For the complex sentences, however, the children with SLI performed significantly worse than the CA children. The SLI and LMM groups performed similarly on both the simple and complex sentences, as would be predicted given the matching procedure used here.

As a group, the CA children showed equally good comprehension of the complex and simple structures (i.e., above 85% correct for each type). The good comprehension of the simple sentences was not surprising given the stimuli were short and conformed to canonical word order (e.g., Booth et al., 2000; Dick et al., 2004). The children's equally good comprehension of the complex sentences was likewise not surprising given that the structures are acquired at a very early age, that is, about 4 or 5 years (e.g., De Villiers & De Villiers, 1973; Maratsos, 1974; van der Lely, 1996, 1998). The lack of correlation between age and either sentence type is further evidence that both sentence types were well within the children's linguistic grasp.

The children with SLI, relative to their CA peers and relative to their own performance on the simple sentences, demonstrated significantly poorer comprehension of the complex sentences. These findings provide strong evidence that even early-acquired complex structures continue to be problematic for children with SLI into the middle school years (Bishop et al., 2000; Norbury et al., 2002; van der Lely, 1996, 1998; van der Lely & Stollwerck, 1997). In fact, children with SLI performed no better than children 4 years their junior. Recall that the SLI and LMM groups performed comparably with one another on the complex sentences (as well as on the simple sentences). The correlation results provide additional important insights into the developmental course of sentence comprehension of the children with SLI. Age was found to correlate significantly with complex sentence comprehension. This finding provides further evidence that understanding of early-acquired complex sentence patterns continues to improve during the middle school years for these children. It was also shown, interestingly, that age correlated with simple sentence comprehension. These findings are especially noteworthy because they suggest that the comprehension of high-frequency, early-acquired canonical structures also continues to improve into the middle school years. Finally, for the younger LMM children, no significant correlations emerged between age and either complex or simple sentence comprehension. Again, such findings might be reflective of the restricted age range of the children and/or the small sample size.

According to the CGC (RDDR) hypothesis (Marshall & van der Lely, 2006; van der Lely, 1996, 1998), the difficulties that the children with SLI had comprehending the complex sentences can be attributed to a deficit in their computational syntactic system. This deficit can be characterized as difficulty building nonlocal syntactic dependencies. For the passives, comprehension required the children to complete a movement operation such that NP1, which originates as the complement of the verb, must move to the specifier position of the tense phrase. The agent role is assigned to NP2, as agency gets transmitted from the passive morpheme (*-ed*) to NP2 located in the *by*-phrase (e.g., Guasti, 2002). Because these children's syntactic system does not treat movement as an obligatory operation, they do not always use it when it is appropriate, thereby leading to inconsistent comprehension. For the reflexive sentences, the children needed to build a syntactic dependency between the anaphor and its closest antecedent (e.g., *Daffy Duck says Bugs Bunny is tickling himself*). That is, because a reflexive must refer to the noun within the same clause, the child can build a short-distance syntactic relationship. For the pronominal sentences, the children needed to establish a syntactic dependency between the anaphor and the more distant antecedent (*Daffy Duck says Bugs Bunny is tickling him*). Because the anaphor in pronominal sentences may only refer to a nonlocal antecedent, this forces the child to build a long-distance syntactic dependency. The children with SLI were less reliable to comprehend the reflexive/pronominal sentences because their syntactic system presumably is free to choose to bind the anaphor to either a local or nonlocal antecedent (van der Lely, 1998).

Explaining the Association Between Working Memory and Sentence Comprehension

The main question here focused on the nature of the association between working memory and the children's sentence comprehension. We predicted that the children with SLI and the LMM children would demonstrate similar correlation patterns to one another but different from the CA children. The predictions for the SLI–LMM comparisons were partially supported in that the groups showed a similar correlation pattern for the complex sentences but not for the simple sentences. The prediction that the SLI and CA groups would produce different patterns was supported.

CA children—As was predicted, neither attentional resource capacity/allocation nor PSTM significantly correlated with complex sentence comprehension. These findings suggest that typically developing 6- to 12-year-old children's comprehension of well-known complex structures does not invite the detectable use of working memory, at least not the PSTM and attentional resource capacity/allocation mechanisms. This finding, at first blush, might appear to be in disagreement with the ubiquitous findings in the adult language processing literature showing an association between complex sentence understanding and resource capacity/allocation (i.e., complex memory span; e.g., Chen et al., 2005; Daneman & Carpenter, 1980, 1983; Just & Carpenter, 1992; King & Just, 1991). Recall that the adult literature shows an association between working memory and the processing of complex sentences requiring the building of syntactic dependencies. The apparent discrepancy can be explained by the fact that the sentences used in adult studies are typically much more complex and lengthy than the ones used in the present study. For instance, most adult studies employ sentences containing object-relative and multiple-embedded clause constructions requiring multiple syntactic dependencies. In the present study, the complex sentences were

on the short side and entailed no (multiple) embeddings. Finally, PSTM was not found to correlate with the comprehension of simple sentences. These findings are not surprising given that although the simple sentences were significantly longer than the complex sentences (e.g., by about .5 words), these sentences, too, were rather short (i.e., only about 8 words).

Children with SLI—The story for the children with SLI was very different. It was hypothesized that the complex sentences would tax the working memory resources of the children. Our predictions were supported in part. Whereas the children's complex sentence comprehension was associated with attentional resource capacity/allocation, it was not associated with PSTM. Even when the effects of age were removed, the correlation remained significant. Recall it was hypothesized that the complex sentences should require children to allocate sufficient resources to (a) the PSTM buffer to keep each new incoming sequence of words in an active state long enough for it to be processed and (b) the language system to retrieve appropriate linguistic properties of the input words and activate appropriate language processing schemes to generate appropriate linguistic representations of the word sequences (e.g., NP, VP). Resource capacity/allocation was also hypothesized to be relevant to the building of nonlocal syntactic relationships entailing a movement operation in the case of passives and anaphoric binding in the case of reflexive/pronominal sentences, as well as to the reactivation (retrieval) of earlier representations being temporarily stored in working memory (Just & Carpenter, 1992; McElree et al., 2003). The correlation between attentional resource capacity/allocation and comprehension suggests that these children's limitation in resource capacity/allocation hampered their ability to complete in a timely fashion the different mental operations supporting comprehension. Moreover, the results suggest that the comprehension of early-acquired complex structures by children with SLI not only requires significant mental resources but also substantial mental effort. There are two sources of evidence from other studies to support the claim that these sentences required significant mental effort. First, relative to CA children, children with SLI have been shown to be less efficient (slower) to process even simple grammar (e.g., Montgomery, 2006, 2008), with speed of processing representing an index of mental effort (e.g., Kail, 1986; Kail & Miller, 2006). Second, children with SLI have been shown to need sustained focus of attention while processing simple grammar, whereas age control children do not (Montgomery, 2008), with vigilance indexing mental effort (e.g., Smit, Eling, & Coenen, 2004). It is thus not unreasonable to assume that the complex sentences used here also invited greater mental effort on the part of the children with SLI than the CA children.

It was also predicted that the PSTM deficit of the children with SLI should be associated with complex sentence comprehension because the amount of incoming material the children could hold in PSTM might not adequately support comprehension (e.g., Montgomery, 1995; Norbury et al., 2002; Vallar & Baddeley, 1984). However, this expectation was not supported. This finding is inconsistent with the positive (though weak) correlation reported by Norbury et al. (2002). However, in the present study, the lack of correlation is based on a partial correlation, whereas in the study by Norbury et al., it is unclear whether the correlation was age adjusted. Our failure to find a correlation could

mean that the complex sentence comprehension and PSTM deficits of these children are independent, coexisting deficits (e.g., Bishop, Adams, & Norbury, 2006). On this view, a PSTM deficit would have no appreciable effect on the children comprehending relatively short complex sentences. That said, the absence of association does not necessarily rule out the possibility that PSTM does not participate in the comprehension of longer/more complex sentences (e.g., center-embedded relative clause structures).

An especially striking and somewhat unexpected finding was that PSTM correlated with simple sentence comprehension, even when the effects of age were partialled out. Recall, though, that these sentences were significantly longer than the complex sentences. Although not providing any essential structural information for the assignment of thematic roles, the extra verbiage (e.g., adjectives and adverbs) was still important to cue comprehension. Assuming that the PSTM buffer takes in sequences of words and not entire sentences (Baddeley, 1998), it is not surprising that the children had little trouble comprehending the sentences. It thus seems reasonable to think that the children had modicum ability to hold a sequence of three or four *familiar* words in PSTM while the language system processed the sequence in a linear and timely fashion. What is interesting about this finding is that although the sentences apparently did not exceed the children's PSTM capacity, they nonetheless still involved significant instantiation of short-term memory storage.

LMM children—The performance of the LMM children was especially interesting when compared with the children with SLI. On the one hand, the groups showed an overall similar performance profile in sentence comprehension. The groups comprehended the simple sentences with comparable accuracy. The complex sentences were also comprehended with comparable accuracy by both groups. This latter finding is inconsistent with the finding reported by van der Lely and Harris (1990), who showed their SLI group was less able to comprehend complex sentences than their receptive vocabulary-matched peers. However, the children in van der Lely and Harris's study were not matched on working memory abilities. This difference in matching procedure, importantly, suggests that when the PSTM and attentional resource capacity/allocation abilities are controlled, the complex sentence comprehension of children with SLI is comparable with that of their younger peers. Also as predicted, the LMM children, like the children with SLI, showed a significant correlation pattern between complex sentence comprehension and attentional resource capacity/allocation but not with PSTM. This association suggests that 6- to 7-year-old children have the ability to marshal their attentional resources to help mediate the putative mental operations underlying complex sentence comprehension, including, in this case, the operations responsible for building nonlocal syntactic relationships.

At the same time, the SLI and LMM groups' performance patterns diverged in two important ways. First, the SLI group yielded significantly poorer comprehension of the complex sentences relative to the simple sentences. The LMM group showed no such difference; they showed comparable accuracy of both sentence types. These findings might seem counterintuitive and counter to prediction because the two groups were matched on working memory. However, they are not. Rather, the findings simply indicate that the SLI group found the complex sentences harder to understand than the simple sentences, which is perfectly consistent with the CGC (RDDR) hypothesis. There was no reason to predict that

the LMM children would have trouble understanding the complex sentences because these structures were well within their linguistic grasp (Booth et al., 2000; De Villiers & De Villiers, 1973; Dick et al., 2004; Maratsos, 1974). The key issue in the present study was whether the SLI and LMM groups would demonstrate a similar correlation pattern between working memory and sentence comprehension.

The second noteworthy difference between the groups concerned the correlation patterns. Whereas the LMM and SLI groups showed a similar correlation pattern with respect to the complex sentences, they did not for the simple sentences. Unlike the SLI group, the LMM children showed no correlation between PSTM and simple sentence comprehension. The lack of correlation is interpreted to indicate that relatively short simple sentences that can be processed using a left to right canonical word order strategy do not instantiate detectable PSTM use by 6- to 7-year-old typically developing children.

Summary interpretation of the findings—Relative to their age mates, the children with SLI demonstrated comparable comprehension of simple sentences but significantly poorer comprehension of complex sentences. However, compared with their younger LMM counterparts, the SLI group yielded comparable comprehension of the complex sentences and simple sentences. Regarding the correlation patterns, the SLI group demonstrated a different pattern than both the CA and LMM children, mostly consistent with our predictions. As hypothesized, the SLI group showed a significant correlation between complex sentence comprehension and attentional resource capacity/allocation but not with PSTM. Unexpectedly, these children also showed a correlation between simple sentence comprehension and PSTM. Also as predicted, the CA children demonstrated no correlation between either of the memory variables and the comprehension of either complex or simple sentences. Finally, the LMM children, like the SLI group, demonstrated a correlation between complex sentence comprehension and attentional resource capacity/allocation but not with PSTM. Unlike the SLI group, the LMM children showed no correlation between either of the memory variables and simple sentence comprehension.

The pattern of results suggests that, relative to age peers, children with SLI continue to have trouble comprehending complex sentences requiring the building of syntactic dependencies, that is, movement dependencies and anaphoric binding dependencies (e.g., Bishop et al., 2000; van der Lely, 1996, 1998; van der Lely & Stollwerck, 1997). The present results add to the extant SLI literature by showing that their comprehension problems appear to be related to their limitation in working memory, especially the attentional resource capacity/allocation mechanism. The similar complex sentence comprehension and correlation patterns of the SLI and LMM groups suggest that 6- to 12-year-old children with SLI are no more efficient in comprehending early-acquired complex sentence patterns than their peers 3–4 years their junior. Equally interesting was the finding that even simple grammar required significant short-term memory resources by the children with SLI but not the LMM children. Together, the present results indicate that, relative to their age mates, children with SLI expend greater mental effort to process both complex and simple grammar.

Conclusions and Future Research Directions

The findings from this study seem clear. The poor comprehension of complex grammar by children with SLI is significantly associated with a limitation in working memory. Reduced attentional resource capacity/allocation appears to play a detectable role in their weak comprehension, but a limitation in PSTM capacity does not. The role of these children's resource capacity/allocation limitations, however, should not be overplayed. We explored only a single candidate cognitive mechanism to help explain these children's problems understanding complex grammar. It is more likely that a cluster of deficient information processing abilities will account for some portion of these children's comprehension impairments (e.g., Bishop et al., 2006; Johnston, 1994; Leonard et al., 2007; Montgomery & Windsor, 2007). What the present findings do tell us, though, is that their difficulty comprehending complex grammar cannot be easily explained by a syntax-specific representational deficit. Also, whereas children with SLI and their typically developing peers demonstrate equally accurate comprehension of simple grammar, the processing path of children with SLI appears to require greater mental resources.

Future studies might expand the scope of study to examine the influence of working memory on a wider range of sentence structures (e.g., various relative clause structures). Future investigations may also wish to take a developmental approach by examining whether different associations might hold between these and other working memory mechanisms (as well as other information processing abilities) and complex sentence comprehension at different ages in children with SLI. Such an approach would yield invaluable information about the pattern of coordination across cognitive systems in these children.

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Appendix Experimental sentences

Simple Sentences

1. The kitty is walking on the old brown fence.
2. The mouse is eating the yellow cheese.
3. The girl is chasing the big brown horse.
4. The tiger is chasing the two little zebras.
5. The woman is drawing a yellow and black bird.
6. The clown is hugging the tiny white elephant.
7. The man is painting the old car blue.
8. The old man is touching the blue-haired woman.

9. The boy is hitting the crying little girl.
10. The girl is pushing the smiling little boy.
11. The boy climbed the skinny tree.
12. The car is going to hit the blue train.

Complex Sentences: Passives

1. The woman is kissed by the baby.
2. The man is eaten by the fish.
3. The girl is patted by the woman.
4. The fish is eaten by the monkey.
5. The woman is painted by the girl.
6. The truck is hit by the car.
7. The monkey is bitten by the dog.
8. The baby is kissed by the woman.
9. The boy is poked by the woman.
10. The cat is shaved by the mouse.
11. The cat is eaten by the dog.
12. The dog is bitten by the monkey.

Complex Sentences: Pronominals

1. Peter Pan says Captain Hook is kicking him.
2. Christopher Robin says Winnie the Pooh is scratching him.
3. Daisy Duck says Minnie Mouse is washing her.
4. Mowgli says Baloo Bear is tickling him.
5. Winnie the Pooh says Christopher Robin is touching him.
6. Mowgli says Baloo Bear is kissing him.
7. Mr. Dog says Mr. Rabbit is licking his dog.
8. Baloo Bear says Mowgli is tickling him.
9. Peter Pan says Captain Hook is pinching him.
10. Tigger says Baloo Bear is tickling him.
11. Christopher Robin says Tigger is touching him.
12. Mickey Mouse says Donald Duck is touching him.

Complex Sentences: Reflexives

1. Mowgli says Baloo Bear is dressing himself.
2. Baloo Bear says Mr. Monkey is licking himself.
3. Bugs Bunny says Elmer Fudd is hugging himself.
4. Mr. Pig says Mr. Donkey is kicking himself.
5. Captain Hook says Baloo Bear is scratching himself.
6. Baloo Bear says Bugs Bunny is tickling himself.
7. Mr. Pig says Winnie the Pooh is feeding himself.
8. Captain Hook says Peter Pan is drying himself.
9. Donald Duck says Bugs Bunny is washing himself.
10. Mowgli says Mr. Monkey is tickling himself.
11. Minnie Mouse says Daisy Duck is washing herself.
12. Elmer Fudd says Bugs Bunny is pointing to himself.

Table 1

Descriptive summary data for the children with specific language impairment (SLI; $n = 24$), age-matched (CA) children ($n = 18$), and language- and memory-matched (LMM) children ($n = 16$).

Group	Age (months)	CELF-3					PPVT _{RS}	EVT _{SS}	IQ
		RI _{SS}	LC _{RS}	LC _{SS}	EL _{SS}	PPVT _{SS}			
SLI									
<i>M</i>	109.2	65.3	11.8	4.7	71.5	92.5	114.5	79.3	95.9
<i>SD</i>	19.5	12.3	6.1	1.4	10.4	14.6	25.6	12.1	6.4
Range	78–153	50–83	3–23	3–8	50–82	74–125	68–156	56–99	87–109
CA									
<i>M</i>	109.0		23.8	10.7	105.3	108.7	136.7	97.7	101.8
<i>SD</i>	19.9		5.4	2.3	9.9	12.8	19.9	8.5	8.5
Range	89–154		11–30	7–16	88–118	88–133	99–170	82–112	87–121
LMM									
<i>M</i>	75.4		13.5	9.3	106.6	114.1	101.9	105.2	105.0
<i>SD</i>	10.3		4.7	2.3	8.7	10.1	17.4	10.1	5.5
Range	55–94		4–23	5–14	90–121	100–133	72–147	84–117	95–113

Note. CELF-3 = Clinical Evaluation of Language Fundamentals, Third Edition; RI_{SS} = overall Receptive Language standard score; LC_{RS} = Linguistic Concepts raw score; LC_{SS} = Linguistic Concepts standard score; EL_{SS} = overall Expressive Language standard score; PPVT_{SS} = Peabody Picture Vocabulary Test–III standard score; PPVT_{RS} = PPVT raw score; EVT_{SS} = Expressive Vocabulary Test standard score.

Table 2

Group descriptive statistics for the children with SLI ($n = 24$), CA children ($n = 18$), and LMM children ($n = 16$) in the nonword repetition (NWR) task and competing language processing task (CLPT).

Group	NWR %	Comp %	CLPT recall %	CLPT span
SLI				
<i>M</i>	79.2	94.6	30.3	1.4
<i>SD</i>	9.2	5.6	15.4	0.72
Range	56–94	83–100	5–53	0.5–3.0
CA				
<i>M</i>	90.3	97.1	62.1	2.6
<i>SD</i>	4.9	6.7	14.3	0.73
Range	78–95	71–100	36–83	1.5–3.0
LMM				
<i>M</i>	80.0	96.1	32.5	1.7
<i>SD</i>	9.3	5.9	16.7	0.84
Range	62–94	86–100	0–55	0–3.5

Note. NWR % = mean percentage of nonwords repeated correctly on the NWR task; Comp % = percentage of sentences correctly comprehended on the CLPT; CLPT recall % = percentage of words recalled on the CLPT; CLPT span = longest span (i.e., sentence set size) for which both sentence comprehension and word recall were correct.

Table 3

Mean percentage of correct comprehension of simple sentences and complex sentences by the children with SLI ($n = 24$), CA children ($n = 18$), and LMM children ($n = 16$).

Sentence comprehension	SLI	CA	LMM
Simple			
<i>M</i>	80.6	85.8	78.7
<i>SD</i>	18.2	11.5	14.8
Range	25–100	58–100	42–100
Complex			
<i>M</i>	74.5	86.6	74.2
<i>SD</i>	18.8	7.3	17.5
Range	17–100	75–100	42–100

Table 4

Correlation and partial correlation matrices (i.e., adjusting for the variance accounted for by age) for the SLI group ($n = 24$).

Matrix type	NWR %	CLPT span	Sentence comprehension	
			Simple	Complex
Correlation matrix				
CLPT	.486 [*]			
Simple comprehension	.711 ^{**}	.636 ^{**}		
Complex comprehension	.362	.637 ^{**}	.516 [*]	
Age	.410 [*]	.840 ^{**}	.551 [*]	.625 ^{**}
Partial correlation matrix (age removed)				
CLPT	.265			
Simple comprehension	.533 ^{**}	-.109		
Complex comprehension	.339	.425 [*]	.318	

Note. Because age covaries with NWR and CLPT, partialing out age also subtracts shared variance in both NWR and CLPT that may contribute to sentence comprehension in Tables 4 and 6.

*
 p .05.

**
 p .01.

Table 5

Correlation and partial correlation matrices (i.e., adjusting for the variance accounted for by age) for the CA group ($n = 18$).

			<u>Sentence comprehension</u>	
Matrix type	NWR %	CLPT span	Simple	Complex
Correlation matrix				
CLPT	.612**			
Simple comprehension	.131	.261		
Complex comprehension	.056	-.117	.001	
Age	.258	.666**	.144	-.109
Partial correlation matrix (age removed)				
CLPT	.610**			
Simple comprehension	.098	.244		
Complex comprehension	.087	-.059	.017	

**
p .01.

Table 6

Correlation and partial correlation matrices (i.e., adjusting for the variance accounted for by age) for the LMM group ($n = 16$).

			<u>Sentence comprehension</u>	
Matrix type	NWR %	CLPT span	Simple	Complex
Correlation matrix				
CLPT	.134			
Simple comprehension	−.438	.357		
Complex comprehension	.175	.409*	.488*	
Age	−.088	.464	.390	.329
Partial correlation matrix (age removed)				
CLPT	.198			
Simple comprehension	−.440	.216		
Complex comprehension	.217	.306*	.413*	

*
 $p < .05$.