



Working memory and comprehension in children with specific language impairment: what we know so far

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Received 30 November 2002; received in revised form 25 February 2003; accepted 25 February 2003

Abstract

Many children with specific language impairments (SLI) demonstrate deficits in the areas of verbal working memory and language learning/processing. In this article, evidence is reviewed suggesting that the lexical/morphological learning and sentence comprehension/processing problems of many of these children are associated with their deficient working memory functioning. Evidence is also reviewed for the possibility that deficient working memory provides a clinical marker of SLI. A number of potentially useful assessment and intervention techniques are offered, as well as several directions for future research.

Learning outcomes: The reader will be introduced to two prominent models of verbal working memory (phonological working memory model, functional working memory) and how each model potentially relates to (a) various language abilities in typically developing children, (b) the morphological and lexical learning abilities in children with specific language impairment (SLI), and (c) the sentence comprehension of children with SLI. The reader will also be provided a variety of clinical suggestions on how to assess and treat the working memory and language processing problems of children with SLI. Finally, some suggestions for future research will also be offered.

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Keywords: Specific language impairment; Children; Working memory; Comprehension

It has only been within the past 12 years or so that researchers have begun to examine the potential role of working memory (WM) on the language learning

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and processing abilities of children with specific language impairment (SLI) (e.g., Ellis Weismer, 1996; Gathercole & Baddeley, 1990a; Montgomery, 1995b, 2000a, 2000b, 2002). While there are two prominent models of working memory, the phonological loop model (Baddeley, 1986) and the capacity theory of comprehension (e.g., Just & Carpenter, 1992), much of the research with children, including children with SLI, has been dominated by Baddeley's phonological loop model. In this article, the extant literature on what is known about the association between WM and language learning and processing in these children will be reviewed.

Working memory according to Baddeley (1986) is a multicomponent, capacity-limited system that comprises a controlling "central executive" and that includes an articulatory loop system. The central executive, the component that is not well understood, is thought to regulate information flow within WM, retrieval of information from other memory systems, and the processing and storage of information. The articulatory loop, the better understood component, includes a capacity-limited phonological short-term store and an articulatory control process (verbal rehearsal) that acts to refresh and maintain speech material in the store for a brief period. The articulatory loop's function is to store verbal input temporarily, especially novel phonological input (Baddeley, Gathercole, & Papagno, 1998), while other cognitive tasks such as auditory comprehension take place. The ability to temporarily store novel material also allows the listener the opportunity to create long-term phonological representations of that material (Baddeley et al., 1998). This view of WM will hereafter be referred to as phonological working memory (PWM).

In most studies, typically developing preschool and young school-age children's PWM ability has been assessed using a nonword repetition task in which they were asked to repeat nonwords varying in length from one to four or five syllables. Because the task uses unfamiliar content, such a task can serve as an unbiased measure of language processing that assesses the functions of the phonological loop (Campbell, Dollaghan, Needleman, & Janosky, 1997; Ellis Weismer et al., 2000). The typical pattern is that children have no difficulty repeating one and two syllable items but by three syllables, repetition accuracy begins to decrease, reflecting the capacity-limited nature of the phonological store. Children with "greater" PWM capacity than those with less capacity show better accuracy for longer items. The logic behind the task is that poor performance reflects a basic language-related processing ability that should be critical to the processing and learning of language. Indeed, many studies report a positive relation between children's PWM and word learning (Avons, Wragg, Cupples, & Lovegrove, 1998; Gathercole & Baddeley, 1989, 1990b; Gathercole, Service, Hitch, & Martin, 1997; Gathercole, Willis, Emslie, & Baddeley, 1992) and expressive skills (Adams & Gathercole, 1995). Although there are no direct data yet, it has been argued that PWM may also play an important role in children's grammatical and morphological learning (Nelson, 1987; Plunkett & Marchman, 1993; Spidel, 1993).

The model of WM by Carpenter, Just and associates is a computational model in which both storage and processing functions of the WM system must share the same limited pool of resources/activation (i.e., amount of attentional energy) during comprehension. Storage is defined as the ability to temporarily retain verbal information that has been processed, while processing is defined as those language computations that generate various types of linguistic representation (e.g., lexical, morphological, grammatical) of the input. It is further assumed that various comprehension processes operate simultaneously in real time. The primary emphasis of the model centers on the trade-off between storage and processing of information when the amount of resources is exceeded by the demands of the task. If the input is grammatically complex, for instance, some of the resources allocated to keeping old representations in an active state may be shifted to comprehension processes, thereby leading to “forgetting” of some or all of the previously processed information. This model will heretofore be referred to as functional working memory (FWM).

To assess FWM capacity, [Daneman and Carpenter \(1980, 1983\)](#) have advocated using tasks that tap the dual functions of storage and processing simultaneously. To this end, these investigators developed a listening span task in which subjects read or listen to sets of sentences (varying in number of sentences to be comprehended) and after each set recall as many sentence-final words as possible (e.g., “Babies drive trucks,” “Pumpkins are purple,” “Balls are square”). The processing component of the task is reflected in the listener processing the truth-value of each sentence and the storage component is reflected in the listener recalling as many words as possible. Functional WM capacity is defined as the maximum number of sentences comprehended while maintaining perfect recall.

Unfortunately, little research has examined the relation between FWM and language learning and/or processing in children. [Gaulin and Campbell \(1994\)](#), using the Competing Language Processing Task (CLPT), a developmentally appropriate version of the listening span task, found that FWM capacity is associated with receptive vocabulary level in 6 to 12 years old children. [Ellis Weismer, Evans, and Hesketh \(1999\)](#) examined in a group of children with SLI and a group of age-matched children (5 to 9 years old) the relation of FWM to performance on a set of standardized nonverbal cognitive and language measures. For the age control children, they found a positive correlation between CLPT (number of words recalled) and sentence comprehension.

1. Working memory in children with SLI

[Gathercole and Baddeley \(1990a\)](#) were the first to study the PWM abilities of children with SLI and to propose the notion of a causal link between PWM and language impairment. Using a nonword repetition task, they showed that children with SLI had significantly greater difficulty repeating three and four

syllable nonwords than two groups of typically developing children (verbal-matched, nonverbal-matched), suggesting that children with SLI have reduced PWM capacity. Since their study, several other investigators have replicated this pattern (Dollaghan & Campbell, 1998; Edwards & Lahey, 1998; Ellis Weismer et al., 2000; Montgomery, 1995a). In general, these findings have been interpreted to suggest that these children have reduced PWM capacity. Although, it is important to point out that it also has been argued that these children's poorer repetition might also reflect difficulty with phonological encoding or difficulty with managing the overall demands of the task (e.g., Edwards & Lahey, 1998).

In contrast to the PWM abilities of children with SLI, these children's FWM have received very little research attention. The results of the few FWM studies that have been done suggest, whereas they have reduced FWM capacity relative to age peers (Ellis Weismer et al., 1999; Montgomery, 2000a, 2000b), they have comparable capacity to language-matched peers (Montgomery, 2000a, 2000b). In the Ellis Weismer et al.'s study mentioned above, children with SLI showed poorer FWM capacity (indexed by poorer overall word recall) compared to their age peers. By contrast, the groups performed very well (near ceiling levels) on the Yes/No comprehension part of the task, suggesting the children with SLI and their age mates had comparable processing ability. Framed within a processing/storage trade-off perspective, such results might be interpreted to suggest that the children with SLI sacrificed remembering the words to maintain good comprehension. That is, they de-allocated their WM resources away from storage to processing, whereas the typically developing children were better able to coordinate both storage and processing functions.

In the Montgomery studies, the FWM abilities of children with SLI were compared with both age-matched (CA) and receptive syntax-matched (RS) children using a modified version of the CLPT. His task was a three condition processing task designed to yield separate estimates of storage and storage + processing. Children were asked to recall as many real words as possible in a no-load condition, a single-load processing condition, and a dual-load processing condition. In each condition, children were presented word lists varying from three to seven words. In the no-load condition (simple recall/span), children were asked to recall the words irrespective of presentation order. This condition served as an index of children's simple storage capacity, independent of any explicit processing demands. In the single-load processing condition, children were asked to recall the list of words but according to physical size of the word referents. This condition thus required children to simultaneously store the words and to perform one mental operation. For instance, when given a word list (e.g., cow, shoe, thumb), children needed to store the words in short-term memory while simultaneously rearranging them by physical size before or during recall (e.g., thumb, shoe, cow). In the dual-load condition (requiring storage + two mental operations), children were asked to recall the words according to both semantic category and physical size, "beginning with the smallest thing and ending with the biggest thing."

For example, when given a word list (e.g., cow, tree, mouse, seed, cat), children thus needed to store the words while at the same time rearrange them into semantic categories and then by physical size within each category (e.g., seed, tree; mouse, cat, cow).

Results from both studies showed that all three groups had a comparable simple span, suggesting that the groups had similar storage capacity, at least when there were no explicit demands for additional processing. Unexpectedly, however, the groups also showed comparable performance in the single-load condition, suggesting that the children with SLI had some ability to coordinate both storage and processing functions, but only when the processing demands were not too taxing. It was in the dual-load condition that the children with SLI demonstrated reduced FWM capacity relative to age control children; however, the children with SLI and the RS children showed comparable recall performance. Collectively, these results were interpreted to suggest that children with SLI have greater difficulty managing the dual functions of storage and processing when the processing demands of a task become too taxing, i.e., when they had to complete two mental operations in a timely fashion. Thus, children with SLI showed a classic [Daneman and Carpenter \(1983\)](#) storage/processing trade-off; storage suffered when the processing demands required a greater allocation of WM resources.

2. Association between working memory and language in children with SLI

There are no direct data linking PWM to language learning in children with SLI, although there is anecdotal evidence suggesting that poor word learning by preschool and young school-age children with SLI may indeed be related to a PWM problem. In several novel word learning studies by Rice and colleagues ([Oetting, Rice, & Swank, 1995](#); [Rice, Cleave, & Oetting, 2000](#); [Rice, Oetting, Marquis, Bode, & Pae, 1994](#)), children with SLI were shown to learn fewer unfamiliar words than CA-matched peers. Ellis Weismer and colleagues ([Ellis Weismer, 1996](#); [Ellis Weismer et al., 1999](#)) have more directly examined the potential role of FWM on the lexical and morphological learning of children with SLI and age-matched children. Children with SLI would be predicted to have trouble learning new words and grammatical morphemes, especially when they are presented under stressful processing conditions (i.e., presented at fast rates), because of a difficulty managing both the storage and processing functions of FWM. In one study, [Ellis Weismer \(1996\)](#) asked children to complete the CLPT and two language learning tasks in which they were exposed to novel monosyllabic words (Task 1) and grammatical morphemes (Task 2) embedded in short simple sentences presented at normal, fast, and slow rates. The results revealed that on the CLPT, the children with SLI recalled fewer words overall than CA-matched children (as mentioned above), suggesting they had reduced FWM

capacity. While comprehension of novel words was reported to be comparable in both groups, children with SLI produced fewer words, especially in the fast rate condition. A similar pattern of results was also reported for the morpheme learning task. Together, the findings were interpreted to suggest that the difficulty children with SLI have managing the dual functions of information storage and processing may in part be responsible for their trouble with lexical and morphological learning. That is, children with SLI have difficulty maintaining the novel phonological information in short-term memory long enough to process its meaning.

Montgomery (1995b) examined the relation between PWM and sentence comprehension in a group of children with SLI and a language-matched (RS) group of children. PWM capacity was indexed by performance on a nonword repetition task. The sentence comprehension task included two sets of sentences (a mix of complex and simple structures) matched for syntactic complexity and semantic content, one set of “long” sentences and one set of “short” sentences. The children with SLI demonstrated a PWM capacity deficit, as reported earlier. On the comprehension task, the two groups comprehended similar numbers of short sentences. However, for the long sentences, the children with SLI comprehended fewer sentences relative to the RS children and compared to themselves. In addition, a positive significant correlation emerged between PWM and comprehension. Together, the results were taken to suggest that the poorer comprehension of long sentences by the children with SLI was related in part to their PWM deficit in that they are less able to store as much speech material at any given moment, thereby hindering their ability to generate a complete sentence representation.

In two additional studies, Montgomery (2000a, 2000b) examined the association between FWM and sentence comprehension in children with SLI. In both studies, a group of children with SLI was compared with a group of CA and RS children on the three condition FWM task described earlier and on a slightly revised sentence comprehension task just described. As already mentioned, children with SLI showed a FWM capacity deficit relative to CA children but comparable capacity to RS children. On the comprehension task, children with SLI once again showed comparable comprehension of the short sentences to the RS children but showed significantly poorer comprehension of the long sentences compared to both control groups. While no positive correlations were found between FWM and comprehension, it was argued that the poorer comprehension of children with SLI was likely a joint function of reduced FWM capacity and an inability to handle the overall information processing demands of the task. That is, children with SLI perhaps not only have greater difficulty retaining/processing the entire input sentence but also completing, in a timely fashion, a number of other information processing demands of such tasks, including scanning and visually processing each of the stimulus pictures, generating a linguistic representation of each of the stimulus pictures, and deciding which picture best matches the input sentence. In another study, Montgomery (2000a) examined the relation between

FWM and real-time (immediate) processing of simple sentence structures in school-age children with SLI and CA and RS children. Children completed the same three-condition memory task and a word-monitoring task in which they listened for a target word embedded in a two-sentence stimulus and immediately pushed a response button (yielding a reaction time) when recognizing the word. The children with SLI again showed a FWM deficit relative to CA children and were also slower to process the sentences compared to both CA and RS children. However, no correlation was found between FWM and reaction time for any of the groups, suggesting that the immediate processing of simple language by children, even children with SLI, does not rely heavily on FWM resources. The lack of correlation was further interpreted to suggest that children with SLI, although they are slower to process simple language, are nonetheless able to coordinate their FWM resources successfully because such input is well within their linguistic grasp.

3. Clinical implications

3.1. Assessment

Some researchers have proposed the idea that poor PWM might serve as a reliable, culture-free marker of SLI (Campbell et al., 1997; Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000). Dollaghan and Campbell (1998) showed that nonword repetition can accurately classify children already identified as SLI from non-SLI children. Ellis Weismer et al. extended these findings in part by showing that nonword repetition can help identify children as SLI or non-SLI but only in conjunction with standardized language performance.

While there are few psychometrically valid assessment measures of WM appropriate for preschool and school-age children, it is possible to make reasonable inferences about their WM using the following suggested procedures. For preschoolers, performance on various standardized STM measures (i.e., digit span, word span) can provide a sensitive index of children's PWM abilities (Gathercole & Adams, 1993). As already mentioned, nonword repetition tasks (Dollaghan & Campbell, 1998; Gathercole, Willis, Baddeley, & Emslie, 1994) provide an especially sensitive measure of children's PWM abilities as they are required to encode, store, and repeat a series of unfamiliar words varying in length. A reduced PWM capacity would be suggested by markedly poorer repetition of the longer items (three-, four-, five-syllable items) versus the shorter items. Dollaghan and Campbell (1998) and Gathercole and Baddeley (1990a) provide examples of such a task. For school-age and older students, FWM can be assessed using a range of standardized and nonstandardized procedures. One standardized measure is the digits backward subtest from the *Wechsler Intelligence Scale for Children: Third Edition* (Wechsler, 1991). This task would appear to be sensitive to the concurrent functions of verbal storage and processing given

the student must retain a series of digits while simultaneously rearrange and recall them in reverse order. The CLPT (Gaulin & Campbell, 1994) could also be used to measure FWM capacity. Recall that in this task the student is read groups of simple sentences that increase in set size and is asked to respond to the truth-value of each sentence and to recall as many sentence-final words as possible. Given that Gaulin and Campbell provide preliminary normative data for 6 to 12 years old children, reasonable judgments about a student's FWM capacity can be made, independent of complex language processing demands. To obtain more "ecologically valid" estimates of a student's FWM ability, the clinician might perform authentic assessments of language functioning during academic activities (Wiig, 1995) to determine which aspect(s) of complex language-based, academic tasks influence the efficiency with which the student can manage his/her FWM resources. For instance, a student's FWM resources may be exceeded when trying to rapidly process new lecture material containing new concepts and vocabulary and complex sentence structures presented without supporting contextual cues.

3.2. *Intervention*

First, it is important to point out that intervention that does not address the bi-directional influences of memory and language will likely fall short in promoting children's language learning and processing. The most successful interventions thus will likely reflect a dual language-memory approach. The following suggested WM activities are probably already part of many clinicians' treatment arsenal and are simply framed here within a WM perspective. To promote better FWM abilities in preschoolers, Mann (1984) has suggested having children practice naming letters and objects, and listening to stories and nursery rhymes, activities that should highlight the phonological structure of language. An adult and child also might play other rhyming games in which they take turns saying as many rhyming words or nonsense words as possible. Having them repeat nonsense words in a game-like situation may also facilitate their ability to abstract the phonological properties of novel input, which may also improve their ability to phonologically encode and represent novel material. For school-age children and adolescents, intervention could emphasize more efficient use of FWM abilities with the intent of facilitating more efficient sentence processing/comprehension. For example, if the student does not already spontaneously use it, verbal rehearsal (which would also promote better use of the phonological loop) could be taught, helping him/her to refresh and retain incoming speech. Teaching the student the technique of chunking might also prove helpful by helping him/her to create prosodic chunks corresponding to phrases or clauses, thereby creating more manageable units of information. Finally, for large discourse units, the student could be taught how to use paraphrasing (Donahue & Pidek, 1993), the focus being to help the student use his/her own words to condense a large volume of language material into smaller, well-integrated units.

4. Research needs

Much remains to be known about the WM abilities of children with SLI and even more about the intersection of WM and language learning and processing. Further research might focus on establishing the developmental sensitivity of the nonsense word repetition task and its ability to accurately classify children as SLI or non-SLI children. Considerably more research is also needed to better understand the structure and functions of the central executive. Along the same lines, further research is needed to establish the CLPT's sensitivity and specificity in discriminating children with SLI from non-SLI children. Additional reliable measures of FWM appropriate to school-age children and adolescents also need to be developed. Future research must focus on establishing links between working memory (PWM and FWM) and specific aspects of language learning and processing. Finally, it is also critical to begin to develop reliable WM training techniques and to establish their potential facilitative effects on language learning and processing.

Appendix A. Continuing education

1. The model of phonological working memory comprises:
 - A. A central executive and a rehearsal process.
 - B. A central executive and a phonological loop.
 - C. A phonological loop and a rehearsal process.
 - D. A rehearsal process and a storage buffer.
2. The phonological working memory capacity of children with SLI has been shown to be:
 - A. Comparable to age peers and comparable to language-matched peers.
 - B. Comparable to language-matched peers but less than age peers.
 - C. Less than age peers and less than language-matched peers.
 - D. Less than age peers but comparable to language-matched peers.
3. The most robust association between working memory and language development in typically developing children and children with SLI is in the area of:
 - A. Morphology
 - B. Syntax
 - C. Phonology
 - D. Vocabulary
4. The relationship between functional working memory and the immediate processing of language in typically developing children and children with SLI reveals:
 - A. Positive relationship in typically developing children but a positive relationship in children with SLI.

- B. A negative relationship in typically developing children but a positive relationship in children with SLI.
 - C. No relationship in either group of children.
 - D. A positive relationship in both groups of children.
5. This task has been shown to be an especially sensitive and robust index of preschool and young school-age children's phonological working memory ability:
- A. Nonsense word repetition
 - B. Sentence imitation
 - C. Face recall
 - D. Tone recall

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