WORKING MEMORY AND LANGUAGE PROCESSES IN CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT

by

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Abstract

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Phonological working memory functions correlate with several language processes in both children and adults (e.g., Daneman & Carpenter, 1980; Gathercole & Baddeley, 1989; Carpenter, Miyake, & Just, 1995). Phonological working memory skills have close links with vocabulary acquisition, with language comprehension, with syntactic processing, and with reading comprehension. The present study was designed to investigate the relationship between phonological working memory and two levels of language processes: such as syntactic processing , speech perception, and speech production.

13 children with specific language impairment (SLI) and 13 children with typical language development (TLD) participated in the first experiment, and three groups of typically developing children differing in age (6;9 - 8;3, 8;4 - 9;10, 9;11 - 11;5) participated in the second experiment. Five working memory tasks were employed in both experiments. These tasks combined the traditional nonword

repetition tests and sentence comprehension by using sentences that differed in length and syntactic complexity.

The results showed that the children with SLI performed more poorly than their age-matched typically developing peers in each working memory task including production of nonwords and real words. There was no difference between the 2 groups in nonword discrimination. The results of Experiment 2 showed that working memory capacity develops with age. The results across tasks in both experiments revealed that an increase in working memory load resulted in a reduction of working memory capacity, consequently in a decrease in performance accuracy. There were individual variations that might have occurred because of the differences in the amount of memory activation available. Alternatively, the same working memory load might have occupied a different amount of working memory capacity in different individuals.

The results suggest that tasks combining nonword repetition and sentence comprehension reflect the dynamic nature of working memory and the individual working memory differences more accurately than the traditional nonword repetition tests.

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CHAPTER 1: INTRODUCTION

Numerous studies have reported that phonological working memory functions correlate with several language processes in both children and adults (Daneman & Carpenter, 1980; Gathercole & Baddeley, 1989; Carpenter, Miyake, & Just, 1995). Phonological working memory skills have close links with vocabulary acquisition (Gathercole & Baddeley, 1989; Gathercole, Willis, Emslie, & Baddeley, 1992), with language comprehension (Just & Carpenter, 1992; Carpenter, Miyake, & Just, 1995), with syntactic processing (King & Just, 1991; MacDonald, Just, & Carpenter, 1992), and with reading comprehension (Daneman & Carpenter, 1980; Gathercole & Baddeley, 1993).

The present study was designed to investigate the relations among phonological working memory and two levels of language processes: syntactic processing , speech perception, and speech production. These relations were studied in different groups of children; in children who have specific language impairment and in groups of typically developing children who differ in age.

There are several views of working memory and of its involvement in language processes. Baddeley's (1986) working memory model includes a central executive component, a phonological loop and a visuo-spatial sketch pad. The central executive component has a supervisory role in directing attentional resources and selecting control processes. It coordinates the different activities within working memory and communicates with the other parts of the cognitive system. Baddeley (1986) described phonological working memory as a subcomponent of the working memory system that is determined by the function of the phonological loop. The phonological loop system is specialized for the storage of verbal material. It includes two subcomponents, the phonological short-term store and the subvocal rehearsal component. The phonological short-term store represents phonologically coded material that decays with time. The rehearsal component serves to refresh the decaying representations in the phonological store to maintain memory items. The recoding of nonphonological inputs such as printed words or pictures into their phonological form also occurs through the rehearsal component. Subvocal rehearsal is what enables the nonphonological inputs to be held in the phonological store. In contrast, spoken language information does not need articulatory rehearsal because it is assumed to have direct access to the phonological store. Gathercole and Baddeley (1993) suggested that both the central executive and the phonological loop are involved in language comprehension. Visual and spatial information are handled by the visuo-spatial sketch pad in this model.

Just and Carpenter (1992) also described a supervisory system in their working memory theory, but this model did not include modality-specific processes such as the phonological loop and the visuo-spatial sketch pad in Baddeley's (1986) model. Their theory described capacity as the maximum amount of activation available to perform storage and computations. According to this theory, there is a minimum amount of activation that is necessary to perform certain tasks. If the individual's total amount of activation is less than that required by a particular task, then information will decay. Thus, there is a limitation in the availability of resources. If any of the tasks require a large amount of resources, then the allocation of these resources will cause a decrease in the efficiency and the speed with which other tasks are carried out (Pichora-Fuller, Schneider, & Daneman, 1995). There are individual differences in working memory capacity that may be determined by the size of the pool (i.e., how much information can be stored and processed during a certain period of time), by the efficiency of the processes that are involved in symbolic computations, or by both (King & Just, 1991).

Working memory and language processes

According to the capacity theory of working memory (Just & Carpenter, 1992), working memory for language refers to a set of processes and resources that are involved in language comprehension. Language production and comprehension both require the processing of a sequence of symbols over time (Carpenter, Miyake, & Just, 1995). In this model, working memory is considered to be a pool of operational resources that perform the symbolic computations. The representational strength of an element (e.g., representing a word, a phrase, a proposition) is determined by its activation level. If there is a shortage in activation of the storage function, information will be forgotten. A shortage in activation of the computational function results in a slow-down in processing (Carpenter, Miyake, & Just, 1995).

The Just and Carpenter (1992) model corresponds to Baddeley's (1986) central executive component, which deals with language processes. In higher-level sentence comprehension processes, Baddeley's phonological loop seems to play only a secondary role. Its major function is the temporary storage of speech-based information. The results of sentence comprehension in patients with a specific deficit in the phonological loop revealed that the phonological loop is not a major component of comprehension (Baddeley, 1996). However, the phonological loop plays an important role in learning to read and in vocabulary acquisition (Gathercole & Baddeley, 1993). There is a relationship between working memory skills and vocabulary acquisition in children between the ages of four and six years (Gathercole & Baddeley, 1993). Children with better working memory skills tended to have larger vocabularies. However, beyond the age of 5-6 years phonological working memory skills seem to be less important for vocabulary development. As children's lexicon expands, analogies of phonological forms may be used more frequently to learn new words. The use of analogies may increase to such an extent that the short-term phonological working memory load diminishes. Reading also seems to become an important factor in vocabulary acquisition during the primary school years (Gathercole & Baddeley, 1993).

Methods for measuring working memory

Nonword repetition

Nonword repetition has been widely employed as a measurement of phonological working memory capacity in children (Gathercole & Baddeley, 1990; Gathercole, Willis, Emslie, & Baddeley, 1992; van der Lely & Howard, 1993; Dollaghan, Biber, & Campbell, 1995; Gathercole, 1995). Nonwords have no long-term lexical representations that could contribute to performance on immediate memory tasks. Immediate recall of familiar words benefits from the availability of phonological specifications in long-term memory (Hulme, Maughan, & Brown, 1991). When nonwords are used to measure the immediate memory, subjects are less likely to use lexical knowledge to supplement phonological short-term memory.

There is evidence in the literature that "wordlikeness" (i.e., similarity to known words) has substantial influence on nonword repetition. Repetition accuracy is greater for nonwords that have higher rated wordlikeness values. As the proportion of familiar segments (i.e., consonants & vowels) increased, repetition performance increased as well (Gathercole, Willis, & Baddeley, 1991).

Dollaghan, Biber, & Campbell (1995) found a difference in performance accuracy between two groups of nonwords. Some of the nonwords had stressed syllables corresponding to real words, others had stressed syllables with no meaning. Words with meaningful syllables (e.g., morphemes, monosyllabic words) were repeated with higher accuracy than words with no meaningful components. It appears that stored lexical knowledge is used to supplement phonological working memory representations for nonwords with high wordlikeness (Dollaghan, Biber, & Campbell, 1993, 1995; Gathercole, 1995). Thus, the repetition of less wordlike nonwords is a better measure of phonological working memory capacity than the repetition of more wordlike stimuli.

The length of the nonwords has also influenced repetition accuracy. Short-term memory performance is better for short than for long words, in children and adults (Baddeley, Thomsons, & Buchaman, 1975). In addition, Snowling, Chiat, & Hulme (1991) pointed out that longer nonwords place greater demands on other phonological processes such as segmentation and the assembly of articulatory motor programs. Repetition performance in 4- and 5-year-old typically developing children and in children with language impairment declined linearly as the number of syllables in the nonwords increased from two to four (Gathercole & Baddeley, 1989, 1990). Thus, nonword repetition seems to be one effective way of measuring working memory abilities in children. However, it focuses on the contribution of the phonological loop and does not provide information about higher level language processes such as sentence comprehension.

Reading span / listening span measurements

Language tasks requiring integration of information are strongly related to working memory (Daneman & Carpenter, 1980). Specifically, working memory capacity for language correlates with reading comprehension. Reading span and listening span tests, in which the subjects were required to read or listen to a set of unrelated sentences and recall the final word of each sentence, correlated with specific measures of language comprehension (Daneman & Carpenter, 1980; Pichora-Fuller, Schneider, & Daneman, 1995). There is also a strong correlation between listening span and reading span (Lyon, 1977). Working memory seems to have a particularly important role in processing syntactically complex sentences through reading or listening.

Syntactic processing requires the temporary storage of word representations while the transformation (i.e. parsing) of the linear word sequence into a hierarchical syntactic structure occurs (King & Just, 1991).

The capacity-constrained parsing model of MacDonald, Just, & Carpenter (1992) characterized working memory capacity as constraining syntactic processes. This is consistent with the findings that the comprehension of syntactically complex sentences requires more working memory resources than the comprehension of syntactically simple sentences (Daneman & Carpenter, 1980). For example, in center embedded sentences, the embedded clause interrupts the constituents in the main clause. Thus, the initial noun phrase must be maintained in working memory while processing the embedded clause. This task reveals individual differences in working memory (Daneman & Carpenter, 1980).

Working memory also has an important role in processing sentences with syntactic ambiguity. Readers construct multiple representations when they encounter syntactic ambiguities. When one interpretation of the ambiguity is syntactically simpler and pragmatically more plausible, this preferred interpretation is maintained at a higher activation level than the less preferred interpretation (MacDonald, Just, & Carpenter, 1992).

There is a similar situation that arises with lexical ambiguity using homographs (written words that have more than one meaning). The resolution of the lexical ambiguity occurs through the maintenance of multiple interpretations determined by context and frequency. When context and frequency provide support for a single interpretation, then only that interpretation will have a high activation level in working memory. If the context and frequency favor different interpretations, then both interpretations are activated (Carpenter, Miyake, & Just, 1995). During the period in which multiple representations are maintained, other processes may be postponed because there may be insufficient resources to execute these processes. These delays increase processing time (MacDonald, Just, & Carpenter, 1992).

Although the results of previous studies (Daneman & Carpenter, 1980; King & Just, 1991; MacDonald, Just, & Carpenter, 1992; Carpenter, Miyake, & Just, 1995) indicate that working memory has an important role in syntactic processing, these findings rely on studies that employed words with varying phonological characteristics. These variations may have influenced subjects' working memory performance. The examples that are mentioned by the authors (e.g., lake, justices, box, commence, raid, explosions, fraud) indicate differences in terms of frequency, number of syllables, syllable structure, and stress pattern. The phonological differences among the words may account for some of the variability observed.

Phonological working memory and specific language impairment (SLI)

There is evidence in the literature that SLI children have difficulty performing tasks involving verbal short-term memory (Kirchner & Klatzky, 1985; Sininger, Klatzky, & Kirchner, 1989; Gillam, Cowan, & Day, 1995). A number of these studies also provided evidence of a limitation in temporal processing of brief stimuli regardless of their modality in SLI children (Sininger, Klatzky, & Kirchner, 1989; Tallal, 1990; Gillam, Cowan, & Day, 1995). Gillam, Cowan, & Day (1995) suggested that language impaired children's deficit in memory tasks may indicate problems in acoustic and phonetic representations of the speech signal and in its more abstract lexical representations. They found a different pattern of list recall in SLI children and in typically developing children. Ordinarily, subjects' performance in list recall showed a preference for the first few items (primacy effect) and for the last few items (recency effect). When a "suffix" (e.g., one additional word) was added after the final item of a list the recency effect was diminished. This is called the "suffix" effect (Greenberg & Engle, 1983). Children with SLI made serial order errors and exhibited a larger "suffix" effect than observed in typically developing children (Gillam, Cowan, & Day, 1995). These findings indicated that SLI children's memory performance reflects difficulty in both areas: memory for serial order and memory for specific serial position.

Children with SLI also performed more poorly than younger, language-age matched children on repetition tests with single nonwords and with non-word lists (Gathercole & Baddeley, 1990). The children with SLI showed severe problems in repeating single nonwords as their length increased, as well as repeating lists of phonologically dissimilar (e.g., bus, clock, hand, horse, girl, and spoon) and similar (e.g., bat, cap, cat, pan, pram, and tap). words. However, the SLI children, similarly to the typically developing children, were sensitive to both the phonological similarity and word length of these lists. All of the children had more difficulty in repeating words that were phonologically similar and long than in repetition of unrelated short words. Thus, there is a similarity in the memory characteristics of children with SLI and their language-age matched peers.

Gathercole and Baddeley (1990) suggested that phonological working memory plays a critical role in language acquisition. Furthermore, they assumed that the deficit in phonological working memory of SLI children is the principal cause of their developmental difficulties with language. Word production constraints were ruled out by using picture pointing as the method of recall, but the causes of repetition difficulties observed in SLI children remain unclear. Slow articulation as a cause of poor working memory performance was also ruled out by the fact that the onset and the rate of articulation in the children with SLI was similar to those of the typically developing children (Gathercole & Baddeley, 1990).

Although the authors concluded that SLI children's working memory difficulties directly cause their language impairments, they were not able to specify those memory processes that are responsible for these problems. Nonword repetition, the method they used, reflects the contribution of the phonological loop in different language related activities. However, the processing of syntactic information, the storage of processed items, the interpretation of words' meaning, and the planning of speech production are all linked to the activity of the central executive component. As mentioned earlier, the phonological loop has only a secondary role in sentence comprehension. By using nonwords, the authors were able to collect information only about certain language skills, specifically those that are involved in vocabulary acquisition. Although vocabulary acquisition is often impaired in children with SLI, their language difficulties must be examined in a broader spectrum including higher-level sentence comprehension and production. Children with SLI also have difficulties in using certain syntactic features such as grammatical morphemes (e.g., Leonard, 1989; Watkins, 1994).

In contrast to the findings of Gathercole and Baddeley (1990), van der Lely and Howard (1993) reported that children with SLI showed no significant differences in working memory tasks when compared to language-age matched children. However, the methods used in the van der Lely and Howard (1993) study were slightly different from the methods in the Gathercole and Baddeley (1990) study. In the latter study, children's memory performance was compared for semantically similar and dissimilar monosyllabic word lists, for the repetition of nonword and word lists, and for the phonologically similar and dissimilar words where rhyming CVC words with varying initial onsets were used. The authors did not find significant differences between the SLI and language-age matched children in these tasks. In addition, both groups showed a phonological similarity effect.

These two studies (Gathercole & Baddeley, 1990; van der Lely & Howard, 1993) reveal a contradiction in the literature about the working memory skills of children with SLI. However, we need to notice that the number of SLI children tested in these studies was very small (6-6).

There is further evidence of working memory difficulties in children with SLI provided by Montgomery (1995) who compared the performance of 13 children with SLI and 13 language-age matched peers. His study involved nonword repetition and discrimination tasks with 1-4 syllable nonwords. The findings suggested that SLI children's poorer performance on the nonword repetition task reflected a limitation in the phonological storage component of their working memory. The poorer performance of the SLI children was not related to the rate of articulation and to encoding difficulties. Reduced phonological storage capacity was also not related to reduced receptive vocabulary. However, the nonwords used in this study were not lexicality free, some of the syllables were meaningful words and real English suffixes (e.g., zopanisful, conishament). Children's stored lexical knowledge supports phonological working memory performance in repetition of nonwords that are not lexicality free (Gathercole, Willis, & Baddeley, 1991; Dollaghan, Biber, & Campbell, 1995). Thus, we don't know the extent to which the stimuli influenced children's performance. Both subject groups showed a phonological similarity effect. Montgomery concluded from the findings on phonological similarity that SLI children's phonological encoding abilities are comparable to those of their typically developing peers, thus, their working memory deficit is not determined by phonological encoding difficulties. However, the SLI children's performance in the discrimination task was also significantly worse for three- and four-syllable words than that of their typically developing peers. These results suggested difficulty in perceptual processing. The SLI children had difficulty in perceiving the differences in nonword pairs that differed only in their initial, medial, or final segments.

The cause of SLI children's relative difficulties in repeating longer nonwords remains undetermined. One possibility is that the same genetic factors that may cause language impairment can also lead to a deficit in nonword repetition (Bishop, North, & Donlan 1996). These authors studied nonword repetition in twins and suggested that nonword repetition abilities are inheritable. Another possibility is that SLI children's working memory capacity is limited to a greater extent than that of typically developing children. This means that the amount of material they are capable to hold in working memory may be more constrained than in typically developing peers. Alternatively, their computational abilities may be more limited or different from those of their typically developing peers. Encoding problems including phonological analysis and segmentation resulting from discrimination difficulties may also influence their performance in working memory tasks. Thus, there is a need for tasks focusing on the contribution of both the phonological loop and the central executive component in language processes, in order to get a clearer picture about the different language skills involved in working memory performance. The methods used to date (word and nonword repetition, recall of word lists) are not able to test how the central executive functions in children with SLI. To understand more about the language processes involved in working memory tasks, we need to extend the experiments including tasks measuring sentence comprehension, and syntactic processing.

Purpose and hypotheses

The two experiments presented here involved the same methods to test working memory performance in different groups of children. Our major focus was on the working memory abilities of children with language impairment. In addition, we were also interested in examining the changes in working memory performance across ages.

The purpose of the present study was to obtain more detailed information about the language processes that are involved in working memory tasks. The methods used to date do not provide a clear distinction between working memory and language processing limitations as they are reflected in the overall scores of working memory tasks. Although there have been attempts to separate the different processes involved in working memory performance, the tasks currently used often involve encoding, storage, computation, and production. Thus, it is not clear in many cases whether the errors reflect encoding, storage, or production constraints.

For the purpose of this study, there was a listening task developed in which children were required to listen to single unrelated sentences and to repeat a nonword at the end of each sentence. In contrast to traditional listening tasks, children were required to repeat a nonword, rather than a real word, that was part of the sentence. The modification was made to minimize the use of stored lexical knowledge. It has been hypothesized that children's performance decreases as the syntactic complexity of the sentences and the length of the nonwords increase, as predicted by the capacity constrained parsing model (MacDonald, Just, & Carpenter, 1992). An additional decrease in children's performance has been expected when they were required to answer questions related to the content of the sentences following the repetition of the final nonword. In this situation, subjects needed to maintain the appropriate information while they were processing the text. Previous studies indicated that when resource requirements were increased, there was a decrease in the efficiency with which other tasks were carried out because of resource allocation (Pichora-Fuller, Schneider, & Daneman, 1995).

The controversial data concerning working memory performance in children with SLI has raised some questions that were addressed in the first experiment. Do these children have a limitation in their storage capacity for working memory items? Does their performance reflect a combination of problems in encoding, in segmenting, and in analyzing the phonological structure measured by nonword repetition? Do these children show a different performance pattern from that of their typically developing peers in tasks that employ nonword repetition under different conditions? Is there a difference between the children with language impairment and their age-matched peers in both the amount of errors and the types of errors they make in nonword repetition tasks? Do language impaired children show the same memory pattern in a list recall task as typically developing children (i.e., primacy and recency effects, influence of the serial order and the serial position on recall accuracy)? If SLI children's language learning difficulties are determined by the limitations of their working memory capacity (Gathercole & Baddeley, 1993, Montgomery, 1995), they would show insufficient resources to execute the required processes in a modified listening task. The shortage of resources would then result in the forgetting of information. In addition, a nonword discrimination task was designed to test SLI children's encoding abilities. This task did not require any kind of speech production from the children.

CHAPTER 2: METHODS

Study 1

Participants

Two groups of children participated in this experiment. All children attended primary school and used English as their primary language. The first group included thirteen children (6;6 - 10;6) who had been diagnosed by a licensed speech-language pathologist as having specific language impairment (SLI). They all were enrolled in speech-language therapy. Their language performance was at least 1.5 SD below the age appropriate language performance level measured by standardized language tests (CELF-R, Semel, Wiig, & Secord, 1987, CELF-3, Semel, Wiig, & Secord, 1995). All SLI children's cognitive abilities, measured by standardized nonverbal intelligence tests, fell within the normal IQ range (i.e., it was not under 80 IQ or above 120 IQ on the WISC-R, Wechsler, 1974).

The second group included 13 children who were typically developing (TLD), ranging in age from 6;9 to 10;6 years. These children were selected from a larger pool of typically developing children (N = 26) we tested to be controls for the children with SLI in this first experiment. The larger group was selected as a result of interviews with 1st-5th grade teachers who ensured that these children followed a typical developmental pattern. Each pattern. Each child in this group was matched to one of the SLI children within ± 3 months of chronological age (CA).

Both groups consisted of 5 girls and 8 boys. All participants passed a pure tone audiometric screening of both ears at 20 dB HL (at 500, 1000, 2000, & 4000 Hz) in accordance with ASHA guidelines (1990). In addition, every child was tested with the digit span subtest of the Stanford-Binet Intelligence Test (Thorndike, Hagen, & Sattler, 1986) and participated in language screening using the CELF-3 Screening Test (Semel, Wiig, & Secord, 1995).

None of the children demonstrated articulatory errors, concomitant motor, emotional, or physical handicaps. Physical and emotional statuses were determined by the school teachers based on a protocol developed by the schools themselves. Normal articulatory performance was a selection criterion, determined by the speech-language pathologist.

Table 1

Participant profiles summarized per group

Subject	Age (mos.)	*Full CELF scores (percentile)	CELF screening (standard scores)	Digit span forward	Digit span backward
SLI N=13					
M	102.31	23.45	11.92	4.92	3.15
SD	14.41	18.98	4.63	0.86	0.69
Control N=13					
M	103.15		21.69	5.46	3.64
SD	13.77		5.76	0.97	1.32

* In addition to the Clinical Evaluation of Language Fundamentals-3 CELF-3 screening test all language impaired children were tested with the full battery of the Clinical Evaluation of Language Fundamentals-3 CELF-3 or Clinical Evaluation of Language Fundamentals-Revised CELF-R tests (Semel, Wiig, & Secord, 1987, 1995). The full CELF test was administered with the SLI children only.

Stimuli

Nonword Repetition Task (NR)

The stimuli were 24 nonwords including 8 two-syllable nonwords, 8 three-syllable nonwords, and 8 four-syllable nonwords (see Appendix A). All the stimuli were free of the influences of lexicality and segment predictability (i.e., none of the syllables had meaning in English). Five independent listeners judged that the words selected had no meaningful syllables.

The stress-pattern of all the nonwords followed the rules of English stress (Halle & Keyter, 1971). When the last vowel was non-tense, primary stress was on the antepenultimate vowel when the penultimate vowel was non-tense and was followed by no more than one consonant (e.g., America, genesis, cinnamon). When the last vowel was non-tense, primary stress was on the penult when the penult itself was tense (e.g., museum, proposal), or when it was followed by two or more consonants (e.g., agenda, orchestral). When the last vowel was tense, it bore primary stress (e.g., regime, parole).

Modified Listening Tasks

The next two listening tasks include 90 sentences (30 syntactically simple, 30 syntactically complex short, and 30 syntactically complex long) with a question for each sentence (see Appendix B). The questions are related to the content of the sentences.

The length of the sentences was determined by the number of syllables. A short sentence included 10 or fewer syllables (these are the syntactically simple and syntactically complex short sentences), whereas a long sentence (syntactically complex long sentences) included at least 15 syllables. The two groups of sentences (short and long) show a significant difference in terms of their length (t = 9.81, p < 0.01). The syntactically complex sentences are sentences with embedded clauses and relative clauses (see Appendix B).

Most of the sentences used in the Modified Listening Tasks and in the List Recall Task were selected from language workbooks for children in second, third, and fourth grades. These workbooks are used by teachers in English Arts in public schools (Gerber, 1992; Terban, 1993; Kule, 1995 a, 1995 b). Others were based on the syntactic structures and vocabulary of the sentences in those sources.

Modified Listening Task 1 (ML1)

The stimuli were 45 unrelated sentences containing 15 syntactically simple, 15 syntactically complex short, and 15 syntactically complex long sentences with a nonword at the end of each sentence. The last word in each sentence was replaced with a nonword, thus the nonwords were part of the syntactic structure of the sentences. All the nonwords for this task were created according to the criteria described in the Nonword Repetition Task.

Modified Listening Task 2 (ML2)

The first part of the task was identical to the ML1 task, with one addition. After the recall of the nonword, the subjects were required to answer a question related to the content of the sentence (see Appendix B). The nonwords used in this task were the same as the nonwords in the ML1 task, but they were used in different conditions (e.g., if a specific 3-syllable nonword occurred at the end of a syntactically simple sentence in the ML1 task, then this nonword occurred at the end of a syntactically complex long sentence in the ML2 task). With the use of the same nonwords in different conditions across the two modified listening tasks we wanted to ensure that we were measuring the effect of syntactic processing on nonword production.

List Recall Task (LR)

This task is an adaptation of the reading span task described by Daneman and Carpenter (1980). The task required from the children to listen to sets of sentences (there were 5 sentences in each set) and recall the sentence final words after the fifth sentence. The words to-be-recalled had been controlled for their phonological features. They were similar in frequency, in word-length measured by syllables, and in syllable structure. The test was constructed with 45 unrelated sentences containing three sets each of 5 syntactically simple, 5 syntactically complex short, and 5 syntactically complex long sentences (see details about sentence structure in the description of the modified listening tasks).

Nonword Discrimination Task (ND)

The nonword pairs (24) of the discrimination task were, in most cases, minimal pairs where the difference was in the stress pattern (the stress was shifted one syllable earlier from the original stressed (primary) syllable) and in any resulting vowel neutralization. The other pairs (7) contained exactly the same words recorded two times without any differences (see Appendix D). English is a language which has not many words that change in meaning when their stress is shifted (e.g., 'record - re'cord). Thus, differentiating nonwords that differ in their stress pattern only requires precise encoding and analysis of the segment sequences.

Procedures

Each child was tested individually in 1 - 2 sessions (approximately 1 and 1/2 hours per session). Some of the children with SLI needed 2 sessions because of their difficulties in understanding and performing in language related tasks. All the stimuli were audio-recorded by a female speaker. The stimuli were presented through headphones using a portable tape recorder. All the children were audio-recorded by another portable tape recorder.

Nonword Repetition

The children listened to the nonwords through headphones. The nonwords were presented in a random order without replacement. This order was held constant across the subjects. The children were told that they would hear some "funny" words, and asked to repeat each nonword immediately after presentation. No practice was provided for the NR task.

Modified Listening Tasks

Half of the subjects in each group listened to the first 45 sentences (15 syntactically simple, 15 syntactically complex short, and 15 syntactically complex long) as the ML1 task and to the second 45 sentences (15 syntactically simple, 15 syntactically complex short, and 15 syntactically complex long) as the ML2 task. The other half of the subjects in each group listened to the first 45 sentences as the ML2 task and to the second 45 sentences as the ML1 task. In this way we were able to see the influence of syntactic processing on working memory performance.

Modified Listening Task 1

The subjects were required to recall the sentence final nonwords. The sentences were presented one at a time to the children in a random order, without replacement. The children listened to the sentences through headphones and repeated the sentence final nonword immediately after presentation. Prior to testing there were a few trials with different words and sentences to ensure that the children understood what they were supposed to do.

Modified Listening Task 2

The procedures were the same as for the ML1 task with one addition. After repeating the sentence final nonwords, the children were asked to answer a question about the content of the sentence. Each sentence was followed by a question. The children listened to the questions through headphones and the answers were tape recorded. There were practice sentences given prior to testing.

List Recall

The children listened to 9 sets of sentences and repeated the sentence final words at the end of each set. Children's responses were audio taped. There were a few trials given prior to testing.

Scoring

Nonword Repetition, Modified Listening Task 1

All children's nonword productions were transcribed using broad phonetic transcription. If a child produced the same nonword two times, then the score of the better production was taken. Nonword production was scored as incorrect when a child produced the following errors: segment substitution, segment addition, segment deletion including consonant cluster simplification, incorrect stress pattern, and the production of the target sounds in an incorrect order. The appropriate reduction of lax vowels was not considered as an error.

Modified Listening Task 2

The nonword repetition part of the task was scored in the same way as in the NR task and the ML1 task. The answers to the questions following nonword repetition were scored as correct or incorrect. If a child remembered only half of the answer, then the answer was scored as incorrect.

List Recall

The subjects' responses to the List Recall task were scored using the system introduced by Gillam, Cowan, & Day (1995). Each response was scored three times. With the "conservative" method children's answers were counted as correct when they recalled the correct items in the correct serial position. With the "liberal" scoring method children received credit for the recall of the correct items in proper order even when they were recalled not in the correct serial position. With the "free" scoring method children got credit for each recalled stimulus item, regardless of its serial position or its serial relationship to the other items.

Table 2

Example of the scoring systems (stimuli: cold, time, cookies, safe, food; response: food, safe, cold, time, cookies)

	Serial position				
Scoring system	1	2	3	4	5
Conservative	–	–	–	–	–
Liberal	–	–	+	+	+
Free	+	+	+	+	+

Nonword Discrimination

Children were required to decide whether pairs of stimulus words were the same or different. Their answers were audio recorded and evaluated as correct or incorrect.

Reliability

The transcriptions by the investigator and a second transcriber were compared for reliability. Interjudge reliability of error coding was calculated segment-by-segment for 200 randomly chosen nonwords (1632 segments). The 200 nonwords included productions of children with SLI as well as productions of children with TLD. The number of identically transcribed segments was divided by the total number of segments in the 200 nonwords to receive the percentage of agreement. The mean of agreement was 92.79% with a range of 89.6%-95.97% between the two transcribers.

CHAPTER 3: RESULTS

Prior to any statistical analysis, the individual scores were calculated as percentages, then transformed using arcsine transformation. The use of percentages enabled us to compare the results of tasks that were different in the number of stimuli. Mixed model ANOVAs were used. The dependent variable was the number of correctly produced nonwords in these tasks. A set of analyses examined variability across multiple productions.

Repetition of nonwords within tasks (NR, ML1, ML2)

The results of the NR task were examined as the percent correct across groups at each word length. The children's performance within the ML1 and ML2 tasks was examined as the percent correct across groups in relation to the variables of word-length, syntactic complexity, sentence length, and on the ML2 task, the accurate answer to the questions. The results were examined with separate follow up ANOVA tests within each task. An error analysis was executed across tasks including nonword repetition.

Nonword Repetition

The results of a repeated measures ANOVA (group x word-length) indicated significant differences between the children with SLI and the children with TLD in the Nonword Repetition Task (F (1, 24) = 15.9, p < 0.0001). There was also a word-length effect (F (2, 48) = 32.6, p < 0.001). This was the only task where the differences in the group x word-length interaction were reliable (F (2, 48) = 3.9, p < 0.05). Post hoc Tukey tests (p < 0.05) showed that the children with SLI performed more poorly in repeating the 3- and 4-syllable nonwords than their age matched peers. There were no significant differences between the two groups in repetition of the 2-syllable words. All children's performance accuracy decreased as the length of the words increased.

Table 3

Means and Standard Deviations of correct words for the NR task (group x word-length)

	Children with TLD	Children with SLI
2-syllable nonwords		
M	6.78(84.69%)	6.26(78.23%)
SD	1.23	1.17
3-syllable nonwords		
M	6.1(76.23%)	3.71(46.38%)
SD	1.49	2.42
4-syllable nonwords		
M	4.56(57%)	2.1(26.15%)
SD	3.03	1.55

Modified Listening Task 1 (ANOVA with group x word-length x sentence type)

On the ML1 task there were also significant differences in nonword repetition between the children with SLI and the children with TLD (F (1, 76) = 7.92 $p < 0.01$). Post hoc Tukey tests revealed significant differences ($p < 0.05$) between the two groups with each sentence type. There were no significant differences across sentence types. The differences in the group x sentence type interaction were not reliable (F (2, 152) = 2.07, $p > 0.05$). The children in both groups exhibited a word-length effect (F (2, 152) = 68.84, $p < 0.001$). Post hoc Tukey tests ($p < 0.05$) indicated that repetition accuracy decreased with an increase in word-length.

Table 4

Means and Standard Deviations of correct words for the ML1 task (group x sentence type)

		Children with TLD	Children with SLI
Simple sentences			
	M	8.46(56.41%)	6.65(44.33%)
	SD	3.74	3.68
Complex short sent.			
	M	8.92(59.49%)	6.77(45.13%)
	SD	3.86	3.38
Complex long sent.			
	M	10.54(70.25%)	7(46.67%)
	SD	3.94	3.92

Modified Listening Task 2 (ANOVA with group x word-length x sentence type)

Children's productions in the ML2 task were examined in two ways. Children's answers to the questions and their repetitions of the nonwords were examined.

Nonword repetition accuracy in the ML2 task

The children with TLD performed significantly better than the children with SLI in nonword repetition in the ML2 task (F (1, 76) = 15.13, p < 0.001). Post hoc Tukey tests revealed significant differences (p < 0.05) with each sentence type. There were no differences in repetition accuracy across sentence types (F (2, 152) = 2.44, p > 0.05) and the differences in the group x sentence types were not reliable (F (2, 152) = 0.18, p > 0.05). Children in both groups exhibited a word-length effect (F (2, 152) = 49.61, p < 0.05).

Table 5

Means and Standard Deviations of correct words for the ML2 task (group x sentence type)

		Children with TLD	Children with SLI
Simple sentences			
	M	9.46(63.08%)	6.54(45.59%)
	SD	3.9	3.54
Complex short sent.			
	M	9.54(63.59%)	6.1(40.51%)
	SD	3.8	4.16
Complex long sent.			
	M	10.31(68.72%)	7.23(48.2%)
	SD	3.04	3.71

Answers to the questions in the ML2 task

The groups also differed in the number of correct answers to the questions following nonword repetition in the ML2 task (F (1, 76) = 12.01, $p < 0.001$). Post hoc Tukey tests ($p < 0.05$) revealed that the children with SLI performed more poorly with all sentence types than their typically developing peers.

Table 6

Means and Standard Deviations of the correct answers to the questions in the ML2 task (group x sentence type)

	Children with TLD	Children with SLI
Simple sentences		
M	12.15(81.02%)	9.7(64.62%)
SD	3.71	3.84
Complex short sent.		
M	9(60%)	6.66(44.62%)
SD	3.76	3.7
Complex long sent.		
M	10.46(69.74%)	7.08(47.18%)
SD	4.67	4.29

Although the children with SLI performed more poorly in the ML2 task than their typically developing peers, the groups had similar patterns of performance. Both exhibited word-length effects (ANOVA group x word-length; F (2, 152) = 4.76, p < 0.05). Post hoc Tukey tests (p<0.05) indicated that repetition accuracy decreased as the length of the nonwords increased with each sentence type in both groups.

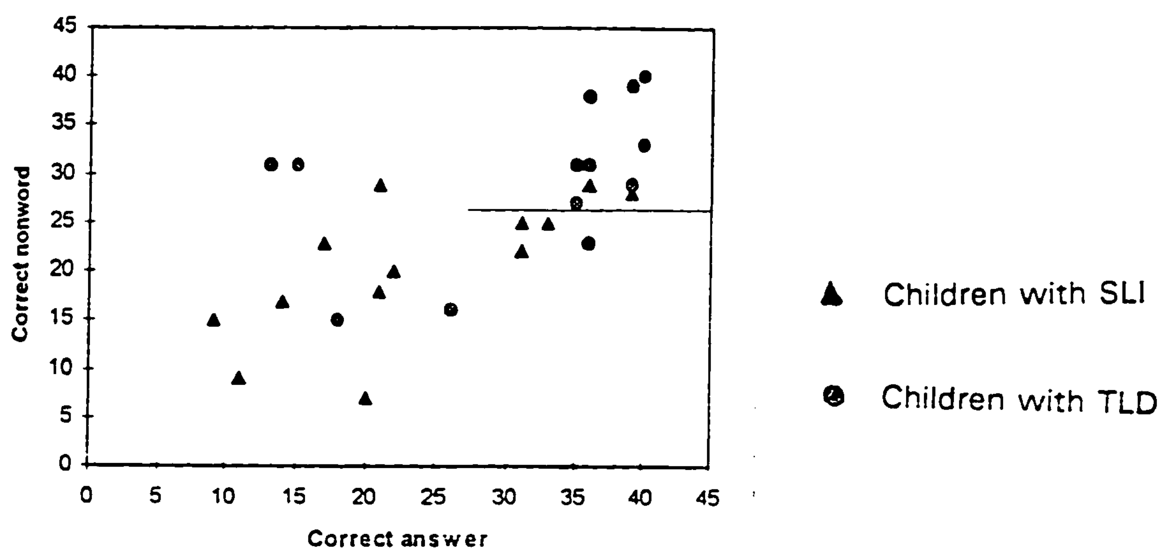
Syntactic complexity and working memory performance.

Syntactic complexity influenced all children's repetition of nonwords. All children's performance accuracy decreased as task complexity increased. Children in both groups produced the nonwords more correctly in the Nonword Repetition Task (NR) than in the Modified Listening Task 1 (F (1, 76) = 4.45, $p < 0.05$).

The influence of sentence complexity on performance was clearly expressed in the number of correct answers to the content of the sentences in the ML2 task in both groups (F (2, 76) = 7.56, $p < 0.01$ for the children with TLD and F (2, 76) = 11.44, $p < 0.0001$ for the children with SLI). The differences in the group x sentence type interaction were not reliable (F (2, 152) = 0.96, $p > 0.05$). Post hoc Tukey tests ($p < 0.05$) showed that the children gave more accurate answers when the sentences were simple than in cases where the sentences were complex short or complex long. There was a significant difference for both groups between the performance of simple and complex short as well as simple and complex long sentences. However, there was no difference in the number of correct answers between the complex short and complex long sentences.

As mentioned earlier, children's productions in the ML2 task were examined in two ways. The relationship between their answers to the questions in the ML2 task and their nonword repetition accuracy was examined. However, we also examined their performance by combining these two aspects. These combined results showed that the children in both groups had increased difficulty in repeating the nonwords accurately and giving a correct answer to the questions. The percentage of correct production for both the nonword and the correct answer was 24% for the children with SLI and 48% for the children with TLD. Figure 1 shows the relationship between correct nonword repetition and correct answers to the proceeding questions.

Figure 1. Number of correct nonword repetition (y) and correct answer to the proceeding question (x) in the ML2 task



In addition to the significant differences between the children with SLI and the children with TLD, there were significant differences in performance between the simple sentences and the complex sentences (F (2, 24) = 8.87, p < 0.01 for the children with TLD and F (1, 24) = 11.88, p < 0.001 for the children with SLI). Post hoc Tukey tests (p < 0.05) revealed no significant differences between the performance on the complex short and complex long sentences in either group.

Table 7

Means and Standard Deviations of the combined results in the ML2 (group x sentence type)

		Children with TLD	Children with SLI
Simple sentences			
	M	8.32(55.46%)	4.59(30.62%)
	SD	3.78	2.23
Complex short sent.			
	M	6.2(41.38%)	2.68(17.85%)
	SD	3.12	2.04
Complex long sent.			
	M	7.21(48.08%)	3.27(21.77%)
	SD	3.43	3.14

Phonological analysis/Error analysis across tasks

The percentage of correct nonword production across the tasks was 46.36% for the children with SLI and 65.46% for the children with TLD. Both groups' performance decreased as the length of the nonwords increased. However, the children with SLI produced 84% of all the segments correctly and the segment production accuracy was 93% for the children with TLD.

Table 8

Correct nonword production across the NR, ML1, and ML2 tasks (group x word-length)

		Children with TLD	Children with SLI
2-syllable nonwords			
	M	29.62 (77.95%)	25.31 (66.61%)
	SD	5.52	6.23
3-syllable nonwords			
	M	26.54 (69.84%)	19.23 (50.61%)
	SD	7.1	7.77
4-syllable nonwords			
	M	18.46 (48.58%)	8.31 (21.87%)
	SD	6.63	4.94

In addition, as the nonwords became longer the rate of multiple errors increased with a higher percentage than the rate of single errors. When a child produced only one segment substitution, addition, or deletion in a nonword and the stress pattern and the order of the segments was correct then, the error was defined as a single error. When a child produced two or more of the above-mentioned errors, it was counted as a production with multiple errors.

Figure 2. Single versus multiple errors in tasks including nonword repetition.

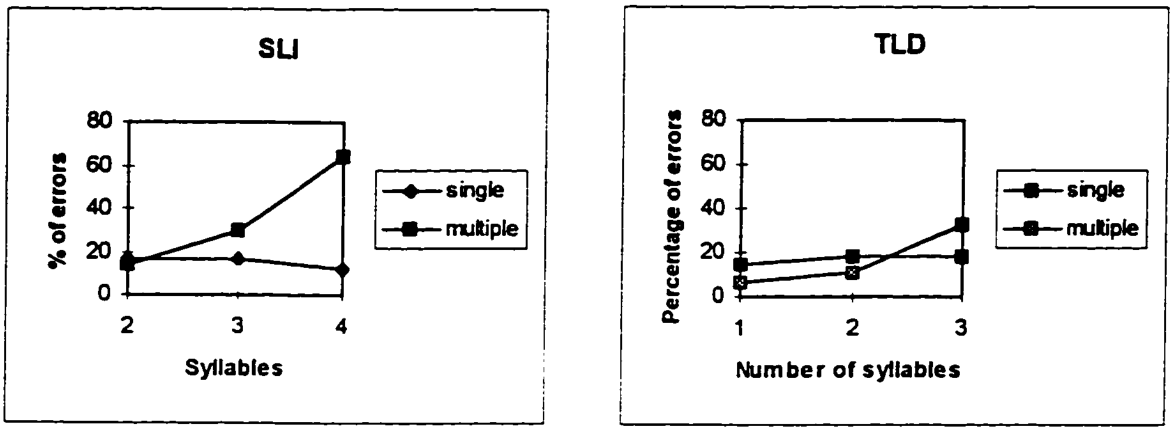
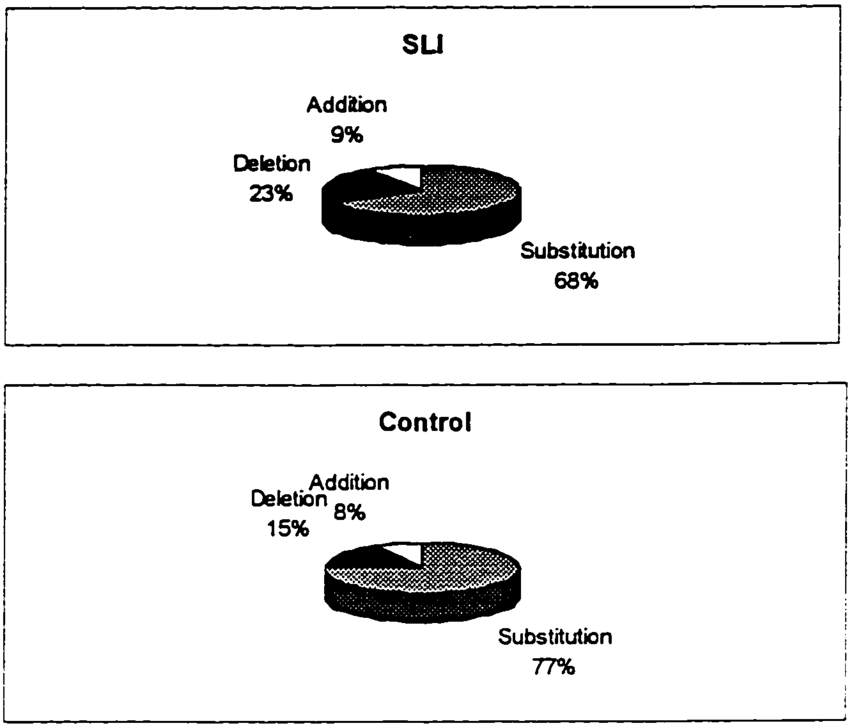


Figure 2 shows that multiple errors were more frequent in the productions of children with SLI than in those of the children with TLD as the length of the nonwords increased. Most of the errors were segment substitutions in both groups. The majority of the substitutions were substitutions of consonants with featural overlap between the substituted sound and the segment it replaced. Many segment substitutions involved assimilation, where children replaced one part of the nonword with another part of the same word.

Figure 3. The distribution of major error types.



Although the children with SLI made significantly more errors in nonword repetition across the different tasks, the error patterns are very similar for the two subject groups. The results of a more detailed error analysis, shown in Table 9, indicate further similarities.

Table 9

Detailed description of the types and rates of segment errors

	Children with TLD		Children with SLI	
	% of total errors	% of total segment production	% of total errors	% of total segment production
Vowel substitution	28%	2%	25%	4%
Consonant substitution	49%	4%	43%	4%
Cons. cluster simplification	5%	<1%	6%	<1%
Vowel deletion	3%	<1%	6%	<1%
Consonant deletion	3%	<1%	4%	<1%
Final consonant deletion	4%	1%	7%	<1%
Vowel addition	2%	<1%	3%	<1%
Consonant addition	6%	<1%	6%	<1%

The errors in Table 9 do not include word productions in which the children produced all the target segments but not in the correct order (e.g., 'neʃɪgɪd – 'negɪdɪʃ). The children with language impairment produced order errors in 6% of the total number of nonwords and this rate was 7% for the children with TLD. Both groups of children tended to produce correct stress pattern in the majority of their nonword productions. The language impaired children showed stress pattern changes in only 4% of all repeated nonwords and the typically developing children's stress errors were <1%.

List recall

All children performed better with the free and the liberal scoring methods than with the conservative. The results of repeated measures ANOVA indicated significant differences between the children with SLI and their peers with each scoring method ($F(1, 24) = 4.71$, $p < 0.05$ with the conservative method, $F(1, 24) = 6.75$, $p < 0.05$ with the liberal method, and $F(1, 24) = 11.01$, $p < 0.01$ with the free scoring method). The free scoring method revealed the largest difference between the two groups where children received credit for each correctly recalled word regardless of its serial order and serial position. The differences in the group x sentence type interaction were not reliable with any scoring methods ($F(2, 48) = 0.43$, $p > 0.05$ with the conservative method, $F(2, 48) = 1.31$, $p > 0.05$ with the liberal method, and $F(2, 48) = 0.77$, $p > 0.05$ with the free method). Post hoc Tukey tests ($p < 0.05$) showed differences for each sentence type between the groups. Thus, the children with SLI performed worse in recalling the final words of the syntactically simple sentences, complex short sentences, and complex long sentences.

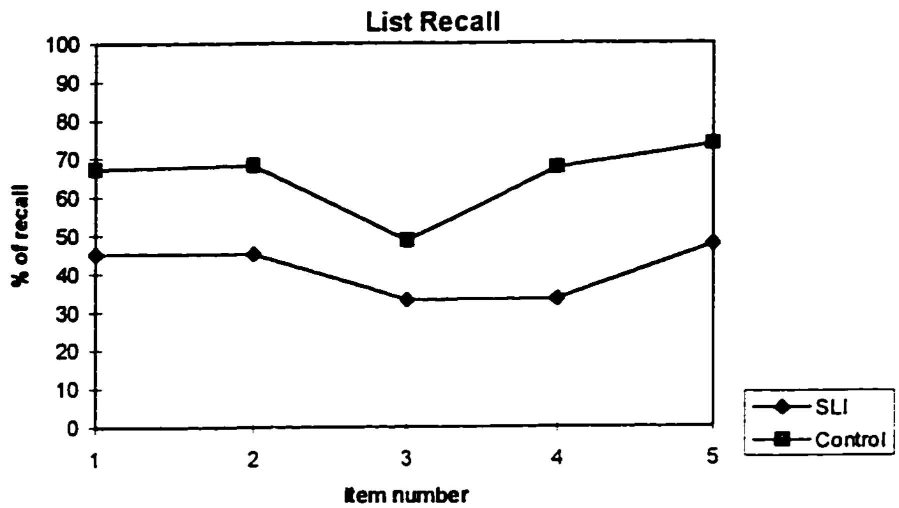
Table 10

Means and Standard Deviations for the List Recall task with the free scoring method (group x sentence type)

		Children with TLD	Children with SLI
Simple sentences			
	M	9.92(66.15%)	6.61(44.08%)
	SD	3.07	3.31
Complex short sent.			
	M	9.91(66.08%)	6.24(41.62%)
	SD	2.66	2.96
Complex long sent.			
	M	9.47(63.15%)	5.86(39.08%)
	SD	3.71	2.58

In addition, there was a significant primacy and recency effect only for the children with TLD. The typically developing children recalled significantly more words from the beginning and from the end of the lists than from the middle (F (4, 48) = 5.66, p < 0.001). In contrast, the number of correctly recalled initial and list final items did not differ significantly from the recall of the middle items for the language impaired children. However, Figure 5 shows a tendency toward primacy and recency effects for the children with language impairment too. Figure 4 also shows that there was no difference in the recall of the third and fourth items for the language impaired children while the children with TLD showed an increase in performance accuracy.

Figure 4. Primacy and recency effect in list recall.



The language impaired children had difficulty in remembering the serial order, the serial position of the words, and they also had more difficulty recalling the correct word regardless of its serial position. The results of the List Recall task also showed that both groups' overall performance was poorer with the conservative and liberal scoring systems than with the free scoring system. Thus, both groups' results indicated difficulty in memory for serial order and in memory for specific serial position.

Nonword Discrimination

The only task where we did not find any significant differences between the children with SLI and their typically developing peers was the Nonword Discrimination task (F (1, 24) = 0.21, p = 0.65). Both groups' performances showed a high percentage of correct responses with a decrease in discrimination of 4-syllable nonwords (word-length effect: F (2, 48) = 20.38, p < 0.001) The differences in the group x word-length were not reliable (F (2, 48) = 2.23, p > 0.05).

Table 11

Mean percentages of correct answers in the Nonword Discrimination task (group x word-length)

	Children with TLD	Children with SLI
2-syllable nonwords		
M	13.44(89.62%)	13.28(88.54%)
SD	1.83	2.08
3-syllable nonwords		
M	14.17(94.46%)	13(86.69%)
SD	0.93	2.23
4-syllable nonwords		
M	11.18(74.54%)	11.6(77.31%)
SD	2.86	1.69

CHAPTER 4: DISCUSSION

The children with SLI performed more poorly than their age-matched typically developing peers in each working memory task including production of nonwords and real words. Language impaired children had more difficulties in verbatim repetition of single nonwords as the length of the words increased. There was no difference in performance between the children with SLI and the children with TLD with 2-syllable nonwords, similar to the findings of Gathercole and Baddeley (1990). However, there were differences with 3- and 4-syllable nonwords. A word-length effect was found in all of our tasks.

The methods employed here to measure working memory capacity enabled us to examine both components of Baddeley's (1986) working memory model, the phonological loop and the central executive. Previous studies (Gathercole & Baddeley, 1990; van der Lely & Howard, 1993, Montgomery, 1995) have focused only on the phonological loop component. By using the traditional word and nonword repetition tasks these investigators were not able to examine the relationship between working memory and language abilities that children need to use in everyday communication (sentence comprehension, syntactic processing, interpreting the meaning of words, etc.). The methods used in this study enabled us to examine the impact of syntax.

All of these children performed more poorly on nonword repetition in sentence contexts than in the Nonword Repetition task. The effect of word-length and syntactic complexity in children with SLI suggested that these children had insufficient resources to execute the required processes in complex working memory tasks. Their poor results in nonword repetition, across the different listening tasks, indicated a limitation in storage capacity for working memory items rather than a combination of difficulty in encoding and analyzing the phonological structure of the nonwords. To support this conclusion, those results will be discussed first that rule out the deficit in encoding or analysis of the speech segments. Afterwards, the results that evidence a capacity limitation in children with SLI will be presented.

Nonword Discrimination

The language impaired children's performance in nonword discrimination ruled out the possibility of perceptual classification problems. The children with SLI performed as well as the children with TLD in discriminating nonwords of varying lengths. Although the findings in the literature concerning the discrimination abilities of children with SLI are contradictory, the results of this study suggest that the discrimination of nonwords is not impaired in children with SLI. As mentioned earlier, English is a language which has not many words that change in meaning when their stress is shifted. Thus, differentiating nonwords that differ only in their stress pattern is not an easy task. It requires precise encoding and analysis of the segment sequences. Because the children with SLI performed similarly to their peers in nonword discrimination, we can conclude that their poor performance in tasks combining nonword repetition and sentence comprehension was not reflecting encoding and discrimination difficulties. The fact that these children have been in speech-language therapy for years might have influenced their discrimination performance.

Nonword repetition across tasks

Performance accuracy decreased as task complexity increased. Children in both groups produced the nonwords more correctly in the Nonword Repetition Task than in the Modified Listening Tasks. The differences in performance accuracy across tasks indicated a capacity limitation rather than difficulties in planning and executing the speech motor program. The planning and execution requirements were equally demanding across tasks. However, there was an increase in capacity requirements for the ML1 and ML2 tasks which resulted in a decrease of performance accuracy. The ML1 and ML2 tasks required simultaneous processing from the children to perform symbolic computations while storing the word representations.

These findings are consistent with previous reports. Performance in adults also deteriorated with the increase of syntactic complexity because it required the temporary storage of word representations (King & Just, 1991). According to MacDonald, Just, & Carpenter (1992), working memory capacity constrains syntactic processing. In the present study, this was reflected in the performance deterioration when the sentences became syntactically more complex in the ML2 task. The children with SLI showed extreme difficulties in this task and performed below 50% accuracy. The notion of storage capacity limitations may also explain earlier contradictory findings on working memory performance in children with SLI. Gathercole & Baddeley (1990) found significant differences between children with SLI and their peers in repeating nonwords. Van der Lely & Howard (1993), however, did not find any differences between children with SLI and their age-matched peers in repeating nonwords and word lists. The tasks in the two studies differed in their working memory capacity requirements because most of the stimuli in the Gathercole & Baddeley study were multisyllabic words, whereas many of van der Lely & Howard's stimuli were CVC monosyllabic words.

These previous studies employed only nonword repetition which is a static measure of working memory capacity (Gaulin & Campbell, 1994). Adding a sentence context requires efficient allocation of resources; that may reveal more information about the relationship between working memory and language processes than the traditional repetition methods. The deterioration in performance with increased task complexity was greater for the children with SLI than for the children with TLD.

Phonological error analysis

The phonological error analysis results also support the conclusion that the locus of deficit in children with SLI is a limitation in working memory capacity rather than a deficit in encoding or in analysis of the segments. The children with SLI made more segment errors than the children with TLD. Montgomery (1995) also reported that children with SLI made more segment deletions and substitutions than their peers. Although the children with SLI produced more errors than the children with TLD, they showed similar error patterns to those of the children with TLD. The error analysis results suggest that the difference between the two groups was determined by their capacity limitations rather than by a difference in their computational abilities. If the SLI children's errors were qualitatively different, we would have to consider difficulties in encoding and analyzing the segments, and in certain computational functions. Because there were only quantitative differences between the two groups' phonological errors, the results suggest that they had comparable computational abilities.

The most common errors in both groups were segment substitutions with featural overlap between the substituted sound and the segment it replaced. Similar to the findings of Treiman & Danis (1988), children's substitutions were often a combination of the onset of one syllable and the rhyme of another. The rate of vowel and consonant substitutions was similar (vowels were substituted in 10% (SLI), 5% (TLD) of all vowel productions; consonants were substituted in 11% (SLI), 6% (TLD) of all consonant productions). In contrast, Hartley and Houghton (1996) found that consonants were more vulnerable to substitutions than vowels. This contradiction may be caused by the differences between the use of nonwords and real words. Many substitutions in this study were anticipatory or perseveratory assimilations, where one part of the nonword was influenced by another part of the same word. Order errors, where an entire syllable was recalled in a wrong serial position, were less common than segment errors at each word-length. This finding is consistent with the results of Treiman & Danis (1988) on one-syllable nonwords. However, it is different from the pattern typically observed with real words. A more detailed analysis of errors may provide information about phonological storage in children's working memory.

Answers to questions in the ML2 task

Children's answers to the questions following nonword repetition also revealed a limitation in storage capacity for the children with SLI. They performed more poorly than the children with TLD at each syntactic level, despite the simplicity of the questions (e.g., "What was the color of the car?", see Appendix B). The same children were able to answer more complex questions in the language screening test where the task demanded fewer working memory resources (i.e., there were no nonwords to be remembered). Maintaining information about the sentence while remembering and correctly producing the sentence-final nonword was too demanding for the language impaired children. The percentage of correct answers decreased when the sentences became more complex, consistent with the findings that the comprehension of complex sentences requires more working memory capacity than the comprehension of syntactically simple sentences (Daneman & Carpenter, 1980, MacDonald, Just, & Carpenter, 1992).

List Recall Task

Gillam, Cowan, & Day (1995) reported that language impaired children's memory performance reflected deficits in memory for serial order and in memory for specific serial position. In the present study both the children with SLI and the children with TLD showed difficulty in remembering the words' serial position and serial order in a list recall task where children were required to recall the sentence final words after sets of five sentences. The language impaired children's results differed significantly from the typically developing children's results with all scoring methods. This means that the language impaired children, unlike their peers, had not only difficulty in remembering the order and the position of the words, but also in remembering the words themselves.

In contrast, Gillam et al. (1995) found significant differences only with the conservative scoring method between children with SLI and their peers in a task using "suffixes". Their task required the children to recall lists of digits that were or were not followed by a "suffix" which was a 1-syllable nonword. They concluded that there was interference between the suffix presented at the end of the lists and the information that was essential to preserve serial position. Because the words that children needed to remember in this study were part of sentences, the same type of interference might have occurred between the information carried in the sentences and the words to be remembered. To perform simultaneous computations, resources were needed. If the storage of the nonword itself required a large amount of capacity, then it might have resulted in a shortage of symbolic computations. Consequently, the limitation in working memory capacity caused an interference between sentence comprehension and the storage of the nonwords.

The capacity limitation and the resulting interference are reflected in children's performance in the LR task. The children with SLI exhibited extreme difficulty with each scoring method in this task. Their performance revealed difficulty in remembering the correct order, the correct serial position, and the words themselves. The children with TLD also indicated difficulty in remembering the correct order with each sentence type. There were no significant differences in children's performance across sentence types in this task.

The limitation in capacity may be responsible for the diminished primacy and recency effects in SLI children's list recall. Primacy and recency effects were well expressed in the performance of children with TLD (see Figure 5). These children were more successful in remembering the list-initial and list-final words than the words from the middle of the lists. Their low scores with the conservative and liberal scoring methods reflected their difficulty in remembering the words from the middle of the lists and the words' serial order. In contrast, the language impaired children had difficulties at each serial position. Their low scores with each scoring method and the diminishment of the primacy and recency effects is consistent with the explanation that these children's storage capacity was overloaded by the resource requirements of the task.

The results of the first experiment revealed differences between and within groups. We had no language matched controls for the children with SLI because the language matched children would have been too young to perform the tasks including nonword repetition with sentence contexts. The results of a pilot study of eight 5-year old children suggested that they were able to perform in the Nonword Repetition and the Nonword Discrimination tasks, but had serious problems in identifying and repeating the sentence final words or word lists in sentence context. There were some noticeable differences in working memory performance even among the chronological age matched children, particularly in the Modified Listening tasks. This was the motivation to conduct a second experiment with typically developing children in different age groups.

CHAPTER 5: METHODS

Study 2

Participants

Three groups of typically developing children (6;9 - 8;3, 8;4 - 9;10, 9;11 - 11;5) participated in this experiment. The age range was 18 months within each age group (the boundaries of the age groups were determined by the ages of the participants). All children were selected following an interview with their teachers to assure that the children were typically developing. Each child participated in digit span testing using the Stanford-Binet Intelligence Test (Thorndike, Hagen, & Sattler, 1986) and in language screening using the CELF - 3, Screening Test (Semel, Wiig, & Secord, 1995). Their primary language was English.

None of the children exhibited articulatory errors, motor, emotional, or physical handicaps. The three groups consisted of 12 girls and 12 boys. Twelve out of these 24 children served as control children in our first study (6 form the first age group, 4 from the second age group, and 2 from the third age group).

Table 12

Participant profiles in Study 2

Subject	Age (mos.)	CELF screening	Digit span forward	Digit span backward
6;9-8;3 N=8				
M	92.13	18.38	5	3.25
SD	6.39	4.14	0.87	0.71
8;4-9;10 N=8				
M	111	24.88	5.75	4.5
SD	4.75	3.56	0.46	0.93
9;11-11;5 N=8				
M	129	26.63	6.13	4.13
SD	8.04	4.14	1.13	1.25

Stimuli and Procedures

The stimuli and procedures in Study 2 were identical to those in Study 1 because some of the children from this experiment served as controls for the children with SLI in the first experiment. In these cases the children's results were examined from two different perspectives.

CHAPTER 6: RESULTS

Overall, there were significant differences between the younger children's performance (6;9 - 8;3) and the performance of the other two groups of children (8;4 - 9;10 and 9;11 - 11;5) in most of the working memory tasks. There were no significant differences between the two older groups on tests including nonwords.

Nonword repetition under different conditions

Nonword Repetition Task

The results revealed no age differences in the Nonword Repetition task, where children were required to repeat single nonwords of different lengths (ANOVA with group x word-length, F (2, 21) = 2.49, $p > 0.05$). However, there was a word-length effect (F (2, 42) = 17.73, $p < 0.001$). Children's performance accuracy decreased as the length of the nonwords increased. There were not reliable differences in the group x word-length interaction (F (4, 42) = 0.088, $p > 0.05$).

Table 13
Means and Standard Deviations of correct words in the Nonword Repetition Task (group x word-length)

	6;9-8;3 Group 1	8;4-9;10 Group 2	10;11-11;5 Group 3
2-syllable nonwords			
M	6.14(76.75%)	7.51(93.88%)	7.26(90.75%)
SD	0.98	1.05	0.88
3-syllable nonwords			
M	5.15(64.38%)	6.29(78.63%)	5.89(73.63%)
SD	1.64	1.44	1.8
4-syllable nonwords			
M	4.03(50.38%)	4.9(61.25%)	4.77(59.63%)
SD	1.61	1.63	2.38

Modified Listening Task 1

A significant main effect for age occurred in the ML1 task, where the nonwords were at the end of sentences. The results of a repeated measures ANOVA (group x sentence type x word-length) showed significant differences with all sentence types (F (2, 69) = 11.15, p < 0.001). Post hoc Tukey tests (p < 0.05) indicated that the children in Group 1 performed more poorly than the older children and there were no significant differences between the performances of Group 2 and Group 3. There was also a word-length effect in the ML1 task (F (2, 138) = 47.32, $p < 0.001$), however, the differences in the group x word-length interaction were not reliable (F (4, 138) = 1.2, $p > 0.05$).

Table 14

Means and Standard Deviations of correct nonword repetition in the ML1 task (group x sentence type)

	Group 1	Group 2	Group 3
Simple sentences			
M	6.13 (40.83%)	10.5 (70%)	13.13 (87.5%)
SD	3.22	3.12	2.64
Complex short sentences			
M	7.5 (50%)	8.75 (58.33%)	11 (73.33%)
SD	3.56	3.67	3.41
Complex long Sentences			
M	8.88 (59.17%)	11.38 (75.83%)	13.13 (87.5%)
SD	3.67	3.21	2.47

Modified Listening Task 2

Similar to Experiment 1, children's productions in the ML2 task were examined in two ways; nonword repetition accuracy and answers to the questions.

Nonword repetition accuracy in the ML2 task

The children in Group 1 performed less well with each sentence type than the children in Group 2 and Group 3 (ANOVA with group x sentence type x word-length, F (2, 69) = 10.67, $p < 0.001$) . Post hoc Tukey tests ($p < 0.05$) showed that the differences between the groups became more definite as the number of the syllables in the nonwords increased. There was a word-length effect for each group (F (2, 138) = 47.95, $p < 0.001$). The differences in the group x word-length and group x sentence type interaction were not reliable (F(4, 138) = 0.94, $p > 0.05$, F (4, 138) = 1.29, $p > 0.05$).

Table 15

Means and Standard Deviations for the ML2 task (group x sentence type)

	Group 1	Group 2	Group 3
Simple sentences			
M	8.13(54.17%)	10.75(71.67%)	11.38(75.83%)
SD	3.85	2.83	2.82
Complex short sentences			
M	8.5(56.67%)	11.75(78.33%)	11(73.33%)
SD	4.37	2.11	2.83
Complex long Sentences			
M	8.5(56.67%)	12(80%)	13.13(87.5%)
SD	2.79	2.37	2.06

Answers to the questions in the ML2 task

An age effect was also reflected in the number of correct answers to the questions following nonword repetition with each type of sentences in the ML2 task (ANOVA with group x sentence type x word-length, F (2, 69) = 10.43, $p < 0.001$). Post hoc Tukey tests ($p < 0.05$) revealed significant differences only between the performance of Group 1 and the older children.

The effect of syntactic complexity on performance accuracy was reflected in the differences in correct answers following nonword repetition across sentence types (F (2, 138) = 25.87, p < 0.001). There were no reliable differences in the group x sentence type interaction (F (4, 138) = 1.1, p > 0.05).

Table 16

Means and Standard Deviations for correct answers in the ML2 task (group x sentence type)

	Group 1	Group 2	Group 3
Simple sentences			
M	11.13 (74.17%)	13.75 (91.67%)	13.5 (90%)
SD	4.4	1.95	0.02
Complex short sentences			
M	7.88 (52.5%)	9.5 (63.33%)	11.13 (74.17%)
SD	4.15	2.4	3.06
Complex long sentences			
M	8.63 (57.5%)	11.63 (77.5%)	12.63 (84.17%)
SD	4.93	2.68	2.1

The combined scores of those test items where the children correctly repeated the nonwords and correctly answered the corresponding questions revealed an age effect (F (8, 56) = 8.47, p < 0.0001). Post hoc Tukey tests (p < 0.05) indicated that the younger children performed more poorly than the children in the two older groups at each syntactic level. Figure 6 shows the relationship between correct nonword repetition and correct response to the following question per group. There are only two children from the youngest group who performed above 50% in both nonword repetition and answering correctly the questions, whereas none of the older children performed under 50%. In addition, there are five children from Group 3 and two children from Group 2 whose percentage of correct responses was above 75%.

<u>Figure 5.</u> Number of correct nonword (y) and correct answer to the following question (x) in the ML2 task.

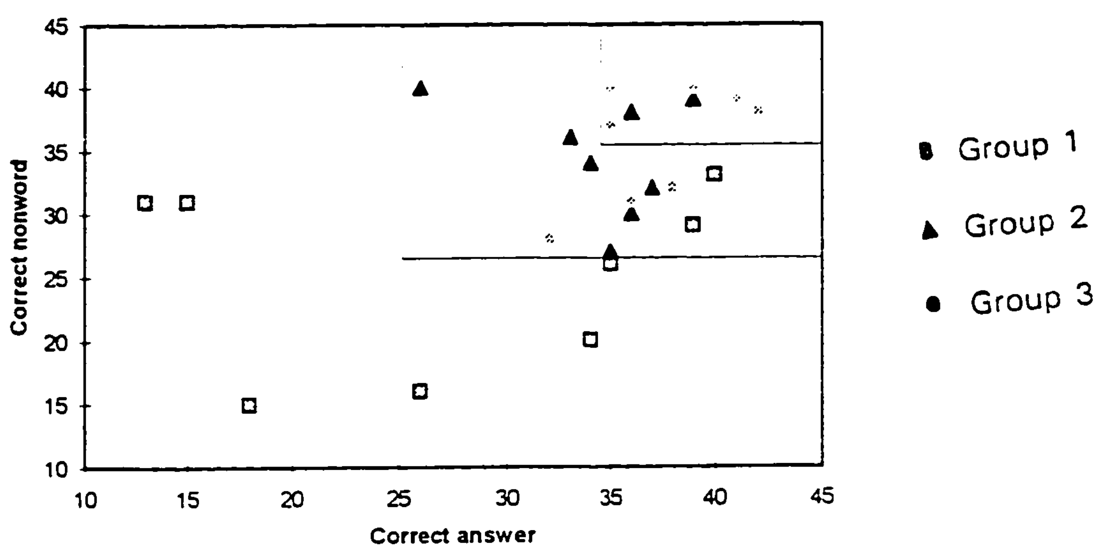


Table 17

Means and standard deviations of combined scores in the ML2 task (group x sentence type)

	Group 1	Group 2	Group 3
Simple sentences			
M	6.24 (41.63%)	9.75 (65%)	10.52 (70.13%)
SD	3	2.33	1.92
Complex short sentences			
M	4.35 (29%)	7.61 (50.75%)	8.36 (55.75%)
SD	3.26	1.18	3.08
Complex long sentences			
M	4.86 (32.38%)	9.26 (55.75%)	11.36 (75.75%)
SD	2.76	3.08	1.09

List Recall

The same scoring system was used as in Experiment 1. An age effect occurred with all three scoring methods. The children in Group 1 performed more poorly than the children in the two other groups (ANOVA with group x sentence type, F (2, 21) = 4.75, $p < 0.05$ with the conservative method, F

(2, 21) = 4.87, $p < 0.05$. with the liberal method, and F (2, 21) = 9.99, $p < 0.001$ with the free scoring method). Post hoc Tukey tests ($p<0.05$) revealed performance differences between Group 1 and Group 3 with the conservative and the liberal scoring methods, and differences between Group 1 and 2, and Group 1 and 3 with the free scoring method. Performance accuracy increased with age. The results suggested that the children in Group 1 had more difficulties in memory for serial order, in memory for specific serial position as well as in remembering the words themselves. Thus, the results revealed that the storage of the serial order and the serial position develops with age. There were no differences across sentence types and in the group x sentence type interaction with any of the scoring methods ($p > 0.05$).

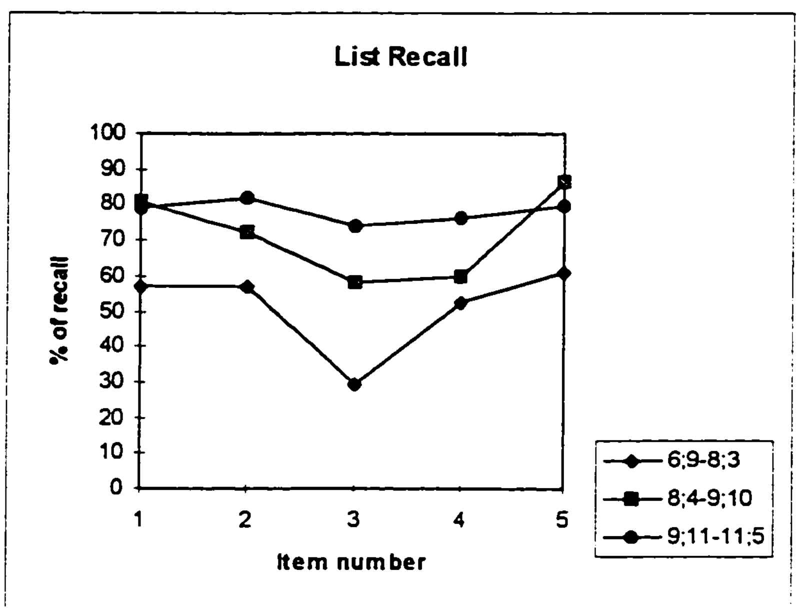
Table 18

Means and Standard Deviations for the List Recall Task (group x sentence type)

	Group 1	Group 2	Group 3
Conservative method			
M	2.71(18.04%)	4.91(32.75%)	8.09(53.92%)
SD	3.97	3.85	4.54
Liberal method			
M	3.74(24.96%)	6.5(43.34%)	9.38(62.54%)
SD	3.97	3.85	4.54
Free method			
M	7.7(51.33%)	10.66(71.08%)	11.95(79.67%)
SD	2.74	1.92	2.01

A comparison of the correctly recalled item numbers, regardless of sentence type and scoring method, revealed that the children in Group 1 recalled fewer items correctly than the children in Group 2 and Group 3 ($F(2, 8) = 15.96$, $p < 0.01$). The performance of the two groups of older children showed a slight difference (see Figure 7), but this difference was statistically not significant. However, they differed in the aspect of primacy and recency effects. Figure 7 shows well expressed primacy and recency effects for the two younger age groups. These children's performance accuracy was significantly better for the initial and final items than for the items in the middle of the lists (F (4, 28) = 3.79, $p < 0.05$ for Group 1 , F (4, 28) = 4.04, $p < 0.05$ for Group 2). The children in the oldest group recalled the items in different positions equally well. Their performance was around 80% for each item. This percentage of correct recall may be close to a ceiling effect which may have diminished the preferences for list initial and list final items.

Figure 6. Correct item recall across age groups.



Nonword Discrimination

The results of the Nonword Discrimination Task did not show significant differences across age groups (ANOVA with group x word-length, F (2, 21) = 1.54, $p > 0.05$). Each group gave a high percentage of correct answers at each word-length. There was a word-length effect for both groups (F (2, 42) = 10.39, p < 0.001). Post hoc Tukey tests (p < 0.05) revealed differences between the 2 and 4, and the 3 and 4-syllable nonwords. The differences in the group x word-length interaction were not reliable (F (4, 42) = 0.43, p > 0.05).

Table 19

Means and standard Deviations for the Nonword Discrimination Task (group x word-length)

	Group 1	Group 2	Group 3
2-syllable words			
M	6.52 (81.5%)	6.77 (84.63%)	7.5 (93.88%)
SD	1.76	1.47	1.05
3-syllable words			
M	7.03 (87.88%)	6.89 (86.13%)	7.88 (98.5%)
SD	0.91	1.87	0.34
4-syllable words			
M	5.43 (67.88%)	6.15 (76.88%)	6.64 (83%)
SD	2.1	1.36	1.06

CHAPTER 7: DISCUSSION

The results of Experiment 2 support the idea that children's working memory performance is determined by capacity. Working memory capacity develops with age.

Nonword Discrimination

The results of the Nonword Discrimination Task showed that none of the children had encoding difficulties. They were able to discriminate word pairs that differed in their stress pattern only. As mentioned earlier, the changes of the stress pattern in words containing the same segments is not very common in English. This task required precise encoding and segment analysis from the children.

Although the children showed no encoding difficulties, the question still remained whether children's performance reflected speech planning and executing problems or working memory capacity limitations. The results of the Nonword Repetition task revealed information on planning and executing the speech motor program.

Nonword Repetition

There were no differences in verbatim nonword repetition among the three groups which is consistent with the findings of Bishop, North, & Donlan (1996) who reported no age differences in nonword repetition between 7- and 9-year old typically developing children. The results of this task ruled out a deficit in speech motor planning and execution. Single nonword repetition required less resource allocation than the tasks where the nonwords had sentence contexts (but the participants did not show a ceiling effect). A word-length effect in the Nonword Repetition task and the differences in performance accuracy between the Nonword Repetition task and the Modified Listening tasks, reflected a working memory capacity limitation.

Nonword repetition in the Modified Listening tasks

The increase in task demands and the concomitant increase of working memory resource requirements resulted in an age effect. The children in Group 1 performed more poorly than the children in Group 2 and in Group 3 in nonword repetition on both Modified Listening tasks. The younger children showed more difficulties at each syntactic level; they exhibited difficulties in repeating the nonwords even with the simple sentence contexts. The children in Group 2 and in Group 3 seemed to have a larger amount of working memory capacity to maintain multiple representations and execute simultaneous processing. All children exhibited a word-length effect as the demands of the tasks increased.

Although performance accuracy decreased when the nonwords became part of sentences, nonword repetition accuracy did not differ across sentence types. There may be several reasons for this finding. One explanation may be the source of sentences. The sentences for this study were selected from books for 7 to 10-year old children, thus, they were less complex than those used in adults' studies. Tasks combining sentence comprehension and nonword repetition were demanding on working memory resources in a different way than the traditional reading span tasks. Children in this study could not use their lexical knowledge in nonword recall, whereas the recall of real words in the reading span tasks is supported by the individuals' long term lexicon. Another reason might be that many studies that focused on the relationship between sentence comprehension and working memory performance accuracy in adults have measured reading or listening spans. The results indicated differences in processing time (e.g. King & Just, 1991; MacDonald et al., 1992). We did not measure children's processing times across the different sentences.

Answers to the questions in the ML2 task

The ML2 task required simultaneous processing when the children repeated the nonwords and stored the information about the sentence content. The answers to the questions revealed an age effect in performance at each sentence level. The children in Group 1 showed more difficulties than the children in Group 2 and in Group 3 in storing information about any sentences while remembering the final nonwords. Group 2 and Group 3 did not differ in this task.

In contrast to nonword repetition accuracy, the analysis of correct answers in the ML2 task revealed a decrement in performance as the syntactic complexity of the sentences increased. These results support the notion of Carpenter, Miyake, & Just (1994) that working memory capacity limitations influence the operation of symbolic computations which are required in complex sentence comprehension.

List Recall

The List Recall Task revealed an age effect with all the scoring methods; performance accuracy increased with age. The children in Group 1 had difficulties in storing the words themselves, their serial order, and their serial position. Paying attention to the sentences, remembering the final word, and recalling the words from the list in their proper order placed too many demands on working memory capacity for the children in Group 1. The older children (Group 2 and 3) seemed to have a larger pool of operational resources indicated by a high percentage of correct responses with the free scoring method. The results revealed that the storage of the words, their serial order, and their serial position improves with age.

In contrast to the results of Group 1, the Group 2 children's performance accuracy in remembering the words themselves was relatively high, but they had difficulties in remembering the correct serial order and serial position of the stimuli. This was reflected in the results with the liberal and conservative methods where only Group 1 and Group 3 differed significantly. The results of Group 3 revealed the highest performance accuracy. There was no significant difference between Group 2 and 3 in the number of correct items recalled. Similarly, Gaulin & Campbell (1994) did not find age differences between 10- and 12-year olds with an adaptation of the original reading span task (Daneman & Carpenter, 1980), using syntactically simple sentences.

There was an age effect in the examination of primacy and recency effects. The children in Group 1 and in Group 2 showed significant differences in recalling the list initial, final, and middle items. The children in

Group 3 did not reveal primacy and recency effects, their performance accuracy was high with each item.

General discussion

The results of the two experiments support the notion that children's working memory capacity, measured by tasks combining nonword repetition and sentence comprehension, influences their integrated language performance. Tasks combining nonword repetition and sentence comprehension measure the contribution of both the phonological loop and the central executive component in language tasks. Thus, they reflect the dynamic nature of working memory and individual working memory differences more accurately. They also provide more information about the relationship between working memory and language processes than the traditional word and nonword repetition tasks.

The results across tasks revealed that an increase in working memory load results in a reduction of resources. The remaining resources showed individual variations between and within groups. These variations might have occurred because of differences in the maximum amount of activation available. Alternatively, the same working memory load might have occupied a different amount of working memory capacity in different individuals. The analysis of individual variations within groups was beyond the aim of the present study, however, it is of interest for further research. There is evidence in the literature on individual differences in reading span tasks among adults (e.g., Daneman & Carpenter, 1980, King & Just, 1991, MacDonald, Just, & Carpenter, 1992,).

In summary, the results of both experiments revealed that an increase in working memory demands results in a decrease in performance accuracy in language related tasks. The first experiment evidenced that children with language impairment have limited working memory capacity. Their performance differed significantly from their peers' when sentence comprehension and word repetition were combined. The tasks measuring the contribution of different working memory components reflected more truly the resource requirements of everyday language use than the traditional repetition tasks. They provided a clearer picture about the relationship between working memory and language processes, however, they did not indicate the direction of causality.

The overall results of the second experiment suggested that simultaneous processing, which is needed to perform symbolic computations, improves with age. This was evidenced by age effects across working memory tasks with different working memory demands.

Directions for further research

Further research focusing on individual differences may contribute to our understanding of working memory's role in children's language performance. One effective way of studying the relationship between working memory and language processes is to use tasks that measure the contribution of both the phonological loop and the central executive component in language processes. However, we noticed some limitations in the methods employed in this study. In traditional reading and listening span tests the sentences are followed by questions (e.g., true or false questions) preceding word repetition. The participants need to pay close attention to the content of the sentences while storing the words to-be-remembered. Because this study employed tasks with nonwords, the questions followed nonword repetition. When the questions preceded the repetition, in a pilot study, children were not able to remember the nonwords. However, when the questions followed nonword repetition, repetition accuracy did not change across sentence types. The percentage of correct answers to the questions did reflect the influence of syntactic complexity on performance accuracy.

A more detailed examination of children's phonological errors in nonword repetition under different conditions may provide further information about the way of storing and occupying verbal input in working memory. The analysis of children's errors in a nonword repetition task where they repeat the same nonword several times, may reveal further information about the way of storage and deterioration with time. Some children needed more trials to produce the nonword. In these cases the form of the word kept changing with each repetition (e.g., bɪ'piməʃɪd - bɪ'mipəʃɪ - bɪ'miʃɪʃɪ) . The comparison of phonological errors in real words and in nonwords could provide a clearer picture about the computational functions involved in working memory performance.

In addition, attention span seems to play a very important role in performing different working memory tasks. Further research needs to take into consideration the contribution of attention capacity in the performance of working memory tasks.

Appendix A

Nonword Repetition (2-, 3-, 4-syllable nonwords in pseudo random order)

gλflɛ'tabən	rə'bɛf	'kird λʃ
'blimafət	'gilɔsəp	ʃɛ'pimλdɪt
pɔ'voul	pɔlətrə'puθ	'fubət
kɪ'rimət	dɔ'fuʃɪd	lλtə'ʃɪd
fo'kuʃəmɪk	'gapəd	rə'kus
'lulλm	ðɔsəbɪ'peik	'salɪməlɔm
pɛklɪ'muk	pɔlλ'fumkλ	dλʃ'mid
'bulətəpɪd	drə'funəθ	trɛbλ'puθ

Appendix B

Modified Listening Task 1, Modified Listening Task 2

(30 syntactically simple sentences, 30 syntactically complex short sentences, 30 syntactically complex long sentences in random order)

1-45

6/ A canary is a small ðɔ'peik.

Is the canary a big ðɔ'peik?

cs/43/ Mom was who got the rose for 'bilɔmɪk.

What did mom get?

24/ We have a big house in ʃə'funəp.

What is in ʃə'funəp?

cl/6/ Kangaroos' defense against their enemies depends on their keen sense of sight, smell, and 'kɛlət.

What kind of animals use their sense of sight and smell in defense against their enemies?

29/ The bunnies began bɪ'piməʃɪd.

Who began bɪ'piməʃɪd?

cl/38/ Anna leaned over to get a life jacket and fell into the cold mountain stream when we were trɛ'voulɔm.

What happened to Anna?

31/ The fire truck heads to 'sarəfəlɔm.

What kind of truck heads to 'sarəfəlɔm?

cs/31/ That is the one Bill likes in mɛklɪ'tus.

Does Bill like many things in mɛklɪ'tus?

cl/25/ The teacher asked what the silly story about the three little kittens was supposed to mean in our pɛθə'tanəp.

What was the story about?

33/ Tom washes the 'pɛrɪnɛʒ.

Who washes the 'pɛrɪnɛʒ?

cs/32/ I tried but could not do flɪgəbə'tup.

Could I do flɪgəbə'tup?

39/ Molly hates the big fat flɪ'peik.

What kind of fIIPpeik does Molly hate?

cl/18/ Benjamin wants to stay at home today and we do not know why is he so plɪnɪ'sat.

What does Benjamin want to do?

cs/1/ Tom promised Joe to leave his spɛdə'muk.

What are the names of the two boys?

21/ Babies are very 'θigəlɛməp.

Who are 'θigəlɛməp?

cs/19/ I love the way Rob sees dʌʃ'voulɔmik.

Who sees dʌʃ'voulɔmik in a lovely way?

27/ Every country has a 'neʃɪgɪd.

Does each country have a 'neʃɪgɪd?

cs/27/ I need Mark to go for me in spæ'dɛʒ.

Who will go for me in spæ'dɛʒ?

19/ Many children like fʊ'sapəmɛg.

Do children like fʊ'sapəmɛg?

cs/28/ Jill asked Paul to make a 'rikətʌdɪt.

Does Jill want a 'rikətʌdɪt?

cl/28/ I saw that the purple car was hit by the yellow truck and turned over to trɛ'biməs.

What was the color of the car that was hit by the truck?

cs/34/ Sue likes Joe who is ʼplikʎʃəmər.

Who is ʼplikʎʃəmər?

cl/40/ Next time we will all remember to put on our life jackets before we get in the rɪʼbuʒ.

What will we put on next time?

cs/39/ Ron lives where Sue would like to ʼlibɛf.

Who wants to ʼlibɛf?

cl/41/ The children followed a little bird through a field of tickly flowers that made them giggle and gɛʼfus.

What made the children giggle?

18/ Mary turned off the drɪʼfut.

Did Mary turn on the drɪʼfut?

cs/44/ My hat is what always gets kɛrsəʼmid.

What is getting kɛrsəʼmid?

26/ Kelly likes to play drɪʃəkəʼbef.

Who likes to play drɪʃəkəʼbef?

cl/1/ A crab spider grabs insects when they land on the colorful ʃɛsəməʼdi.

What do the crab spiders grab?

36/ Joseph reads a səvouʼpuθ.

What does Joseph do?

cl/2/ Vincent has a great brother even if he does not like klisəʼkirbən.

Does Vincent have a brother or sister?

cs/40/ Mary asked if Jim was ʼkuʃɔm.

Who did Mary ask about?

cl/8/ A baby kangaroo is called a "joey" and lives in the mother's pouch, where it stays for about six months after klɪ'mim.

Where does the baby kangaroo live?

28/ The little bird whistled 'mɛkrɪn.

Was the bird sleeping?

cl/14/ Robin Hood was a thief who stole from the rich and gave what he stole to the poor and spə'lusət.

Did Robin Hood help the poor?

cs/26/ Jack told Jim what to do with a 'nɛbəʒ.

Who knows what to do with a 'nɛbəʒ?

cl/15/ The king was mad because he did not want Robin Hood, a thief, to be a hero in trɛ'pimʊlət.

Was the king happy?

cs/3/ Brett wants Bob to work on gɛ'fusəpəm.

Who should work on gɛ'fusəpəm?

41/ The conductor blows his gʌ'voumət.

How does the conductor signal?

cs/38/ What Jim wrote was 'gibɛʒɪg.

Did Jim write anything?

cl/26/ Jonathan is the boy in our class that everyone who meets likes a lot because of his 'tɔʃɪg.

Do people like Jonathan?

cs/24/ Bill thinks that Sue likes 'pɔlʌm.

What is the boy's name?

cl/31/ I saw what the artist who painted that large picture ate for 'taləmɪk.

Who painted the large picture?

34/ Sam feeds the rɪn'voup.

Is Sam eating?

cl/42/ The children took turns throwing the ball until it fell into some tall sɪgλ'furɪn.

What did the children play?

46-90

2/ Mary went to the pɛθə'tanəp.

Who went to the pɛθə'tanəp?

cs/33/ Ann tickled the baby who was gɛ'fus.

Who tickled the baby?

cl/24/ The thieves wanted to know who would bring the treasures back to the castle after the rɪn'voup.

Where did the treasures belong?

9/ Sharon dances to the 'plikλʃəmər.

What does Sharon do?

cl/12/ When the raccoon heard the squirrel's cry, he ran as fast as he could to the 'pɛrɪnɛʒ.

Who ran to the 'pɛrɪnɛʒ?

16/ Lauren's house is flɪgəbə'tup.

What is flɪgəbə'tup?

cs/14/ The deer hunted by the men was drɪ'fut.

What did the men do?

23/ Rabbits eat red 'taləmɪk.

What kind of 'taləmɪk do rabbits eat?

37/ Sam walked slowly to spæ'dɛʒ.

Did Sam run to spæ'dɛʒ?

cs/23/ The girl who the man watched had ʃə'funəp.

What was the man doing?

5/ Beth wrote a story in trɛ'pimʊlət.

What did Beth do?

cl/19/ Let Rebecca close the two gates so the red and blue trains will not come out from the 'libɛf.

What are the colors of the trains?

44/ A plane needs strong 'bilɔmɪk.

What has strong 'bilɔmɪk?

cl/7/ My favorite story is about a dog who helped a monkey that was in trouble with a bɪ'piməʃɪd.

Who was helpful?

cs/6/ Joe who saw the crash, ran to trɛ'voulɔm.

Who did run to trɛ'voulɔm?

43/ Jim is going to plɪnɪ'sat.

Is Jim staying?

cs/8/ Brett who had no food was gʌ'voumət.

Who was gʌ'voumət?

7/ Spiders spin webs of 'nɛbəʒ.

What do spiders spin?

cl/32/ The old woman dressed as a young girl looked quite ridiculous in her 'gibɛʒɪg.

Who looked ridiculous?

cs/9/ The mouse chased by the cat is flɪ'peik.

What did the cat do?

cl/30/ The teacher knows that the children in the movie about the dinosaurs liked the gɛ'fusəpəm.

Who knows what the children liked?

cs/30/ I wonder who Joe called from trɛ'biməs.

What did Joe do?

cl/33/ Captain Ronald decided that Benjamin would lead the parade at 'sarəfəlɔm.

Who will lead the parade?

15/ Tom did not eat the ʃɛsəmə'di.

Did Tom eat the ʃɛsəmə'di?

cs/22/ The man helped by the girl wore 'mɛkrɪn.

Who wore 'mɛkrɪn?

cl/45/ All the children loved the man with the black umbrella because he was such a wonderful 'neʃɪgɪd.

What was the color of the umbrella?

11/ Spiders climb on kɛrsə'mid.

What kind of animals climb on kɛrsə'mid?

cs/16/ The doctor watched by Beth was səvou'puθ.

What did Beth do?

17/ The car stopped at the spə'lusət.

What happened to the car?

cs/35/ Jim pushed Ann who fell and drɪʃəkə'bef.

What did Jim do to Ann?

cl/29/ I know what the book about the endangered animals discussed in the ðɔ'peik.

What was the book about?

cs/42/ Jack seems to want to klisə'kirbən.

Who wants to klisə'kirbən?

cl/27/ The silly boy hugged the girl with the flowers and kissed the baby in the spɛdə'muk.

Who kissed the baby?

cs/45/ Bill liked the party given by 'kɛlət.

What did Bill like?

cl/4/ The stolen money was given to anyone who was poor or 'rikətʌdɪt.

What kind of money was given to the poor?

14/ Firemen save 'tɔʃɪg.

Who saves 'tɔʃɪg?

cl/13/ Ann is glad that she and Bill are in line to go on the roller coaster after dʌʃ'voulɔmik.

What are Ann and Bill doing?

cs/12/ Bob who pushed the cat was 'θigəlɛməp.

Who pushed the cat?

cs/4/ Sue told Jim to leave the sɪgʌ'furɪn.

Who wants Jim to leave the sɪgʌ'furɪn?

cl/17/ I will try to get grandmother's rocking chair for you to sit on after mɛklɪ'tus.

What am I going to do?

cl/21/ The little boy is bumping the truck while he is watching the children push their trucks in the 'pɔlʌm.

Who watches the children?

cs/20/ I made the car work with fʊ'sapəmɛg.

Does the car work?

cl/39/ Peter quickly grabbed a life jacket and threw it out to help Anna when she was ˈkuʃɔm.

How did Peter help Anna?

35/ The doll crashed to the rɪˈbuʒ.

What happened to the doll?

8/ Girls do not like to play klɪˈmim.

Is klɪˈmim girls' favorite game?

Appendix C

List Recall

Syntactically simple sentences (3X5)

1/ Dad washed the car last night.

3/ The baseball players lost their game.

4/ Today is the first day of school.

10/ The flowers are yellow.

30/ The man drives the truck.

13/ Bill is waiting for the bus.

20/ Red is my favorite color.

22/ The school guard helps the children.

25/ Computer games are fun.

12/ Sam has a new desk.

42/ Trains go from city to city.

32/ The pumper truck is black.

38/ Jack never drinks coke.

40/ Sue likes my toys.

45/ Buses carry people.

Syntactically complex short sentences (3X5)

cs/11/ Ask the man who plays with the ball.

cs/2/ Dad told me to give him the bread.

cs/7/ The city near New York is big.

cs/5/ The dog saw the cat chasing the mouse.

cs/10/ The boy who watched the baby was happy.

cs/29/ She drank it like it was soda.

cs/15/ The boy scratched by the cat was sick.

cs/17/ I will make the ball stay on that shelf.

cs/18/ Watch me run the car.

cs/21/ The girl who helped the man had red hair.

cs/25/ Joe ate the soup that went cold.

cs/37/ We can leave if Bill gets back on time.

cs/41/ I like the way Mom bakes cookies.

cs/13/ The girl helped by the man was safe.

cs/36/ The cat ate the plastic like it was food.

Syntactically complex long sentences (3X5)

cl/3/ Sometimes I wish I did not have to clean my room every week.

cl/5/ I needed three guesses until I learned what the content of those boxes was.

cl/35/ The children think that Jacob is always being picked on by our teacher.

cl/10/ The elephant risked his life to save the squirrel who could not swim.

cl/11/ He lives in a small house, but he has plenty of room to play.

cl/16/ The teacher loved by the students was very knowledgeable and nice.

cl/20/ The boy carrying the big truck is watching the girl who pulls the boat.

cl/22/ Jonathan remembered the homework in English was easy to write.

cl/23/ Robin Hood wanted to know if his men would bring us back to the forest.

cl/34/ It was finally decided for Harry to receive the green bicycle and Joanne the yellow roller skates.

cl/9/ Even though I forgot to study, I still did well on the test.

cl/36/ There was so much camping gear that the children had to get behind Daddy and push to make it all fit into the car.

cl/43/ The little rabbit who ran into a gooseberry net got caught by the large buttons on his coat.

cl/44/ The young deer who was hunted by the men never stopped running or looked behind him till he got home.

cl/37/ While everyone helped prepare dinner, Grandpa spoke to the children.

Appendix D

Discrimination of nonword pairs

dλʃ'mid	'dλʃmɪd	'bulʊtəpɪd	bulutə'pid
pɛklɪ'muk	pɛk'limʊk	'gaped	ga'ped
ðɔsəbɪ'peik	'ðɔsəbɪpeik	pɔ'voul	'pɔvoul
trɛbλ'puθ	trɛ'bλpʊθ	pɔlətrə'puθ	pɔlətrə'puθ
rə'bɛf	rə'bɛf	lλtə'ʃid	lλtə'ʃid
'lulλm	lu'lλm	bi'puk	'bipuk
fɔ'kuʃəmɪk	'fɔkuʃemɪk	'salɪməlɔm	salɪmə'lɔm
'blimǝfǝt	'blimǝfǝt	'fubǝt	'fubǝt
'kirdλʃ	kir'dλʃ	ʃɛ'pimλdɪt	ʃɛ'pimλdɪt
gλ flɛ'tabən	gλ f'lɛtabən	kɪ'rimət	'kirɪmət
dɔ'fuʃɪd	'dɔfuʃɪd	tɛ'rimλ	' tɛrimλ
drə'funəθ	drə'funəθ	pɔl λ'fumk λ	pɔ'l λfumk λ

References

American Speech-Language-Hearing Association. (1990). Guidelines for screening for hearing impairment and middle ear disorders. ASHA, 32 (Supplement 2), 17-24.

Baddeley, A. D. (1986). The articulatory loop. In A. D. Baddeley (Ed.), Working Memory (pp. 75-101). Oxford Science Publications.

Baddeley, A. D. (1996). The fractionation of working memory. Proc. Natl. Acad. Sci. USA, 93, 13468-13472.

Baddeley, A. D., Thomsons, N., & Buchaman, M. (1975). Word-length and the structure of working memory. Journal of Verbal Learning and Verbal Behavior, 14, 575-589.

Bishop, D. V. M., Donlan, C., & North, T. (1996). Nonword repetition as a behavioral marker for inherited language impairment: Evidence from a twin study. Journal of Child Psychology & Psychiatry, 37, 391-403

Carpenter, P. A., Miyake, A., & Just, M. A. (1995). Language comprehension: Sentence and discourse processing. Annual Review of Psychology, 46, 91-100.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behavior, 19, 450-466.

Dollaghan, C. A., Biber, M. E., & Campbell, T. F. (1993). Constituent syllable effects in a nonsense-word repetition task. Journal of Speech and Hearing Research, 36, 1051-1054.

Dollaghan, C. A., Biber, M. E., & Campbell, T. F. (1995). Lexical influences on nonword repetition. Applied Psycholinguistics, 16, 211-222.

Gathercole, S. E. (1995). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. Memory and Cognition, 23, 83-94.

Gathercole, S. E., & Baddeley, A. D. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. Journal of Memory and Language, 28, 200-213.

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? Journal of Memory and Language, 29, 336-360.

Gathercole, S. E., & Baddeley, A. (1993). Working memory and language. Hove , UK: Lawrence Erlbaum Associates Ltd.

Gathercole, S. E., Willis, C. S., & Baddeley, A. (1991). The influences of number of syllables and word-likeness on children's repetition of nonwords. Applied Psycholinguistics, 12, 349-367.

Gathercole, S. E., Willis, C. S., Baddeley, A., & Emslie, H. (1994). The children's test of nonword repetition: A test of phonological working memory. Memory, 2, 103-127.

Gathercole, S. E., Willis, C. S., Emslie, H., & Baddeley, A. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. Developmental Psychology, 28, 887-898.

Gaulin, C. A., & Campbell, T. F. (1994). Procedure for assessing verbal working memory in normal school-age children: Some preliminary data. Perceptual and Motor Skills, 79, 55-64.

Gerber, C. (Ed.) (1992). English Grammar & Writing 3rd grade. American Education Publishing Company.

Gillam, R. B., Cowan, N., & Day, L. S. (1995). Sequential memory in children with and without language impairment. Journal of Speech and Hearing Research, 38, 393-402.

Greenberg, S. N., & Engle, R. W. (1983). Voice change in the stimulus suffix effect: Are the effects structural or strategic? Memory & Cognition, 11, 551-556.

Halle, M., & Keyter, S. J. (1971). English Stress. New York, NY: Harper & Row Publishers.

Hartley, T. & Houghton, G. (1996). A linguistically constrained model of short-term memory for nonwords. Journal of Memory and Language, 35, 1-31

Hulme, C., Maughan, S., & Brown, G. D. A. (1991). Memory for familiar and unfamiliar words: Evidence from a long-term memory contribution to short-term memory span. Journal of Memory and Language, 30, 685-701.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. Psychological Review, 99, 122-149.

King, J., & Just, M. A. (1991). Individual differences in syntactic processing. The role of working memory. Journal of Memory and Language, 30 (5), 580-602.

Kirchner, D., & Klatzky, R. (1985). Verbal rehearsal and memory in language-disordered children. Journal of Speech and Hearing Research, 28, 556-565.

Kule, E. A. (1995, a). English 2. School Zone Publishing Company.

Kule, E. A. (1995, b). English 3-4. School Zone Publishing Company.

Leonard,L. B. (1989). Language learnability and specific language impairment in children. Applied Psycholinguistics, 10, 179-202.

Lyon, D. R. (1977). Individual differences in immediate serial recall: A matter of mnemonics? Cognitive Psychology, 9, 403-411.

MacDonald, M. C., Just, M. A., & Carpenter, P. A. (1992). Working memory constraints on the processing of syntactic ambiguity. Cognitive Psychology, 24, 56-98.

Montgomery, J. W. (1995). Examination of phonological working memory in specifically language impaired children. Applied Psycholinguistics, 16, 335-378.

Pichora-Fuller, M. K., Schneider, B. A., & Daneman, M. (1995). How young and old adults listen to and remember speech in noise? Journal of the Acoustic Society, 97, 593-608.

Semel, E., Wiig, E. H., & Secord, W. A. (1987). Clinical Evaluation of Language Fundamentals-Revised CELF-R. San Antonio: The Psychological Corporation.

Semel, E., Wiig, E. H., & Secord, W. A. (1995). Clinical Evaluation of Language Fundamentals CELF-3 Screening Test. San Antonio: The Psychological Corporation.

Sininger, Y. S., Klatzky, R. L., & Kirchner, D. M. (1989). Memory scanning speed in language-disordered children. Journal of Speech and Hearing Research, 32, 289-297.

Snowling, M., Chiat, S., & Hulme, C. (1991). Words, nonwords, and phonological processes: Some comments on Gathercole, Willis, Emslie, and Baddeley. Applied Psycholinguistics, 12, 369-373.

Swanson, H. L., Cochran, K. F., Ewers, C. A. (1989). Working memory in skilled and less skilled readers. Journal of Abnormal Child Psychology, 17, 145-156.

Tallal, P. (1990). Fine-grained discrimination deficits in language-learning impaired children are specific neither to the auditory modality nor to speech perception. Journal of Speech and Hearing Research, 33, 616-617.

Terban, M. (1993). Checking your grammar. New York, NY: Scholastic Inc.

Thorndike, R. L., Hagen, E. P., & Sattler, J. M. (1986). The Stanford Binet Intelligence Scale. Chicago: The Riverside Publishing Company

Treiman, R. (1995). Errors in short-term memory for speech: A developmental study. Journal of Experimental Psychology: Learning, Memory, and Cognition, 21, 1197-1208.

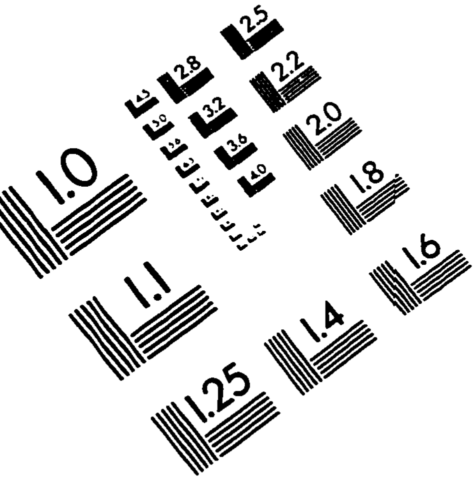
Treiman, R., & Danis, C. (1988). Short-term memory errors for spoken syllables are affected by the linguistic structure of the syllables. Journal of Experimental Psychology: Learning, Memory, and Cognition, 14, 145-152

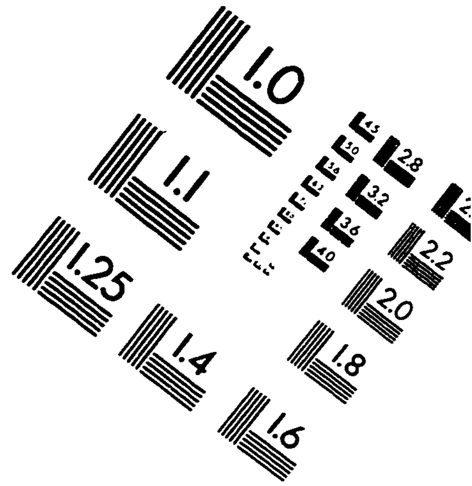
van der Lely, H., & Howard, D. (1993). Children with specific language impairment: Linguistic impairment or short-term memory deficit? Journal of Speech and Hearing Research, 36, 1193-1207.

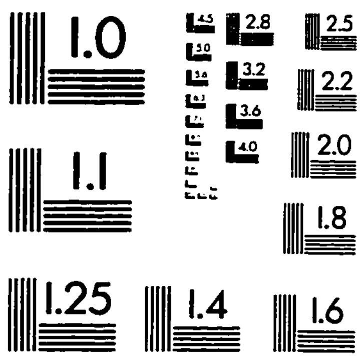
Watkins, R. V. (1994).Grammatical challenges for children with specific language impairments. In. Watkins, R. V., & Rice, M. L. (Eds.). Specific language impairments in children. pp. 53-68.

Wechsler, D.(1974). Wechsler Intelligence Scale for Children-Revised. San Antonio, TX: Psychological Corporation

IMAGE EVALUATION TEST TARGET (QA-3)







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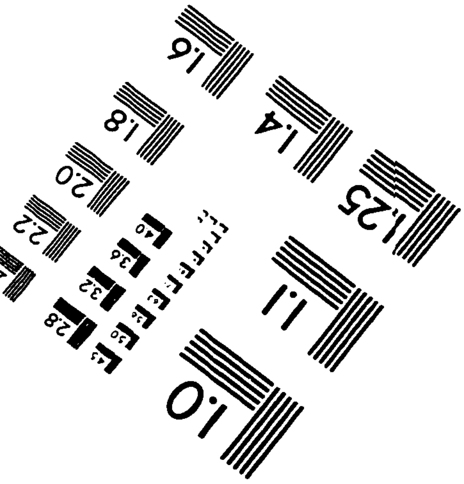

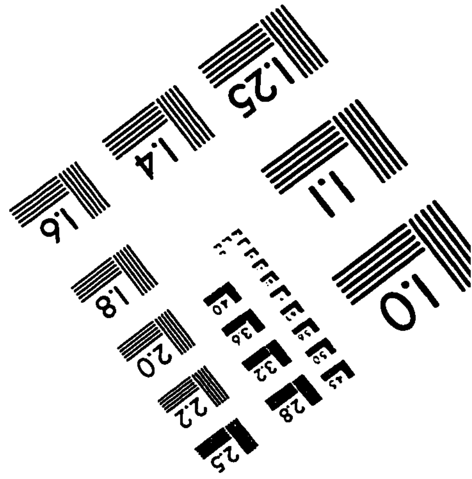

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