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Effect of sentence length and complexity on working memory performance in Hungarian children with specific language impairment (SLI): a cross-linguistic comparison

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Abstract

Background—English-speaking children with specific language impairment (SLI) perform more poorly than their typically developing peers in verbal working memory tasks where processing and storage are simultaneously required. Hungarian is a language with a relatively free word order and a rich agglutinative morphology.

Aims—To examine the effect of linguistic structure on working memory performance. It was examined whether syntactic complexity has a larger impact on working memory performance than sentence length in Hungarian-speaking children, similar to the findings in English speaking children.

Methods & Procedures—In Experiment 1, performance accuracy was measured with two linguistic span tasks that included stimuli with varying sentence length and syntactic complexity. Experiment 2 examined the impact of sentence length and morphological complexity on working memory performance.

Outcomes & Results—Children with SLI performed more poorly than their age-matched peers in all working memory tasks. Their error patterns differed from those of children with typical language development. Children with SLI produced a high number of interference errors that indicate poor executive functions. The findings were compared with previous results of English-speaking children. Complexity affected working memory performance accuracy differently across languages. In English, it was the increase of syntactic complexity that resulted in a decrease in performance accuracy, whereas in Hungarian, it was the morphological complexity that had a large impact on working memory performance.

Conclusions—Working memory performance depends on the linguistic characteristics of the language tested. In both English- and Hungarian-speaking children, complexity has a larger effect on verbal working memory performance than the length of the stimuli. However, complexity affects working memory performance accuracy differently across languages.

Keywords

specific language impairment (SLI); verbal working memory; executive functions; cross-linguistic analysis

Introduction

There is a relationship among working memory, executive functions, and language comprehension and production in children and adults. Working memory capacity measures reflect multiple constructs, domain-specific memory storage and domain-general executive processes (Engle and Kane 2004). Working memory span is constrained by controlled attention (Engle *et al.* 1999), task switching ability (Towse *et al.* 1998), and inhibition of irrelevant information (Hasher and Zacks 1988). Individual differences on complex working memory tasks reflect not the number of items stored in memory but the differences in simultaneous processing and executive functions (Engle *et al.* 1999, Miyake *et al.* 2001). Better working memory performance is the result of greater ability to control attention, suppress irrelevant information, avoid distraction, focus on task-relevant thoughts, and coordinate simultaneous processing and storage (Engle *et al.* 1999, Lustig *et al.* 2001, Miyake 2001).

Executive functions are used when individuals need to develop goals, hold these goals in active memory, and monitor performance to achieve their goals (Stuss 1992). Attentional capacity is responsible for sustaining focus on goal information in the context of distracting stimuli. The ability to inhibit irrelevant information is a fundamental mechanism that underlies cognitive development (Dempster 1992). The present study examines working memory in children with SLI within a theoretical framework that suggests an important role for executive functions, particularly for attentional capacity (e.g. Barrouillet and Camos 2001, Kane and Engle 2002, Cowan *et al.* 2003).

Children with specific language impairment (SLI) perform more poorly than their typically developing peers in working memory tasks where processing and storage are simultaneously required. Their performance indicated a deficit in processing syntactically simple, short sentences (Ellis Weismer *et al.* 1999) and sentences of various lengths (Montgomery 2000). Accuracy scores dramatically deteriorated with an increase in syntactic complexity and word length.

Processing differences between children with SLI and the control group were found in the coordination of information storage and retrieval within and across modalities (Hoffmann and Gillam 2004). An increase in the amount of information to be processed resulted in a decrease of resource coordination. The authors concluded that significant constraints on information processing for children with SLI involve limitations in general cognitive capacities and in working memory, particularly in executive functions.

Our previous study on working memory and language comprehension in English-speaking children with SLI revealed a larger effect of syntactic complexity than sentence length on performance accuracy (Marton and Schwartz 2003). Both children with SLI and their age-matched peers showed great difficulty in the Listening Span task (ML), where they listened to sentences with various lengths and syntactic complexity and performed simultaneous processing. They recalled a non-word that was embedded in the sentence and answered a question targeting sentence content. The task required from the participants to pay close attention to sentence content while storing the words to be remembered. Most children with SLI were not able to process simultaneously the non-words and the semantic and syntactic information of the sentences thus, they performed more poorly than their age-matched peers.

The effects of syntactic complexity on language comprehension were consistent with adults' performance on traditional Listening Span tasks. In adults, increased complexity resulted in increased reaction time and decreased repetition accuracy (MacDonald *et al.* 1992). The authors interpreted their data within the framework of a processing capacity theory (Just and Carpenter 1992) and concluded that processing more complex sentences requires more working memory capacity. Alternatively, the retrieval of words to be remembered in complex sentence

contexts may result in prolonging the recall process for a longer time period than in simple sentential contexts. This prolongation may be long enough for some information to be lost (Cowan *et al.* 2003). The efficiency of sentence processing is highly related to the demands that sentence structure variations place on memory resources (McElree *et al.* 2003).

Difficulty with simultaneous processing was also evidenced in the List Recall task (LR), where children listened to sets of sentences and recalled the sentence-final words. In this task, children with SLI made frequent interference errors and showed diminished primacy and recency effects (Marton and Schwartz 2003). These children showed difficulty in switching attentional focus according to test requirements. They were not able to switch their attention from encoding to rehearsal and vice versa.

A storage and processing trade-off was used to explain the performance of children with SLI in tasks that focused on functional working memory capacity (Montgomery 2000). The children recalled as many words as possible under three conditions: no load (simple span), single load (storage and one mental operation) and dual load (storage and two mental operations). The children with SLI had a storage capacity similar to their peers' when the processing requirements were low. As the processing requirements increased (dual load) children with SLI exhibited a trade-off between storage and processing. In the same study, children with SLI comprehended fewer redundant (long) sentences than the age-matched and the vocabulary-matched younger children. The findings were interpreted as further support for a processing deficit in children with SLI.

The overall objective of the current study was to examine whether the differences in the linguistic structures of English and Hungarian impact verbal working memory performance. Verbal working memory is not a language-independent system (Thorn and Gathercole 1999). Just as SLI may be manifested differently cross-linguistically, reflecting the features of a given language (Leonard 1998, Gosy 2002), the present authors expected that verbal working memory deficits would reflect an interaction of the core deficits associated with SLI and language-specific features. Therefore, working memory performance between groups of Hungarian and English-speaking children with and without language impairments was compared. This issue was addressed in two experiments. The stimuli in this study varied in grammatical (syntactic and morphological) complexity and in length.

Hungarian is a language with relatively free word order and a rich agglutinative morphology (Vinkler and Pleh 1995). The first experiment used an adaptation of our ML and LR tasks (Marton and Schwartz 2003) to compare working memory performance of Hungarian children with SLI with our previous findings in English-speaking children. The effect of syntactic complexity and of sentence length on working memory were examined. Of interest was whether Hungarian children with SLI show a similar deficit to English-speaking children in language comprehension with syntactically complex sentences if the memory load is high. There are no previous studies in Hungarian examining the effects of memory load on working memory by comparing syntactic complexity versus sentence length in children with SLI. A group effect was hypothesized and the effect of syntactic complexity on working memory performance, similar to the English-speaking children's results, was expected. With regard to the multiple constructs of working memory (Engle and Kane 2004), it was hypothesized that the results on the non-word repetition part of the ML task will reflect storage capacity, whereas the answers to the questions and the results of the LR task will indicate processing capacity. Our previous findings on working memory performance in typically developing children and adults indicated that the two dependent measures of the ML task reflect the contribution of storage and processing efficiency separately (Marton *et al.* 2005). Whereas processing efficiency was influenced by sentence complexity, non-word repetition performance, reflecting the storage function rather than processing, showed a word-length effect.

The second experiment investigated the impact of specific morphological patterns of Hungarian on working memory performance. Given the agglutinative nature of Hungarian, the authors were able to compare performance on short sentences with simple morphological structures with long sentences with simple morphology, and with long sentences with complex morphological structures. It was hypothesized that sentences with complex morphological structures are more demanding on working memory than sentences with simple morphological structures, even when the sentence length is the same. A group effect was expected with each sentence type.

Experiment 1

Methods

Participants—Seventeen children with SLI (age: 7;6–10;5, mean: 8;11, gender: six girls, 11 boys) and 17 age-matched children with typical language development (TLD) (age: 7;6–10;5, mean: 8;9; gender: six girls, 11 boys) participated in the first experiment (table 1). All children with SLI had been diagnosed by a speech–language pathologist as language impaired, with both receptive and expressive deficits. They were all receiving speech–language therapy at the time of testing. There is no comprehensive standardized language test in Hungarian, but all children performed about 2 years below age average on a series of Hungarian language items that targeted their active and passive vocabularies, and sentence repetition and comprehension. Hungarian-speaking children with SLI, similar to English-speaking children with SLI, make more errors than their typically developing age-matched peers in processing sentences with grammatical complexity, e.g. detecting agreement violations. The language tasks used were tasks that are typically used by speech–language pathologists to evaluate children’s language performances. Each child showed a normal range of non-verbal IQ (90–120) on the Snijders–Oomen Nonverbal Intelligence Test — Revised (Snijders *et al.* 1989).

The children in the control group had no history of speech–language problems or any learning difficulties. They all performed at age-average level academically, according to reports from parents and classroom teachers. None received any special services.

All participants were monolingual Hungarian speakers. Normal articulatory performance was an inclusion criterion and was determined by the speech–language pathologist. Each child was tested with a non-word repetition task that was adapted for Hungarian and included two-, three- and four-syllable non-words. This provided a baseline measure for non-word repetition and verified that the Hungarian children with SLI show a similar pattern of phonological working memory performance to that of the English-speaking children. This was important because our Modified Listening Span task included non-word repetition in a more demanding context, with a higher level of simultaneous processing requirements. All children passed a pure tone audiometric screening of both ears at 20 dB HL (at 500, 1000 at 500, 2000 and 4000 Hz). None of the children had a history of frank neurological impairment or psychological disturbance.

There was no language-matched group in the current study because some of the language-matched children were too young to perform on the following tasks. In a pilot study with eight younger children (5 years of age), it was noticed that the children showed extreme difficulty with simultaneous processing; segmenting the sentences, processing its semantic content and syntactic structure, and remembering the sentence-final non-words or words. If one considers the demands of these tasks on executive functions, their performance limitations are age appropriate.

Stimuli

Modified Listening (ML) span task—The ML task was developed to measure simultaneous processing and storage, the involvement of executive functions in working

memory. The task included 90 sentences (30 syntactically simple short sentences, 30 syntactically complex short sentences and 30 syntactically complex long sentences) with a question for each sentence. The last word in each sentence was replaced with a non-word two, three and four syllables in length. The non-words were part of the syntactic structure of the sentences (e.g. 'Sue likes Joe who is 'plikʌʃəmər; for more examples, see the appendix).

The task required that children listen to a sentence, repeat the sentence final non-word and answer a question about the content of the sentence (for further details, see Marton and Schwartz 2003). The simple sentences were all short (ten or fewer syllables), whereas the complex sentences were either short (ten or fewer syllables) or long (>15 syllables). The complex short sentences included object complementation and Wh embedded clauses, the complex long sentences included relative clauses. Every effort was made to match the Hungarian sentences to the previously used English stimuli. All sentences in the current study were selected from elementary school textbooks for grades 2–3.

List Recall (LR) task—There were nine sets of sentences with five sentences in each set (three sets with syntactically simple short sentences, three sets with syntactically complex short sentences and three sets with syntactically complex long sentences). Children were asked to listen to a set of sentences and repeat the five sentence-final words. The words were real words with similar phonotactic patterns, syllable length, and frequency of occurrence (for examples, see the appendix). This task was also designed to measure simultaneous processing (for further details, see Marton and Schwartz 2003).

Procedures

Participants were tested individually in a single session in their schools. Stimuli were audio recorded by a female speaker. The participants listened to the stimuli through headphones and their responses were tape-recorded. The stimuli of the ML task were presented in a random order. The sentences were presented one at a time. Children were instructed to pay close attention to the sentences and repeat the sentence-final non-word following sentence presentation. After they repeated the non-word, a question was asked about the content of the sentence. Practice trials with different stimuli were provided for each child.

The sentence sets of the List Recall task were presented in a random order. Participants were asked to listen to a set at a time and repeat the five sentence-final words of that set in the same order as they were presented. To ensure that children processed the entire sentence, not only the final word, a question was asked about the content of one sentence in each set, following the repetition of the sentence-final words. Practice trials with different stimuli preceded testing.

Data analysis

Different investigators performed testing and data analysis. All non-words from the ML task were transcribed by two research assistants using broad phonetic transcription. Any segment substitutions, additions, deletions, and order errors counted as incorrect production. Interjudge reliability for error coding was calculated for 150 randomly chosen non-words (1224 segments) produced by children from both groups. The two transcribers provided identical transcriptions for 1194 segments (mean percentage of agreement: 97.56%).

The answers to the questions in the ML task were scored as correct or incorrect. If only part of an answer was correct, then the answer was scored as incorrect. Children's errors were categorized as omissions, semantic substitutions, phonological substitutions, interference errors, and other. Omission errors were counted in those cases where children did not respond to the questions or said that they forgot. Semantic substitutions were considered as errors where the child substituted the correct answer with another one that belonged to the same grammatical

category and expressed similar meanings (e.g. *water* for *river*, *green* for *yellow*, etc.). Phonological substitutions were errors where the child answered with a word that sounded similar to the correct answer, but expressed a different idea. The word differed only in one or two segments from the target (in most cases, it was a consonant substitution). Interference errors were those where the child gave an answer that was related to a previously asked question. All other errors were considered as ‘other’ category.

The results of the LR task were scored in two ways: with the free scoring method, each correctly recalled item received a credit, regardless of the order of recall. With the second scoring method, word order was also considered and children’s responses were only accepted if the items were recalled in the order of presentation. To compare the error patterns of the two groups, the errors were categorized as omission, intrusion, movement error, and ‘other’. If the child deleted one or more items, it was considered an omission. If the child recalled an item from the previous list or a word (not a sentence-final word) from one of the sentences within the given set, that was counted as an interference error. If a child recalled the given items in an order that differed from the original order of presentation, the error was categorized as a movement error. ‘Other’ errors were words that were not presented in the task.

Results

Modified Listening Span task—Mixed model analyses of variance (ANOVAs) were used to analyse the differences between and within groups for the ML task. Non-word repetition accuracy was analysed with a group \times sentence type \times word-length design, whereas the independent variables for the answers to the questions were group and sentence type. Effect sizes (d) were calculated and categorized as small effect size: $d=0.2$; medium, $d=0.5$; and large, $d=0.8$ (Cohen 1988).

The results of the Hungarian children in a baseline measure of single non-word repetition were similar to the results of English-speaking children: children with SLI performed more poorly than their age-matched peers ($F(1, 91)=55.75, p<0.001, d=1.51$). There was also a word-length effect for both groups ($F(2, 91)=16.5, p<0.001$), but there was no group \times word-length interaction ($F(2, 91)=1.58, p=0.19$). Children with SLI showed lower scores than their typically developing peers at each word length.

In the Modified Listening Span task, children with TLD repeated significantly more non-words correctly than the children with SLI at each word-length and with each sentence type ($F(1, 96)=184.5, p<0.001$). The effect sizes were large for each sentence type (simple, $d=1.74$; complex short, $d=1.35$; complex long, $d=1.66$). There was a significant word-length effect for both groups ($F(2, 96)=118.23, p<0.001$). A significant group \times word-length interaction was also found ($F(2, 96)=4.88, p<0.01$). A post-hoc Tukey analysis ($p<0.05$) revealed no significant difference in non-word repetition accuracy between the two- and three-syllable non-words for the children with TLD, their performance deteriorated only with the four-syllable non-words. In contrast, the children with SLI showed difficulty beginning with the three-syllable non-words (the same group difference for word length was found for the English-speaking children; Marton and Schwartz 2003).

Syntactic complexity and sentence length did not affect non-word repetition accuracy ($F(2, 96)=1.61, p>0.05$). Table 2 shows all means and standard deviations for this task. The data from an error analysis indicate that the increase in word length resulted in more complex errors, particularly in the children with SLI. There were more single errors (only one phoneme substitution or deletion) with the shorter words than with the longer ones. The number of multiple errors (more than one error within a word) increased with the increase of word length (figure 1). Thus, the word-length effect was reflected not only in a larger number of errors, but also in more complex errors, especially in the children with SLI.

The second dependent variable of the ML task, the answers to the questions, was analysed with a factorial ANOVA (group \times sentence type). Both independent variables had an effect on performance accuracy (group, $F(1, 64)=7.08, p<0.05, d=0.7$; sentence type, $F(2, 64)=68.51, p<0.001$). There was no group \times sentence type interaction ($F(2, 64)=0.4, p=0.67$). Children with SLI performed more poorly than the typically developing children with each sentence type. To examine the effect of different sentence types on performance accuracy, pair-wise comparisons with one-way ANOVAs were used. The results showed significant differences between the simple short and complex long sentences ($F(1, 64)=41.2, p<0.001, d=1.68$) and between the complex short and complex long sentences ($F(1, 64)=21, p<0.001, d=1.34$). The effect sizes were large in both cases. There was no significant difference in performance accuracy between the simple short and complex short sentences ($F(1, 64)=2.06, p>0.05, d=0.31$). These results indicate a larger effect of sentence length than syntactic complexity on language comprehension. Children's performance in both groups deteriorated more as the length of the sentences increased (table 2).

There were also some qualitative differences between the groups. Most of the errors made by the children with TLD were omissions and semantic substitutions, whereas the children with SLI produced a high number of interference errors (table 3).

List Recall task—First, the results were analysed with the free scoring method (each correctly recalled item received a credit regardless of the order of recall) using a factorial ANOVA (group \times sentence type). There was a main effect for both variables (group, $F(1, 48)=12.54, p<0.01, d=1.18$; sentence type, $F(2, 48)=9.77, p<0.001$). There was no group \times sentence type interaction (for means and standard deviations, see table 2). Pair-wise comparisons of sentence types, using one-way ANOVAs, showed that performance accuracy decreased as the length of the sentences increased. List Recall was significantly better for the simple short sentences than for the complex long sentences ($F(1, 48)=5.09, p<0.05, d=0.78$), and better for the complex short sentences than for the complex long sentences ($F(1, 48)=5.62, p<0.05, d=1.09$). There was no significant difference in list recall between the simple short and complex short sentences ($F(1, 48)=2.4, p>0.05, d=0.09$). Children with SLI performed more poorly than the children with TLD with each sentence type. Their performance pattern across sentence types was similar to that of the typically developing children. Thus, the results are comparable to our findings with the ML task.

Children in both groups showed lower performance scores when the order of recall was also considered. The analysis with the order scoring method showed significant differences between the groups ($F(1, 48)=4.27, p<0.05, d=1.12$), but not within groups. Children with SLI performed more poorly than their peers. There was no main effect for sentence type ($F(2, 48)=0.91, p>0.05$).

Similar to the results of the ML task, the error analysis revealed different patterns for the groups. Most of the errors made by the children with SLI were interference errors. In contrast, the main error category for the children with TLD was 'omissions' (table 3).

Discussion

Children with SLI performed more poorly than their peers in both tasks that focused on working memory and required simultaneous processing. Children with SLI showed a deficit in both storage — that was measured with non-word repetition — and processing, which was reflected by the correct answers in the ML task and by the results in the LR task.

Modified Listening Span task—There was a word-length effect in non-word repetition for both groups in the ML task. Repetition accuracy for two- and three-syllable non-words did not differ in the group of children with TLD; their performance decreased only with the four-

syllable non-words. In contrast, children with SLI had difficulty with the three-syllable non-words and their performance further deteriorated with the four-syllable non-words. These findings are consistent with our previous results from English-speaking children (Marton and Schwartz 2003).

In the ML task, sentence-type variations did not affect non-word repetition accuracy, but they influenced the answers to the questions. This is a consistent finding in our studies with different populations (Marton and Schwartz 2003, Marton *et al.* 2005). Non-word repetition is not influenced by sentence type variations because it reflects storage rather than processing. Sentence type variations are based on an increase in stimulus complexity and length therefore, they are highly demanding on processing capacity and executive functions. In the ML task, it is the answers to the questions that are highly influenced by the processing demands. Children answered more questions correctly following the simple short and complex short sentences than they did with the complex long sentences. Their performance decreased with the increase of sentence length (table 2). These results are in contrast to our previous findings on English-speaking children and show the impact of language-specific structures on working memory performance and language comprehension. The results from the English-speaking children indicated a larger effect of syntactic complexity than sentence length on working memory (Marton and Schwartz 2003).

One explanation for these differences is related to the morphological differences between the languages. Hungarian is an agglutinative language with a rich morphological system, whereas English has relatively sparse morphology. The increase in sentence length did not change the morphological complexity in English, but it did in Hungarian.

List Recall task—Sentence-type variations also affected recall in the LR task. With the free scoring method, children in both groups recalled more items correctly from sets with simple short and complex short sentences than from sets with complex long sentences. Because these findings are consistent with the results of the ML task in the present study, but contradict our findings on English-speaking children, further research was needed to determine whether sentence length or morphological complexity had a larger effect on working memory performance. This was the rationale for conducting Experiment 2.

The second analysis of the results in the LR task considered the order and accuracy of recall. Children in both groups showed great difficulty with recalling the items in the order of presentation. Although there was a group difference, there was no difference across sentence types. Performance accuracy was very low for each sentence type. These task requirements were highly demanding on working memory and particularly on the executive functions. Even the typically developing children showed great difficulty processing the sentences (with different length and complexity), storing the sentence-final items, and remembering the order of presentation. Children did not appear to have enough processing capacity to monitor simultaneously rehearsal and encoding of the new incoming items.

Error analysis

The error analysis data for the ML and LR tasks were similar to the data from the English-speaking children (Marton and Schwartz 2003). Children typically make three types of errors on serial recall: intrusion, omission, and movement. Young children (<6;0) produce many intrusions (items outside of the list). With an increase in age and the development of executive functions, intrusions decrease; 10 year olds produce more omissions and movement errors than intrusions. Adults still make movement errors, but the number of omissions decreases (McCormack *et al.* 2000). The main error category for the children with TLD in the present study was omissions in both tasks (ML, LR). Children with TLD did not produce intrusion errors, but made omissions and movement errors (intrusion errors were counted as ‘other’

errors; table 3). Executive functions are not fully developed while the frontal lobes are still developing. Therefore, 10-year-old children exhibit slower memory search and retrieval processes than adults (McCormack *et al.* 2000). This may result in more omission errors.

Another common error among the children with TLD was semantic substitutions. The use of synonyms and words with similar meanings within the same grammatical category indicate large and flexible vocabularies in these children.

Children with SLI did not produce many semantic substitutions. One possible reason for it might be their limitation in vocabulary size (Leonard 1998). In contrast to the error pattern of the children with TLD, the majority of the errors produced by the children with SLI were interference errors in both the ML and the LR tasks. Their answers were often words from previous lists or items that were presented in the middle of one of the preceding sentences, but were not sentence-final items that had to be remembered. Children with SLI had difficulty inhibiting previously activated items. The interference errors reflect poor executive functions. Inhibitory processes affect the operation of working memory in a number of ways; they allow only those items to enter working memory that are consistent with the goals of the listener. Furthermore, inhibitory mechanisms suppress the activation of irrelevant information (Lorsbach and Reiner 1997).

In summary, the results of Experiment 1 indicate group differences between the children with SLI and TLD in both storage and processing. Hungarian-speaking children in both groups and in both tasks performed with higher accuracy when the sentences were short, either simple or complex, than when they were long. These results contrast with our findings from English-speaking children. One possible reason for these differences is the morphological structure of Hungarian and its relationship to sentence complexity. With increasing sentence length, the morphological structure becomes more complex in Hungarian. Therefore, the following research question in Experiment 2 was examined: Is it the increase in sentence length or the increase in morphological complexity that has a larger impact on working memory performance and language comprehension?

Experiment 2

Methods

Participants—The participants were 25 children with SLI (age: 8;1–11;0, mean: 9;10, gender: 17 males, eight females) and 25 children with TLD (age: 8;3–11;0, mean: 9;9, gender: 17 males, eight females). None of these children participated in Experiment 1, but the inclusion criteria were the same for the two experiments (for details, see Experiment 1, Participants). Participant profiles for Experiment 2 are included in table 4.

Stimuli

The stimuli were 45 sentences and 45 questions targeting sentence content to measure the impact of sentence length and morphological complexity on working memory performance. Children were asked to listen to the sentences (one at a time), to memorize the sentence-final word, to answer a question following presentation, and finally to repeat the sentence-final word in each task.

There were three types of stimuli: 15 short sentences with a sentence-final free (simple) morpheme, 15 long sentences with a complex morpheme at the end of each sentence, and 15 long sentences with a sentence-final free morpheme. Sentence length was ten to 12 syllables for the short sentences. All sentence-final items in the first 15 sentences were frequently occurring common nouns typically used by young children.

The second 15 sentences were long (16–19 syllables) and ended with a four-syllable complex morpheme. These sentence-final words included a two-syllable base morpheme, which was a common noun, and two inflectional morphemes: a possessive and an inflection for person (number).

The last 15 sentences were morphologically simple, but also long (16–19 syllables) with a two-syllable free morpheme at the end. This free morpheme was a frequently occurring common noun (for examples, see the appendix). There was a significant difference in sentence length between the short and long sentences ($t(15)=26.88, p<0.01$). The sentences were matched for syntactic complexity across the three sentence groups and within each sentence group. They all included a relative clause.

Procedures

Participants were tested individually in two sessions in their schools. There was one week between the two sessions. The rationale for scheduling two sessions was to decrease the learning effect. The order of stimulus presentation was counterbalanced. In addition to the tasks in the present study, children performed other verbal and non-verbal tests during these sessions (those tasks are not in the focus of the current study).

Stimuli were presented from a PC notebook through headphones. All sentences and accompanying questions were recorded by a female speaker. The participants' responses were recorded by a digital recorder. The sentences were presented one at a time. Children were instructed to pay close attention to the sentences and to remember the sentence-final word. Following sentence presentation, a question was asked about the content of the sentence. Once children answered the question, a picture of the microphone appeared on the screen that reminded them to repeat the sentence-final word. Practice trials with different stimuli were provided for each child.

Data analysis

Testing and data analysis were performed by different people. All sentence-final words were transcribed and analysed for error type. Any substitutions and deletions were counted as incorrect production. The answers to the questions were scored as correct or incorrect.

Children's word repetition errors were categorized as omissions, substitutions, interference errors, and other (for details on error categorization, see Experiment 1). For the sentences with complex morphemes, a category was included for grammatical morpheme substitutions and omissions. In these cases, the stem was produced correctly, but the child substituted or deleted the inflectional morphemes.

Results

The results of word repetition were analysed with a factorial ANOVA (group \times sentence type) for main effects. There was a significant difference in performance accuracy between the children with TLD and SLI ($F(1, 144)=131.65, p<0.001, d=2.78$) and across sentence types ($F(2, 144)=16.77, p<0.001$). (See means and standard deviations in table 5.) The effect sizes were large with each sentence type: $d=2.59$ for the short sentences with simple morphology, $d=3.49$ for the long sentences with complex morphemes, and $d=2.13$ for the long sentences with simple morphemes. There was also a significant interaction for group and sentence types ($F(2, 144)=6.31, p<0.01$). The post-hoc Tukey test ($p<0.05$) revealed group differences with each sentence type. There was a significant difference in word repetition accuracy for both groups between the sentences with simple and complex morphology. There was no difference between the morphologically simple short and long sentences. Thus, morphological complexity and not sentence length affected performance.

Similar to Experiment 1, the main error categories for children with TLD were omissions and substitutions, whereas the children with SLI produced a high number of interference errors (for error type differences, see table 6).

With a further analysis, the production of the stem (base morpheme) was compared with the whole word (base morpheme plus inflections) in order to see whether children make errors with both the stem and the inflections or they repeat the correct stem but have difficulty with the inflections. There was a significant main effect for group ($F(1, 96)=105.86, p<0.001, d=2.07$); for morpheme type error ($F(1, 96)=20.85, p<0.001, d=1.05$), and there was an interaction between group and morpheme type error ($F(1, 96)=6.54, p<0.01$). A post-hoc Tukey test ($p<0.05$) showed that the children with SLI performed significantly better in repeating the stem than the whole word with inflections; there were no significant within group differences for the children with TLD (figure 2).

One could argue that the differences in word repetition accuracy may not only reflect morphological complexity differences, but a word-length effect because the morphologically complex words were four-syllables long, whereas the simple words were only two-syllables long. Therefore, the effect of morphological complexity on working memory performance was examined by analysing the answers to the questions. The results of a Factorial ANOVA (group \times sentence type) showed a main effect for group ($F(1, 96)=48.71, p<0.001, d=1.16$); for sentence type ($F(2, 96)=5.14, p<0.01$); and there was a group \times sentence type interaction ($F(2, 96)=5.66, p<0.01$). A post-hoc Tukey test ($p<0.05$) showed that the children with SLI performed significantly better in answering the questions following the sentences with simple morphology than the ones with complex morphemes. There was no difference in their answers between the short and long sentences with simple morphology. Thus, the pattern was similar to word repetition. The children with TLD answered each question with high accuracy (table 5).

Discussion

The aim of Experiment 2 was to examine further the effect of language structure on working memory performance. The research question was whether sentence length or morphological complexity has a larger impact on word repetition accuracy in a language that has a rich morphological system. Children's working memory performance was measured with a task, in which the sentences differed in their morphological complexity and length. Syntactic complexity was similar across the sentences.

Children with SLI performed more poorly than their age-matched peers with each sentence type: they repeated significantly fewer words and answered fewer questions correctly. The within-group analyses showed no difference in word repetition accuracy nor in the answers to the questions between the short and long sentences when morphology was simple. Performance accuracy decreased as morphological complexity increased. Thus, morphological complexity had a larger effect on both word repetition accuracy and answers to the questions than the length of the sentences. Children with TLD showed a similar pattern in word repetition accuracy.

To our knowledge, only one unpublished study has examined the relationship between working memory and morphological complexity in Hungarian (Nemeth *et al.* 2005). The authors used a single-word repetition task with college students. The words varied in length (two and three syllables) and complexity (free morpheme, free plus inflectional morpheme). Similar to our results, participants showed an effect of morphological complexity. They recalled more free morphemes than complex words correctly, even if the length of the words was the same.

The results of Experiment 2 support those theories that suggest a critical role for executive functions in complex working memory tasks (Engle *et al.* 1999, Barrouillet and Camos 2001). Individual variations in the ability to control attention, suppress irrelevant information, focus on task-relevant thoughts, and coordinate simultaneous processing and storage are the determinants of working memory performance (Engle *et al.* 1999, Miyake *et al.* 2001). The error analysis data, the high number of interference errors produced by the children with SLI (table 6), suggest a deficit in attention switching and in inhibition in this group.

General discussion

The differences between English and Hungarian had an impact on working memory performance in each group (SLI, TLD). The current results clearly support the language-specific effects of verbal working memory functions (Thorn and Gathercole 1999). Experiment 1 revealed better performance accuracy when the sentences were short, either syntactically simple or complex, than when they were long. There was no significant difference between the simple short and complex short sentences. These results differed from our previous findings with English-speaking children. Those children's verbal working memory performance on similar tasks was more affected by syntactic complexity than sentence length (Marton and Schwartz 2003). Experiment 2 examined the relative influence of sentence length and morphological complexity on working memory performance. It was hypothesized that an increase in morphological complexity caused the decrease in working memory performance accuracy. Previous findings (Engle *et al.* 1999, Lustig *et al.* 2001, Miyake 2001) evidenced that working memory performance depends more on the ability to control attention, to suppress irrelevant information and to focus on task-relevant goals than on the ability to store more items. Thus, the simple increase of the number of words in a sentence, without an increase in grammatical complexity, does not influence performance accuracy to the same extent as the increase in morphological complexity. In Experiment 2, children recalled more words and answered more questions correctly following sentences with simple morphological structures than with complex morphology. There was no difference in performance accuracy between the short and long sentences, when morphology was simple. The results of the current study and previous findings (Marton and Schwartz 2003) suggest a larger impact of linguistic complexity than sentence length on performance accuracy. However, complexity affected working memory performance differently across languages. In English, it was the increase in syntactic complexity that resulted in a decrease in working memory performance accuracy. In Hungarian, a language with a rich morphological system, it was the increase in morphology that resulted in decreased performance accuracy, particularly in the children with SLI.

These findings raise issues regarding the nature and role of working memory in language comprehension. Various models of working memory provide different characterizations of the work-space or storage that might be devoted to language processing in general or more specifically to processing words, syntax, and morphosyntax (e.g. Just and Carpenter 1992, Ellis Weismer *et al.* 1999). The consistency of complexity effects, manifested differently across these languages, suggests that the deficit may best be described by those models that posit a workspace with limited capacity rather than a more traditional capacity-limited storage for material. Tasks that more directly examine memory processes during sentence comprehension may shed additional light on these mechanisms.

The children with TLD produced errors that were predominantly omissions and semantic substitutions comparable to other reported findings (McCormack *et al.* 2000). As the demands on working memory increased, typically developing children forgot some information or substituted a synonym for the target word. In contrast, the children with SLI produced a high number of interference errors. These errors indicate a deficit in executive functions in children with SLI. Further research is needed to examine whether the errors reflect a problem in

suppressing irrelevant information, in attention switching, or in keeping task goals active. There is evidence from an electrophysiological study of lack of localization in brain activity in discourse processing that may be interpreted as poor inhibition (Shafer *et al.* 2000). Alternatively, these children's limitations in working memory capacity may have prevented them from keeping task goals active resulting in an apparent deficit in flexibility. The present results are consistent with those of Hoffmann and Gillam (2004), who found that children with SLI show difficulty in coordinating information-processing resources.

The findings of the current study clearly show that children with SLI have difficulty in working memory tasks that are highly demanding on executive functions. It was also evidenced that working memory performance depends on the linguistic characteristics of the language tested. In both English- and Hungarian-speaking children linguistic complexity seems to have a larger effect on verbal working memory performance than the length of the sentences. However, complexity appears to affect working memory performance accuracy differently across languages. Studies examining working memory and language comprehension in children with SLI in languages other than English need to consider the language specific characteristics of that particular language. Furthermore, the results clearly show that sentence complexity has a larger impact on working memory performance than the length of the sentences. Clinicians, who work with children with language processing difficulties, need to consider that even short sentences can be highly demanding if their structure is not simple.

'What this paper adds'

English-speaking children with specific language impairment (SLI) perform more poorly than their typically developing peers on verbal working memory tasks, particularly if the sentences are syntactically complex. The present study examined the effect of language structure on working memory performance in Hungarian-speaking children. Hungarian is a morphologically rich language with free word order. We examined whether grammatical complexity affects working memory similarly across languages.

The results of the present study clearly show that sentence complexity has a larger impact on working memory performance than the length of the sentences. Grammatical complexity affected working memory performance accuracy differently across languages. In English, it was the increase of syntactic complexity that resulted in a decrease in performance accuracy, whereas in Hungarian, it was the morphological complexity that had a large impact on working memory performance. Clinicians, who work with children with language processing difficulties, need to consider that even short sentences can be highly demanding if their structure is not simple.

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Appendix

Examples for the ML task in Experiment 1

	Stimulus sentence with a sentence-final non-word	Questions about the content
Syntactically simple short sentence	1. <i>A kutya bator fipelk</i> The dog is a brave <i>fipelk</i> 2. <i>Jozsi megtanult salunep</i> Joseph learned to <i>salunep</i>	1. Who is brave? 2. What was the boy’s name?
Complex short sentence	1. <i>Kati nem nezte, hol a gimezsig</i> Kate did not watch where <i>gimezsig</i> 2. <i>Ha szello volna, en mindig nibizs</i> If I were the wind, I would always <i>nibizs</i>	1. What did Kate miss? 2. What would I be?
Complex long sentence	1. <i>A vadászok meglattak a roka mögött a tigris ami remulten linuszut</i> The hunters saw the tiger behind the fox that was in a frightening <i>linuszut</i> 2. <i>A muzeumban, ahol szép kepek, érdekes régi fegyverek, szerszámok vannak összegyűjtve, ott mindenki libef</i> In the museum, where nice pictures, interesting old weapons, and tools are collected, everyone <i>libef</i>	1. Who saw the tiger? 2. Where are the nice pictures and old weapons?

Examples for the LR task in Experiment 1

Examples of syntactically simple sentences with a real word to be recalled at the end:

- *Golya szállt a hazak **folott**.* (A stork flew above the houses.)
- *Peti rosszkedvuen ment **haza**.* (Peter went home in a bad mood.)
- *A mokus kedves kis **allat**.* (The squirrel is a nice little animal).
- *Viz nélkül nincs **elet**.* (There is no life without water.)

Examples of syntactically complex long sentences with a real word to be recalled at the end:

- *Golyane nagyszeruen mulatott azon, ahogy elfutott a ket ravaszdi **roka**.* (The stork amused herself greatly as she saw the two foxes running away.)
- *A szememmel latom, a fejemmel megertem, mikent lesznek a betubol **szavak**.* (I see it with my eyes, I understand it with my mind how the letters form words together.)
- *Segíteni szeretnek Sarinak, hogy jobban tanuljon es vidamabb **legyen**.* (I would like to help Sarah, so she could become a better student and be a happier child.)
- *Messze tajon, ahova a tel elol koltozik a fecske, elt egy oreg **kiraly**.* (The old king lived in a faraway land, where the swallow moves to before the winter.)

Examples from Experiment 2

Short sentences; simple morpheme	<i>A nyul elszalad, ha jön a roka</i> The rabbit runs away when the fox is coming <i>Ha nagy a víz, elúszik a csonak</i> If the water level is too high, the boat floats away	Who runs away? What happens if the water level is too high?
Long sentences; complex morpheme	<i>Bar <u>szarny/a</u>/ik <u>nincsen</u>/ek, megis el/<u>szall</u>/nak a <u>pihe</u>/i/tek*</i> Your flakes are flying, although they do not have wings <i>A <u>méh</u>/ei/nk <u>van</u>/nak olyan <u>szorgalmas</u>/ak, mint a ti <u>hangya</u>/i/tok*</i> Our bees are working as hard as your ants do	What happens to the flakes? What are the bees like?
Long sentences; simple morpheme	<i>Elszall a fehér házi galamb, ha kergeti a vidám gyerek</i> The white domesticated pigeon flies away if the playful child chases him <i>Ha uvolt a felelmetes nagy tigris, elszalad a felelnek zebra</i> The shy zebra runs away when the tremendously big tiger roars	Who chases the pigeon? Who roars?

* Slashes within the complex words in the morphologically complex sentences mark the number of morphemes. The base morphemes are underlined in these words.

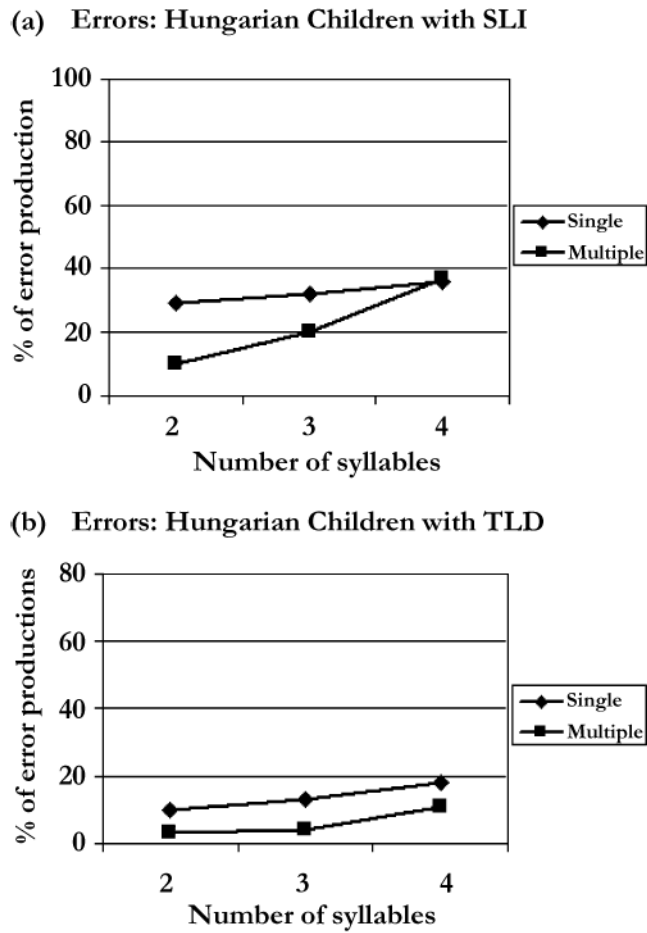


Figure 1. Complexity of errors in non-word repetition in the modified Listening Span task. a: Errors by Hungarian children with SLI. b: Errors by Hungarian children with TLD.

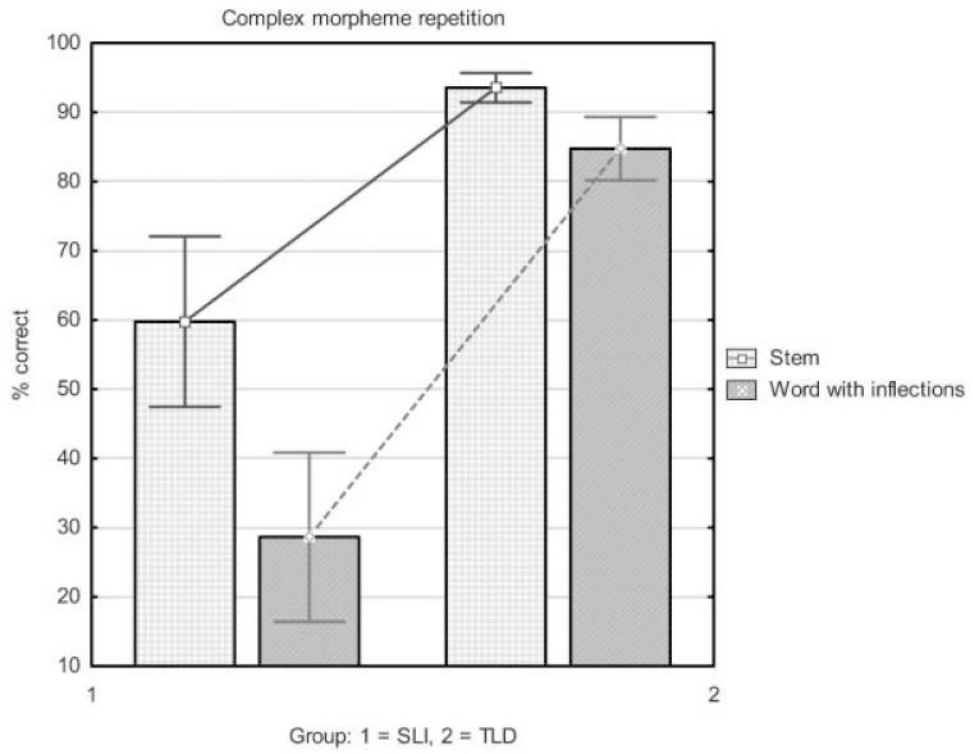


Figure 2. Complex morpheme repetition in Experiment 2.

Table 1

Participant profiles in Experiment 1

Participants	Age (months)	Non-verbal IQ	Non-word repetition (% accuracy)		
			Two-syllable	Three-syllable	Four-syllable
SLI (<i>n</i> =17) Mean (SD)	107.18 (15.6)	101.6 (10.2)	61.03 (19.2)	44.12 (19.82)	29.41 (19.74)
TLD (<i>n</i> =17) Mean (SD)	105.35 (16.47)	108.3 (7.8)	77.08 (16.74)	75.91 (16.07)	60.68 (12.53)

Table 2
Means and standard deviations across tasks in Experiment 1 (percentage correct)

Sentence type/group	Non-word repetition	Question answers	List Recall — free	List Recall — order
Simple (SLI): mean (SD)	46.67 (23.21)	72.92 (18.18)	37.46 (15.43)	10.59 (7.23)
Simple (TLD): mean (SD)	75.18 (17.47)	88.61 (18.38)	52.31 (12.53)	25.3 (15.66)
Complex short (SLI): mean (SD)	40.20 (23.26)	67.51 (19.98)	37.23 (13.64)	9.38 (6.59)
Complex short (TLD): mean (SD)	78.33 (19.97)	81.93 (16.76)	54.54 (16.41)	18.46 (12.92)
Complex long (SLI): mean (SD)	37.06 (24.04)	45.83 (21.25)	28.54 (11.46)	5.91(3.69)
Complex long (TLD): mean (SD)	76.67 (19.71)	54.49 (15.06)	43.23 (9.98)	15.23 (9.38)

Table 3

Error types for questions in the modified listening (ML) task and for item recall in the list recall (LR) task, Experiment 1 (percentage of all errors)

Task/ group	Omissions	Semantic substitutions	Phonological substitutions	Interference	Movement errors	Other
ML- SLI	12	10	3	68	—	7
ML- TLD	39	32	2	22	—	5
RL- SLI	28	—	—	49	19	4
RL- TLD	57	—	—	9	28	6

Table 4

Participant profiles in Experiment 2

Participants	Age (months)	Non-verbal IQ
SLI (<i>n</i> =25) Mean (SD)	118.12 (9.74)	108.3 (11.72)
TLD (<i>n</i> =25) Mean (SD)	117.16 (9.22)	116.53 (8.77)

Table 5

Means and standard deviations for word repetition (WR) and answers (ANS) to the questions (percentage correct) across sentence types in Experiment 2

	WR ST 1	WR ST2	WR ST3	ANS ST 1	ANS ST2	ANS ST3
SLI: mean (SD)	56.48 (18.07)	29.68 (19.53)	65.72 (16.76)	87.47 (13.38)	75.73 (16.98)	85.87 (10.4)
TLD: mean (SD)	92.8 (8.14)	85.04 (11.04)	93.76 (8.2)	97.6 (3.79)	92 (6.9)	95.73 (6.1)

ST1, short sentences, simple morphology; ST2, long sentences, complex morphology; ST3, long sentences, simple morphology.

Table 6
Error patterns (per cent of all errors) of word repetition across sentence types in Experiment 2

Sentence type/ group	Word omission	Grammatical morpheme omission	Semantic substitution	Phonological substitution	Grammatical morpheme substitution	Interference	Other
ST1-SLI	7	—	0	3	—	90	0
ST1-TLD	68	—	0	0	—	27	5
ST2-SLI	13	17	0	1	15	49	5
ST2-TLD	18	28	0	2	39	13	0
ST3-SLI	18	—	4	2	—	73	3
ST3-TLD	66	—	4	4	—	21	5

ST1, short sentences, simple morphology; ST2, long sentences, complex morphology; ST3, long sentences, simple morphology.