The Impact of Dual Tasking on Sentence Comprehension in Children With Specific Language Impairment

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Purpose: In this study, the authors assessed the hypothesis of a limitation in attentional allocation capacity as underlying poor sentence comprehension in children with specific language impairment (SLI).

Method: Fifteen children with SLI, 15 age-matched controls, and 15 grammar-matched controls participated in the study. Sixty sentences were presented in isolation, and 60 sentences were presented with a concurrent choice reaction time task in which colored stimuli randomly appeared at the center of the computer screen.

Results: Sentence comprehension was affected by the dual-task condition to a greater extent in children with SLI relative to age controls but not relative to grammatical controls.

Conclusion: This study does not support limitations in attentional allocation capacity as representing a core deficit in SLI. Rather, the data show that these children show attentional allocation capacity comparable to that of younger children having similar language level, suggesting that SLI is characterized by a slowed development of both attentional and language domains.

Key Words: syntax, specific language impairment, executive functions

Children with SLI are considered to show important morphosyntactic deficits. However, although grammatical production has been widely investigated, sentence comprehension in children with SLI has received only little research interest (Montgomery & Evans, 2009). We know that many of these children show important comprehension deficits (Bishop, Bright, James, Bishop, & van der Lely, 2000; Norbury, Bishop, & Briscoe, 2002). Some authors have proposed that a limitation of domain-general processing resources may lead to the poor sentence comprehension performance in children with SLI (e.g., Evans & MacWhinney, 1999; Montgomery, 1995, 2000a, 2000b). However, the relation between limited processing resources and sentence comprehension in children with SLI remains to be explored directly.
is the capacity constrained comprehension theory (Just & Carpenter, 1992). This computational theory presents a model of sentence processing in which storage and processing are fueled by the same pool of activation. Each representational element (e.g., a word) has an associated activation level. In this theoretical framework, many of the processes that underlie comprehension are assumed to occur in parallel: the processing of each word as it occurs, the integration of the words in a significant meaning, and the storage of the partial products of the computations while continuing to process the incoming words. However, if the amount of activation required to perform all the processes concurrently exceeds the available resources, then the processing will slow down and some partial results may be forgotten. When the task demands actually exceed the available resources, a trade-off between storage and computation occurs, and both functions are degraded. This model, thus, predicts that the time course and content of language processing will depend on the total amount of available cognitive resources. On the basis of this theoretical framework, many studies have shown that sentence comprehension performance correlates with working memory capacities (King & Just, 1991; MacDonald, Just, & Carpenter, 1992; Miyake, Just, & Carpenter, 1994). However, this framework is limited to the description of how the cognitive resources are shared between the maintenance and processing tasks inside the language system. It does not describe how a limitation in general attentional resources may interfere with language processing.

A recent theoretical model, the time-based resource-sharing (TBRS) model (Barrouillet et al., 2004, 2007), provides a more specific account of attentional resources and their sharing between processing and maintenance processes. The TBRS model proposes that attentional focalization is required for activating and maintaining an element in working memory. As soon as attention is switched away, activation of the memory traces suffers from time-related decay. The refreshment of the traces necessitates their retrieval from memory through attentional focalization. However, according to Barrouillet et al., the focus of attention can select only one element of knowledge at a time. Consequently, when the focus of attention is occupied by other processes, it is not available for maintenance processes, and any task that occupies the attentional focus will have a detrimental effect on the maintenance of the memory traces by preventing their refreshment. The sharing of attentional resources is supposed to be achieved through a rapid switching between maintenance and other target processes. This theory further predicts that the detrimental impact of concurrent processes is a direct function of their duration: the more time demanding the concurrent process, the greater the decay of memory traces and the greater the detrimental impact of the concurrent process on maintenance. Furthermore, in the TBRS framework, the cognitive load of a process is measured by the time this process captures the attentional focus. The cognitive load of an activity, thus, depends on the number of cognitive processes it involves and their respective duration times relative to the total duration of the activity.

The TBRS model has been used to describe the processes at play while performing complex tasks that require concurrent processing and storing multiple information, such as the counting span task or the reading span task. However, it may also be applied to sentence comprehension. Indeed, sentence comprehension is a complex task that requires processing a sequence of words, accessing lexical long-term memory, and maintaining and updating the products of sentence analysis while temporarily maintaining the partially interpreted linguistic material so that the incoming words may be integrated with it (Gibson, 1998; Just & Carpenter, 1992; Lewis & Vasishth, 2005; McElree, Foraker, & Dyer, 2003). Multiple processes are being carried out more or less simultaneously, and sentence processing may, thus, be considered as a multiple-task activity that requires the simultaneous storage and maintenance of verbal information. Following the TBRS framework, any concurrent task that effectively occupies the attentional focus during the sentence processing will hinder the processing and/or maintenance of the sentence components, limiting sentence comprehension performance. Consequently, the TBRS model helps us to understand how a possible limitation in processing capacities may lead to poor sentence comprehension in SLI. If children with SLI suffer from limitations in processing capacities, they should be less able to efficiently allocate their attentional resources to the various processes involved in a sentence comprehension task. In this study, we used the TBRS model to assess the hypothesis that a restriction in attentional allocation capacities is at the root of poor sentence comprehension performances in children with SLI.

**Attentional Allocation Abilities in Children With SLI**

Some recent studies have assessed the attentional allocation abilities in children with SLI. Most of these studies used the listening span task. This task requires combining at least three different tasks: the processing of the meaning of sentences, the maintenance of the final word of each sentence, and then the serial recall of all the final words of the different sentences that have been processed. Children with SLI consistently show poorer performance than their age controls in listening span tasks (e.g., Mainela-Arnold & Evans, 2005; Marton & Schwartz, 2003; Montgomery & Evans, 2009; Weismer, Plante, Jones, & Tomblin, 2005). Children with SLI, thus, seem to be impaired in their ability to simultaneously process and
store multiple types of verbal information. However, other studies provide partial evidence for problems in the allocation of attentional resources also in the nonverbal domain. Archibald and Gathercole (2007) observed more severely impaired performance in children with SLI as compared with age-matched peers on verbal memory tasks that were combined with either verbal or visuospatial secondary processing tasks. Hoffman and Gillam (2004) observed poor performance in children with SLI when recalling spatial information while simultaneously performing a pointing (spatial) color identification task. These data are consistent with the view that children with SLI show problems in flexible attentional allocation. Given the multiple storage and processing demands associated with the processing of sentences, it is possible that the sentence comprehension problem observed in children with SLI depends—at least partially—on attentional allocation problems. The following section will describe previous data that are consistent with this view.

**Attentional Allocation Capacities and Sentence Comprehension in Children With SLI**

Previous studies have shown a relationship between poor performance on sentence comprehension and typical working memory tasks, such as nonword repetition and listening span, in children with SLI. Nonword repetition has long been considered as a typical short-term memory task (e.g., Baddeley, Gathercole, & Papagno, 1998; Gathercole & Baddeley, 1990). However, it has also been recently considered as a complex task requiring the performance of multiple processes simultaneously: It requires segmenting the input signal, matching the signal with phonological representations in long-term memory, integrating the segamental and suprasegmental information, maintaining them activated, and planning speech motor programs (for a discussion on this topic, see Marton, 2006). Ellis Weismer and Thordardottir (2002) showed that performance on both nonword repetition and listening span tasks accounted for a significant portion of variance in language comprehension and production scores in children with or without SLI. Montgomery (1995) observed that children with SLI were poor at repeating nonwords and at comprehending longer sentences and that these two abilities were strongly correlated. Montgomery and Windsor (2007) observed that nonword repetition accounted for a significant proportion of the variance in offline language composite score, including a sentence comprehension task, in children with SLI but not in age-matched children without language problems. Montgomery and Evans (2009) showed that children with SLI had lower scores than age-matched controls on a listening span task, a nonword repetition task, and a sentence comprehension task. Moreover, the nonword repetition performance correlated with simple sentence comprehension, whereas the listening span performance correlated with the complex sentences comprehension in these children. Finally, Montgomery, Evans, and Gillam (2009) showed that complex sentence comprehension in SLI was correlated with both sustained auditory attentional capacities and attentional allocation capacity, as assessed by word span under a dual load recall condition (the children had to complete two mental operations—semantic categorization and size processing—while retaining the words of the word span task).

At the same time, these findings are difficult to interpret because nonword repetition, word recall, and listening span tasks not only involve working memory processes such as processing and storage. These tasks also strongly depend on linguistic knowledge. It is therefore difficult to decide whether the poor performances are attributable to general attentional allocation capacities or language processing difficulties. Nonword repetition tasks are complex psycholinguistic tasks depending on lexical and phonological sublexical knowledge (e.g., Coady & Aslin, 2004; Gathercole, 1995; Majerus & Van der Linden, 2003). If a child shows problems in segmenting the phonological input and matching this input to the sublexical and lexical representations in the language network, difficulties in nonword repetition will be very likely. Likewise, accurate semantic categorization and size processing during a word recall task tap on developed lexical and semantic knowledge. Last, listening span tasks (that require simultaneously processing the meaning of sentences, maintaining the final word of each sentence, and then recalling the final words of each sentence after an increasing number of successive sentences) also necessitate access to lexical and syntactic knowledge. Indeed, the effects of language knowledge on listening span tasks, as assessed by the manipulation of lexical frequency of the words to be stored, have been demonstrated in children with SLI and in controls (Mainela-Arnold, Evans, & Coady, 2010). Moreover, word recall performance in children with SLI is significantly poorer than that of their age peers when processing low frequency words but not when processing high frequency words (Mainela-Arnold & Evans, 2005). These data, and other findings in typical adult sentence processing (e.g., Pearlmutter & MacDonald, 1995), suggest that complex verbal tasks are, in fact, tightly related to language knowledge (MacDonald & Christiansen, 2002). If children experience problems in lexical and/or syntactic processing, they will, thus, be impaired in both sentence processing and listening span tasks.

We should note that most authors tried to control for the impact of linguistic representations on working memory performance. For example, Montgomery et al. (2009) only used highly familiar words in their word recall task, minimizing the likelihood that poor performance
on the semantic categorization and size processing would be attributed to representational deficits. Ellis Weismer and Thordardottir (2002) attempted to control for the impact of lexical knowledge: The nonwords they used were of low wordlikeness. Similarly, in their nonword repetition task, Montgomery and Evans (2009) excluded real word syllables and used consonants in nontypical positions to minimize wordlikeness. However, using nonwords of low wordlikeness does not rule out the influence of sublexical phonological knowledge on nonword repetition. For example, phonotactic knowledge, that is, sublexical knowledge about the frequency of phoneme co-occurrences in a given language, is known to influence nonword repetition accuracy (e.g., Majerus & Van der Linden, 2003). Montgomery (1995) argued that because children with SLI were especially poor at repeating three- and four-syllable nonwords as compared with controls and because these differences remained even after receptive lexical knowledge was partialled out, a specific deficit in short-term memory abilities is to explain their poorer performance on the nonword repetition task. However, long nonwords, as compared with short nonwords, not only require larger phonological storage demands but also larger phonological processing demands (Snowling, Chiat, & Hulme, 1991). Consequently, the assertion that the association between poor performance on these working memory tasks and sentence comprehension is due to limited working memory capacities (and thus attentional allocation capacities) is uncertain because this association could also be due to poor linguistic abilities that underlie diminished performance in both working memory and sentence processing tasks. Moreover, a more direct approach to study the impact of attentional allocation capacities on sentence comprehension would be to directly induce an experimentally controlled situation in which children have to split up their attentional resources between the sentence comprehension task and an interfering task. However, as far as we know, no study has yet adopted such a direct approach on sentence comprehension in children with SLI.

Some empirical data are consistent with the idea that additional processing load interferes with language comprehension in adults (Aydelott & Bates, 2004; Blackwell & Bates, 1995; Dick et al., 2001; Kilborn, 1991; Wingfield, Tun, Koh, & Rosen, 1999) and children (Hayiou-Thomas, Bishop, & Plunkett, 2004; Leech, Aydelott, Symons, Carnevale, & Dick, 2007). For example, Aydelott and Bates (2004) have shown that an increase in attentional demand, as achieved through a time compression manipulation, interferes with lexical processing in a sentence context. Blackwell and Bates (1995) produced agrammatic performance profiles in healthy adults whose processing capacity was diminished through the concurrent performance of a secondary task (digit list recognition task) during a grammatical judgment task. Kilborn (1991) also demonstrated selective impairment for grammatical morphology under stress conditions in normal adults. Hayiou-Thomas et al. (2004) observed the same pattern of errors on a grammatical judgment task in normal children under stress condition (compressed speech signal) as in children with SLI.

**Purpose**

This study aimed at assessing the hypothesis of a limitation in attentional allocation capacity on sentence comprehension performance in children with SLI by inducing an experimentally controlled situation in which attentional resources had to be shared between sentence processing and an interfering nonverbal task. This was achieved by using a dual-task paradigm, the primary task being the sentence comprehension task and the secondary task being a nonlinguistic paradigm. In contrast to previous studies, a nonlinguistic secondary task was used to rule out the possibility that the cognitive load induced by the dual-task condition may be caused by an increase in linguistic processing demands. This study is the first to adopt this approach, by directly testing attentional resource sharing between two tasks, the target task being a sentence comprehension task. If poor attentional allocation capacity is a core deficit in children with SLI, limiting their grammatical learning and performance, children with SLI should be impaired to a greater extent in the dual-task condition relative to a control group matched on grammatical abilities. On the contrary, a comparable performance decrement under the dual-task condition in children with SLI and their younger language controls would attest to cognitive abilities that mature slowly across domains.

As far as we know, no study has yet assessed the impact of an interfering secondary nonverbal task on sentence comprehension performance. Thus, we adapted a nonlinguistic secondary task that has demonstrated an interfering impact on another sentence processing task in adults: a sentence recall task (Jefferies, Lambon Ralph, & Baddeley, 2004). This attentional demanding interfering task consisted of a visual display of four boxes aligned horizontally: A star appeared randomly in one of the boxes, and the participant was required to press the corresponding response key (out of a choice of four keys) as fast as possible. The task was self-paced, with the next trial being presented immediately after a correct sentence recall response. We further adapted this visual-choice, reaction time task following the recommendations by Rohrer and Pashler (2003). First, we ensured that stimulus–response spatial compatibility was low, to ensure that this task actively occupied the attentional resources during response selection. For example, in the task proposed by Jefferies et al. (2004), given the
high stimulus–response spatial compatibility, practice may lead to quasiautomatic response-selection processes, placing few demands on attentional resources during response selection. In our adaptation of the task, we presented stimuli of three different colors randomly appearing at the center of the screen; the response selection had to be made on the basis of the stimuli color by pressing one of the three adjacent keys on the keyboard having the same colored dot as the target stimulus on the screen. Second, to prevent self-paced allocation of attentional resources between the main and the secondary tasks and to ensure that the task occupied the same proportional amount of attentional resources in each child, the interstimulus interval was fixed and adapted to each participant’s response speed.

Furthermore, we explored possible interactions between the increase of attentional demands due to the interfering task and those due to the manipulation of linguistic parameters such as lexical frequency and sentence length. The TBRS model defines the load of a cognitive process as the time during which it captures the attentional resources, preventing their usage in another processing or storage activity. This model, thus, suggests that increasing the number of concurrent processes, or their duration, will affect sentence comprehension performance. When a person processes long sentences, he or she must temporarily store more words than when processing short sentences. A greater number of words will, thus, have to be maintained and refreshed, recruiting attentional resources to a higher extent. Furthermore, the impact of the interfering task on performance in comprehending long sentences is expected to be larger than in comprehending short sentences. Indeed, a larger time-related decay is supposed to be observed for the multiple memory traces that have to be maintained in long sentences relative to short sentences. Concerning lexical frequency, the TBRS model proposes that the slower the process, the higher its cognitive load. Previous studies have shown that the processing of low-frequency words takes more time than the processing of high-frequency words (Ferreira, Henderson, Anes, Weeks, & McFarlane, 1996; Henderson & Ferreira, 1990). Hence, a larger impact of the interfering task is expected on the processing of sentences containing low- than high-frequency words. Aydelott and Bates (2004) provided partial evidence for this hypothesis: They demonstrated that increasing the attentional load of the task impairs word processing (lexical selection and lexical integration) in sentence context. Moreover, Majerus and Lorent (2009) showed that slowed access to word meaning (due to ambiguity) leads to a delayed integration in sentence meaning, increasing short-term memory storage demands.

In this study, we compared the children with SLI with children of the same age. If children with SLI suffer from poor attentional allocation capacities, performance trade-off should be larger in these children than in typically developing children of the same age. However, we know that children with SLI also show poorer syntactic abilities than their age-matched peers. Consequently, the complexity of this dual task may not be exactly the same in children with SLI than in controls of the same age because of differences in initial language processing abilities. To control for this confounding factor, we also compared the children with SLI with younger typically developing peers matched on initial sentence comprehension abilities. Two versions of our hypotheses may be formulated: a strong and a weak version. In the strong version, poor attentional allocation capacity is considered to be a core deficit in children with SLI, limiting their grammatical learning and performance. In agreement with Bishop (1997), if children with SLI are impaired to a greater extent in the dual-task condition relative to the grammatical AC group, then we cannot dismiss difficulties in attentional allocation capacities as secondary to language processing difficulties but rather as reflecting a core deficit of SLI. On the contrary, following the weak version of our hypothesis, the attentional allocation capacity is not at the root of poor sentence comprehension performance in children with SLI but, like language processing difficulties, stems from more general processing limitations. Following the weak account, we would expect comparable performance decrement under the dual-task condition in children with SLI and their younger language controls, attesting to cognitive abilities that maturate slowly in all domains. In recent years, this dimensional view has been adopted by several authors who have questioned the specificity of the language impairment in these children given the robust finding that children identified with SLI show deficits in a variety of nonverbal cognitive and perceptual–motor tasks that do not tap linguistic knowledge (e.g., Dollaghan, 2004; Leonard et al., 2007; Windsor, Milbrath, Carney, & Rakowski, 2001).

Method
Participants

Fifteen French-speaking children with SLI ages 8–13 years (12 boys; mean age = 11;3 [years;months], SD = 1;8), 15 typically developing children matched for chronological age and nonverbal reasoning (6 boys; mean age = 11;3, SD = 1;8), and 15 younger typically developing children matched for their sentence comprehension abilities (8 boys; mean age = 7;11, SD = 1;7) participated in the study. The SLI group and the AC group were comparable in age, t(28) < 1, ns, and nonverbal reasoning (Wechsler Intelligence Scale for Children—Fourth Edition; WISC–IV; Wechsler, 2005), t(28) < 1, ns (see Table 1). They, however, differed in their phonological abilities,
All children were French native speakers, had no history of psychiatric or neurological disorders, and had no neurodevelopmental delay or sensory impairment. Children with SLI were recruited from specific language classes in special needs schools. They were diagnosed as presenting with SLI prior to the study by certified speech-language pathologists. Moreover, we ensured by using standard clinical tests that all of the children with SLI met the following criteria: (a) They scored more than −1.25 SD below expected normative performance in two language areas (according to SLI criteria adopted by Leonard et al., 2007) and (b) the children demonstrated normal-range nonverbal IQ (≥ 80; see Leonard, 2009; WISC–IV; Wechsler, 2005). Control children scored in the normal range on all language tests.

### Materials and Procedure

#### Sentence Comprehension Task

One hundred twenty sentences with relative clauses were created. In order to minimize possible semantic factors having an impact on sentence comprehension (van der Lely & Dewart, 1986), we used only fully reversible sentences, whereby semantic knowledge is not sufficient to achieve a correct sentence interpretation. Two factors were manipulated: sentence length and lexical frequency of the constituent words. Two levels were considered for each factor so that sentences were either short or long and contained words of either high or low lexical frequency, yielding four sentence types. Thirty sentences were created for each sentence type (see the Appendix). The sentences were recorded by a female speaker in an isolated acoustic booth using a high-quality microphone connected.
to a Minidisc digital recorder. Sentences were read at a normal rate and prosodic variation, digitized at 44 kHz, and edited to eliminate any noise at the beginning or the end of the sound file. The 120 sentences were divided into two parallel sets containing 15 sentences of each sentence type. Each set was presented to half of the participants for the simple task condition and to the other half of the participants for the dual-task condition. Moreover, each set was divided in two parts containing seven or eight sentences of each type to present only 30 sentences at a time to the children, to avoid fatigue effects. Order of presentation of the different sets was counterbalanced across participants. The cross-factorial design, combining each level of task condition (single vs. dual), lexical frequency (low vs. high), and sentence length (short vs. long), yielded eight task conditions.

Sentence length. Short sentences contained seven words and nine syllables—for example, “La madame voit le garçon qui glisse.” (“The woman sees the boy who is gliding.”). Long sentences contained 15 words and 17 syllables—for example, “Ce soir la belle dame noire appelle la petite fille qui lit dans le pré.” (“This evening, the beautiful Black woman calls the little girl who is reading in the meadow.”). The added elements in long sentences were redundant, that is, they were not necessary to understand the sentence meaning. Added elements were adjectives, adverbs, and time and location complements. These added elements had to be processed (and consequently consumed processing resources), but they could not help in the making of a decision when matching the sentence to one of the four presented pictures (see below), such that the picture choice had to be based on the analysis of syntactic roles of the sentence arguments, not on semantic indices.

Lexical frequency. The sentences were created by using words of either high or low lexical frequency, based on the Novlex French Data Base (Lambert & Chesnet, 2001). Only the verbs and the core of their arguments varied in lexical frequency, as these elements were the target words to process to understand the sentence. The four target words varying in frequency encompassed, thus, the verb, the subject, and the object of the main clause, as well as the verb of the relative clause. Sentences with low lexical frequency contained target words with low lexical frequency ($M = 1,681$, range = 238–7,140; Lambert & Chesnet, 2001), such as, “Le policier filme l’apache qui skie.” (“The policeman films the Apache who is skiing.”), whereas sentences with high lexical frequency contained target words with high lexical frequency ($M = 58,562$, range = 12,139–272,542; Lambert & Chesnet, 2001), such as, “La madame voit le garçon qui mange.” (“The woman sees the boy who is eating.”). We presented the images as being part of a trip in an imaginary world: The child was informed that he would encounter the inhabitants of this world and discover their own various habits, which might differ from those with which he is familiar, to avoid rejection of sentences on the basis of potential differences in perceived semantic plausibility.

Prior to the start of the experiment, the children’s knowledge of the nouns used in the sentences was assessed using a picture-pointing task. Children were presented a picture including five or six toy figures and were asked to point to a specific figure. The examiner asked the child, “Find out which of these is the X” (for example, “the policeman”). The same procedure was used to assess children’s knowledge of the verbs used in the study. The examiner requested that the child “Find out which of these figures is X” (e.g., “is drinking”). For the experimental task, the children were told that they would have to help a detective to find a thief in an imaginary land. The children were told to listen carefully to the sentences they would hear through headphones and that after each sentence, they would have to choose the accurate picture among the four that would appear on the computer screen. The pictures appeared immediately after the end of presentation of the stimulus sentence. The pictures depicted the target situation conveyed by the sentence and three foil situations corresponding with the incorrect syntactic parsing of the sentence; that is, confounding the subject and the object of the main clause and ascribing the relative clause to the wrong antecedent. The children were instructed to point to the correct picture. A touch-screen recorded response accuracy and latency. Four practice items were used to familiarize the child with the task, and feedback was provided during the practice trials but not during the experimental trials. Across the practice and experimental trials, the location of the target picture appeared equally often at the top left, top right, bottom left, and bottom right of the screen. Sentences were presented binaurally through high-quality headphones at a comfortable listening level.

Serial Choice-Reaction Time Task

The serial choice-reaction time task (CRT) was adapted from Rohrer and Pashler (2003). Participants were asked to respond to red, green, or blue stimuli that were randomly and continuously appearing for 200 ms at the center of the computer screen by pressing one of the three adjacent keys on the keyboard carrying the same colored dot. To adjust the task to each participant’s response speed, we varied the interstimulus interval (ISI) across participants. During the first 3-min practice period, the ISI was set to 1,800 ms for all participants. Participants were asked to respond as quickly but as accurately as possible. In the second 3-min practice period as well as in the experimental trials, the ISI was set to the 90th percentile of the participant’s reaction times (RTs) collected during the last minute of the first practice period. The task was presented as a game: The children were asked to catch a thief that appeared in a large red, green, or blue
square. To catch the thief, the child had to press on the key of the corresponding color.

Dual task. Such as in Jefferies et al. (2004), there was a period of 10 s before the sentence presentation during which the CRT task was performed alone. Participants were required to continue the CRT task while they listened to the sentence. When the sentence was finished, the task stopped, and four pictures appeared on the screen, among which the children had to choose the one that accurately depicted the sentence they just heard (see Figure 1). Four practice trials for the dual task were proposed to familiarize the children with the task.

Working Memory Tasks

A dual-task paradigm by Baddeley, Della Sala, Papagno, and Spinnler (1997) was administered to provide an external measure of the children's ability to simultaneously process verbal and visual information. This task assesses the ability to recall digit sequences while marking as many boxes as possible on a sheet. This task is divided into three parts: First, participants performed the verbal task in a single-task condition; next, they performed the visual task in a single-task condition; and third, both tasks were performed as a dual-task condition. To be more precise, after a standard digit span task, participants were presented with lists of digits at their own span level, and they had to recall the lists during a period of 2 min. The percentage of sequences correctly repeated was computed. Next, using a pen, the participants had to mark as rapidly as possible a chain of boxes. The total number of boxes crossed within the time of 2 min was computed. In the dual-task condition, the participants had to perform the two tasks simultaneously. The proportional loss of performance under dual-task conditions was derived by comparing the proportion of lists recalled under the single- and dual-task conditions and by comparing the proportion of boxes crossed in dual- and single-task conditions. Finally, the Digit Span Backward task from the WISC–IV was administered to provide an external measure of maintenance and processing capacities in working memory.

Procedure

The sentence comprehension task was presented using E-Prime 1.0 Psychology Software (Schneider, Eschmann, & Zuccolotto, 2002) in four different sessions. During the first and second sessions, children performed the isolated sentence comprehension task (divided into two homologous parts) as well as the working memory tasks. During the third session, they completed two 3-min practice trials with the serial CRT task (on the first practice trial, the ISI was fixed at 1,800 ms; on the second practice trial, the ISI was set to the 90th percentile of the participant’s RTs). They also completed the first part of the dual-task condition, beginning with four practice trials, during the third session. During the fourth session, they completed a 1-min practice trial with the serial CRT task (with the ISI adapted to their RTs) and then performed the second part of the dual-task condition.

Results

Generally, the performances observed in the SLI and the GC groups were rather similar. Performance in these groups was globally lower than that observed in the AC group, in terms of response accuracy (see Table 2) or RTs (see Table 3).

Analysis of Variance (ANOVA): The Sentence Comprehension Task

Both response accuracy and RTs for correct answers were subjected to mixed ANOVAs. For each analysis, the between-subjects factor was participant group (children with SLI, AC, or GC), the within-subjects factors were lexical frequency (high or low), length (short or long), and task condition (single or dual). We performed distinct mixed ANOVAs on response accuracy on the one hand and on RTs on the other hand, but for the sake of clarity, we have regrouped the results of both analyses. After a precise look at each participant’s RTs, we observed that a
child in the SLI group was systematically slower than 2 SDs of the mean of the RTs of the child’s SLI peers. We, thus, decided to exclude this child from our analyses.

A first ANOVA revealed a main effect of sentence length on both accuracy and RTs. Children responded more accurately, $F(1, 41) = 82.09, p < .001$, partial $\eta^2 = .67$, and more quickly, $F(1, 41) = 31.16, p < .001$, partial $\eta^2 = .44$, to short than long sentences. However, the Group × Length interaction effect was significant neither for response accuracy, $F(2, 41) = 1.18, p = .32$, partial $\eta^2 = .05$, nor for RTs, $F(2, 41) = 2.02, p = .15$, partial $\eta^2 = .09$. Likewise, the Condition × Length interaction effect was significant neither for response accuracy, $F(1, 41) < 1$, ns, partial $\eta^2 = .01$, nor for RTs, $F(1, 41) < 1$, ns, partial $\eta^2 = .00$. Consequently, we decided to collapse the data across sentence length in further analyses.

Once more, we performed distinct mixed ANOVAs on response accuracy on the one hand and on RTs on the other hand, but for the sake of clarity, we will regroup the results of both analyses. Results revealed a main effect of group on response accuracy, $F(2, 41) = 8.73, p < .001$, partial $\eta^2 = .29$. Newman–Keuls post hoc analyses revealed that both the SLI group and the GC group performed significantly worse than the AC group ($p < .01$ for both groups). The SLI group did not differ from the GC group ($p = .60$). RTs for correct responses did not significantly differ from one group to another, $F(2, 41) = 1.41, p = .25$, partial $\eta^2 = .06$. A main effect of lexical frequency was observed, for both response accuracy and RTs. Children responded more accurately, $F(1, 41) = 8.90, p < .01$, partial $\eta^2 = .18$, and more quickly, $F(1, 41) = 57.00, p < .001$, partial $\eta^2 = .58$, to sentences containing high- than low-frequency vocabulary. The Group × Lexical Frequency interaction effect was not significant for response accuracy, $F(2, 41) < 1$, ns, partial $\eta^2 = .00$, or for RTs, $F(2, 41) = 2.93, p = .07$, partial $\eta^2 = .12$. The main effect of task condition was not significant for response accuracy, $F(1, 41) = 3.33, p = .08$, partial $\eta^2 = .08$, nor was the Group × Task Condition interaction effect, $F(2, 41) = 2.51, p = .09$, partial $\eta^2 = .11$. However, children’s RTs were slower under the dual-task condition, $F(1, 41) = 14.54, p < .001$, partial $\eta^2 = .26$. Moreover, the Group × Task Condition effect was also significant on RTs, $F(2, 41) = 4.39, p < .05$, partial $\eta^2 = .18$. Newman–Keuls post hoc analyses revealed that both the SLI group ($p < .01$) and the GC group ($p < .05$) showed slower RTs under the dual-task condition than under the single-task condition. This was not the case for the AC group ($p = .99$; see Figure 2). A significant Frequency × Task Condition effect was observed for response accuracy, $F(1, 41) = 6.63, p < .05$, partial $\eta^2 = .14$. Newman–Keuls post hoc analyses revealed that lexicality affected performance only in the single-task condition ($p < .001$; dual-task

**Table 2.** Means (and SDs) for response accuracy for each experimental condition, as a function of participant group for children with specific language impairment (SLI), grammatical controls (GC), and age controls (AC).

<table>
<thead>
<tr>
<th>Group</th>
<th>Short</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HF</td>
<td>LF</td>
</tr>
<tr>
<td>SLI</td>
<td>11.2 (2.21)</td>
<td>10.2 (2.65)</td>
</tr>
<tr>
<td>GC</td>
<td>12.07 (2.31)</td>
<td>10 (2.83)</td>
</tr>
<tr>
<td>AC</td>
<td>14.27 (0.79)</td>
<td>13.47 (1.25)</td>
</tr>
</tbody>
</table>

**Table 3.** Means (and SDs) for reaction times for each experimental condition, as a function of participant group for children with SLI, GC, and AC.

<table>
<thead>
<tr>
<th>Group</th>
<th>Short</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HF</td>
<td>LF</td>
</tr>
<tr>
<td>SLI</td>
<td>5361 (1591)</td>
<td>6169 (2060)</td>
</tr>
<tr>
<td>GC</td>
<td>5758 (1981)</td>
<td>6612 (1903)</td>
</tr>
<tr>
<td>AC</td>
<td>5098 (1001)</td>
<td>6297 (1630)</td>
</tr>
</tbody>
</table>

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condition, \( p = .50 \), performance being even better for low-frequency words under dual- than under single-task condition (\( p < .01 \)).

**ANOVA: The Serial CRT Task**

As described in the Method section, speed of target presentation was adjusted to each participant’s response speed. An ANOVA was performed on the adjusted speed of the target presentation (corresponding to the 90th percentile of each participant’s response speed), with participant group as the between-subjects factor. This analysis showed that the groups differed in RTs for accurate trials in the simple CRT, \( F(2, 41) = 4.42, p < .05 \), partial \( \eta^2 = .18 \): Children with SLI were significantly slower than their ACs (\( p < .05 \)), but not as compared with their language controls (\( p = .24 \)). The two control groups did not significantly differ from one another (\( p = .09 \)). A final analysis explored response accuracy on the serial CRT task under single- or dual-task condition. The between-subjects factor was participant group (children with SLI, AC, or GC), the within-subjects factor was task condition (single or dual). The dual-task effect was significant, \( F(1, 41) = 12.14, p < .01 \), partial \( \eta^2 = .23 \): Performance on the serial CRT were more accurate when the task was performed in isolation than in the dual-task condition. However, neither the group effect, \( F(2, 41) = 2.43, p = .10 \), partial \( \eta^2 = .11 \), nor the Group × Task Condition interaction effect were significant, \( F(2, 41) < 1 \), \( ns \), partial \( \eta^2 = .04 \).

**Additional Results From Working Memory Measures**

Dual-task paradigm. For the dual-task paradigm developed by Baddeley et al. (1997), we observed a main effect of group on initial digit span performance, as expected, \( F(2, 41) = 51.53, p < .001 \), partial \( \eta^2 = .72 \): Digit span was significantly lower in children with SLI (\( M = 3.4, SD = 0.5; \) range = 3–4) than in AC (\( M = 6.4, SD = 0.9; \) range = 4–8) and GC (\( M = 6.1, SD = 1.0; \) range = 4–8). The spans of the two control groups did not significantly differ from one another. In the single-task condition, the groups did not significantly differ in the proportion of digit lists accurately repeated at their own span level, \( F(2, 41) = 1.59, p = .21 \), partial \( \eta^2 = .07 \), but they differed in the number of boxes crossed, \( F(2, 41) = 25.05, p < .001 \), partial \( \eta^2 = .55 \): The AC group (\( M = 127.33, SD = 20.66 \)) performed significantly better than the SLI group (\( p < .001 \); \( M = 91.0, SD = 23.86 \)) and the GC group (\( p < .001 \); \( M = 66.0, SD = 26.73 \)), and the SLI group performed significantly better than the GC group (\( p < .01 \)). Finally, global dual-task decrement as calculated by combining performance decrement in both tasks in the dual-task condition also did not differ between groups, \( F(2, 41) < 1 \), \( ns \), partial \( \eta^2 = .01 \).

To further characterize the impact of dual tasking on each task separately, we performed mixed ANOVAs on the proportion of sequences accurately repeated under single- and dual-task conditions. The group effect was not significant, \( F(2, 41) < 1 \), \( ns \), partial \( \eta^2 = .04 \); neither were the condition, \( F(1, 41) = 2.74, p = .11 \), partial \( \eta^2 = .06 \), nor the Group × Task Condition effects, \( F(2, 41) = 2.24, p = .12 \), partial \( \eta^2 = .12 \). These results mirror the lack of dual-task impact on response accuracy on the sentence comprehension task in the dual-task condition. At the same time, a mixed ANOVA performed on the number of boxes crossed (secondary task) revealed a main effect of group, \( F(2, 41) = 21.76, p < .001 \), partial \( \eta^2 = .51 \), observed in the single-task condition, the AC group performing better than the SLI group (\( p < .001 \)), which performed better than the GC group (\( p < .05 \)). We also observed a main effect of dual tasking, performance being lower under the dual- than the single-task condition, \( F(1, 41) = 7.79, p < .01 \), partial \( \eta^2 = .16 \); as for the other tasks, there was...
no significant Group × Task Condition effect, \(F(2, 41) = 1.26, p = .29\), partial \(\eta^2 = .06\). These results also mirror the impact of the dual-task condition we observed on the secondary visual task in the sentence comprehension dual-task condition. Overall, we observed exactly the same pattern of results for both dual tasks used in this study: The dual-task condition leads to decreased performance especially in the secondary task. Moreover, we used the same formula as above for computing an estimate of overall dual-task performance decrement in the sentence comprehension task, revealing again no group effect, \(F(2, 41) < 1, ns\), partial \(\eta^2 = .05\).

Reverse span task. There was a main effect of group, \(F(2, 41) = 5.32, p < .01\), partial \(\eta^2 = .21\): Performance was significantly lower in the SLI group \((M = 2.8, SD = 0.8; \text{range} = 2–4)\) and in the GC group \((M = 2.9, SD = 0.7; \text{range} = 2–4)\) relative to the AC group \((M = 3.9, SD = 0.8; \text{range} = 3–5)\). These results suggest that children with SLI and their grammatical controls were also matched on more general working memory abilities.

**Discussion**

Our study aimed at exploring the hypothesis of a limitation in attentional allocation capacities as underlying difficulties in sentence comprehension in children with SLI. To do so, we assessed the impact of a controlled attention-demanding nonlinguistic task on sentence comprehension abilities in children with SLI as compared with both chronological age-matched controls and grammatical age-matched controls. Following the TBRs model, we expected to observe a resource-sharing trade-off when both tasks had to be performed simultaneously. We had formulated two versions of our hypotheses: Following the strong version, children with SLI were expected to be impaired to a greater extent in the dual-task condition relative to the grammatical AC group, revealing poor attentional allocation capacity as a core deficit in children with SLI, limiting their grammatical learning and performance. Following the weak version of our hypothesis, we expected comparable performance decrement under the dual-task condition in children with SLI and their younger language controls, showing that the attentional allocation capacity is not at the root of poor sentence comprehension performance in children with SLI but is proportionate to their language level.

In accordance with previous studies (e.g., Bishop et al., 2000; Montgomery & Evans, 2009; Norbury et al., 2002), we observed that children with SLI performed more poorly on sentence comprehension relative to age-matched typically developing children. The SLI children in this study performed at the same level as typically developing children who are 3 years younger. These data confirm the severity of sentence comprehension difficulties in children with SLI. A resource-sharing trade-off between our main and secondary tasks was observed in the three groups: Response accuracy for the interfering task was lower under dual- than single-task conditions. This result confirms that our main and secondary tasks share and compete for a common pool of attentional resources, as predicted by the TBRs framework. For the main task, a resource-sharing trade-off was also observed for RTs: Children with SLI and their grammatical controls showed slowed RTs under dual- versus single-load conditions. This was not the case with their age-matched peers. Main effects of sentence length and lexical frequency were observed on response accuracy and RTs in all groups: Children responded more accurately and more quickly on short than long sentences and on sentences containing high as opposed to low lexical frequency vocabulary. At the same time, children with SLI were no more affected than the control groups by sentence length and low lexical frequency of the sentences to be processed, and this under both single- or dual-task conditions.

**Sentence Comprehension and Attentional Allocation Capacities**

Our data confirm the existence of attentional resource sharing between linguistic and nonlinguistic tasks, as described by the TBRs model: Under dual-task condition, performance decrement was observed on response accuracy in the interfering task in all children. This demonstrates that part of attentional resources necessary to perform the interfering visual serial CRT task had to be shared with the processing of the sentences and that children had to efficiently allocate their attentional resources between both tasks. Moreover, performance decrement was observed on RTs in the main task in children with SLI and their grammar-matched peers. Efficient sentence processing, thus, partially depends on the availability of domain-general attentional resources.

Our experimental task was well designed to assess attentional resource sharing between our main linguistic task and the secondary nonverbal task. First, the interfering task was derived from a similar task that demonstrates a significant impact on sentence repetition performance in adults (Jefferies et al., 2004). Moreover, we adapted this task to maximize attentional demands during the response-selection process of the sentence processing task, following the recommendations of Rohrer and Pashler (2003). Second, performance of the same children on another task especially designed by Baddeley et al. (1997) to assess dual-tasking abilities led to similar results as those observed for our experiment task. The fact that the same performance pattern was observed on an additional dual task suggests that (a) our experimental task was well designed to assess attentional allocation capacities and (b) irrespective of the type of dual task,
performance decrement was observed for the interfering task but not the linguistic task in either group. Thus, children appeared to dedicate their attentional resources preferentially to the linguistic task. This may also be the reason why an impact of the dual condition on sentence comprehension was nevertheless observed in terms of RTs in both children with SLI and their grammatical controls.

Moreover, our data are also consistent with previous studies that assessed attentional allocation capacities by using listening span tasks that compared children with SLI to children of the same linguistic level. Actually, most of the previous studies compared performance in children with SLI to performance in children of the same chronological age, and the researchers observed a larger impact of the secondary task on performance by children with SLI (e.g., Isaki, Spaulding, & Plante, 2008; Mainela-Arnold & Evans, 2005; Weismer et al., 2005). In our study, we also found a larger impact of the secondary task on performance in children with SLI, as compared with control children of the same age. Only a few studies have compared children with SLI to children of the same linguistic level for these types of paradigms. The researchers of these studies also observed no differences between children with SLI and children of the same linguistic knowledge. For example, in a listening span task, Montgomery (2000a) observed that children with SLI performed worse than their age peers but at the same level as their language-matched peers. In complex processing and storage tasks, Archibald and Gathercole (2007) observed comparable performance in children with SLI and their lexical controls when performing a verbal storage task concurrently with a visual or a verbal processing task. Similar results were observed by Montgomery (2000b) when comparing performance on a verbal working memory task, under single- and dual-load conditions. Finally, Montgomery and Evans (2009) showed that children with SLI performed at the same level as their language-matched peers on both a listening span task and a sentence comprehension task.

An alternative explanation could be that the increase in RTs observed under the dual-task condition in children with SLI and their grammatical control peers is not due to dual load but to the application of a rehearsal strategy just before response selection. The use of this strategy was actually possible because there was no dual-task processing anymore at the response stage. However, this possible intervention of rehearsal is actually in line with the idea that the secondary task interferes with sentence processing. Recent working memory models explicitly consider that attentional resources are needed to refresh memory traces (e.g., Barrouillet et al., 2004, 2007; Cowan, 1999). If we accept that longer RTs, in fact, reflect verbal rehearsal, then we also have to accept that this is so because rehearsal had to been postponed until the end of the attention-demanding interfering task. This necessity to postpone rehearsal reflects an inability to rehearse during the sentence processing, due to the cognitive load of the secondary task that captures the attention and prevents the refreshment of memory traces (Barrouillet et al., 2004). Consequently, the increase in RTs in children with SLI and their language-matched peers during the dual-task condition very likely reflects the negative impact of the secondary task on sentence processing performance.

**Attentional Allocation Capacities in Children With SLI**

No group effects were observed on the external dual-task paradigm proposed by Baddeley. There are two possible reasons for this result: either (a) children with SLI are as able as their age peers to efficiently allocate their attentional resources when the verbal task is adapted to their language level (as it is the case in the dual-task paradigm by Baddeley) or (b) the differences between children with SLI and their controls are to be observed in terms of RTs (not measured in this paradigm) rather than response accuracy, as was the case in our sentence comprehension dual-task paradigm. Concerning the sentence comprehension task, results showed a larger impact of the interfering task on sentence comprehension performance in children with SLI and their grammar-matched controls as compared to their age-matched controls. Sentence comprehension performance in children with SLI and their grammatical controls, relative to ACs, was thus impaired to a greater extent by the necessity to allocate attentional resources between multiple processing and storage processes. At the same time, the difficulties in efficiently allocating attentional resources in children with SLI are not disproportionate relative to their language level.

Our data are consistent with the idea that children with SLI were matched with the younger controls not only on language abilities but also on general attentional or processing abilities. First, children with SLI and their younger peers showed comparable performance levels on the Digit Span Backward task. Second, these groups showed comparable reaction times in the CRT task (single-task condition). Numerous studies have revealed limited processing capacities in children with SLI and have proposed that this deficit could be at the root of their language problem (e.g., Evans & MacWhinney, 1999; Leonard et al., 2007; Montgomery, 1995, 2000a, 2000b). The fact that children with SLI show RTs that are slower than expected given their chronological age is in line with a general processing speed limitation in children with SLI, as observed in previous studies (Kail, 1994; Leonard et al., 2007; Miller et al., 2006; Windsor & Hwang, 1999). However, this limited speed of processing is not disproportionate to their receptive language level because
it did not differ from the speed of processing observed in younger children matched on receptive grammatical abilities. More generally, our study shows that children with SLI experience problems in general attentional (or processing) capacities that are not disproportionate relative to their receptive language level. Our results are, thus, in line with our weak hypothesis proposing that attentional allocation capacity interacts with sentence comprehension performance to the same extent in children with SLI and their younger peers matched on language knowledge. Our results are, thus, more consistent with a dimensional view of SLI as proposed in previous studies (e.g., Dollaghan, 2004; Leonard et al., 2007; Mainela-Arnold & Evans, 2005). However, we must acknowledge that the children with SLI and their language controls were not matched on all language level measures (e.g., they were not matched on expressive abilities). Consequently, we cannot exclude that, had they been matched on another language level measure, different results would have been observed.

Attentional Allocation Capacities and Linguistic Factors

Following the TBRS model, we expected a larger impact of the visual interfering task on long than short sentences. Indeed, in this framework, verbal storage requires attentional focalization, and as soon as attention is switched away from the memory traces, their activation suffers from a time-related decay. Because more words had to be stored in long than short sentences, the impact of the interfering task on their storage was expected to be larger in long than short sentences. However, no larger impact of the interfering task on long than short sentences was observed. An alternative explanation is that our interfering visual processing task does not actually affect the temporary storage of the verbal information during the sentence comprehension. Indeed, other theoretical models of working memory such as the Baddeley and Hitch (1974; Baddeley, 2000) model separate the resources devoted to the processing and the storage of verbal information. Because our manipulation of sentence length was achieved by increasing redundancy only (without altering the core structure of the sentence), it is likely that it mainly increased the storage but caused less central sentence processing demands. Thus, theoretical models that separate cognitive resources devoted to processing and storage of verbal information do not necessarily expect a larger impact of a secondary attentional processing task (carried out by the supervisory attentional system within the Baddeley and Hitch model) on long sentences than on short sentences. At the same time, we should note that the working memory model as described by Baddeley is not sufficiently detailed with regard to the processes at play during sentence processing, nor does it give very specific predictions concerning the possible interactions between attentional processes and storage processes, as compared with the TBRS model. In addition, it may even be the case that the added redundant information in long sentences did not lead to a significantly larger load on semantic temporary storage processes than in short sentences because it did not increase the number of semantic chunks that were necessary to maintain in short-term memory. At the same time, these data also indirectly show that a linguistic deficit is not the only possible explanation of our results either: If a core linguistic deficit was to explain our results, then sentences containing a larger amount of linguistic information, as was the case for the longer sentences, should have been particularly difficult to process for children with SLI. This was obviously not the case.

The TBRS model also proposes that the cognitive load of a process (and, thus, its vulnerability to interference) directly depends on its duration. Because the activation process is slower for low- than for high-frequency words, a larger impact of the interfering task was expected on the processing of sentences containing low-than high-frequency words. However, this is not what we observed. We, in fact, observed better performance when processing sentences with low-frequency words under the dual-task condition as compared with the single-task condition. Our procedure may partly explain these results: Children performed the dual-task condition after the single-task condition. Consequently, the familiarity of the initially less frequent vocabulary may have increased between the single-task and the dual-task conditions.

In this study, we aimed at assessing the impact of attentional allocation capacities on sentence comprehension by using a nonlinguistic interfering task. Our results confirm that children with SLI have lower attentional allocation capacities than expected relative to their chronological age and that this affects their sentence processing capacities. However, our data also show that this deficit is not disproportionate relative to their receptive language level: They are consistent with a dimensional view of SLI in which the observed impact is comparable to what is observed in younger children of the same receptive grammatical abilities.

References


### Appendix
Examples of the items used in the experiment.

<table>
<thead>
<tr>
<th>Sentence type</th>
<th>Length</th>
<th>Lexical frequency</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short sentences with high lexical frequency vocabulary</td>
<td>Short</td>
<td>High</td>
<td><em>La fille appelle la madame qui monte.</em> [The girl calls the woman who is going up.]</td>
</tr>
<tr>
<td>Short sentences with low lexical frequency vocabulary</td>
<td>Short</td>
<td>Low</td>
<td><em>L’archer ligote le cow-boy qui skie.</em> [The archer ties up the cowboy who is skiing.]</td>
</tr>
<tr>
<td>Long sentences with high lexical frequency vocabulary</td>
<td>Long</td>
<td>High</td>
<td><em>Ce matin, dans la cour, la grande fille jaune regarde l’homme rouge qui balaie.</em> [This morning, in the yard, the tall yellow girl sees the red man who is sweeping up.]</td>
</tr>
<tr>
<td>Long sentences with low lexical frequency vocabulary</td>
<td>Long</td>
<td>Low</td>
<td><em>Ce matin, dans le grand jardin, l’archer coiffe l’apache qui skie très vite.</em> [This morning, in the big garden, the archer combs the hair of the Apache who is skiing very fast.]</td>
</tr>
</tbody>
</table>