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

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Abstract

Purpose: This study assesses the hypothesis of a limitation in attentional allocation capacity as underlying poor sentence comprehension in children with 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 coloured stimuli randomly appeared at the centre 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.

Conclusions: Our study does not support limitations in attentional allocation capacity as representing a core deficit in SLI. Rather, our 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.

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 performances 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.

Processing capacities can be viewed as the perceptual or cognitive processing abilities limiting the amount of information that can be processed during a given period of time; resource generally refers to the cognitive abilities that are actually available (Snyder, Dabasinskas, & O'Connor, 2002). Many authors propose that there is a limited amount of cognitive resources that can be used to perform multiple verbal or non-verbal tasks (e.g. Baddeley, 2003; Barrouillet, Bernardin, & Camos, 2004; Rohrer & Pashler, 2003). In this view, the same pool of processing resources must be shared between the processing and maintenance processes of the various tasks that have to be performed (e.g. Barrouillet et al., 2004; Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007). Performances will thus depend on efficient resource allocation, i.e. the dynamic sharing of the available resources between the multiple processes of a complex activity. This resource allocation capacity can thus be considered as a part of a broader working memory construct that is often described as a resource-sharing system between processing and maintenance processes (Baddeley, 2003; Barrouillet et al., 2004; Barrouillet et al. 2007; Cowan, 2010; Engle, 2002; Towse, Hitch, & Hutton, 2002).

Probably the best-known theory investigating the impact of processing capacity on sentence comprehension is the capacity constrained comprehension theory (Just & Carpenter, 1992). This computational theory presents a model of sentence processing in which storage and processing are fuelled 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 underlying comprehension are assumed to occur in parallel: the processing of each word as it occurs, their integration 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. Based on this theoretical framework, many studies have shown that sentence comprehension performances correlate 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; Barrouillet et al., 2007) provides a more specific account of attentional resources and their sharing between processing and maintenance processes. The TBRS model proposes 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 via attentional focalization. However, according to the authors, 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 via 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 requiring to concurrently process and store 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, 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 requiring 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 performances. 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. This study will use the TBRS model to assess the hypothesis following which 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 performances 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 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 to 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) colour 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 to perform multiple processes simultaneously: it requires segmenting the input signal, matching the signal with phonological representations in long-term memory, integrating the segmental 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 performances 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 problem. 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 performances

correlated with simple sentence comprehension while the listening span performances correlated with the complex sentences comprehension in these children. Finally, Montgomery, Evans, and Gillam (2009) showed that complex sentence comprehension in SLI was correlated to 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 since 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 their 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. Lastly, listening span tasks (requiring to simultaneously process 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, Evans, and Gillam (2009) only used highly familiar words in their word recall task, minimizing the likelihood that poor performance on the semantic categorization and size processing has to be attributed to representational deficits. Ellis Weismer and Thordardottir (2002) attempted to control for the impact of lexical knowledge: the nonwords they employed were of low wordlikeness. Similarly, in their nonword repetition task, Montgomery and Evans (2009) excluded real word syllables and used consonants in nontypical positions in order 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, i.e. 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 since children with SLI were especially poor at repeating 3- and 4-syllable nonwords as compared to controls, and since these differences remained even after receptive lexical knowledge was partialled out, a specific deficit in STM abilities is to explain their poorer performances on the nonword repetition task. However, long nonwords, as compared to 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 since this association could also be due to poor linguistic abilities underlying 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, Simons, Carnevale, & Dick, 2007). For example, Aydelott and Bates (2004) have shown that an increase in attentional demand, as achieved via 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 via the concurrent performance of a secondary task (digit list recognition task) during a grammatical judgement task. Kilborn (1991) also demonstrated selective impairment for grammatical morphology under stress conditions in normal adults. Hayiou-Thomas and her colleagues (2004) observed the same pattern of errors on a grammatical judgement task in normal children under stress condition (compressed speech signal) as in children with SLI.

Aim

This study aims 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 have to be shared between sentence processing and an interfering non-verbal task. This will be achieved by using a dual task paradigm, the primary task being the sentence comprehension task, and the secondary task being a non-linguistic target detection task. In contrast to previous studies, a non-linguistic secondary task was used in order 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 performances, 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 of cognitive abilities that mature slowly across domains.

As far as we know, no study has yet assessed the impact of an interfering secondary non-verbal task on sentence comprehension performances. We thus adapted a non-linguistic 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, in order to ensure that this task actively occupies 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 quasi-automatic response-selection processes, placing few demands on attentional resources during response selection. In our adaptation of the task, we presented stimuli of three different colours randomly appearing at the centre of the screen; the response selection had to be made on the basis of their colour, by pressing one of the three adjacent keys on the keyboard carrying the same coloured dot as the target stimulus on the screen. Second, in order to prevent self-paced allocation of attentional resources between the main and the secondary tasks and to ensure that the task occupies the same proportional amount of attentional resources in each child, the inter-stimulus 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 performances. When processing long sentences, more words are to be temporarily stored 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 performances 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) provide 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 the present study, we compared the children with SLI to 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 due to differences in initial language processing abilities. In order to control for this confounding factor, we also compared the children with SLI to 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 performances. In agreement with Bishop (1997), if children with SLI are impaired to a greater extent in the dual task condition relative to the grammatical age control 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 performances 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 of cognitive abilities that mature 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).

Methods

Participants

Fifteen French-speaking children with SLI aged 8 to 13 years (12 boys; mean age = 11;3 years; $SD= 1;8$), 15 typically developing children matched for chronological age and nonverbal reasoning (6 boys; mean age = 11;3 years; $SD= 1;8$), and 15 younger typically developing children matched for their sentence comprehension abilities (8 boys; mean age = 7;11 years ; $SD= 1;7$) participated in the study. The SLI group and the age control (AC) group were comparable in age, $t(28) < 1$, *n.s.*, and non-verbal reasoning (WISC-IV, Wechsler, 2005), $t(28) < 1$, *n.s.* (see Table 1). They however differed in their phonological abilities ($t(28)=5.04$, $p<.001$) as measured by the word repetition task of the *Evaluation du Langage Oral* (Khomsî, 2001), lexical abilities ($t(28)= 4.37$, $p<.001$) as measured by the French adaptation of the Peabody Picture Vocabulary Test (Dunn, Thériault-Whalen, & Dunn, 1993), receptive grammatical abilities ($t(28)= 7.56$, $p<.001$) as measured by the French adaptation of the TROG (Lecocq, 1996) and productive grammatical abilities ($t(28)= 7.49$, $p<.001$) as measured by the sentence production task of the *Evaluation du Langage Oral* (Khomsî, 2001). The SLI group and the receptive grammar control group (GC) were matched for sentence comprehension accuracy performance in the single task condition, $t(28) < 1$, *n.s.*

They also performed at similar levels on measures of receptive grammar ($t(28) = 1.74$, $p = .09$), and receptive vocabulary ($t(28) < 1$, *n.s.*). However, children significantly differed in their phonological abilities ($t(28) = 4.53$, $p < .001$) and productive grammar abilities ($t(28) = 3.05$, $p < .01$), the SLI group performing lower on these tasks. Finally, the GC group showed significantly lower phonological ($t(28) = 2.97$, $p < .01$), lexical ($t(28) = 5.21$, $p < .001$), receptive grammatical ($t(28) = 5.64$, $p < .001$), and productive grammatical ($t(28) = 4.81$, $p < .001$) abilities than the AC group.

Children from the control groups were recruited in schools in the neighbourhood of the city of Liege (Belgium). Informed consent was obtained from the parents of all participating children. All children came from families with low or middle-class socioeconomic background, as determined by their parents' profession. The parents were administered an anamnestic questionnaire, allowing us to ensure that all children were French native speaker, had no history of psychiatric or neurological disorders, and 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. (1) They scored more than -1.25 SD below expected normative performance in 2 language areas (according to SLI criteria adopted by Leonard et al., 2007). (2) 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 and twenty sentences with relative clauses were created. In order to minimize possible semantic factors impact on sentence comprehension (van der Lely &

Dewart, 1986) only fully reversible sentences were used, where 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 4 sentence types. Thirty sentences were created for each sentence type (see *Appendix*). The sentences were recorded by a female speaker in an isolated acoustic booth using a high-quality microphone connected to a Minidisc^(R) digital recorder. Sentences were read at 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 hundred and twenty 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 double task condition. Moreover, each set was divided in two parts containing 7 or 8 sentences of each type in order 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 8 task conditions.

Sentence length.

Short sentences contained 7 words and 9 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, i.e. 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 resource), but they could not help making 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 in order 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 (mean: 1681, range: 238 – 7140; Lambert & Chesnet, 2001), such as '*Le policier filme l'apache qui skie.*' ('*The policeman films the Apache who is skiing.*'), while sentences with high lexical frequency contained target words with high lexical frequency (mean: 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 he is familiar with, in order 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 asked the child '*Find out which of these figures is X*' (for example, '*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 child was told to listen carefully to the sentences he/she would hear through headphones and that after each sentence, he/she 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 3 foil situations corresponding to the incorrect syntactic parsing of the sentence, i.e., 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-CRT task was adapted from Rohrer and Pashler (2003). Participants were asked to respond to red, green, or blue stimuli randomly and continuously appearing for 200 ms at the centre of the computer screen by pressing one of the three adjacent keys on the keyboard carrying the same coloured dot. In order to adjust the task to each participant's response speed, the inter-stimuli interval (ISI) varied across participant. 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 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 colour.

Dual task.

Such as in Jefferies, Lambon Ralph and Baddeley (2004), there was a period of 10s 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 amongst which the children had to choose the one accurately depicting the sentence they just heard (see Figure 1). Four practice trials for the dual task were proposed in order to familiarize the children with the task.

Working memory tasks.

A dual task paradigm by Baddeley and colleagues (Baddeley, Della Sala, Papagno, & Spinnler, 1997) was administered in order 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: participants first performed the verbal task in a single-task condition, then the visual task in a single-task condition, and third both tasks were performed as a dual-task condition. More precisely, 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 backwards digit span task from the WISC-IV (Weschler, 2005) was administered in order 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-choice-reaction time task (on the first practice trial, the ISI was fixed at 1800 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 4 practice trials, during the third session. During the fourth session, they completed a 1-min practice trial with the serial-choice-reaction time 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. These performances were globally lower than the performances observed in the AC group, either in terms of response accuracy (Table 2) or in terms of response times (Table 3).

Analysis of Variance: the Sentence Comprehension Task

Both response accuracy and response times for correct answers were subjected to mixed ANOVA. For each analysis, the between-subjects factor was participant group (children with SLI, age-controls, AC, or grammatical-controls, 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 ANOVA on response accuracy on the one hand and on

response times on the other hand, but for the sake of clarity, we will regroup the results of both analyses. After a precise look at each participant response times, we observed that a child in the SLI group was systematically slower than two standard deviations of the mean of the response times of its SLI peers. We thus decided to exclude this child from our analyses.

A first analysis of variance revealed a main effect of sentence length on both accuracy and response times. 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-by-length interaction effect was significant neither for response accuracy ($F(2,41)=1.18, p=.32.$, partial $\eta^2 = .05$), nor for response times ($F(2,41)=2.02, p=.15.$, partial $\eta^2 = .09$). Likewise, the condition-by-length interaction effect was significant neither for response accuracy ($F(1,41)<1, n.s.$, partial $\eta^2 = .01$), nor for response times ($F(1,41)<1, n.s.$, partial $\eta^2 = .00$). Consequently, we decided to collapse the data across sentence length in further analyses.

Once more, we performed distinct mixed ANOVA on response accuracy on the one hand and on response times 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 ($p=.60$). Response times 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 response times. 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-by-lexical frequency interaction effect was not significant for response accuracy ($F(2,41)<1, n.s.$, partial $\eta^2 = .00$), or for response times

($F(2,41)=2.93, p=.07, \text{partial } \eta^2 = .12$). The main effect of task condition was not significant for response accuracy ($F(1,41)=3.33, p=.08, \text{partial } \eta^2 = .08$), nor was the group-by-task condition interaction effect ($F(2,41)=2.51, p=.09, \text{partial } \eta^2 = .11$). However, children response times were slower under the dual task condition ($F(1,41)=14.54, p<.001, \text{partial } \eta^2 = .26$). Moreover, the group-by-task condition effect was also significant on response times ($F(2,41)=4.39, p<.05, \text{partial } \eta^2 = .18$). Newman-Keuls post-hoc analyses revealed that both the SLI group ($p<.01$) and the GC group ($p<.05$) showed slower response times 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-by-task condition effect was observed for response accuracy ($F(1,41)=6.63, p<.05, \text{partial } \eta^2 = .14$). Newman-Keuls post-hoc analyses revealed that lexicality affected performances only in the single-task condition ($p<.001$; dual task condition: $p=.50$), performances being even better for low frequency words under dual- than single-task condition ($p<.01$).

Analysis of Variance: The Serial-CRT Task

As described in the methods 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 reaction times for accurate trials in the simple CRT ($F(2,41)=4.42, p<.05, \text{partial } \eta^2=.18$): children with SLI were significantly slower than their age controls ($p<.05$), but not as compared to 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, age-controls or grammatical-controls), the within-subjects factor was task condition (single or dual). The dual task effect was significant ($F(1,41)=12.14,$

$p < .01$, partial $\eta^2 = .23$): performances on the serial-CRT were more accurate when the task was performed in isolation than in dual-task condition. However, neither the group effect ($F(2,41)=2.43$, $p=.10$, partial $\eta^2 = .11$), nor the group-by-task condition interaction effect were significant ($F(2,41)<1$, *n.s.*, partial $\eta^2 = .04$).

Additional Results from Working Memory Measures

Dual-task paradigm.

For the dual-task paradigm developed by Baddeley and colleagues (1997), we observed a main effect of group on initial digit span performance, as expected ($F(2,41)=51.53$, $p<.001$, partial $\eta^2 = 0.72$): 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 $\eta^2 = 0.07$), but they differed in the number of boxes crossed ($F(2,41)=25.05$, $p<.001$, partial $\eta^2 = 0.55$): the AC group ($M=127.33$; $SD=20.66$) performed significantly better than the SLI group ($p<.001$; $M=91$; $SD=23.86$) 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 ($F(2,41)<1$, *n.s.*, partial $\eta^2 = 0.01$).

In order to further characterize the impact of dual-tasking on each task separately, we performed mixed ANOVA on the proportion of sequences accurately repeated under single and dual task condition. The group effect was not significant ($F(2,41)<1$, *n.s.*, partial $\eta^2 = 0.04$), nor were the condition ($F(1,41)=2.74$, $p=.11$, partial $\eta^2 = 0.06$), or the group-by-condition effects ($F(2,41)=2.24$, $p=.12$, partial $\eta^2 = 0.12$). 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 ($F(2,41)=21.76, p<.001, \text{partial } \eta^2 = 0.51$) 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 ($F(1,41)=7.79, p<.01, \text{partial } \eta^2 = 0.16$); as for the other tasks, there was no significant group-by-condition effect ($F(2,41)=1.26, p=.29, \text{partial } \eta^2 = 0.06$). 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 observe 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 ($F(2,41)<1, n.s., \text{partial } \eta^2 = 0.05$).

Reverse span task.

There was a main effect of group, ($F(2,41)=5.32, p<.01, \text{partial } \eta^2 = 0.21$): 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. In order to do so, we assessed the impact of a controlled attention demanding non-linguistic task on sentence comprehension abilities in children with SLI as compared to 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 age control group, revealing poor attentional allocation capacity as a core deficit in children with SLI, limiting their grammatical learning and performances. 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 performances 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 the present study performed at the same level as three years younger typically developing children. 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 response times: both children with SLI and their grammatical controls showed slowed response times under dual- vs. single-load conditions. This was not the case in their age-matched peers. Main effects of sentence length and lexical frequency were observed on response accuracy and response times 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 non linguistic 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 response times 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 non-verbal task. First, the interfering task was derived from a similar task demonstrating a significant impact on sentence repetition performance in adults (Jefferies et al., 2004). Moreover, we adapted this task in order to maximize attentional demands during the response selection process of the sentence processing task, following the recommendations of Rohrer & Pashler (2003). Second, performance of the same children on another task especially designed by Baddeley and colleagues (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 1) that our experimental task was well designed to assess attentional allocation capacities 2) that 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 response times, in both children with SLI and their grammatical controls.

Moreover, our data are also consistent with previous studies assessing attentional allocation capacities using listening span tasks that compared children with SLI to children of the same linguistic level. Actually, most of the previous studies compared performances in children with SLI to performances in children of the same chronological age, and observed a larger impact of the secondary task on children with SLI performances (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 performances in children with SLI, as compared to 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. 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 performances 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 performances 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 response times observed under the dual task condition in 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 since 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 response times in fact reflect verbal rehearsal, then we also have to accept that this is so because rehearsal had to be 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 response times 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 performances.

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 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 the differences between children with SLI and their controls are to be observed in terms of response times (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 age controls, 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 to efficiently allocate 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 to 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 backwards digit span 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 response times 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 since 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-Arnolds & 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. Since 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 model (1974; Baddeley, 2000) separate the resources devoted to the processing and the storage of verbal information. Since 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 less central sentence processing demands. Theoretical models separating cognitive resources devoted to processing and storage of verbal information thus 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 than 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 to the TBRS model. And 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 since 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, than sentences containing a larger amount of linguistic information, as was the case for the longer sentences, should have been particularly difficult to process for SLI children. 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. Since the activation process is slower for low- than 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 to 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.

The present study aimed at assessing the impact of attentional allocation capacities on sentence comprehension by using a non linguistic 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

- Archibald, L. M., & Gathercole, S. E. (2007). The complexities of complex memory span: Storage and processing deficits in specific language impairment. *Journal of Memory and Language*, 57(2), 177-194.
- Aydelott, J., & Bates, E. (2004). Effects of acoustic distortion and semantic context on lexical access. *Language and Cognitive Processes*, 19(1), 29-56.
- Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4(11), 417-423.
- Baddeley, A. (2003). Working memory and language: An overview. *Journal of Communication Disorders*, 36(3), 189-208.
- Baddeley, A., Della Sala, S., Papagno, C., & Spinnler, H. (1997). Dual-task performance in dysexecutive and nondysexecutive patients with a frontal lesion. *Neuropsychology*, 11(2), 187-194.
- Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review*, 105(1), 158-173.
- Baddeley, A., & Hitch, G. (1974). Working memory. In G. A. Bower (Ed.), *Recent advances in learning and motivation* (Vol. 8, pp. 47-90). New York: Academic Press.
- Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time Constraints and Resource Sharing in Adults' Working Memory Spans. *Journal of Experimental Psychology: General*, 133(1), 83-100.
- Barrouillet, P., Bernardin, S., Portrat, S., Vergauwe, E., & Camos, V. (2007). Time and cognitive load in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 33(3), 570-585.
- Bishop, D. (1997). Cognitive neuropsychology and developmental disorders: Uncomfortable bedfellows. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, 4(4), 899-923.
- Bishop, D., Bright, P., James, C., Bishop, S., & van der Lely, H. (2000). Grammatical SLI: A distinct subtype of developmental language impairment? *Applied Psycholinguistics*, 21(2), 159-181.
- Blackwell, A., & Bates, E. (1995). Inducing agrammatic profiles in normals: Evidence for the selective vulnerability of morphology under cognitive resource limitation. *Journal of Cognitive Neuroscience*, 7(2), 228-257.
- Coady, J. A., & Aslin, R. N. (2004). Young children's sensitivity to probabilistic phonotactics in the developing lexicon. *Journal of Experimental Child Psychology*, 89(3), 183-213.
- Cowan, N. (1999). An Embedded-Processes Model of working memory *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 62-101). New York, NY: Cambridge University Press; US.
- Cowan, N. (2010). Multiple concurrent thoughts: The meaning and developmental neuropsychology of working memory. *Developmental Neuropsychology*, 35(5), 447-474.
- Dick, F., Bates, E., Wulfeck, B., Utman, J. A., Dronkers, N., & Gernsbacher, M. A. (2001). Language deficits, localization, and grammar: Evidence for a distributive model of language breakdown in aphasic patients and neurologically intact individuals. *Psychological Review*, 108(4), 759-788.
- Dollaghan, C. A. (2004). Taxometric Analyses of Specific Language Impairment in 3- and 4-Year-Old Children. *Journal of Speech, Language, and Hearing Research*, 47(2), 464-475.
- Dunn, L., Thériault-Whalen, C., & Dunn, L. (1993). *Échelle de Vocabulaire en Images Peabody*. Toronto: Psycan.

- Ellis Weismer, S., & Thordardottir, E. (2002). Cognition and language. In P. Accardo, A. Capute & B. Rogers (Eds.), *Disorders of language development* (pp. 21-37). Timonium: York Press.
- Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science*, *11*(1), 19-23.
- Evans, J. L., & MacWhinney, B. (1999). Sentence processing strategies in children with expressive-receptive specific language impairments. *International Journal of Language & Communication Disorders*, *34*(2), 117-134.
- Ferreira, F., Henderson, J. M., Anes, M. D., Weeks, P. A., & McFarlane, D. K. (1996). Effects of lexical frequency and syntactic complexity in spoken-language comprehension: Evidence from the auditory moving-window technique. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*(2), 324-335.
- Gathercole, S. E. (1995). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory & Cognition*, *23*(1), 83-94.
- Gathercole, S., & Baddeley, A. (1990). The role of phonological memory in vocabulary acquisition: A study of young children learning new names. *British Journal of Psychology*, *81*, 439-454.
- Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition*, *68*(1), 1-76.
- Hayiou-Thomas, M. E., Bishop, D. V., & Plunkett, K. (2004). Simulating SLI: General Cognitive Processing Stressors Can Produce a Specific Linguistic Profile. *Journal of Speech, Language, and Hearing Research*, *47*(6), 1347-1362.
- Henderson, J. M., & Ferreira, F. (1990). Effects of foveal processing difficulty on the perceptual span in reading: Implications for attention and eye movement control. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*(3), 417-429.
- Hoffman, L. M., & Gillam, R. B. (2004). Verbal and Spatial Information Processing Constraints in Children With Specific Language Impairment. *Journal of Speech, Language, and Hearing Research*, *47*(1), 114-125.
- Isaki, E., Spaulding, T. J., & Plante, E. (2008). Contributions of language and memory demands to verbal memory performance in language-learning disabilities. *Journal of Communication Disorders*, *41*(6), 512-530.
- Jefferies, E., Lambon Ralph, M. A., & Baddeley, A. D. (2004). Automatic and controlled processing in sentence recall: The role of long-term and working memory. *Journal of Memory and Language*, *51*(4), 623-643.
- Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review*, *99*(1), 122-149.
- Kail, R. (1994). A method for studying the generalized slowing hypothesis in children with specific language impairment. *Journal of Speech & Hearing Research*, *37*(2), 418-421.
- Khomsi, A. (2001). *Evaluation du langage oral*. Paris: ECPS.
- Kilborn, K. (1991). Selective impairment of grammatical morphology due to induced stress in normal listeners: Implications for aphasia. *Brain and Language*, *41*(2), 275-288.
- King, J., & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language*, *30*(5), 580-602.
- Lambert, E., & Chesnet, D. (2001). Novlex: une base de données lexicales pour les élèves de primaire. *L'Année Psychologique*, *101*, 277-288.
- Lecocq, P. (1996). *Epreuve de Compréhension Syntaxico-Sémantique*. Villeneuve d'Ascq Presses universitaires du Septentrion.
- Leech, R., Aydelott, J., Symons, G., Carnevale, J., & Dick, F. (2007). The development of sentence interpretation: Effects of perceptual, attentional and semantic interference. *Developmental Science*, *10*(6), 794-813.

- Leonard, L. B. (2009). Some reflections on the study of children with specific language impairment. *Child Language Teaching and Therapy*, 25(2), 169-171.
- Leonard, L. B., Weismer, S. E., Miller, C. A., Francis, D. J., Tomblin, J., & Kail, R. V. (2007). Speed of processing, working memory, and language impairment in children. *Journal of Speech, Language, and Hearing Research*, 50(2), 408-428.
- Lewis, R. L., & Vasishth, S. (2005). An Activation-Based Model of Sentence Processing as Skilled Memory Retrieval. *Cognitive Science: A Multidisciplinary Journal*, 29(3), 375-419.
- MacDonald, M. C., & Christiansen, M. H. (2002). Reassessing working memory: Comment on Just and Carpenter (1992) and Waters and Caplan (1996). [Comment/Reply]. *Psychological Review*, 109(1), 35-54.
- MacDonald, M. C., Just, M. A., & Carpenter, P. A. (1992). Working memory constraints on the processing of syntactic ambiguity. *Cognitive Psychology*, 24(1), 56-98.
- Mainela-Arnold, E., & Evans, J. L. (2005). Beyond capacity limitations: Determinants of word recall performance on verbal working memory span tasks in children with SLI. *Journal of Speech, Language, and Hearing Research*, 48(4), 897-909.
- Mainela-Arnold, E., Evans, J., & Coady, J. A. (2010). Beyond capacity limitations II: Effects of lexical processes on word recall in verbal working memory tasks in children with and without specific language impairment. *Journal of Speech, Language, and Hearing Research*.
- Majerus, S., & Lorent, J. (2009). Is phonological short-term memory related to phonological analysis stages in auditory sentence processing? *Journal of Cognitive Psychology*, 21(8), 1200-1225.
- Majerus, S., & Van der Linden, M. (2003). Long-term memory effects on verbal short-term memory: A replication study. *British Journal of Developmental Psychology*, 21(2), 303-310.
- Marton, K. (2006). Commentaries: Do nonword repetition errors in children with specific language impairment reflect a weakness in an unidentified skill specific to nonword repetition or a deficit in simultaneous processing? [Comment/Reply]. *Applied Psycholinguistics*, 27(4), 569-573.
- Marton, K., & Schwartz, R. G. (2003). Working Memory Capacity and Language Processes in Children with Specific Language Impairment. *Journal of Speech, Language, and Hearing Research*, 46(5), 1138-1153.
- McElree, B., Foraker, S., & Dyer, L. (2003). Memory structures that subserve sentence comprehension. *Journal of Memory and Language*, 48(1), 67-91.
- Miller, C. A., Leonard, L. B., Kail, R. V., Zhang, X., Tomblin, J., & Francis, D. J. (2006). Response time in 14-year-olds with language impairment. *Journal of Speech, Language, and Hearing Research*, 49(4), 712-728.
- Miyake, A., Just, M. A., & Carpenter, P. A. (1994). Working memory constraints on the resolution of lexical ambiguity: Maintaining multiple interpretations in neutral contexts. *Journal of Memory and Language*, 33(2), 175-202.
- Montgomery, J. W. (1995). Sentence comprehension in children with specific language impairment: The role of phonological working memory. *Journal of Speech & Hearing Research*, 38(1), 187-199.
- Montgomery, J. W. (2000a). Relation of working memory to off-line and real-time sentence processing in children with specific language impairment. *Applied Psycholinguistics*, 21(1), 117-148.
- Montgomery, J. W. (2000b). Verbal working memory and sentence comprehension in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, 43(2), 293-308.

- Montgomery, J. W., & Evans, J. L. (2009). Complex sentence comprehension and working memory in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 52*(2), 269-288.
- Montgomery, J. W., Evans, J. L., & Gillam, R. B. (2009). Relation of auditory attention and complex sentence comprehension in children with specific language impairment: A preliminary study. *Applied Psycholinguistics, 30*(1), 123-151.
- Montgomery, J. W., & Windsor, J. (2007). Examining the language performances of children with and without specific language impairment: Contributions of phonological short-term memory and speed of processing. *Journal of Speech, Language, and Hearing Research, 50*(3), 778-796.
- Norbury, C. F., Bishop, D. V., & Briscoe, J. (2002). Does impaired grammatical comprehension provide evidence for an innate grammar module? *Applied Psycholinguistics, 23*(2), 247-268.
- Pearlmutter, N. J., & MacDonald, M. C. (1995). Individual differences and probabilistic constraints in syntactic ambiguity resolution. *Journal of Memory and Language, 34*(4), 521-542.
- Rohrer, D., & Pashler, H. E. (2003). Concurrent task effects on memory retrieval. *Psychonomic Bulletin & Review, 10*(1), 96-103.
- Schneider, W., Eschmann, A., & Zuccolotto, A. (2002). *E-Prime user's guide*. Pittsburgh: Psychology Software Tools.
- Snowling, M. J., Chiat, S., & Hulme, C. (1991). Words, nonwords, and phonological processes: Some comments on Gathercole, Willis, Emslie, and Baddeley. [Comment/Reply]. *Applied Psycholinguistics, 12*(3), 369-373.
- Snyder, L. E., Dabasinkas, C., & O'Connor, E. (2002). An information processing perspective on language impairment in children: Looking at both sides of the coin. *Topics in Language Disorders, 22*(3), 1-14.
- Towse, J. N., Hitch, G. J., & Hutton, U. (2002). On the nature of the relationship between processing activity and item retention in children. *Journal of Experimental Child Psychology, 82*(2), 156-184.
- van der Lely, H., & Dewar, H. (1986). Sentence comprehension strategies in specifically language impaired children. *British Journal of Disorders of Communication, 21*(3), 291-306.
- Wechsler, D. (2005). *Wechsler Intelligence Scale for Children 4e Edition*. Paris: ECPA.
- Weismer, S. E., Plante, E., Jones, M., & Tomblin, J. (2005). A Functional Magnetic Resonance Imaging Investigation of Verbal Working Memory in Adolescents With Specific Language Impairment. *Journal of Speech, Language, and Hearing Research, 48*(2), 405-425.
- Windsor, J., & Hwang, M. (1999). Testing the generalized slowing hypothesis in specific language impairment. *Journal of Speech, Language, and Hearing Research, 42*(5), 1205-1218.
- Windsor, J., Milbrath, R. L., Carney, E. J., & Rakowski, S. E. (2001). General slowing in language impairment: Methodological considerations in testing the hypothesis. *Journal of Speech, Language, and Hearing Research, 44*(2), 446-461.
- Wingfield, A., Tun, P. A., Koh, C. K., & Rosen, M. J. (1999). Regaining lost time: Adult aging and the effect of time restoration on recall of time-compressed speech. *Psychology and Aging, 14*(3), 380-389.

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Table 1

*Descriptive Summary Data for Children with Specific Language Impairment (SLI),
Grammatical-Age Control Children (GC) and Chronological-Age Control Children (AC)*

	Age (months)	PIQ	EVIP	E.CO.S.SE	ELO	
					Word repetition	Sentence production
SLI						
Mean	135.87	98.40	95.67	77.47	22.53	13.27
SD	20.88	9.09	18.27	4.73	7.21	4.46
Range	96-167	86-119	55-124	68-84	3-30	4-20
GC						
Mean	95.67	-	93.27	80.4	31.07	17.73
SD	19.90	-	13.88	4.50	1.09	3.51
Range	61-133	-	66-119	70-86	28-32	11-22
AC						
Mean	135.47	99.07	126.87	87.80	31.93	22.8
SD	20.88	6.54	20.77	8.37	0.26	2.08
Range	95-168	90-111	85-154	84-91	31-32	17-25

Note. PIQ, Performance IQ: Perceptual Reasoning Index of the WISC-IV (not measured in GC children); EVIP, French version of Peabody Picture Vocabulary Test; E.CO.S.SE, French version of Test for the Reception of Grammar; ELO, Evaluation du Langage Oral Test.

Table 2

Means (and Standard Deviations) 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)

	Single Task				Dual Task			
	Short		Long		Short		Long	
	HF	LF	HF	LF	HF	LF	HF	LF
SLI	11.2 (2.21)	10.2 (2.65)	9.47 (2.47)	8 (3.4)	11.27 (2.63)	11.2 (2.46)	9.33 (2.87)	9.47 (2.42)
GC	12.07 (2.31)	10 (2.83)	9.13 (2.17)	8.47 (2.72)	12.27 (2.94)	11.87 (2.85)	9.33 (2.89)	9 (2.75)
AC	14.27 (0.79)	13.47 (1.25)	12.13 (1.46)	11.67 (2.26)	13.6 (0.74)	13.53 (1.59)	12.33 (2.38)	11.2 (2.31)

Note. *HF*, Sentences containing words of high lexical frequency; *LF*, Sentences containing words of low lexical frequency; *Short*, Short sentences; *Long*, Long sentences. The maximum possible score is 15.

Table 3

Means (and Standard Deviations) for Response Times for Each Experimental Condition, as a Function of Participant Group for Children with Specific Language Impairment (SLI), Grammatical Controls (GC) and Age Controls (AC)

	Single Task				Dual Task			
	Short		Long		Short		Long	
	HF	LF	HF	LF	HF	LF	HF	LF
SLI	5361 (1591)	6169 (2060)	5835 (1886)	7332 (4948)	7144 (2495)	7664 (2336)	8208 (4441)	9012 (3778)
GC	5758 (1981)	6612 (1903)	6494 (1940)	7619 (2436)	6879 (2481)	8088 (3187)	7944 (2837)	8147 (3158)
AC	5098 (1001)	6297 (1630)	6045 (1327)	7669 (2371)	5118 (1324)	6265 (1816)	6452 (2447)	7333 (1857)

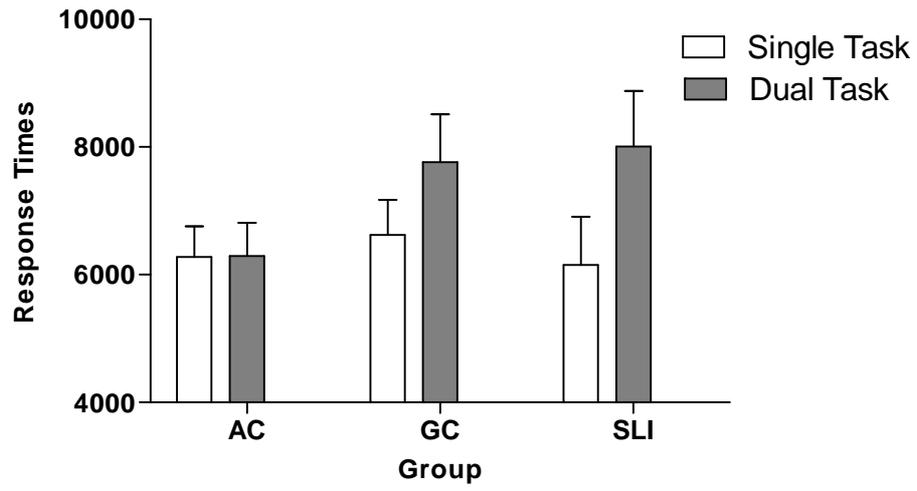
Note. *HF*, Sentences containing words of high lexical frequency; *LF*, Sentences containing words of low lexical frequency; *Short*, Short sentences; *Long*, Long sentences.

Figure Captions

Figure 1. Illustration of the Sequence of Events in the Dual Task Condition

Figure 2. Response Times in Sentence Comprehension for Each Group (AC, Age Controls; GC, Grammatical Controls; SLI, Children with Specific Language Impairment) as a Function of Task Condition (Single vs. Dual)





Appendix

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