The Role of Working Memory in the Comprehension of Phrasal Movement in Children with Learning Difficulties [*]

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1. INTRODUCTION

1.1. Specific learning disorder (SLD)

Specific learning disorder (SLD), one of the most frequently diagnosed developmental disorders in childhood, is characterized by unexpectedly poor attainment in key academic domains, such as literacy and numeracy, with prevalence rates of 3-10% for the former (Snowling 2008) and 5-8% for the latter (Geary 2004). According to the fifth edition of the Diagnostic Statistical Manual (DSM-5; American Psychiatric Association, 2013), SLD is a neurodevelopmental disorder that manifests itself during the formal years of schooling as persistent difficulties in at least one of three primary academic domains: reading, writing and/or mathematics. The specific learning difficulties are unforeseen in that other areas of development appear to be unaffected, and they are often identified due to a discrepancy between the child's actual achievement and expected achievement based on IQ measurements. Reid (2016) conceptualizes SLD as unexpected underachievement with a genetic etiology that reflects a set of core cognitive deficits across academic domains: attention difficulties, memory problems and poor processing speed. These pockets of weakness lead to a variety of symptoms that can range from mild to severe, such as inaccurate or slow and effortful reading, poor reading comprehension, written expression that lacks precision and clarity, difficulty remembering number facts, and inaccurate mathematical reasoning. Furthermore, learning difficulties often appear in comorbidity with other developmental disorders, such as attention difficulties[1], with recent research suggesting that the interaction of neurological processing mechanisms makes the co-occurrence of two disorders more probable than the occurrence of either disorder in isolation (Reid 2016, Snowling 2008).

While SLD is an all-encompassing label that allows clinicians to make a single diagnosis based on the unification of a range of typically co-occurring symptoms, children with SLD are often separated into more dichotomous categories that describe impairment in

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[1] Although the DSM-5 does not consider attention deficit hyperactivity disorder (ADHD) a learning disability, it is recognized as a prevalent neurodevelopmental disorder of childhood that is commonly associated with SLD, with research indicating that roughly 33% of children with specific learning difficulties also have ADHD (Margari et al. 2013). Characteristic markers of the disorder include inattention, hyperactivity and impulsivity, with the DSM-5 delineating three sub-types: predominantly inattentive, predominantly hyperactive-impulsive, and combined inattentive and hyperactive-impulsive. When ADHD interacts with SLD, learning can be extremely challenging, and differentially diagnosing the two conditions is not always obvious as behavioral patterns such as dysfluent reading, poor memory recall, slow completion of written work, inability to focus and inaccurate note-taking are common to both disorders (Gathercole & Alloway 2008, Martinussen et al. 2005).

terms of one specific learning domain, such as literacy or numeracy, and which are considered subtypes of SLD. Developmental dyslexia (henceforth dyslexia) is the diagnostic term given to children who present enduring difficulties in literacy acquisition despite normal intelligence and adequate instruction and it is the most extensively investigated subtype of SLD (Ramus et al. 2003). The dominant causal stance of dyslexia is that the disorder stems from a phonological deficit that affects how phonological representations are stored, retrieved and manipulated (Castles & Coltheart 2004, Fawcett & Nicolson 2008, Ramus 2003, Ramus et al. 2003, Reid 2016, Snowling 2008, Stein 2008). This deficit is typically demonstrated by poor performance on tasks that tap one's ability to temporarily hold or manipulate phonological information that is being processed, such as phonological awareness tasks that assess one's metacognitive ability to consciously discriminate, remember and manipulate the phonological system of his/her language, and tasks that tap phonological skills, such as rapid automatized naming and nonword repetition (Shankweiler et al. 1979, Snowling 2008, Snowling & Hulme 1994, Lyon et al. 2003, Ramus et al. 2003;2013).

However, additional research indicates that difficulties in linguistic domains other than phonology may also be present in children with dyslexia, such as difficulties producing and comprehending certain complex grammatical structures (Byrne 1981, Stein et al. 1984, Wiseheart et al. 2009, Fiorin 2010, Guasti et al. 2015, Arosio et al. 2017), contributing to the ongoing debate regarding the overlap of dyslexia and specific language impairment (SLI)[2]. For example, Scarborough (1990) reported that children who were at risk of dyslexia produced shorter and less complex sentences at 30-40 months, suggesting that the learning of letter-sound correspondences in school-aged children is related to early morphosyntactic aptitude and that initial syntactic skills may presage reading difficulties. Additionally, crosslinguistic evidence from older children shows that individuals with dyslexia perform poorly on tough constructions, such as relatives and passives, when compared to age-matched typically-developing (TD) controls (see Leikin & Assayag-Bouskila 2004 for Hebrew, Talli et al. 2011 for Greek, Stein et al. 1984, Bar-Shalom et al. 1993, Robertson & Joanisse 2010 for English, Cardinaletti & Volpato 2015 and Arosio et al. 2017 for Italian, and Sevcenco et al. 2012 for Romanian). In light of these observations, Fiorin (2010) suggests that dyslexia might be more accurately described as a disorder that affects how verbal information in general, rather than simply phonological information, is processed, as vulnerability in grammar seems to be a common feature of the disorder despite the fact that morphosyntactic deficits are not typically included in its formal description. Such an assumption would allow for the possibility that a core deficit in phonological processing may be necessary in order for the primary symptoms (literacy difficulties) of dyslexia to surface, while simultaneously accounting for the syntactic difficulties that have been observed in this population.

Developmental dyscalculia (henceforth dyscalculia) refers to a specific difficulty in numeracy that impairs one's ability to acquire basic numerical competences and fundamental mathematical skills. Consequently, children with dyscalculia often struggle to learn number concepts and tend to employ inefficient and time-consuming strategies when making numerical computations (Attout & Majerus 2015). A large body of research suggests that dyscalculia results from a core deficit in numerical processing (Butterworth 2010), with children with dyscalculia performing poorly on tasks that involve approximating numerosity and estimating the position of a specific number on a number line (Geary et al. 2009). As with phonological processing in dyslexia, the ability to retain, retrieve and manipulate verbal

[2] While it is traditionally assumed that dyslexia is essentially a reading disorder with an underlying phonological basis and that SLI is a language disorder with moderate to severe comprehension and production impairments, many deficits found in dyslexia often appear in SLI and vice versa (Fletcher et al. 1994, Snowling 1987, Leonard 2014). For an in-depth view on how these two disorders should be classified, consult Bishop & Snowling (2004) and Catts et al. (2006).

information has been shown to play an important role in numerical processing, with studies on school-aged TD children revealing a significant correlation between initial numerical capacity and one's ability to accurately repeat nonwords and to recall forwards and backwards digits (Gathercole & Pickering 2000, Geary et al. 2000, Swanson & Kim 2007, Noël 2009). In the same vein, the literature on children with dyscalculia reports a specific deficit in the short-term storage and retrieval of the successive order of a series of verbal items (Attout & Majerus 2014). This suggests that the inability of children with dyscalculia to efficiently problem solve and use effective strategies when completing arithmetic tasks is causally linked to cognitive weakness related to storing and manipulating verbal content over brief periods.

Thus, it seems to be the case that operative cognitive competences are compromised in both dyslexia and dyscalculia. Indeed, there is strong evidence that working memory (WM), a mental workspace where a limited amount of information is temporarily maintained and manipulated, influences academic attainment as it underpins many formal learning activities and is a reliable predictor of success in core academic areas (Gathercole & Baddeley 1993, Gathercole & Pickering 2001, Gathercole & Alloway 2008). Children with poor WM profiles often struggle to attain age-appropriate literacy and numeracy skills as inability to meet the WM demands of many learning situations often results in missed learning opportunities and eventually learning delay, and WM limitations are now consistently reported to be one of the main cognitive deficits of children who significantly underperform at school (Gathercole & Alloway 2008). However, there is reason to believe that poor WM may influence more than the acquisition of reading and arithmetic in children with SLD, as robust empirical evidence highlights the important contribution of WM to various domains of language development, such as lexical acquisition and syntactic development (Majerus et al. 2006, Leclercq & Majerus 2010, Adams & Gathercole 2000, Willis & Gathercole 2001, Engel de Abreu et al. 2011, Montgomery et al. 2008). This has led researchers to form new questions about the language development of this population, particularly in the domain of syntax, which theorists suppose is heavily reliant on WM (Jakubowicz 2011).

1.2 Working memory (WM)

As previously stated, WM refers to the cognitive activity of temporarily holding and, if necessary, transforming information during an ongoing mental task. According to the most influential WM model in psycholinguistics, Baddeley & Hitch's (1974) multicomponent model, the central executive, a limited-resource attentional control system, coordinates two slave systems: the phonological loop which stores verbal information and the visuospatial sketchpad which stores visuospatial information. Additionally, a fourth component, the episodic buffer, was added to the model and is described as a functional interface between the slave systems and long-term memory (Baddeley 2000). For the purposes of this paper, WM refers to the joint functioning of the central executive and the phonological loop to support the temporary storage and processing of verbal information.

One advantage of Baddeley's multicomponent model is that it allows simple cognitive activities, such as storing verbal items in the phonological loop, to be dissociated from more complex cognitive activities that require the important involvement of the supervisory central executive system, such as storing verbal items while simultaneously performing an additional processing task. It has been suggested that the most accurate way to assess phonological loop capacity is through simple span tasks, such as the repetition of nonwords or the forwards repetition of digits, and that central executive capacity is best measured through complex span tasks, such as the backwards repetition of digits or listening span tasks (Barrouillet & Camos 2007).

With regard to the relationship between WM and language skills, empirical evidence supports a link between both simple and complex span and syntactic development. Willis &

Gathercole (2001) observed that weak simple span capacity negatively affects the number of complex sentences repeated by 4- to 5-year-old TD children. However, in 6- to 8-year old children with SLI, Frizelle & Fletcher (2015) found that complex span rather than simple span is associated with the repetition of complex syntactic structures such as relative clauses. Likewise, Durrleman & Delage (2016) found a significant positive correlation between complex span and the production of 3rd person accusative clitics in French speaking children and adolescents with SLI. In comprehension, Marinis & Saddy (2013) found a relationship between performance on passives and complex span in children with SLI, and Montgomery and colleagues (2008) observed a significant positive correlation between complex span and the comprehension of copular passives and of structures containing various binding principles in 6- to 12-year-old TD children. A similar association was found in French-speaking TD children aged 5 to 12 when they were tested for the comprehension of various complex structures, such as structures containing clitic pronouns, passives and relative clauses, findings that have been replicated with French- and English-speaking children with SLI (Delage & Frauenfelder [submitted], Montgomery & Evans 2009).

1.3 Syntactic complexity

It is widely accepted that the mental process of assigning a syntactic structure to an incoming string of words, or parsing, relies on WM, with Gibson (2000) suggesting that WM resources are crucially needed (i) for integrating new information into the structure as it arrives and (ii) for storing the structure as it is being built and processed. At least two of Baddeley's four WM components, the phonological loop and the central executive, are crucially involved in keeping track of the phonological and grammatical properties of the linguistic input to be parsed, and it has been proposed that difficulty understanding certain complex structures is due to the cognitive overload that occurs when WM resources are insufficient to compute the incoming information.

When investigating the relationship between complex span and complex syntax, relative clauses are particularly interesting. Although both (1) and (2) contain an element whose interpretation is specified by means of an antecedent, and although both sentences consist of exactly the same words with only the sequence varying, a robust body of research shows that the structure in (1), which extracts an object, induces a processing disadvantage when compared to the structure in (2), which extracts a subject. This asymmetry is present across different age groups, different cognitive profiles and different languages (see Friedmann et al. 2009 for TD children, Friedmann & Novogrodsky 2011 for children with SLI, and MacKenzie et al. 2015 for individuals with aphasia).

(1) [The mailman]$_1$ that [the fireman] pulled t_1
(2) [The mailman]$_1$ that t_1 pulled the fireman

The difficulties associated with fronted object structures have been demonstrated by poorer performance and longer response times on tasks that test the comprehension of phrases containing an object relative (OR) than on tasks that test the comprehension of phrases containing subject relatives (SR) (Guasti 2002, Friedmann et al. 2009), significantly longer reading times of critical words in ORs than in SRs (Gibson 2000, Gibson & Ko 1998), and the systematic avoidance of structures containing an OR in elicitation tasks (Belletti & Contemori 2010, Guasti et al. 2012). In the syntactic literature, these findings have been interpreted in terms of an intervention effect that stems from syntactic theories of locality, namely featural Relativized Minimality (f-RM) (Rizzi 1990;2001, Starke 2001)[3]. According to this account, ORs are difficult to compute when a lexically-headed object crosses over an intervening lexical subject, as it is assumed that the overlapping +N feature carried by the two noun phrases (NP) obstructs the creation of the long distance dependency that must be formed between the headed object and its trace (3). In other words, the dependency relation, which is sensitive to distance, must be established across the embedded subject despite its featural similarity to the target head. This is true not only for ORs, but also for certain object questions. For example, *which* questions in which both arguments are lexical and thus share a +N feature (4) are associated with poorer comprehension than *who* questions in which the featural specifications of the arguments are distinct (5)[4].

(3) The mailman$_1$ that **the fireman** pulled t_1
[+R, +N] [+N]

(4) Which mailman$_1$ did **the fireman** pull t_1 ?
[+Q, +N] [+N]

(5) Who$_1$ did the fireman pull t_1 ?
[+Q] [+N]

In computational terms, ORs and *which* object questions are difficult to process because they require the temporary storage of two structurally similar NPs, with the embedded lexical subject behaving as a memory distractor that competes with the displaced element for retrieval at the position of the trace as they share a similar retrieval cue. The process of differentiating the two NPs thus taxes WM, as computing a dependency in the presence of an intervener consumes more computational resources than computing a dependency in which intervention is absent (Gibson 2000).

Evidence that processing disturbance is linked to similarity-based interference comes from a number of studies that have modified the degree to which an intervening element is similar to a preceding element. Warren & Gibson (1999) performed a questionnaire study with adult English-speaking participants, which showed that exchanging a referential NP with a pronoun NP facilitates comprehension, as it leads to feature mismatch between the fronted object and the embedded subject. Gordon and colleagues (2001) found a similar result when they measured adult reading times and comprehension accuracy of structures containing altering types of NPs: cases when the headed object and the preverbal subject were structurally dissimilar were linked to substantially better performance. Other studies performed on adults, children and pathological populations have found that different types of mismatch, such as mismatch of number and animacy features, have an ameliorating effect on processing (see Lowder & Gordon 2014 for adults, Friedmann et al. 2009, Adani et al. 2010 and Arosio et al. 2011 for children, Garraffa & Grillo 2008 for individuals with aphasia).

1.4 Aim of current study

Most studies investigating complex syntax and learning difficulties focus exclusively on dyslexia. To our knowledge, no systematic existing empirical research has evaluated the capacity of children with dyscalculia to process complex syntax, or this capacity in children

[3] For this article the following definition of f-RM has been adopted: In the configuration …X…Z…Y…, a local relation cannot hold between X and Y when
a. Z intervenes between X and Y, and
b. Z fully matches the relevant featural specification of X

[4] +R and +Q are the scope discourse or ‘criterial’ features that attract the target to the corresponding A’-position.

with SLD as a collective group. In the literature on dyslexia, several studies have reported OR comprehension deficits (Mann et al. 1984, Stein et al. 1984, Bar-Shalomet al. 1993). From a syntactic point of view, Arosio and colleagues (2017) link these processing problems to the movement of an object across a subject intervener, as they found the comprehension of object relative clauses to be more problematic than subject and passive relative clauses for children with dyslexia. From a computational point of view, Robertson & Joanisse (2010) found that in children with dyslexia, simple span was significantly correlated with comprehension accuracy in high-demand storage and processing conditions, such as when they were asked to process ORs. However, as previously mentioned, children with SLD have been associated with both simple and complex span limitations. Furthermore, empirical evidence suggests that a specific relationship exists between complex span and the comprehension of complex syntax, and that complex span capacity might be a better indicator of how complex structures are processed in children with SLI (Delage & Frauenfelder [submitted], Montgomery et al. 2008, Montgomery & Evans 2009, Frizelle & Fletcher 2015). For this reason, we chose to focus exclusively on complex span in this study.

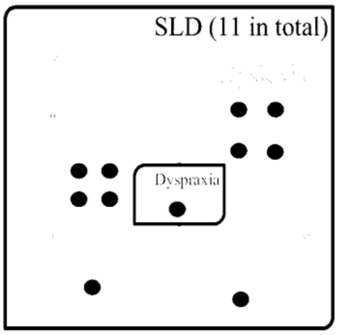
As far as we know, no studies have investigated the relationship between complex span and complex syntax in SLD, but we justify combining the subtypes of SLD in our study as we accept the premise that both dyslexia and dyscalculia stem from the same set of core cognitive deficits. Based on the syntactic principle of fRM, WM models of cue-based retrieval parsing, and evidence that complex span may be a better predictor of syntactic performance than simple span, the current study aimed to examine the relationship between backwards digit span and the comprehension of syntactic structures containing intervention in children with SLD in order to better understand how this complex span interacts with grammar in children who underperform at school. Specifically, two referent decision tasks were used to study the effect of the presence or absence of intervention on comprehension in school-aged Anglophone children with documented learning difficulties, and to evaluate the relationship of this effect to complex span. Concerning syntax, based on what has been observed in studies on TD children (Friedmann et al. 2009) and children with SLI (Friedmann & Novogrodsky 2011), we predict (i) that a significant intervention effect will be found in the accuracy and response time measurements of SLD children, with the processing complexity associated with the presence of intervention leading to a decrease in accuracy and an increase in response time and (ii) that the intervention effect will be significantly stronger for SLD children than it is for TD children, as computational limitations in the SLD group are expected to negatively influence how these children process complex syntax. Concerning WM, we predict (i) that, as was found by Helland & Asbjørnsen (2004), children with SLD will have complex span limitations, demonstrated by poor backwards digit span performance, and (ii) that complex span and the comprehension of complex syntax (structures containing intervention) will be correlated in SLD, as was the case for SLI (Delage & Frauenfelder [submitted], Montgomery et al. 2008, Montgomery & Evans 2009, Frizelle & Fletcher 2015).

2. Method

2.1 Participants

Eleven native English-speaking children (10 monolingual, 1 bilingual) who had been formally diagnosed with SLD and whose ages ranged from 7;8 to 11;6 (*M* = 9;8, SD = 1;1) participated in this study. All of these children received regular learning support, either from a specialist school for children with learning difficulties or from a qualified learning support teacher at a mainstream school. The participants were primarily recruited through three specialist schools:

Oak Hill[5] in Nyon, Switzerland, The Hill Center in Durham, North Carolina and The Royce Learning Center in Savannah, Georgia. Inclusion criteria were an SLD diagnosis by a qualified educational psychologist and mother tongue mastery of English. All of the SLD children in our study were receiving regular learning support from a certified specialist. Of the 11 children, the majority had been diagnosed with dyslexia and more than half of the children had comorbid attention difficulties. Only one participant had been diagnosed with dyscalculia, and one other participant had been diagnosed with SLD with a specific deficit in reading comprehension. Figure 1 outlines the distribution of learning difficulties in this group.



*RCD = Reading Comprehension Disorder

Figure 1: Distribution of learning difficulties in the SLD group

In order to provide age-matched controls for the children with SLD, 11 native English-speaking TD children aged 7;4 to 11;2 (M = 9;4, SD = 1;6) were also tested. The SLD and TD means of age did not differ ($p = 0.6$). Of the children in the TD group, 7 were monolingual, 3 were bilingual and 1 was trilingual. All TD children attended conventional schools and, according to their parents and teachers, had no history of learning difficulties and had never needed the targeted help of specialized learning support. Group data of children with SLD and their TD controls are presented in Table 1.

It is worth noting that the majority of the participants in the SLD group were boys. This highlights the fact that there is typically a higher prevalence of SLD among males than females, although researchers disagree on whether or not this is due to actual biological vulnerability, or simply referral bias (Hallahan & Kauffman 2003).

Table 1: Overview of participant information: mean age and SDs in years and months, gender of participants, and number of languages spoken by participants

Group	**Number of participants**	**Age**		**Sex**		**Lingualism**		
		Mean (y;m)	*SD*	F	M	Mo.	Bi.	Tri.
SLD	11	9;8	1;1	2	9	10	1	0
TD	11	9;4	1;6	7	4	8	2	1

2.2 Material and procedure

2.2.1 Complex span assessment

To measure the children's ability to temporarily store and manipulate verbal information, complex span was assessed in both SLD and TD participants using the backwards digit component of the digit memory test, a WM subtest of the Wechsler Intelligence Scale for

[5] Oak Hill is a specialist center for SLD that serves the international community in the Lake Geneva area. The language of instruction is English and children accepted to attend the school must be native English speakers.

Children Fourth Edition (WISC-IV, 2003). For this task, each participant was verbally presented with an item containing a series of digits (e.g. 2, 7) that were to be immediately recalled in the reverse order as read aloud by the examiner. Item length grew successively and the testing ended when the participant failed to correctly repeat two consecutive items of the same length. Each child received a backwards digit score that was matched to a standard score, and which placed the child on a ranked scale for complex span capacity. For this study, scores equal to or below the 10th percentile were considered to represent impairment. This decision was based on the discrepancy criteria recommended in the DSM-5 (2013).

2.2.2 Comprehension tasks I and II

Animations

To evaluate the comprehension of subject- and object-extracted structures, we devised two different comprehension tasks: one to test *wh* questions and one to test relative clauses. Eighteen animations were created using Anime Studio Debut 10 from Smith Micro Software.

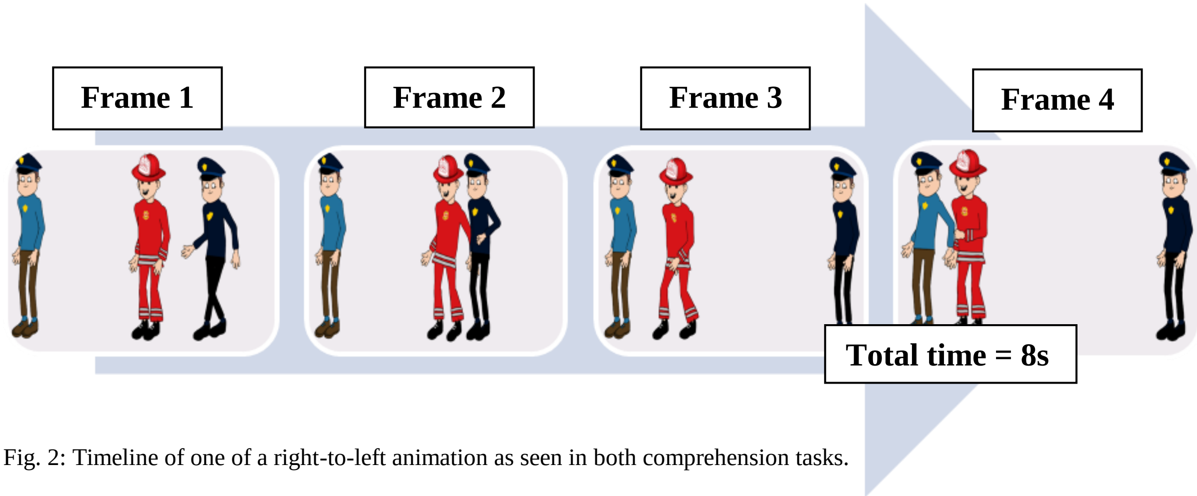


Fig. 2: Timeline of one of a right-to-left animation as seen in both comprehension tasks.

For these animations, three categories of figures, female, male and animal were designed, and each category contained three types (e.g. male: policeman, fireman and mailman). Each animation depicted three aligned figures in which one of the peripheral figures performed an action corresponding to an agentive transitive verb (e.g. pull) on the middle figure and the middle figure performed the same action on the other peripheral figure. The direction of the action was randomized but counterbalanced so that it proceeded from left to right in half of the animations and from right to left in the other half. For the actions that proceeded from right to left, the figure on the right always represented the agent and the figure on the left always represented the theme. The opposite was true for actions occurring in the reverse direction. Fig. *2* shows the timeline of one of the right-to-left animations. Only figures from the same category appeared together in the animations, and the two peripheral figures were always of the same type (e.g. **policeman** – fireman – **policeman**) but differed in one feature, such as color of clothing. Each figure appeared in each possible position (left – central – right) throughout the experiment.

Tasks I and II

The comprehension of subject- and object-extracted structures was assessed using two different tasks: task 1 required the participants to respond to either subject or object *who* and *which* questions (6 to 9), and task 2 required the participants to respond to commands containing either an SR or an OR (10 and 11 respectively).

(6) Who pulled the fireman?
(7) Who did the fireman pull?
(8) Which policeman pulled the fireman?
(9) Which policeman did the fireman pull?
(10) Point to the policeman that pulled the fireman.
(11) Point to the policeman that the fireman pulled.

Table 2: A summary of the distribution of test items for comprehension tasks 1 and 2. In bold are the conditions containing intervention.

Comprehension Task 1	Who S 18 items	Which S 18 items	Who O 18 items	**Which O 18 items**	Total 72
Comprehension Task 2	Subject Relative 18 items		**Object Relative 18 items**		Total 36

Table 3: Examples of test items for tasks 1 and 2.

Task 1	**Subject *wh* questions**	**Object *wh* questions**
	<u>Audio recording:</u> Which policeman/who pulled the fireman? <u>Expected response:</u> 	<u>Audio recording:</u> Which policeman/who did the fireman pull? <u>Expected response:</u> 
Task 2	**Subject relatives**	**Object relatives**
	<u>Audio recording:</u> Point to the policeman that pulled the fireman. <u>Expected response:</u> 	<u>Audio recording:</u> Point to the policeman that the fireman pulled. <u>Expected response:</u> 

For both comprehension tasks, the participants watched an animation (refer to Fig. *2* for the timeline of one of the animations), heard either an audio recorded *wh* question or an audio recorded command while looking at a blank screen, and responded while looking at a static image of the three figures in their original positions. The participants responded by pressing one of two designated keys, one corresponding to the agent of the action and the other corresponding to the theme, which varied according to the direction of the animation. In task 1, every animation was repeated four times so that the participants were presented with a total of 72 randomized animations: 18 followed by *who* subject questions, 18 followed by *who* object questions, 18 followed by *which* subject questions and 18 followed by *which* object questions. The *which* object condition was the only one to contain intervention in this task. In task 2, each animation was repeated twice so that the participants were presented with a total of 36 randomized animations: 18 followed by a command containing an SR, the non-intervention condition, and 18 followed by a command containing an OR, the intervention condition. Before each task, the children took part in a brief training session in order to ensure that they could recognize the characters and to get familiarized with the procedure. Including training, the entire experiment took 90 minutes and was either completed in one session with several pauses, or in two sessions of 45 minutes. Table 2 summarizes the distribution of test items[6] for the two comprehension tasks and Table 3 gives examples of test items based on the animation seen in Fig. *2*.

3. RESULTS

As our experimental design asked participants to press one of two designated keys, we wanted to exclude any children who displayed random performance by performing at chance level in both the subject and the object condition. Binomial analysis determined that none of the children in either group (SLD/TD) displayed random performance. Additionally, outliers were removed from the data by excluding response times that were +/- three standard deviations from that individual's mean per condition. Finally, due to non-conformity to normality of distributions (ascertained by a Shapiro-Wilk test), non-parametric statistics are reported throughout this paper. We used the Mann-Whitney test for inter-group comparisons between the SLD and TD participants and the Wilcoxon test for intra-group comparisons within the SLD group. The Spearman rank-order correlation coefficient was used to measure the strength of the relationship between complex span and syntax.

3.1. Syntax

Firstly, as an intervention effect has been found in both TD children and children presenting atypical WM and language development, such as children with SLI, we expected to find a significant intervention effect in the accuracy and response time measurements of children with SLD. In order to determine if this effect was indeed present in SLD, intragroup comparisons were made by analyzing how accuracy and response time varied as a function of intervention in the two comprehension tasks.

For task 1, the results in Figure 3 and Figure 4 indicate a clear difference between *wh* questions with and without intervention: children with SLD easily understand questions in the –INT condition in which intervention is absent (both types of subject questions and *who* object questions), whereas they have difficulty understanding questions in the +INT condition in which intervention is present (*which* object questions). There was a significant effect of intervention in the accuracy measurements ($Z = 2.29$, $p = 0.022$) and in the response time

[6] All test items were experimental as neither task contained fillers.

measurements (Z = 2.93, p = 0.003) for this task. The accuracy and response time results are summarized in

Table 4.

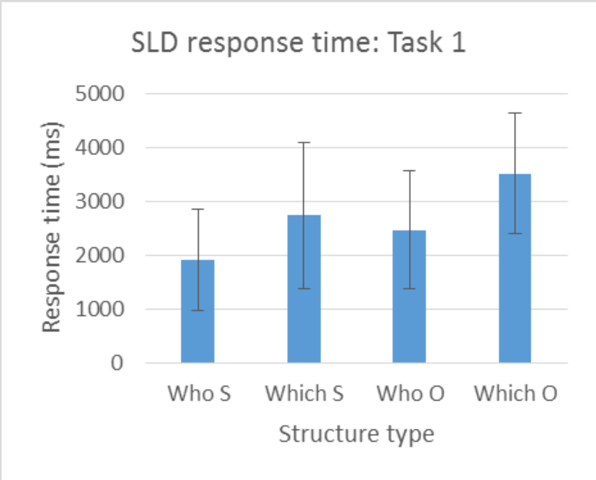


Figure 3Figure 4: Response time in comprehension of wh questions in children with SLD.

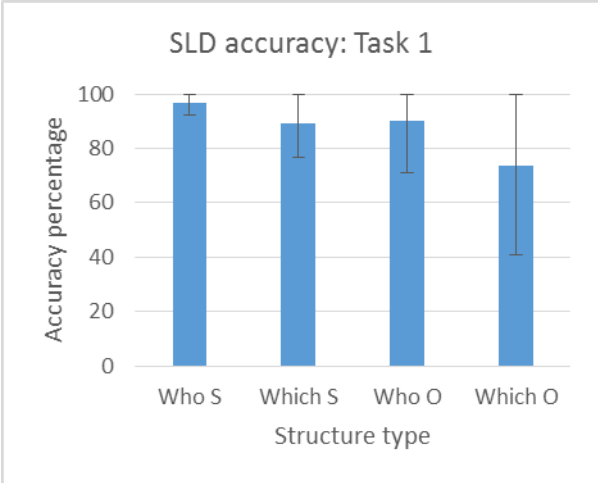


Figure 5: Response accuracy in comprehension of wh questions in children with SLD.

Table 4: A summary of the Task 1 findings.

	-INT	+INT	-INT vs. +INT
Accuracy (%)	92.3 (SD = 7.8)	73.7 (SD = 32.9)	***p* = 0.022**
Response time mean (ms)	2376 (SD = 1019)	3513 (SD = 1114)	***p* = 0.003**

Additionally, as response times for *which* subject questions were slower than those for *who* subject questions and this is paired with lower accuracy for the former structure as compared to the latter, these two conditions were compared to see if these differences were significant. The results show that there was a significant difference between the comprehension of subject questions with a bare *wh* operator (*who* questions) and questions with a lexically-headed *wh* operator (*which* questions), for both response time (Z = 2.94, *p* = 0.004) and accuracy (Z = 2.20, *p* = 0.028). For task 2, SRs were associated with good comprehension, while ORs were associated with poor comprehension (Table 5). A significant effect of intervention was found in the accuracy measurements (Z = 2.20, *p* = 0.028) but not in the response time measurements (Z = 0.98, *p* = 0.328) for this task.

Table 5: SLD comprehension of subject and object relatives.

Task 2	Subject relatives [-INT]	Object relatives [+INT]	Subject vs. Object
Accuracy (%)	92.4 (SD = 15.2)	80.8 (SD = 23.7)	***p* = 0.028**
Response time mean (ms)	3103 (SD = 1722)	3463 (SD = 1675)	ns

Next, to determine whether children with SLD demonstrate impaired comprehension when intervention is present, intergroup analyses compared SLD performance to TD performance for the intervention conditions (*which* object questions in task 1 and ORs in task 2). For task 1, the results in Table 6 show a significant SLD-TD difference in the response time measurements (U = 28, *p* = 0.034) but not in the accuracy measurements (U = 33, *p* = 0.076), although there was a tendency for SLD participants to be less accurate in their responses than the TD participants.

Table *7* shows the opposite pattern for task 2, with a significant SLD-TD difference being found for the accuracy measurements (U = 19, p = 0.005), but not for the RT measurements (U = 58, p = 0.898).

Table 6: A comparison of SLD-TD accuracy and response time measurements for which object questions.

Task 1	SLD [+INT]	TD [+INT]	SLD vs. TD
Accuracy percentage	73.7 (SD = 32.9)	92.9 (SD = 9.7)	tendency
Response time mean (ms)	3513 (SD = 1114)	2655 (SD = 1975)	***p* = 0.034**
	SLD [-INT]	TD [-INT]	SLD vs. TD
Accuracy percentage	92.3 (SD = 7.8)	99.0 (SD = 1.0)	***p* = 0.007**
Response time mean (ms)	2375 (SD = 1019)	2133 (SD = 1093)	ns

Table 7: A comparison of SLD-TD accuracy and response time measurements for object relatives.

Task 2	SLD [+INT]	TD [+INT]	SLD vs. TD
Accuracy percentage	80.8 (SD = 23.7)	99.5 (SD = 1.7)	***p* = 0.005**
Response time mean (ms)	3463 (SD = 1675)	3021 (SD = 1468)	ns
	SLD [-INT]	TD [-INT]	SLD vs. TD
Accuracy percentage	92.4 (SD = 15.2)	97.5 (SD = 3.8)	ns
Response time mean (ms)	3103 (SD = 1722)	2615 (SD = 996)	ns

Table 8: Individual SLD analysis of accuracy in tasks 1 and 2. In bold are scores that are 1.5 SDs or more below the TD mean, while scores highlighted in grey represent performance that is at or below chance level.

SLD participants	**Task 1 ACC % [+INT]**	**Task 1 ACC % [-INT]**	**Task 2 ACC % [+INT]**	**Task 2 ACC % [-INT]**
RT	**78**	**89**	**83**	**83**
BR	100	100	100	100
JF	89	100	100	100
LV	100	**96**	**83**	100
MV	**72**	**94**	**94**	100
CH	**22**	**80**	**33**	**50**
MH	94	98	100	100
BK	94	**96**	**94**	100
LD	89	**87**	**89**	**89**
CS	**0**	**78**	**39**	94
PK	**72**	**96**	**72**	100
TD participants	**Task 1 ACC % [+INT]**	**Task 1 ACC % [-INT]**	**Task 2 ACC % [+INT]**	**Task 2 ACC % [-INT]**
mean	93	99	100	98

While the results reveal that children with SLD tend to demonstrate poorer comprehension of structures containing intervention than age-matched control children, the large SLD standard deviations, especially for accuracy, indicate a high degree of variability within this group, suggesting that some SLD children performed very well while others performed poorly. In order to investigate if a particular subgroup of children with SLD have problems with structures containing intervention, we performed an individual analysis by examining the proportion of children with SLD that had difficulties comprehending structures containing intervention. Replicating analyses that have been performed in studies on relative clauses in dyslexia (Guasti et al., 2015), we examined individual SLD accuracy measurements in +/-intervention questions and +/-intervention relative clauses, and considered children who scored 1.5 SDs or more below the TD mean but were still above chance level as having subtle comprehension difficulties[7]. Scores that were at or below chance level were taken to indicate more severe comprehension difficulties. For the first task, 5 of the 11 children with SLD were at least 1.5 SDs below the mean of the TD group on +intervention questions, and 8 SLD children were at least 1.5 SDs below the TD mean for -intervention questions. For task 2, 8 of the SLD children were at least 1.5 SDs below the TD mean for +intervention relative clauses, and 3 were at least 1.5 SDs below the TD mean for -intervention relative clauses. In the SLD group, 2 children performed below chance level in the +intervention condition for both tasks, with 1 of them also performing at chance level in the subject condition of task 2. Table 8 summarizes our findings.

3.2. Working memory

Concerning WM, children with SLD were expected to have complex span limitations, demonstrated by impaired performance on the backwards digit memory span task when compared to their TD age-matched peers. In the SLD group, 2 children performed within the impaired range (≤ 10th percentile), with a third child ranking in the 11th percentile. All TD children had complex span measurements that fell within the normal range (> 10th percentile) (see Figure 6 for the distribution of percentile rankings for backwards digit span for the two groups). The results of the Mann-Whitney test reported no statistically significant difference between the two groups for backwards digit span (U = 34, p = 0.088), although there was an important tendency for percentile rankings to be lower in the SLD group (M = 51, SD = 34) than in the TD group (M = 76, SD = 21).

Table 9: Individual SLD analysis of backwards digit span. In bold are scores that are at least 1.5 SDs below the TD mean.

SLD participants	Backwards span (percentile ranking)
RT	67
BR	97
JF	96
LV	57
MV	**8**
CH	**11**
MH	50
BK	68
LD	77
CS	**5**
PK	**24**
TD participants	**Backwards span (percentile ranking)**
mean	76

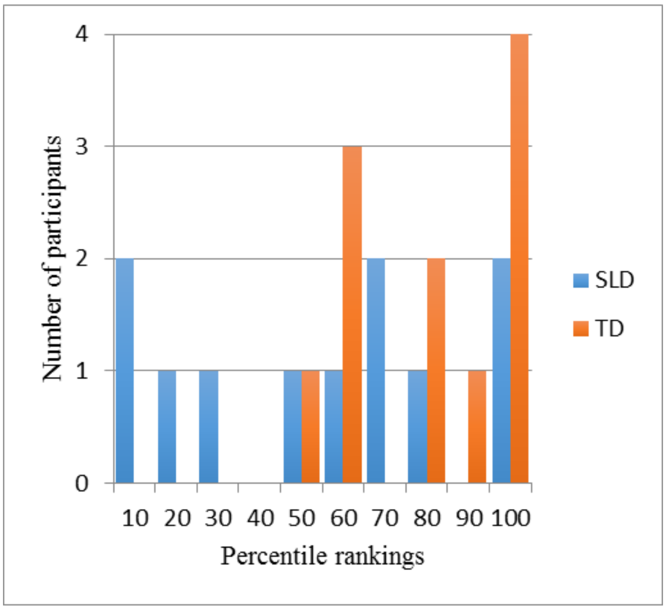


Figure 6: Distribution of percentile rankings for backwards digit span for the SLD and TD participants.

[7] It should be noted that the TD mean was rather high with very little variance in the data. This means that some SLD children performed close to ceiling, while still scoring at least 1.5 SDs below the TD mean.

Because, as for syntax, there was a high degree of variability in the SLD performance, we investigated if a particular subgroup of children with SLD has complex span limitations. This was done by considering each individual SLD score and examining how it deviated from the TD mean. Four of the 11 SLD participants scored at least 1.5 SDs below the TD mean (summarized in Table 9), and the children who performed poorly on the digit memory test also performed poorly on the comprehension tasks.

Finally, correlational analyses were performed to explore the relationship between complex syntax and complex span in children with SLD. Table 10 shows that for the intervention condition, a positive, statistically significant correlation was found between accuracy measurements and complex span for both task 1 (R = 0.73, $p = 0.011$) and task 2 (R = 0.63, $p = 0.037$). However, there was no significant relationship between response time and complex span, neither for task 1 (R = -0.28, $p = 0.401$), nor for task 2 (R = -0.22, $p = 0.519$). Concerning the non-intervention condition, a positive, statistically significant correlation was found only between accuracy and complex span in task 1 (R = 0.62, $p = 0.042$).

Table 10: Correlations between complex span and syntactic performance in children with SLD.

Task 1	Complex span	Task 2	Complex span
Accuracy [+INT]	**0.73****	Accuracy [+INT]	**0.63***
RT [+INT]	-0.28	RT [+INT]	-0.22
Accuracy [-INT]	**0.62***	Accuracy [-INT]	0.21
RT [-INT]	0.09	RT [-INT]	-0.37

*** p <.001; ** p <.01; * p <.05.

Table 11: Correlations between complex span and syntactic performance in TD children.

Task 1	Complex span	Task 2	Complex span
Accuracy [+INT]	-0.18	Accuracy [+INT]	-0.40
RT [+INT]	0.00	RT [+INT]	-0.23
Accuracy [-INT]	0.17	Accuracy [-INT]	-0.31
RT [-INT]	-0.04	RT [-INT]	-0.12

4. DISCUSSION

The main goal of this work was to investigate the relationship between complex syntax and complex span in SLD with the aim of (i) gaining insight into how children that are typically associated with complex span limitations comprehend complex syntax and (ii) examining how syntactic performance relates to complex span capacity in this population. Specifically, we assessed the comprehension of lexically-headed object structures because research has shown that non-canonical structures containing intervention are computationally complex and an excellent tool for detecting grammar difficulties, although studies on this type of difficulty in SLD are rare. Additionally, based on empirical evidence that a particularly important relationship exists between complex syntax and complex span in both atypically- and typically-developing children, we examined the relationship between backwards digit span and the comprehension of the intervention configuration in children with SLD.

Firstly, our results are in line with our first prediction, which stated that a significant intervention effect should be present in SLD. These results replicate what has already been observed cross-linguistically and across various age groups and cognitive profiles, and confirm that 7 to 11-year-old children with SLD are sensitive to syntactic intervention: structures in which intervention is absent (subject questions, *who* object questions and SRs in our study) are easily comprehended, whereas structures containing intervention (*which* object questions and ORs in our study) are problematic. That children with SLD easily comprehend subject-extracted structures is unsurprising as there is no intervening element between the moved head and the trace in dependencies with subject gaps. The fact that *who* object questions are also unproblematic for children with SLD suggests that moving an object across a subject is not the main source of complexity in comprehension. Rather, it is when the internal structure of the moved object and that of the intervening subject are similar that comprehension difficulties emerge. This pattern supports syntactic theories of locality that postulate that headed object structures are difficult to compute when a long-distance dependency must be formed between a lexical object head and its trace despite the presence of an embedded lexical subject because, in such a case, the headed object and embedded subject both carry the same +N feature (Rizzi 1990;2001, Starke 2001, Friedmann et al. 2009). In the still-developing or impaired system in which processing capacity is weaker, holding in memory two elements with overlapping featural specifications yields less accurate results and longer response times as such a syntactic configuration is associated with increased computational costs (Delage 2008, Delage & Frauenfelder [submitted], Garraffa & Grillo 2008). It is interesting, however, to note that this rule seems to apply to all instances of featural overlap rather than applying exclusively to instances in which overlap occurs between a moved element and an intervener. Although SLD performance was close to ceiling for both *who* and *which* subject questions, there was a significant difference between the two conditions, for both response time and accuracy. This suggests that the featural make-up of a *wh* element also plays a role in comprehension, regardless of intervention. Questions containing a *wh* operator with a rich morphosyntactic featural specification [+Q, +N] are more taxing than questions in which the [+N] feature is absent. Similar results have been reported for French-speaking TD children (Bentea & Durrleman 2014) and for Hebrew-speaking TD children (Friedmann et al. 2009).

Our next prediction stated that the intervention effect should be stronger for the SLD group than for the TD group. Our data indicate that this is indeed the case: children with SLD are not only sensitive to intervention, but this sensitivity is outside of the typical range as SLD performance in the +intervention condition tended to be poorer than that of the TD participants. For *which* object questions, there was a strong tendency for SLD accuracy to be lower than TD accuracy, and SLD response time was significantly longer than TD response time. For ORs, SLD accuracy was significantly lower than TD accuracy, but response time was largely similar for the two groups. The results of the examination of individual performance for accuracy suggest that at least a subgroup of children with SLD has greater difficulty than TD children in successfully performing complex syntactic operations involving intervention, although this difficulty seems to range from subtle to quite severe. In the case of severe comprehension difficulty, performance begins to resemble that of children with SLI (Contemori & Garraffa, 2010, Håkansson & Hansson 2000, Novogrodsky & Friedmann 2006). These findings are not necessarily surprising as 9 of our 11 SLD participants were diagnosed as having dyslexia, and the dyslexia-SLI overlap is well documented (Bishop & Snowling 2004, Catts et al. 2002;2005, Flax et al. 2003, McArthur et al. 2000). What is surprising, however, is the fact that not all of the children associated with poor syntactic performance had been diagnosed with SLD on the basis of literacy difficulties: one child who had difficulty comprehending ORs had been exclusively diagnosed with numeracy-based SLD. None of the children who showed impaired syntactic abilities in our study had been reported or diagnosed as having language deficits, mirroring findings that have been described in the literature on Italian-speaking children with dyslexia (Guasti et al. 2015). According to Guasti and colleagues, late identification of SLI and failure to evaluate the language abilities of children presenting symptoms of dyslexia can lead to under-identification of SLI. They suggest that some portion of SLI children may be misdiagnosed as having dyslexia, or that a subgroup of children with dyslexia may also be affected by unidentified comorbid SLI. We interpret our results similarly: although the difficulties reported for our SLD population prior to our study were limited to the domains of literacy and numeracy, a number of our SLD participants demonstrated deficits in syntax that may indicate the presence of unidentified SLI, whether misdiagnosed or co-occurring. However, in order to justify the supposition that a subgroup of children with SLD demonstrates language profiles similar to those of children with SLI, a detailed, standardized evaluation of the linguistic abilities of children with SLD is needed in future research.

To determine the source of the processing discrepancy between SLD and TD children, we follow the same line of thought presented by Friedmann and colleagues (2009) for the processing differences between children and adults. According to Friedmann and colleagues, calculating an inclusion relation[8] taxes the early computational system, as the correct comprehension of such a configuration requires the retention and comparison of two featurally similar NPs, a high-cognitive-load task that may exceed the capacity of a still-developing system. In other words, children seem to follow a stricter set of f-RM guidelines, in which a dependency relation cannot hold between X and Y when

a. Z intervenes between X and Y, and
b. Z partly matches the relevant featural specification of X

From early childhood to adolescence children experience developmental increases in processing efficiency, with steady growth in simple and complex span capacity, which presumably contributes to the progressive amelioration in TD performance on comprehension tasks that test complex syntax (Delage & Frauenfelder 2012).

What, then, differentiates SLD from TD children? As previously described, WM capacity is closely linked to syntactic performance, and children with SLD are known to have simple and complex span limitations. Jakubowicz (2011) hypothesizes that the persistent grammar difficulties observed in SLI, such as the poor comprehension of structures containing intervention, is the result of span weaknesses that limit one's ability to process complex syntax, a claim that is supported by empirical evidence (Montgomery et al. 2008, Montgomery & Evans 2009). Otherwise stated, immature WM development is assumed to be at least partly responsible for immature grammar in SLI. It is thus possible that a similar conclusion can be made for SLD. If span development does not follow a typical, age-dependent trajectory in SLD, this might account for the atypical comprehension patterns seen in this population when compared to age-matched TD peers.

We used the digit memory test in order to investigate span capacity in children with SLD. Because complex span has been closely linked to the comprehension of complex syntax, we chose to focus exclusively on backwards digit span performance in our participants, predicting that as a group, the SLD participants would demonstrate impaired performance when compared to the TD group. This, however, was not the case as the two groups could not be statistically distinguished based on global complex span performance. This finding is unexpected as it contradicts what has been previously reported for children with literacy- and numeracy-based difficulties (Helland & Asbjørnsen 2004). Nonetheless, the digit span assessment revealed different TD and SLD complex span profiles. SLD scores were widely distributed and could be classified as impaired to above average, with scores ranging from the 5^{th} to the 97^{th} percentile. Individually, 4 of the 11 SLD participants scored at least 1.5 SDs below the TD mean for complex span, but overall, the SLD children in this study performed within the average range, and sometimes above average range, for complex span, with only 2 SLD participants in our study demonstrating significant complex span impairment

[8] +A, +B….. +A….. <+A,+B>

(≤ 10th percentile). TD scores, on the other hand, showed a narrower distribution, with no below average TD performance. These findings seem to indicate that while limitations in complex span are systematically associated with academic under-attainment, it is not a condition sine qua non of SLD and that only a subgroup of children with SLD suffers from complex span impairment. However, one shortcoming of this study is that, due to time constraints, our WM measurements were limited to a singular evaluation. While the digit memory test is widely used for measuring simple and complex memory span and is a common component of IQ tests (e.g. the WISC), pairing it with other complex span tasks, such as the running span task (Pross et al. 2008) or the counting span task (Danahy et al. 2007), would give a much more precise indication of WM capacity in SLD children.

Finally, to investigate the relationship between the comprehension of complex syntax and complex span capacity in SLD, we performed correlation analysis. Our results confirm our prediction that the two are closely related in this population, with lower complex span capacity being associated with less accurate performance in both comprehension tasks. These findings are in line with research that has reported a close relationship between complex span and complex syntax in children with SLI (Delage & Frauenfelder [submitted]) and suggest that, as with children with SLI, complex span weakness in children with SLD limits the ability to process complex syntax, in particular structures containing a structurally similar intervener. Thus, not only do our results support syntactic theory that describes performance differences associated with certain syntactic structures in terms of a distinctness hierarchy of featural specifications that constrain syntactic computations, they also support a WM model of cue-based retrieval parsing, which postulates that the storage of similar memory traces hinders retrieval as similar traces often share the same retrieval cue and must compete for recovery. One advantage of converging syntactic theory and a WM model that interpret certain instances of processing difficulty in terms of similarity-based interference is its descriptive and predictive power: processing asymmetries, such as those observed for subject-object relatives and who-which questions, should occur when one of the constructions contains an intervener, which imposes greater demands on the WM system as it requires the storage of two featurally similar elements that must later compete for retrieval. When WM power is reduced due to complex span limitations, as is the case for a subgroup of children with SLD, processing is disrupted to an even greater extent.

The results presented in this paper open up a number of new research questions. New studies should investigate how attentional mechanisms influence performance on syntactic tasks in children with SLD. While the WM system and the attentional system are two separate cognitive structures, they are nonetheless closely related, with an attentional component being included in a number of WM models, such as Baddeley’s (2003) central executive, Barrouillet et al.’s (2004) attentional focus, and Cowan’s (1999) focus of attention. In order to coordinate the storage and computational operations necessary for the efficient processing of complex syntactic structures, both WM and attentional resources are recruited: WM resources support the temporary retention of verbal information so that it can be immediately accessed and processed, and attentional resources are responsible for selecting the specific information to be encoded in WM, maintaining focus on that information, inhibiting distractors from interfering with the processing of the information, and efficiently switching between the processing and storage aspects of a WM task (Gathercole & Alloway 2008). Indeed, Majerus and colleagues (2009) found that attentional processing explained more than 30% of the variance in verbal WM capacities of children with SLI, and that attention acts as an essential intermediary between WM and linguistic processing. Thus, there is some empirical evidence that both cognitive systems are relevant for the comprehension and production of complex syntax, but literature on the relationship between attention and syntax is scarce. As both attention and syntactic deficits have been recognized in children with SLD, this population is ideal for further exploration of the relationship between attention and language performance.

Finally, the findings that a selective intervention effect is present in English-speaking children with SLD and that this effect is stronger in children with WM limitations have clear clinical implications. If WM limitations are indeed responsible for deficits computing complex syntax in SLD, it may be of interest to train WM in this population to investigate the possibility that WM rehabilitation positively influences syntactic performance. In fact, such a training study with promising preliminary results is currently underway with children with SLI (Delage et al. 2017). Considering the similarities between children with SLI and a subgroup of children diagnosed with SLD, it would not be unreasonable to test the efficiency of such a training program in both populations.

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