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RUNNING HEAD: Span in DLD

Reduced deficits observed in children and adolescents with developmental language disorder using proper nonverbalizable span tasks

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Reduced deficits observed in children and adolescents with developmental language disorder using proper nonverbalizable span tasks

Abstract

Background: Children with developmental language disorder (DLD)—previously called Specific Language Impairment (SLI)—often perform poorly in verbal working memory (WM) tasks, but the picture is less clear regarding their visuospatial WM capacity. Recent research has been inconclusive regarding whether visuospatial working memory is impaired in DLD. Additionally, it is still unclear whether the putative disparity of WM performance persists in adolescence.

Aims: The aim of the current study was to unveil potential impairments in verbal and visuospatial working memory in DLD by exploring two developmental age groups of French-speaking children and adolescents.

Methods: This study examined verbal and nonverbal short-term and working memory capacity using digit span and Corsi block tasks in twelve children (7-11-year-olds) and twelve adolescents (12-18-year-olds) with developmental language disorder (DLD) in comparison to that in their typically developing peers.

Results: Our findings showed that both children and adolescents with DLD have deficits in storage and processing ability for the verbal domain. However, both the short-term and working memory estimates of immediate capacity for visuospatial information in adolescents with DLD were virtually intact.

Conclusions: These results indicate that both verbal and nonverbal storage and processing capacity are largely modulated by age, suggesting that the children with DLD show virtually intact nonverbal working memory capacity as they reach adolescence.

Keywords: developmental language disorder; working memory; short-term memory; nonverbal memory span

What this paper adds?

This research has generated new knowledge regarding verbal and visuospatial short-term and working memory capacity in both French-speaking children and adolescents with expressive developmental language disorder (DLD). Recent research examining children with DLD's potential impairments in verbal and visuospatial domains—which mainly concentrated on early childhood only, leaving working memory in adolescents with DLD unexplored—showed indecisive patterns regarding whether nonverbal working memory was impaired in DLD. Outcomes from the current paper fill this gap in knowledge regarding how DLD impacts later stages of cognitive development in adolescents. Our results showed that both the children and adolescents with DLD have deficits in storage and processing ability in the verbal domains. Concerning the visuospatial storage capacity, by contrast, the children with DLD were not different from the typically developing children. We only found limitations in working memory performance when the task required the children with DLD to both maintain and process visuospatial information, however, this was not observed in the typically developing children, nor in either group of adolescents. The data imply that children with DLD encounter difficulty in the visuospatial domain when a task requires greater processing demands and that this difficulty disappears at later stages of cognitive development as they reach adolescence.

1. Introduction

Developmental language disorder (DLD) has been documented as a difficulty in acquiring and using language, causing individuals to require special assistance (e.g., Bishop, 2006; Leonard, 2014). Language deficits in DLD have been shown to correlate with deficits in working memory capacity (Archibald, Joanisse, & Edmunds, 2011; Lidstone, Meins & Fernyhough, 2012) leading to limitations in both storing and processing information (Archibald & Gathercole, 2006a; Gathercole & Baddeley, 1990; Henry, Messer & Nash, 2012; Montgomery, 2000, 2003) and hence putatively impacting general cognitive development. Working memory (WM) is defined as a cognitive system that allows individuals to maintain and manipulate information, enabling complex processes such as language processing and learning possible, while short-term memory (STM) conceptually refers to the capacity to store information for a short amount of time (see e.g. Baddeley, 1992). School-age children typically perform virtually faultlessly in phonological WM tasks that require immediate repetition of nonexisting words of up to 2-3 syllables, whereas children with DLD perform poorly in such tasks (Gathercole & Baddeley, 1990; Weismer et al., 2000). The lower performance of children with DLD suggests that learning new phonological forms tends to be difficult in DLD. However, the picture is less clear regarding the visuospatial WM capacity: while some authors have shown that the span of children with DLD is comparable with that of typically developing children (Archibald & Gathercole, 2006a, 2006b; Botting, Psarou, Caplin, & Nevin, 2013), others have reported poor performance in this domain (Hoffman & Gillam, 2004).

Although simplistic, there are roughly two different explanations for why children with DLD perform poorly on certain span tasks (see Bishop, 1992, for a complete review of hypotheses). First, Gathercole and Baddeley (1990) proposed that poor phonological storage capacity is the main reason for verbal difficulties in DLD. The verbal short-term memory deficit hypothesis was based on the evidence that children with DLD tend to perform poorly in span

tasks that exclusively require repeating nonwords. Because their performance on such tasks correlates with other language skills, this hypothesis holds that children with DLD have selective language processing difficulty. A second account, by contrast, proposes that children with DLD have limitations in their general processing capacity, which in turn leads them to encounter difficulty in processing verbal information (Bishop, 1992; Kail, 1994; Weismer, 1996). This latter account has provided an explanation for data indicating impairments in both the verbal and visuospatial domains.

The available studies examining the potential asymmetrical performance of children with DLD in the verbal and visuospatial domains have been inconclusive to date (see below). Furthermore, the current state-of-the-art in working memory research on DLD has largely focused on early childhood (i.e., prepuberty ages), leaving a fairly large gap regarding how DLD impacts later stages of cognitive development in adolescents (but see Botting & Conti-Ramsden, 2008; Weismer, Plante, Jones, & Tomblin, 2005). The aim of the current study was therefore to unveil potential impairments in verbal and visuospatial working memory in DLD by exploring two remote developmental age groups of French-speaking school-age children (i.e., aged 7-11) and adolescents (aged 12-18). A more specific goal in exploring visuospatial span in addition to the verbal domain here was to detect broader potential cognitive impairments underlying DLD with minimal involvement of linguistic processing. Importantly, being influenced by a number of factors, including familiarity with stimulus properties, individuals' experience, or frequency of characters in a language, typical development of working memory has been shown to follow slightly different paths depending on stimulus material (see Cowan, 2016; Reder, Liu, Keinath & Popov, 2015; Simmering, Miller & Bohache, 2015). It is thus conceivable that reliance on nonverbal visual strategies in the presence of specific language deficits may help children with DLD to overcome their difficulty by resorting to visualization strategies to encode verbal information by the time they arrive later stages in their cognitive

development (see, e.g., Gill, Klecan-Aker, Roberts & Fredenburg, 2003), reducing the gap between the two groups.

As no study reported to date has examined both verbal and visuospatial working memory in an extended age sample of participants with DLD ranging from early childhood to adulthood, we believe this examination would help shed light on potential delays in developmental trajectories of working memory or phenomena of compensation arising during development.

1.1. Studies on working memory in DLD and the current study

Within the framework of Baddeley's model (Baddeley, 2000; Baddeley & Hitch, 1974), storage of both visual and verbal information is conceptualized to be subserved by the central-executive system. There is evidence that the central-executive component, indexed by WM tasks, and the storage component indicate related but distinct processes in typically developing children (de Abreu, Conway, & Gathercole, 2010). These components are often tested using complex span tasks that involve both storage and processing activity (i.e, using a dual task; see Barrouillet, Portrat & Camos, 2011; Conway et al., 2005; Unsworth & Engle, 2007). The complex span tasks are also adequate to test concurrent models based on the idea that working memory components share a common pool of attentional resources during the execution of complex span tasks (see Case, Kurland, & Goldberg, 1982; Just and Carpenter, 1992; see Gaillard, Barrouillet, Jarold, & Camos, 2011, for a developmental study). In contrast, simple span tasks which involve only intermediate recall of items from the memory are traditionally associated with the concept of STM. Simple span tasks are often considered to measure the storage capacity only. However, when backward recall is performed, complex processing demands increase, requiring involvement of the central-executive component.

Archibald and Gathercole (2006a, 2006b) used several span tasks to investigate groups of children with DLD (aged 7–12, $N = 15$ and 20, respectively), including digit recall,

visuospatial block recall tasks, visual patterns test, and a series of working memory span tasks (e.g., backward digit recall). Their results showed that the children with DLD had greater difficulty in both verbal WM and STM tasks compared to their age-matched typically developing peers, but no evidence was found that the children with DLD were impaired in visuospatial WM and STM tasks. Similar results were reported by Alloway and Archibald (2008) for a group of children with DLD (aged 6-11, $N = 11$). The authors concluded that memory deficits in DLD selectively concern verbal domains, in line with the verbal short-term memory deficit account (Gathercole & Baddeley, 1990). In their study on 5-year-old children ($N = 97$), van Daal, Verhoeven, van Leeuwe, and van Balkom (2008) showed that the children with DLD performed more poorly on the central-executive function and phonological working memory tasks than did their typically developing peers, whereas these children showed identical levels of performance in visuospatial WM tasks.

However, another cluster of studies showed significant visuospatial storage and/or processing impairments in DLD. For instance, in their study with a group of 24 children with DLD (aged 8-11), Hoffman and Gillam (2004) used several recall tasks (e.g., pointing and naming span tasks) to investigate visuospatial and verbal WM. The authors found that children with DLD performed more poorly on both visuospatial and verbal span tasks than did their typically developing peers, suggesting that the underlying nature of DLD in young children is not selective to verbal domains. In a further study, Bavin, Wilson, Maruff and Sleeman (2005) showed that a group of children with DLD recalled visual patterns in a visuospatial WM task with lower accuracy than did their typically developing (TD) children, but not in recalling the location of visual items. Marton (2008) examined two groups of children with DLD (aged 5-7, $N = 40$ and 8-11, $N = 25$) using verbal and visuospatial WM tasks, including space visualization, position in space, and design copying tasks. Their findings showed that children with DLD performed more poorly than did their TD peers in all visuo-spatial working memory tasks. The authors argued that factors such as executive function and attention control have

important effects on WM performance in DLD, suggesting that tasks requiring greater attentional demands are more challenging to children with DLD. Leclercq, Maillart, Pauquay, and Majerus (2012) studied 15 French-speaking children with DLD (aged 6–13) using visual STM tasks and found that the children with DLD performed more poorly than did typically developing children. Furthermore, a meta-analysis reported in Vugs, Cuperus, Hendriks, and Verhoeven (2013) showed that the performance of children with DLD was largely below that of their TD peers on average for both storage (i.e., measured by STM tasks including forward recall) and processing components of visuospatial WM. Their meta-analysis therefore suggests that children with DLD appear to encounter difficulty in both storing and processing visuospatial information. A further study with 51 children with DLD using the visuospatial Serial Reaction Time task reported by Lum, Conti-Ramsden, Page, and Ullman (2012) found visuospatial storage, as indexed by short-term memory, to be intact in DLD. However, this study found that processing ability for visual information, as indexed by working memory, was impaired.

In summary, while a number of studies have shown that children with DLD (aged approximately 5-12) experience problems in storing and processing verbal but not visuospatial information, others have shown that children with DLD have similar difficulties in the two respective domains. Moreover, there is still no direct evidence whether (non)verbal working memory difficulties (and potentially larger difficulties impacting visuospatial information) persist in later stages of cognitive development in adolescents with DLD. The current study thus explored verbal and visuospatial (non-verbal) immediate memory in two developmental age groups of French-speaking school-age children and adolescents with expressive DLD (i.e., aged 7-11 and 12-18, respectively) and their age-matched typically developing peers. Here we assume that visuospatial material (i.e. Corsi blocks, see below) contains lower amount of verbal information than digit span tasks (see e.g., Vandierendonck, Kemps, Fastame, and Szmalec, 2004). We estimated immediate capacity based on two different constructs (Unsworth & Engle,

2007): 1) short-term memory, based on a simple span task mainly involving storage of information, and 2) working memory, based on a complex span task involving manipulation of the stored items. Our research questions were (i) whether French-speaking individuals with DLD have difficulties in the verbal span tasks that persist with age in comparison to a control group and (ii) whether they experience the same magnitude of difficulty between verbal and visuospatial working memory performance in childhood and adolescence. We chose to measure both STM and WM capacity because it has been shown that verbal and spatial complex spans can be clearly separated from verbal and spatial simple spans (see Kane, Hambrick, Tuholski, Wilhelm, Payne & Engle, 2004).

The two theoretical approaches to working memory impairment in DLD presented above have different lines of predictions for each of our research questions. First, under the verbal short-term memory hypothesis (e.g., Gathercole & Baddeley, 1990), children with DLD are expected to perform poorly on verbal span tasks compared to nonverbal (i.e. visuospatial) tasks. However, following the general processing limitation account (e.g., Bishop, 1992; Kail, 1994; Weismer, 1996), children with DLD are predicted to perform poorly on both the verbal and nonverbal span tasks compared to their typically developing peers. Therefore, the inclusion of nonverbal (i.e., visuospatial) span tasks is likely to suggest whether children and adolescents with DLD have a general difficulty in processing.

2. Methods

2.1. *Participants*

Participants in this study included twenty-four native French speakers with DLD who were primarily described as having expressive language difficulties (i.e. expressive developmental language disorder, henceforth, referred to as 'DLD' for simplicity). Figure 1 shows the participants' ages. These 24 participants were divided into two subgroups: (i) twelve children with DLD (10 boys) in elementary mainstream school between the ages of 7 and 11 (from 7.66

years old to 11.00 years old; mean age = 8.94) and (ii) twelve adolescents with DLD attending middle and high school (7 boys) between the ages of 12 and 18 (from 12.08 years old to 17.50 years old; mean age = 14.05). In addition, a group of 48 typically developing (TD) participants, matched with the participants with DLD on chronological age, gender, and parental socioeconomic status, was recruited as a reference group (i.e. two TD children matched with one child with DLD). The TD group included 24 children (from 7.50 years old to 11.2; mean age = 8.85) and 24 adolescents (from 12.3 to 17.8; mean age = 14.05).

[FIGURE 1 ABOUT HERE]

Our participants with DLD were diagnosed according to the Referral Center for Language Disorders of Poitiers (France) and met the criteria for “expressive language disorder” (F80.1 / ICD-10, World Health Organization, 2001). The participants were screened using a battery of diagnostic tests used as standard in France, including the Computerized Assessment of Oral Language (Khomsi, Khomsi & Pasquet, 2007), the New Tasks for the Language Assessment (Chevrie-Muller & Piazza, 2001), and the Wechsler Intelligence Scale for Children (WISC III, Wechsler, 1996). The participants with DLD exhibited a stable expressive speech production disability with at least -1.25 SD or above on average according to the Leonard criteria (2014); however, they had retained cognitive abilities and this was evident in their Intellectual Quotient Performance (IQP) which proved to be greater than or equal to 80 on the intelligence scale (Wechsler, 1996).¹ Full procedures in recruitment and screening of the participants with DLD were described by Broc et al. (2013). None of the participants were

¹ Please note that the participants with DLD met the criteria for expressive language impairments as verified by language assessment and IQ measures mentioned here, however, these measures were not collected from the TD group participants and therefore a direct group comparison of IQ and language outcomes was not possible.

experiencing from any neurological, sensory or psychiatric disorder. The experiments reported here took around an hour per participant and work described has been carried out in accordance with the Code of Ethics for experiments involving human subjects in the Declaration of Helsinki.

2.2. Procedure

After screening, the participants were tested on four different measurements: (i) *verbal STM* was measured with a forward digit span task, and (ii) *verbal WM* was measured with a backward digit span task (taken from the WISC III, Wechsler, 1996), as these tasks have been shown to tap into verbal storage and processing capacity in children with and without DLD (see, e.g., Alloway, Gathercole and Pickering, 2006; Archibald and Gathercole, 2006a). Also, importantly, digit span tasks have been argued to reflect linguistic experience to a greater extent (see e.g. Jones & Macken, 2015). Digit span tasks required the participants to recall and repeat auditorily presented sequence of digits, in either forward or backward order, ranging from two digits in length up to a maximum of 8 digits. The participants were presented with three trials for each level of span length. When participants correctly recalled three or two trials within the same span length, they were given the full score and were presented with the trials containing $n+1$ digits. Participants were credited half the score when they succeeded in only one trial. The task terminated when the participants failed all trials of the same length. (iii) *Visuospatial STM* was evaluated by an adaptation of the Corsi block tapping test (Corsi, 1972), and (iv) *visuospatial WM* was assessed with the same experimental setting, yet in the reverse order of recall. The task required the participants to recall the order of pointing to different sequences of blocks on a printed 5×5 grid of 25 blocks. The experimenter pointed to at least 2 and at most 8 blocks in a specific sequence, and the participants were required to immediately repeat this sequence back by pointing. There were three trials in each level of span length. The participants were given a full score when they correctly recalled at least two trials within a

specific level; however, the task was terminated when participants made three mistakes and were still credited half the score whenever there was one correctly recalled trial for a given length.

3. Results

Table 1 presents the mean spans and standard deviations of the children with DLD and their typically developing peers (see for an illustration in Figure 1). We ran an initial mixed-effects regression model with Age Group, Task (WM vs. STM), Group (DLD vs. TD), and Domain (Verbal vs. Visual) as fixed effects and participants as random intercepts. The model returned strong effects for Domain ($\beta = 1.04$, $SE = 0.31$, $t = 3.36$, $p < .001$) and a four-way interaction between these fixed effects ($\beta = -1.50$, $SE = 0.75$, $t = -1.99$, $p = .04$). The full outputs from this model are presented in Appendix 1.

[TABLE 1 ABOUT HERE]

[FIGURE 2 ABOUT HERE]

To better disentangle the task and group effects, subsequent models were built for visuospatial and verbal tasks separately (see Table 2). The statistical outputs from the model for verbal tasks showed significant fixed effects for Group (TD vs. DLD), Task (WM vs. STM) and of Age Group without any significant interactions between these factors. This finding suggests that TD children performed better than did the children with DLD on both verbal WM and STM tasks and that both groups of participants performed lower on the WM than on the STM task. Finally, the adolescents performed better than did the children independent of task and group. Outputs from the mixed-effects regression model for the visuospatial data showed a different pattern, however. We found significant fixed effects for Task (STM vs. WM) and Age Group, but not

for the experimental Group (TD vs. DLD). The model indicated significant interactions between Task and Age Group and a three-way interaction between Group, Task and Age Group.

[TABLE 2 ABOUT HERE]

Further post hoc comparisons for the visuospatial tasks, using Tukey's tests, were conducted to examine the nature of interactions between Task and Group across children and adolescent participants. The post hoc test revealed strong age effects for both the DLD ($\beta = -0.99$, $SE = 0.18$, $z = -5.24$, $p < .001$) and TD groups ($\beta = -1.29$, $SE = 0.41$, $z = -3.13$, $p = .001$), indicating that the adolescents in both groups performed better than did the children. A further set of between-task comparisons for the children groups did not reveal any differences between STM and WM tasks in either DLD ($\beta = 0.41$, $SE = 0.25$, $z = 1.62$, $p = .10$) or TD children ($\beta = -0.31$, $SE = 0.18$, $z = -1.72$, $p = .08$). The adolescents with DLD, however, performed better in the STM task than in the WM task ($\beta = -0.75$, $SE = 0.29$, $z = -2.52$, $p = .01$), while this task difference was marginal but statistically nonsignificant in the TD adolescents ($\beta = 0.36$, $SE = 0.20$, $z = -1.78$, $p = .07$).

A specific aim of the current study was to compare verbal and visuospatial domains. Outputs from a set of Tukey tests showed that the performance of the participants with DLD showed no differences in responding to verbal and visuospatial STM tasks in children ($\beta = 0.29$, $SE = 0.29$, $z = -1.0$, $p = .31$), whereas the adolescents with DLD performed better in the verbal task than in the visuospatial task ($\beta = -0.58$, $SE = 0.28$, $z = -2.08$, $p = .03$). The better performance of the adolescents with DLD was also reflected in the typically developing children ($\beta = -1.93$, $SE = 0.17$, $z = -11.23$, $p < .001$) and adolescents ($\beta = -2.06$, $SE = 0.22$, $z = -9.24$, $p < .001$). The picture slightly changed for the WM tasks as only a meaningful cross-domain comparison was found in the responses of adolescents with DLD, who showed poorer performance in verbal than in visuospatial WM capacity ($\beta = 1.04$, $SE = 0.29$, $z = 3.57$, $p <$

.001), while all other groups did not show significant differences between their verbal and visuospatial WM task responses (all $ps > .13$). Finally, we found significant positive correlations between span task scores and our participants' ages, suggesting that both the DLD and TD groups tend to achieve improved span scores as they grow older, especially in the visuospatial domain (see Appendix 2 and 3 for further details).

4. Discussion

In this study, we explored verbal and nonverbal storage and complex processing capacity, as measured with span tasks administered to groups of French-speaking children and adolescents with expressive DLD. Our research questions were (i) whether French-speaking individuals with DLD have difficulties in the verbal span tasks that persist with age compared to a control group until adolescence and (ii) whether the developmental groups under investigation experience the same magnitude of difficulty between verbal and visuospatial task performance. The rationale was that the putative impairments in both the verbal and visuospatial domains during childhood could be reduced in adolescence as children with expressive DLD could progressively develop visual recoding abilities, compensating for their verbal impairments (and potentially augmenting their span in the nonverbal modality) but also leading to intact visual capacity. Alternatively, differences in memorization performance between the DLD and TD groups could be expected to increase even further as typical children, in the absence of any verbal impairments, are assumed to take advantage of verbalization strategies to encode visual stimuli.

The results of the current study showed that expressive DLD severely impacts both storage and processing ability for verbal information in both children and adolescents, as demonstrated by forward and backward digit span tasks, respectively. This observation is in line with the view that DLD is primarily a language disorder that leads to difficulty in verbal

communication ability (see, e.g., Bishop, 1992; Leonard, 2014). Our results nevertheless show that visuospatial storage capacity (as measured with the forward Corsi block tapping test) in the children with expressive DLD is not significantly different from that of the TD children. However, we found a significant limitation in the children with DLD compared to the TD group when we measured the processing capacity for visuospatial information, as indexed by the backward Corsi block tapping test. It is important to note that our sample was drawn from a population of individuals with expressive DLD, and thus, considering the cognitive outcomes reported here, the situation is not merely about problems expressing language but also with complex processing. Finally, we found no group differences for either visuospatial measure in adolescents, suggesting that children with DLD encounter difficulty processing visuospatial information when the task requires more demanding processing and that this difficulty seems to disappear when they reach adolescence. A potential reason for the observed visuospatial WM problem in the children with DLD may be stemming from the fact that the children were experiencing greater receptive difficulties relative to the adolescents.

The answer to our first research question is clearly affirmative. In verbal span tasks, both the children and adolescents performed more poorly compared to their typically developing peers. It is conceivable that the expressive difficulties in our participants with DLD aggravated their performance in digit repetition as a correct recall in this task typically requires pronouncing a list of digits, and hence, any verbal difficulty can easily influence the digit span performance (see e.g. Schweickert & Boruff, 1986). In the visuospatial domain, by contrast, we only observed lower performance in the backward Corsi block tapping task in children with expressive DLD than that exhibited by typically developing children. In all other group comparisons, both children and adolescents with DLD were found to perform similarly to their typically developing peers in their responses to visuospatial span tasks. Recall that previous studies on visuospatial memory in DLD supplied mixed results. The data presented in the current study supports the view that visuospatial storage capacity is intact in DLD (e.g.

Archibald & Gathercole, 2006a, 2006b; Botting, et al., 2013, but c.f., Bavin, et al. 2005; Hoffman & Gillam, 2004). Given that the children with DLD showed difficulties with backward visuospatial recall, we suggest that those children may be experiencing a central WM deficit, which does not seem to continue into adolescence. How can these data be accounted for?

Under the general processing limitation account (e.g., Bishop, 1992; Kail, 1994; Weismer, 1996), a potential explanation for our data is that the children with DLD encounter general processing limitations, while they process both verbal and visuospatial information, but because our data did not show a parallel impairment in the adolescents with DLD, their selective difficulty in the verbal modality suggests that the general processing limitation hypothesis does not hold true for the adolescents with DLD. Additionally, it is worth mentioning that because we observed no radical change in the patterns of results of the typical children, it is unlikely that the children could make use of verbal strategies to increase performance in the Corsi block task with age. The change in the patterns of the results is more likely due to a change in the DLD group.

Regarding the second question, following the verbal short-term memory hypothesis (Gathercole & Baddeley, 1990), we may have expected our children with DLD to perform relatively more poorly on verbal tasks than on visuospatial tasks. This relationship was, however, not exactly what the data indicated. Recall that we expected a larger magnitude of difference between visuospatial and verbal performance in the STM condition, as STM estimates are more domain-specific than WM estimates (Kane, Hambrick, Tuholski, Wilhelm, Payne & Engle, 2004). However, the children with DLD showed reduced differences between the verbal and the visuospatial STM tasks compared with those observed for the TD group. Additionally, although the difference between the verbal and the visuospatial WM spans was virtually null for children with DLD, the adolescents with DLD performed better than expected on the WM forward span task in the visuospatial condition, with performance mirroring that of the typically developing adolescents. Importantly, the verbal span task that required backward recall still proved difficult for the adolescents with DLD in comparison to the visuospatial

counterpart, compatible with the idea of selective verbal working memory difficulty. Overall, we found greater support for the verbal short-term memory hypothesis, as we found greater evidence for a selective deficit in the storage of verbal information over nonverbal when the task particularly taps on domain-specific storage.

5. Conclusions, clinical implication and limitations

This study investigated verbal and visuospatial storage and complex processing capacity, as measured with span tasks, in French-speaking children and adolescents with DLD. Both children and adolescents with DLD showed difficulty storing and processing verbal information. In the visuospatial domain, by contrast, the children with DLD showed limited working memory span, whereas no group differences were found in adolescents. Based on these findings, we arrived at two major conclusions. First, the impairments of children with DLD in storing and processing verbal information, as measured with digit span tasks, persist in later stages of cognitive development in adolescents with DLD, although adolescents with DLD show a developmental advantage in processing verbal information. Second, children with DLD have intact visuospatial storage capacity, but they encounter difficulty in the visuospatial domain only when the task requires processing demands, and this difficulty disappears during adolescence.

A potential clinical implication one can draw from this study is that for young children with expressive DLD, in whom we found WM deficits in both verbal and visuospatial backward recall, a comprehensive WM training is advisable in clinical intervention. However, for adolescents with expressive DLD, we found no visuospatial WM difficulty but extensive verbal memory problems. Considering that during the adolescence, language acquisition process is virtually complete in typical development, but in adolescents with DLD, verbal problems seem to hold still, therefore, we recommend language intervention and communication support in expressive DLD even when the childhood stage is complete.

The main limitation of the present study is that there may be differences in how serial order is encoded in the digit span task and the Corsi blocks (Gmeindl, Walsh & Courtney, 2011), suggesting that children with DLD could have particular difficulty in encoding serial order as it appears to be more readily bound to verbal than to spatial representations. However, note that what actually Corsi block-tapping task measures is often argued to be visuospatial processing intertwined with verbalization strategies, which bear large individual differences (see, e.g. Berch, Krikorian & Huha, 1998; Hilbert et al., 2019 for a consideration). This limitation should lead future research to develop span tasks differing in the verbalizability of visual material rather than opposing verbal and spatial information. Also, importantly, we would like to caution the reader that the children and adolescents recruited in our study are different individuals, in whom potential effects of severity in language disorder, education, linguistic experience have been left uncontrolled for. Thus, a future longitudinal study in visuospatial memory in DLD with the same individuals is worthwhile.

Declaration of conflict of interest.

None declared.

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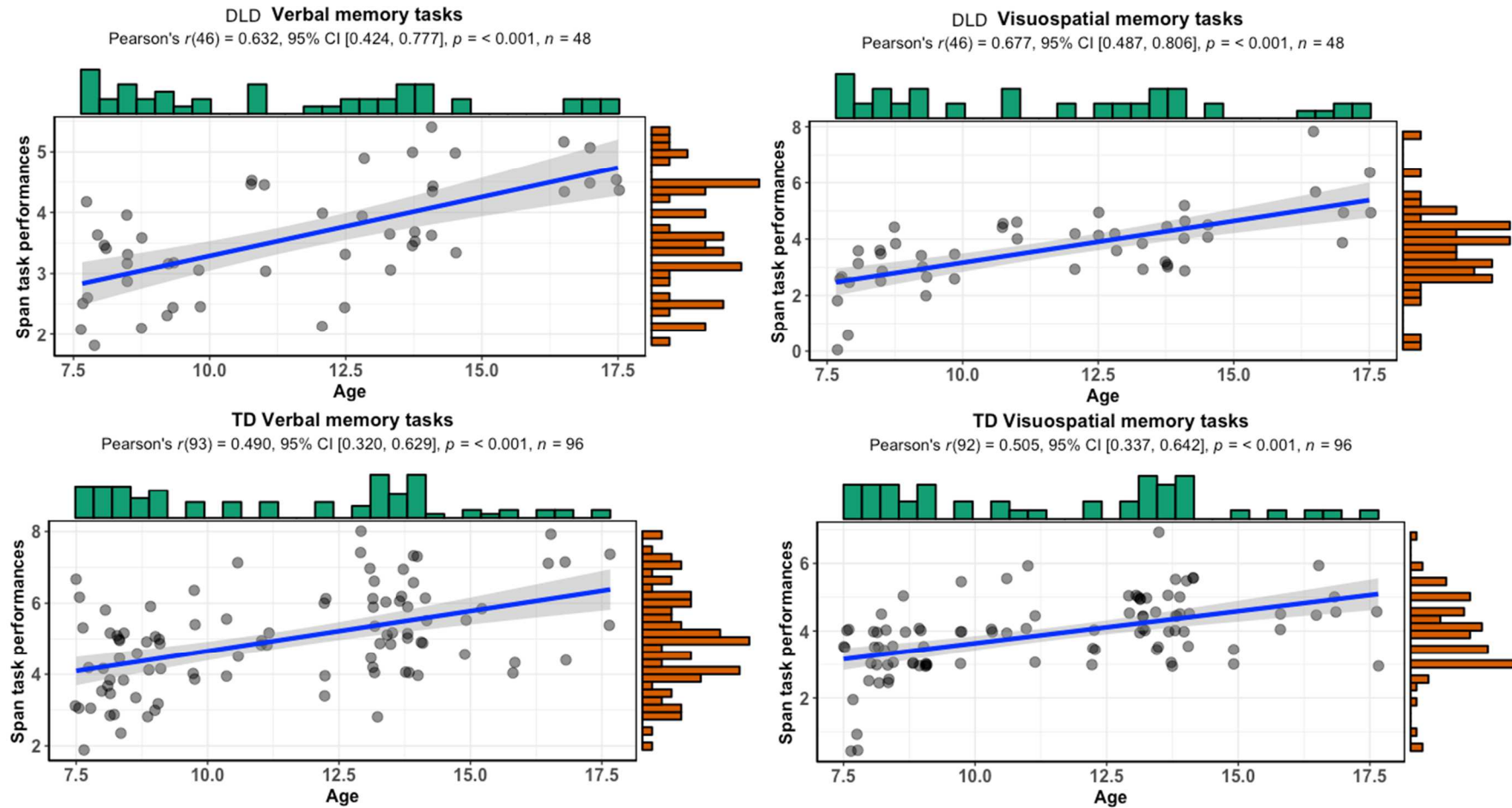
Appendix 1. *Statistical outputs from the initial mixed-effects regression model*[†]

	Estimate	SE	<i>t</i>	
(Intercept)	3.62	0.27	12.98	***
Group	1.22	0.34	3.59	***
Task	0.87	0.30	2.83	**
Domain	1.04	0.31	3.36	***
Age Group	-0.83	0.39	-2.11	*
Group × Task	0.50	0.37	1.32	
Group × Domain	-1.36	0.37	-3.59	***
Task × Domain	-1.62	0.43	-3.71	***
Group × Age Group	-0.41	0.48	-0.86	
Task × Age Group	-0.16	0.43	-0.38	
Domain × Age Group	-1.04	0.43	-2.38	*
Group × Task × Domain	-0.11	0.53	-0.21	
Group Task × Age Group	0.39	0.53	0.73	
Group × Domain × Age Group	1.34	0.53	2.50	*
Task × Domain × Age Group	1.33	0.61	2.15	*

Group \times Task \times Domain \times Age Group -1.50 0.75 -1.99 *

[†] Code in R: `lmer(value ~ Groupe * Order * Condition * Age_Group + (1|Participant))`

Appendix 2. Plotted correlation effects between age and span task scores in DLD and TD children.



Appendix 3. Linear regression lines fitted to DLD (shown in red dashed line) and TD (blue line) responses to visuospatial WM task. Linear regression models confirmed that backward recall in visuospatial tasks is significantly modulated by Age in both the DLD ($\beta = 0.41$, $SE = 0.06$, $t = 6.38$, $p < .001$) and TD ($\beta = 0.21$, $SE = 0.05$, $t = 3.88$, $p < .001$).

