

## Research Article

# Sustained Attention in Developmental Language Disorder and Its Relation to Working Memory and Language

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**Purpose:** Based on evidence of deficits in domain-general cognitive abilities associated with developmental language disorder (DLD), the current study examined sustained attention performance in children with DLD compared to children with typical language development (TLD) and the interrelations between visual–spatial sustained attention, visual–spatial working memory, and language abilities across groups.

**Method:** Participants included 67 children at 7 years of age: 25 children with DLD (13 girls and 12 boys) and 42 children with TLD (23 girls and 19 boys). We assessed children’s visual–spatial sustained attention, visual–spatial working memory, and language ability on a test of narrative language.

**Result:** Children with DLD scored significantly below their peers on a measure of visual–spatial sustained attention. Significant intercorrelations were observed between sustained attention, working memory, and language ability within the DLD group, but no correlations were observed between these measures in the TLD group.

**Conclusion:** Children with DLD have domain-general deficits in sustained attention, and correlational results have implications for whether and how language abilities are supported by domain-general cognition in both typical and disordered development.

Approximately 7% of children have developmental language disorder (DLD), which is characterized by a functional impairment of language in the absence of intellectual disability or overt neurological or physical cause (Bishop et al., 2016; Norbury et al., 2016). The deficits associated with DLD include difficulties with production and comprehension of morphosyntax, sentences, and discourse, reduced vocabulary breadth and depth, and word learning problems (see Leonard, 2014, for a review). In addition to difficulties with language comprehension and production, many (though not all) children with DLD also demonstrate deficits in domain-general cognitive abilities such as working memory and other executive functions (Archibald & Joanisse, 2009; Ebert & Kohnert, 2011; Im-Bolter et al., 2006; Montgomery et al., 2010). The precise causal nature of these deficits is unclear, though there are three possibilities: (a) language

impairments and domain-general deficits are likely to co-occur, (b) domain-general deficits cause language impairments, or (c) language impairments cause domain-general difficulties (Kapa & Plante, 2015). Detailed research into the interrelations between different executive function components and language abilities in children with DLD and children with typical language development (TLD) is necessary to begin to understand whether and how domain-general deficits contribute to differential language development (Kapa & Plante, 2015). In line with this logic, in the current study, we investigate domain-general sustained attention in children with DLD compared to children with TLD and examine how sustained attention relates to working memory performance and language ability in those groups.

We begin with an overview of models of attention and the theoretical relation between attention and working memory. We then review evidence of attention and working memory deficits in children with DLD, with a focus on how each relates to language abilities. We acknowledge that DLD historically had many labels including specific language impairment and primary language impairment, with each label of the disorder entailing slightly different inclusionary and exclusionary criteria. For example, specific language impairment is generally applied to children with average or above-average nonverbal cognition, whereas

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Editor-in-Chief: Stephen M. Camarata

Editor: Susan Nittrouer

Received May 18, 2020

Revision received August 25, 2020

Accepted August 29, 2020

[https://doi.org/10.1044/2020\\_JSLHR-20-00265](https://doi.org/10.1044/2020_JSLHR-20-00265)

**Disclosure:** The authors have declared that no competing interests existed at the time of publication.

DLD covers a range of nonverbal cognitive abilities that are above the level of intellectual disability. In our review, we include studies of populations with language disorders of all labels and definitions, but for ease, we will use the term *DLD* for the remainder of the article.

### **Attention**

Attention is a basic-level cognitive mechanism that is important for information processing, working memory, and other executive function abilities (Baddeley, 2001; Cowan et al., 2005). Most theoretical models of attention describe it as a limited-capacity system that can be divided into separate components or networks associated with distinct neural regions (Mirsky et al., 1991; Peterson & Posner, 2012; Posner & Rothbart, 2007). These components include alerting (arousal and vigilance, or readiness of attention to be used for processing), orienting (attention directed to a stimulus in external or internal space), selective attention (selection of a specific target at the exclusion of distractors for the purpose of enhanced processing), and sustained attention (maintenance of focus and alertness over time). Additionally, some researchers delineate selective sustained attention, defining it as the enhanced processing of a specific stimulus (in the face of distracting stimuli) for a prolonged period of time. The tasks of sustained attention contained in this review and this study involve both sustained and selective attention; however, we use the term *sustained attention* to refer to these tasks throughout the remainder of the article.

Alerting, orienting, and, to some extent, selective and sustained attention may be somewhat automatic depending on the novelty and/or salience of external stimuli. These external effects on attention are referred to as exogenous factors. Endogenous factors, on the other hand, are associated with the voluntary control of attention. Endogenous control of attention is limited in capacity, develops over childhood, and varies across individuals (Gomes et al., 2000). Endogenously driven attentional control governs which information in the environment will be selected and processed at the exclusion of other information, monitors and resolves/switches between conflicting sources of information, and has a role in storing and processing incoming information. As is clear from this description, attentional control is necessarily related to working memory, which is the short-term maintenance and manipulation of a limited amount of information for the purpose of cognitive processing. Indeed, attention and working memory are increasingly considered to be highly overlapping constructs (Baddeley, 2001; Cowan et al., 2005). Empirical evidence has revealed that working memory performance is related to individual differences in sustained attention and that the controlled-attention component of working memory is the basis of the relation between working memory capacity and complex cognition (Engle, 2002; Gazzaley & Nobre, 2012; Kane et al., 2001). For example, individual differences in working memory (which involves controlling attention and manipulating information) are related to complex

cognition (e.g., reading comprehension, IQ), whereas individual differences in simple span or memory load are not.

Attention and working memory relate to language acquisition and language comprehension/production abilities (Gillam et al., 2009). For example, individual differences in attention in children have been shown to be positively associated with vocabulary development, word planning, and narrative abilities (Jongman et al., 2015, 2017; Kannass & Oakes, 2008; Yu et al., 2019). Similarly, phonological working memory is associated with novel word learning in both children and adults, and the central executive (the system involved in control of working memory while attending to a given activity or goal) is associated with reading comprehension and complex sentence comprehension (Baddeley, 2003; Montgomery et al., 2008). As such, both attention and working memory are hypothesized to be domain-general mechanisms that contribute to language deficits in DLD. Given that individual differences in attention are associated with working memory performance, it is important to examine deficits of attention in children with DLD. In fact, some researchers have suggested that impairments in working memory and language may be a function of impairments in controlled attention. For example, Marton (2008) found larger visuospatial working memory deficits in children with DLD only in tasks that had a high demand on attentional control.

### **Attention and DLD**

In the past 2 decades, there has been an increasing body of evidence for nonclinical attention deficits associated with DLD. Deficits have been observed for endogenous control of selective and sustained attention, but not for alerting and orienting, which require less endogenous attentional control (Noterdaeme et al., 2001). The current study focuses on sustained attention, which is capacity-limited by an individual's level of endogenous attention control, making it important for both working memory performance and language abilities.

Children with DLD perform significantly below their peers with TLD on measures of auditory sustained attention (Duinmeijer et al., 2012; Jongman et al., 2017; Montgomery, 2008; Montgomery et al., 2009; Noterdaeme et al., 2001; Spaulding et al., 2008; but cf. Hanson & Montgomery, 2002). In one case, group differences were no longer significant after controlling for nonverbal IQ (Spaulding et al., 2008). Because these studies used auditory, or sometimes, linguistic stimuli, the poor performance of children with DLD could be due to a difficulty with auditory processing rather than a domain-general deficit in sustained attention. The evidence regarding deficits in visual-spatial sustained attention associated with DLD is somewhat equivocal, with some studies finding significant group differences (Ebert et al., 2019; Finneran et al., 2009; Jongman et al., 2017; Kapa et al., 2017) and others finding none (Noterdaeme et al., 2001; Spaulding et al., 2008). Yet, a meta-analysis concluded that children with DLD exhibit significant deficits in *both* auditory and visual-spatial sustained attention

(Ebert & Kohnert, 2011). Specifically, this meta-analysis found that children with DLD performed .69 *SD* below their TLD peers in sustained attention tasks (.82 for auditory linguistic tasks, .61 for auditory nonlinguistic tasks, and .47 for visual tasks). Across all studies, deficits in sustained attention were reported for task accuracy but not reaction time.

This research has also revealed that individual differences in sustained attention abilities in children with DLD are correlated with working memory and language abilities. Specifically, auditory sustained attention performance is associated with narrative production and comprehension, comprehension and production of morphosyntax, online sentence processing, sentence comprehension, vocabulary size, and picture naming latencies (Duinmeijer et al., 2012; Jongman et al., 2017; Kapa et al., 2017; Montgomery, 2008; Montgomery et al., 2009; Spaulding et al., 2008). Similarly, visual sustained attention performance is associated with morphosyntactic abilities, vocabulary comprehension, and picture naming latencies (Finneran et al., 2009; Jongman et al., 2017; Kapa et al., 2017). Two longitudinal studies of sustained attention in monolingual and bilingual children revealed that sustained attention (in an integrated audio-visual task) partially mediated the relation between language diagnosis and later language abilities (Blom & Boerma, 2016; Boerma et al., 2017). Finally, Kapa et al. (2017) found that both verbal and visual-spatial sustained attention were related to verbal and visual-spatial working memory. Furthermore, both attention and working memory were related to language abilities in DLD and TLD groups. In contrast, some studies have found that sustained attention is related to language abilities in children with DLD, but not children with TLD (Montgomery, 2008; Montgomery et al., 2009). This may suggest that the language ability assessed in these studies (speed of word recognition during sentence processing) was sufficiently difficult to tax the attention abilities of children with DLD but not children with TLD.

This research base provides a comprehensive account of sustained attention deficits in DLD and their association to working memory and language abilities. However, there are limitations to be addressed. First, all prior studies used a measure of sustained attention that involves not only sustained attention abilities but also memory encoding and retention and response inhibition. Specifically, the most common task used to measure sustained attention is the continuous performance task. In this task, a participant is presented with a stream of stimuli in which one stimulus is a target with the other(s) being distractors. The goal is to make a response to the target stimulus but not the distractor stimulus or stimuli. As the task proceeds (5–10 min), decrements in performance evinced by reduced target responses or increased distractor responses indicate reduced ability to sustain attention to task goals. However, the continuous performance task also requires memory encoding/maintenance for the target stimulus. It is unknown whether children with DLD might also have trouble with maintenance of task goals and memory for the target stimulus

over time. This could result in performance deficits on the continuous performance task that do not result from deficits in sustained attention. Because the continuous performance task yields a single score, it is impossible to tease apart the relative contributions of these processes. Second, the bulk of the research on sustained attention and working memory in children with DLD utilizes tasks with auditory or linguistic stimuli, limiting the conclusions we can draw about domain-general processes. Third, few researchers (Kapa et al., 2017; Noterdaeme et al., 2001) have investigated the interrelations between domain-general attention and working memory and language in typical and disordered development, a necessary prerequisite for understanding the nature of domain-general processes in DLD (Kapa & Plante, 2015).

## Current Study

The goals of the present research are to clarify whether children with DLD exhibit deficits in sustained attention relative to children with TLD and to describe how sustained attention, working memory, and language ability are interrelated in both groups. The current study addresses gaps in prior research by using a child-friendly task that controls for potential memory retention deficits. Furthermore, we use visual-spatial measures of sustained attention and working memory. We note that the use of nonlinguistic material decreases the extent to which language abilities are necessary to succeed on the tasks but does not eliminate it. Indeed, verbal mediation is associated with performance on visual working memory and attention tasks, as is evident by decreased performance on dual-task conditions involving articulatory suppression (e.g., Fatzer & Roebers, 2012). Thus, the level of involvement of the language system in performance on working memory and attention tasks varies along a continuum, and we have chosen tasks with a more limited reliance on language, although we acknowledge children may use verbal strategies to complete these visual-spatial tasks.

We have two research questions and associated hypotheses that guide this study:

1. Is domain-general sustained attention a weakness among people with DLD? Based on extant literature, we predict that the children with DLD will perform significantly below their TLD peers on the measure of visual-spatial sustained attention.
2. What is the relation of domain-general sustained attention to working memory and language ability in children with DLD compared to children with TLD? We hypothesize that sustained attention and working memory are related processes that support language processing; therefore, we predict that both sustained attention and working memory will be associated with language abilities in children with DLD. We may or may not see this relationship among the TLD group as it may be evident only when the language system is duly taxed.

## Method

### Participants

Participants included 25 children (13 girls and 12 boys) with DLD and 42 children (23 girls and 19 boys) with TLD. Four additional children (two TLD, two DLD) participated in data collection but were not included in the current study due to missing data ( $N = 3$ ), or subsequent diagnosis exclusionary to DLD ( $N = 1$ ). Participants were recruited through school and community screenings, social media advertisements, and word of mouth. All children were monolingual English-speaking and were in first grade at the time of participation: The mean age for the DLD and TLD groups was 7;3 (years;months, range: 6;0–8;0) and 7;3 (range: 6;4–8;2), respectively. There was no statistical difference in age between groups,  $t(65) = -.24$ ,  $p = .81$ . Years of parental education, a proxy for socioeconomic status, for the DLD and TLD groups was 14.40 ( $SD = 2.58$ ) and 16.93 ( $SD = 2.23$ ), respectively. The parents of one child in the TLD group did not report parental education. Parental education of the TLD group was significantly higher than that of the DLD group,  $t(64) = 4.21$ ,  $p < .001$ . Ethnicity and race were approximately balanced between the two groups. Across groups, 84% ( $N = 56$ ) of the sample was Caucasian, 4% ( $N = 3$ ) was Black or African American, and 12% ( $N = 9$ ) was multiracial; 97% ( $N = 65$ ) was not Hispanic or Latino, with 3% ( $N = 2$ ) not reporting.

Children were first identified as potential participants based on their performance on the Redmond Sentence Recall task (Redmond, 2005). Children who scored below the 15th percentile were recruited as potential DLD participants, and children with higher scores were recruited as potential TLD participants. Once recruited, all children completed a preliminary visit that evaluated their eligibility for inclusion in a longitudinal study, the Dynamics of Word Learning (Karla K. McGregor, principal investigator). To qualify, children had to pass a hearing screening at 25 dB bilaterally at 500, 1000, 2000, and 4000 Hz and demonstrate a nonverbal IQ of 70 or above on a standardized measure (Wechsler Abbreviated Scale of Intelligence–Second Edition [WASI-II], Performance Index; Wechsler, 2011). These cutoffs helped to ensure that the language learning deficits of the DLD group were due to DLD rather than hearing loss or intellectual disability, as is consistent with accepted definitions of DLD (Bishop et al., 2016). One child in the DLD group failed to complete the WASI-II. However, this child did complete a separate nonverbal IQ test (Kaufman Brief Intelligence Test–Second Edition; Kaufman & Kaufman, 2004) and scored within the normal range, consistent with a diagnosis of DLD. Although all children scored in the normal range, the DLD group did exhibit significantly lower nonverbal IQs than their TLD peers,  $t(64) = 6.05$ ,  $p < .001$ . Children were not included in this study if they had been diagnosed with an exclusionary disorder including autism spectrum disorder or traumatic brain injury. However, children were not excluded on the basis of attentional problems (including an attention-deficit/hyperactivity disorder [ADHD] diagnosis), motor impairments,

or social-emotional-behavioral problems, as these are often comorbid with DLD (Bishop et al., 2016). Two children (5%) in the TLD sample and three children (12%) in the DLD sample had a diagnosis of ADHD. Since the current study addresses attention, and ADHD is not a diagnosis exclusionary to DLD, we chose to include children diagnosed with ADHD in both the DLD group and the TLD group (which is defined as TLD, but not necessarily typically developing in all respects). In the results section, we assess whether comorbidity of ADHD and DLD contributes to sustained attention performance across groups.

Children in the DLD group met all inclusion criteria and obtained a standardized score at or below 92 on the Test of Narrative Language–First or Second Edition (TNL-1, Gillam & Pearson, 2004; TNL-2, Gillam & Pearson, 2017). Children in the TLD group met the all inclusion criteria, had no history of language problems, and scored above 92 on the TNL. The TNL was chosen as the primary measure of qualification for DLD versus TD groups because it assesses children's comprehension and production of narrative language, a discourse-level assessment of language ability that necessitates skills across domains of language (morphology, semantics, syntax, and discourse). A cutoff score of 92 was considered to maximize sensitivity and specificity (.92 and .92, respectively). Analyses of the diagnostic accuracy of the TNL-2 revealed an area under the curve of .97 indicating excellent overall discrimination between DLD and TD groups (Gillam & Pearson, 2017). See Table 1 for group performance on relevant demographic and standardized measures.

### Measures

#### Track-It Task

Children's visual sustained attention was assessed using a child-friendly computerized assessment called the Track-It task (Erickson et al., 2015; Fisher et al., 2013, downloaded from <http://www.psy.cmu.edu/~trackit>). During each trial of the Track-It task, the child views an  $N \times N$  grid of boxes, some of which contain shapes. A red circle surrounds one of the shapes in one box of the grid: This is the target shape. Then, the circle disappears, and the shapes randomly move around the grid in a smooth path. After a prespecified minimum time period, the shapes stop moving and immediately disappear. The child is asked to select the last grid location of the target shape. After each tracking trial, a  $2 \times 2$  grid appears with the target shape and three distractor shapes and children are asked to identify the shape they had been tracking. The purpose of the memory check is to identify the reason for an incorrect tracking response, which could be due to a failure of sustained attention or a failure to accurately encode/retain the identity of the target object. In this way, the Track-It task differs from common continuous performance tasks of sustained attention by assessing memory separately from sustained attention.

There are two conditions of the Track-It task: homogeneous and heterogeneous. In the homogeneous condition,



**Table 1.** Group means (range) on demographic and diagnostic measures.

Group	Age in months	Biological sex	Parental education	TNL narrative language index	WASI nonverbal IQ
DLD	87.00 (72–96)	13 F 12 M	14.40* (10–20)	82.84* (61–91)	90.71* (71–116)
TLD	86.69 (76–98)	23 F 19 M	16.93* (12–22)	111.50* (94 – 127)	107.20* (86–130)

Note. Parental education is measured in years of school completed. The TNL and WASI are standard scores with a mean of 100 and *SD* of 15. TNL = Test of Narrative Language; WASI = Wechsler Abbreviated Scale of Intelligence; DLD = developmental language disorder; TLD = typical language development; M = male; F = female.

\* $p < .05$  group comparison on an independent-samples *t* test.

all the distractor objects are the same shape, with the target object being a different shape. In the heterogeneous condition, all shapes are different. The purpose of these conditions is to differentiate exogenous from endogenous factors of sustained attention. Specifically, the homogeneous condition is driven primarily by exogenous factors: The target object is the only unique shape and is therefore more salient than the distractor objects, making the task driven less by the child's sustained attention abilities and more by the salience of the target. In contrast, in the heterogeneous condition, the target object is equally salient relative to the distractors; thus, the child's endogenous sustained attention abilities are recruited to a greater extent for this condition relative to the homogeneous condition.

The downloaded version of the Track-It task is modifiable such that many of the task demands can be altered, making the test appropriate for a range of ages and ability levels. Pilot testing using the parameters of the Track-It task in the original publication (Fisher et al., 2013) revealed that children in the age range of the current study demonstrated ceiling effects on the task. Results from Fisher et al. (2013) with 3- to 5-year-old children and personal communication with Dr. Fisher revealed that increasing the number of distractors, the length of each trial, and the grid size increased difficulty of tracking but not target memory and is more appropriate for older children. For the purposes of the current study, we changed several parameters to increase difficulty for 7-year-olds. Specifically, the grid size was set to  $4 \times 4$ , the number of distractor objects was set to 8, the number of trials was set to 6, and the minimal trial length was set to 20 s. Further pilot testing of this version of the Track-It task with typically developing children did not result in ceiling or floor effects, so these modifications were retained. Exact trial length varied due to path restrictions of the target object: The target object must visit each box in the grid before it disappears, and it disappears in the middle of a box in the grid to reduce the possibility of confusion for its last location. Average trial length was 22.81 s for the homogeneous condition (range: 20.31–31.28 s) and 22.90 s for the heterogeneous condition (range: 20.04–34.80 s).

The task was administered on a touch-screen laptop. Children completed three training trials, and then six trials each of the homogeneous and heterogeneous conditions

(order of conditions was counterbalanced across subjects, and the condition of the training trials was set to whichever condition a child was to complete first during test). At the beginning of training, children were instructed to look at the grid and the circled shape. They were told: When the game starts, the circle will disappear and all of the shapes will start to move; keep your eyes on the shape that was circled; after a time, all the shapes will disappear; I want you to touch the box where you last saw this shape. During the memory check, children were asked to identify which shape they were supposed to follow. Primary variables of interest included proportion of correct tracking trials and proportion of correct memory trials for the homogeneous and heterogeneous trials separately.

Research using the Track-It task has shown that performance increases with age, and heterogeneous performance is protracted relative to homogeneous performance consistent with the hypothesis that heterogeneous trials recruit endogenous attention factors more than homogeneous trials and are thus more difficult (Fisher et al., 2013). In general, considering tracking accuracy while removing trials on which the memory probe was incorrect increased tracking accuracy performance but did not change patterns of performance across conditions and ages. Split-half reliability of the task is adequate ( $r = .73-.84$ ; Doebel et al., 2017). Convergent validity of the Track-It task is shown by associations between heterogeneous tracking/memory accuracy and classroom learning (Erickson et al., 2015; Fisher et al., 2013). Accuracy is also related to measures of proactive control, suggesting the Track-It task may also measure proactive control or that sustained attention is related to proactive control (Doebel et al., 2017).

### Odd One Out

Children's visual-spatial working memory was assessed using the Odd One Out task. The version of this task used in this study was based on Henry (2001). It involves remembering the spatial locations of figures in the order they were presented. Children are shown a screen displaying a horizontal array of three images (black and white line drawings of shapes and figures). One of the images is slightly different than the other two (the odd one out): Children are asked to touch the image that is different and remember the relative spatial location of that image memory for which

it is tested after all object presentations. As the difficulty of the task increases, increasing set sizes of three images are presented; children select the odd one out on each then report the spatial location of each odd one out in order.

Administration of the Odd One Out task began with training trials. First, children were given a practice trial with one set of shapes. They were asked to decide which shape was the odd one out and point to it. Then, a screen with three side-by-side boxes appeared and children were asked to indicate where the odd one out had previously appeared. Children were then given a subsequent practice trial with two sets of shapes. First, one screen with a set of three shapes appeared and children were asked to decide which was the odd one out. This was repeated with a second screen and a new set of three shapes. Finally, a third screen appeared with two rows of three side-by-side boxes and children were asked to point to where the odd one out shape on each page appeared. A trial was considered correct if the child identified the correct spatial locations in the correct order. In the event a child misidentified the odd one out in a set of images, the trial was considered correct if the child's spatial location memory response matched the location they chose as the odd one out, regardless of whether or not that was the correct odd one out. Once children completed practice trials, they proceeded to the test trials. The test began with four trials of set length one and continued until children reached their span or until they completed trials of list length six. All four trials of a particular list length were administered. If children were correct on three out of four trials, they continued to the next higher list length; otherwise, children were considered to be at their span length and testing stopped. The primary measure of interest was total number of trials correct. This measure was chosen instead of span length because it yields a greater range of performance and therefore more power to detect individual differences and correlations with performance on other measures. However, we note that, in this study, total number of trials correct was highly correlated with span length,  $r(65) = .95, p < .001$ .

Performance on odd one out span increases with age (Archibald, 2013). Reliability of the odd one out task, as determined by correlations with other types of span tasks, is considered moderate to good with an average  $r = .80$  (range: .66–.90; Henry, 2001). Finally, in a principal components analysis of measures of language, working memory, and intelligence, Archibald (2013) found that the Odd One Out task loaded strongly on a general working memory factor with a minimal secondary loading (.26) on a phonological storage factor. Together, these findings suggest odd one out is a valid assessment of visual-spatial working memory.

#### TNL-1 or TNL-2

The TNL is designed for individuals ages 4;0–15;11 and assesses children's comprehension and production of narrative language. It takes the form of a dynamic assessment by providing children with story models prior to children's own narrative productions. During the test, children

listen to an adult model the type of story they will tell, answer comprehension questions about that story (comprehension of narrative), and produce a similar type of story themselves (production of narrative). There are three types of narrative assessed in the TNL: a script, a personal narrative, and a fictional narrative. The primary variable of interest was the Narrative Language Ability Index, an age-referenced standardized score with a mean of 100 and *SD* of 15. We also investigated performance on narrative language comprehension and narrative language production separately. These variables of interest derived from the TNL are the Narrative Comprehension and Oral Narration scores, respectively, each an age-referenced standardized score with a mean of 10.

Three children with DLD and two children with TLD were given the TNL-1; the rest of the sample was given the TNL-2. The two editions differ slightly in normative samples and exact questions; however, the structure of the test remains the same across editions. Due to the fact we are using TNL standard scores as our measure of language ability, and standard scores should be comparable across editions, we include all children in the results regardless of whether they received the first or second edition. The normative sample for the TNL-2 included a demographically representative sample of children across the United States ranging in age from 4;0 to 15;11 (Gillam & Pearson, 2017). Internal consistency of the TNL ranged from good to excellent (Cronbach's  $\alpha = .73$ –.94) as did test-retest reliability ( $r = .81$ –.96). Performance on the test did not significantly differ across males and females or across race and ethnic groups. Finally, scores on the TNL correlate with language sample measures with coefficient strengths ranging from moderate to large ( $r = .38$ –.70).

#### WASI-II

The WASI is a test of intellectual ability designed for use with individuals 6–90 years old. It contains four subtests: Vocabulary and Similarities comprise the Verbal Comprehension Index, whereas Block Design and Matrix Reasoning comprise the Perceptual Reasoning Index (PRI). We administered the Block Design and Matrix Reasoning subtests to assess children's nonverbal IQ. In Block Design, children replicate a modeled two-dimensional geometric pattern of red and white using two-color cubes. It involves nonverbal reasoning, fluid and visual intelligence, and visual perception and analysis. In Matrix Reasoning, children see a series of incomplete designs, matrices, and series, and complete the picture by selecting among image response options. It involves fluid and visual intelligence, spatial ability, organization, and classification. Scores from Block Design and Matrix Reasoning combine to yield the primary variable of interest, an age-referenced standardized PRI, with a mean of 100 and *SD* of 15.

The average split-half reliability of the WASI-II ranges from .89 to .92 for the subtests included in the current study, which is considered good to excellent reliability. Test-retest stability for the study sample age range ranged from .78 to .85, suggesting adequate to good stability and increases in

scores from 0.2 to 4.8 suggesting some practice effects. Exploratory and confirmatory factor analyses revealed that Block Design and Matrix Reasoning loaded strongly on a perceptual reasoning factor, but not on a Verbal Comprehension factor. Finally, construct validity is given by correlations between the WASI-II and other standardized assessments of intellectual or cognitive ability, with correlations in the moderate to strong range ( $r = .54-.83$ ).

## Procedure

This study obtained ethics approval from the institutional review board at Boys Town National Research Hospital (Protocol No. 17-04-XP). Parents of participating children gave their informed consent, children gave informed assent prior to the start of the study and children were recruited, enrolled, and tested according to procedures approved by the institutional review board. Children and families who agreed to participate in the longitudinal project first completed the preliminary screening visit. At this visit, parents consented to the study and children who were aged 7 years and older gave their verbal and written assent. Then, children were given a hearing screening, the TNL, and the WASI. Parents also completed a demographic information form with information including parental education, child's race/ethnicity, birth history, and any history of medical or psychiatric diagnoses. Children who met all inclusion criteria were invited to begin the primary testing sessions for the project. The average length of time between the preliminary screening visit and the first visit of primary testing was 4 months and 28 days (range: 0;0–14;13). The Track-It and Odd One Out tasks were administered as part of a larger battery of assessments given in three separate sessions. The Track-It task was administered during Session 2 and the Odd One Out task was administered during Session 3, which occurred 3–5 days after Session 2 ( $M = 3.96$  days). The order of tasks and sessions was consistent across participants. Families were compensated 20 dollars per hour of participation, and children were given a small toy after each visit.

## Results

### Sustained Attention

#### Memory Accuracy

Proportion of accurate trials in the memory check portion of the Track-It task (memory for the target object) in the TLD and DLD groups was .95 ( $SD = .11$ ) and .85 ( $SD = .22$ ) in the homogeneous condition, and .95 ( $SD = .12$ ) and .85 ( $SD = .19$ ) in the heterogeneous condition, respectively. Welch two-sample  $t$  tests revealed that children with DLD performed significantly below children with TLD in both the homogeneous,  $t(30.74) = 2.25, p = .03$ , and heterogeneous,  $t(34.72) = 2.31, p = .03$ , memory trials. Because Fisher et al. (2013) report increases in tracking performance with the removal of incorrect memory trials and because we were interested in differences in sustained attention, not memory encoding, we report tracking accuracy results after

removing all incorrect memory check trials. Thus, if group differences in Track-It exist, we can conclude this is due to differences in sustained attention and not differences in memory. One child in the DLD group had no correct memory trials in the homogeneous condition and was given a score of 0 for this condition. See Table 2 for tracking scores prior to and after the removal of incorrect memory trials.

#### Tracking Accuracy

The first goal of the current study was to investigate whether there were significant group differences in homogeneous and/or heterogeneous Track-It performance. We constructed a linear mixed-effects model using the lme4 package (Bates et al., 2015) in R Version 3.6.1 (R Core Team, 2019). Proportion of correct trials in the homogeneous and heterogeneous conditions (for correct memory trials only) was the dependent variable. We included parent education and nonverbal IQ as covariates because of significant group differences in these measures. For ADHD diagnosis, a visual inspection of the data revealed that the range of performance across children with or without an ADHD diagnosis in homogeneous (ADHD:  $M = .48$ , range: 0.00–.83; No ADHD:  $M = .87$ , range: 0.00–1.00) and heterogeneous conditions (ADHD:  $M = .51$ , range: 0.00–1.00; No ADHD:  $M = .81$ , range: 0.00–1.00) largely overlapped. Thus, presence of an ADHD diagnosis was not included as a covariate. The final fixed effects in the model were condition (homogeneous or heterogeneous), diagnosis (DLD or TLD), sex (male or female), parental education, nonverbal IQ, and finally a Condition  $\times$  Diagnosis interaction. Random effects included a random intercept for subject. Because one child with DLD did not have WASI data and one child with TLD did not have parental education data, the sample size for this analysis was 65. Significance of effects was tested using the lmerTest package (Kuznetsova et al., 2017).

The interaction between Condition and Diagnosis was not significant ( $p = .80$ ), so it was removed from the final model for purposes of parsimony. Numerically, performance in the heterogeneous condition was lower than performance in the homogeneous condition across groups but this effect was not significant,  $B = -.05, t(1, 64.00) = -1.90, p = .06$ . There was a significant effect of Diagnosis,  $B = -.14, t(1, 60.00) = -2.13, p = .04$ , indicating that children with DLD performed significantly worse than TLD children across both conditions of the Track-It task. There were no other significant effects (all  $ps > .22$ ). See Figure 1 for Track-It performance by condition and diagnostic group.

### Relations Between Sustained Attention, Working Memory, Narrative Language, and Nonverbal Cognition

The second goal of this study was to assess interrelations between sustained attention, working memory, and narrative language across DLD and TLD groups. Of additional interest are the interrelations between these variables

**Table 2.** Group means (range) in tracking accuracy with incorrect memory trials retained and with incorrect memory trials removed.

Group	Homogeneous tracking (all trials)	Heterogeneous tracking (all trials)	Homogeneous tracking (correct memory trials only)	Heterogeneous tracking (correct memory trials only)
DLD	.75 (0.00–1.00)	.62 (0.00–1.00)	.72 (0.00–1.00)	.68 (0.00–1.00)
TD	.91 (0.50–1.00)	.83 (0.00–1.00)	.92 (0.50–1.00)	.86 (0.00–1.00)

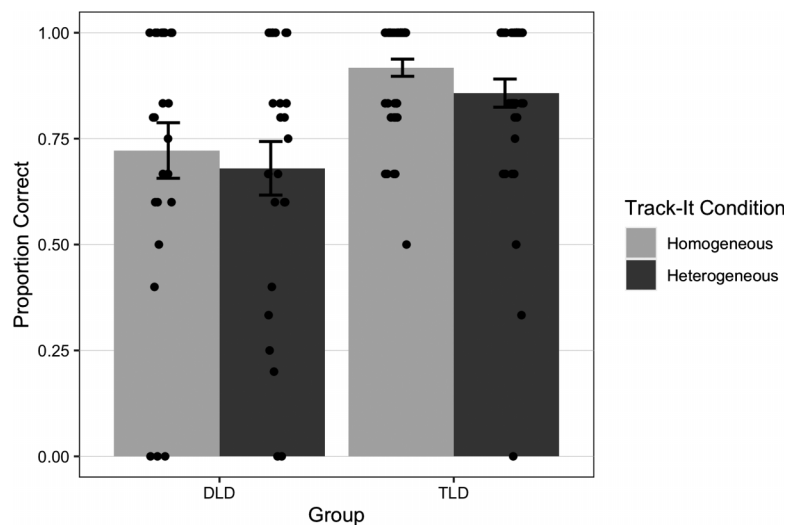
*Note.* DLD = developmental language disorder; TLD = typical language development.

and nonverbal cognition, which was lower in the DLD group and could be differentially related to performance across groups. We conducted correlations between sustained attention (Track-It proportion correct on heterogeneous trials) working memory (odd one out total number of trials correct), language ability (TNL), and nonverbal cognition on the WASI (standardized PRI). We operationalized sustained attention as performance in the heterogeneous condition due to evidence that this condition assesses endogenous attention and is more highly correlated with classroom learning than is performance in the homogeneous condition (Erickson et al., 2015). Moreover, since narrative comprehension and narrative production may place differential demands on the language system, we investigate interrelations with the overall TNL standardized score as well as standardized scores for narrative language comprehension and narrative language production separately.

We present results separately in DLD and TLD groups to assess whether relations differ across groups. We present a total of 12 correlations per group. In order to correct for multiple comparisons, we used the Benjamini–Hochberg procedure, which controls for the false discovery rate and decreases the chance for false positives. We set the number

of tests at 12 and the nominal alpha at .05. In the DLD group, we first visually examined relations between our variables of interest. Regarding the association between sustained attention and working memory, one participant was an outlier. This was confirmed with a regression model in which the participant’s scores were more than 3 *SDs* away from the regression line. This participant was therefore excluded from the following correlation analyses. Furthermore, regarding relations with narrative language production, one participant was an outlier on this measure and was subsequently excluded from all correlations involving narrative language production. See Table 3 for correlation results. In the DLD group, results revealed that sustained attention was significantly associated with overall narrative language,  $r(22) = .53, p = .008$ ; narrative language production,  $r(21) = .65, p = .008$ ; and working memory,  $r(22) = .54, p = .006$ . Working memory was also associated with narrative language,  $r(22) = .45, p = .03$ , although this was no longer significant after correcting for multiple comparisons. Narrative language comprehension, on the other hand, was not significantly associated with any variable. Finally, nonverbal cognition on the WASI was not significantly associated with any other variable.

**Figure 1.** Track-It performance by condition (homogeneous vs. heterogeneous) and diagnostic group (DLD vs. TD). DLD = developmental language disorder; TLD = typical language development.





**Table 3.** Correlations between measures of interest.

Variable	1	2	3	4	5	6
1. Narrative language	—	—	—	$r(39) = .23$	$r(39) = .20$	$r(39) = .08$
2. Narrative language comprehension	—	—	—	$r(39) = .15$	$r(39) = .01$	$r(39) = .15$
3. Narrative language production	—	—	—	$r(39) = .21$	$r(39) = .28$	$r(39) = -.004$
4. Sustained attention	$r(22) = .53^a$	$r(22) = .32$	$r(21) = .65^a$	—	$r(39) = .13$	$r(39) = .04$
5. Working memory	$r(22) = .45$	$r(22) = .29$	$r(21) = .25$	$r(22) = .54^a$	—	$r(39) = .23$
6. WASI	$r(22) = .17$	$r(22) = .15$	$r(21) = .24$	$r(22) = .25$	$r(22) = .05$	—

Note. Correlations for the DLD group are presented in the lower diagonal, and for the TLD group in the upper diagonal. DLD = developmental language disorder; TLD = typical language development; WASI = Wechsler Abbreviated Scale of Intelligence.

<sup>a</sup>indicates significance after Benjamini–Hochberg correction for multiple comparisons.

In the TLD group, visual inspection of the relations again revealed a single outlier, and after confirmation with a regression model, this participant was excluded. Results revealed that sustained attention was not associated with narrative language performance,  $r(39) = .23$ ,  $p = .15$ , or with working memory,  $r(39) = .13$ ,  $p = .43$ . Finally, working memory was not associated with narrative language,  $r(39) = .20$ ,  $p = .22$ . These results did not differ when examining correlations with narrative language production or narrative language comprehension. Finally, nonverbal cognition on the WASI was not significantly associated with any other variable.

## Discussion

The goals of this study were to clarify whether children with DLD exhibit deficits in sustained attention relative to children with TLD and to describe how sustained attention, working memory, and language ability are interrelated in these two groups. Evidence suggests that, although the primary deficits associated with DLD are those of language comprehension and production, these children also have difficulty with other cognitive abilities such as executive functioning (Im-Bolter et al., 2006; Leonard, 2014). Indeed, a growing body of work has revealed deficits of both sustained attention and working memory in children with DLD, with individual differences in these abilities associated with language performance (Baddeley, 2003; Ebert & Kohnert, 2011; Montgomery et al., 2008). The current study extended this work by (a) employing a child-friendly sustained attention task that controls for potential differences in memory maintenance, (b) using solely visual–spatial tasks, and (c) investigating the interrelations between domain-general sustained attention and working memory, and language in groups of children with DLD and TLD separately.

### Sustained Attention

The first goal of the current study was to assess sustained attention abilities in children with DLD relative to children with TLD, considering both exogenous and endogenous factors on sustained attention performance. Results revealed, first, that children in both DLD and TLD groups numerically performed worse in the heterogeneous

condition relative to the homogeneous condition, but this effect was not significant. That this effect was nonsignificant is somewhat surprising because prior research on the Track-It task repeatedly revealed significant differences in performance across conditions (Erickson et al., 2015; Fisher et al., 2013). There are two possibilities for this finding in this study. First, it is possible that the task settings used in this study were not sufficiently difficult for children such that ceiling effects limited our ability to find differences across conditions. For example, Fisher et al. (2013) found that when the task settings were too easy, performance differences across conditions were not observed for older children. Possible ceiling-level performance was observed in the homogeneous condition for children with TLD, with the data exhibiting a negative skew. However, there was a range of performance in the heterogeneous condition for children with TLD and in both conditions for children with DLD. A second possibility is that this study was underpowered to observe a significant effect of task in our statistical model especially because we also controlled for effects of group, socioeconomic status, and nonverbal cognition.

Importantly, results did reveal a significant effect of group such that children with DLD performed significantly below their peers with TLD. This finding is consistent with our hypothesis that, if the previously observed reduced performance on the part of children with DLD on sustained attention tasks is due to domain-general deficits in attentional control, children with DLD should also exhibit deficits in a visual–spatial sustained attention task. The interaction between group and task condition was not significant, suggesting that the deficit in performance was equivalent across homogeneous and heterogeneous conditions. In other words, regardless of the support of exogenous factors, children with DLD were less able to sustain their attention on the location of the target compared to children with TLD. This finding has important clinical implications: If a clinician knows that a child with DLD also has difficulty sustaining their attention, the clinician can focus on intervention procedures that target a child's language limitations while also improving endogenous attentional control. For example, it may be possible to introduce a cognitive processing treatment (as in Ebert et al., 2012) using linguistic stimuli to meet language goals while supporting sustained attention. Ebert et al. (2012) found small but significant

improvements to linguistic processing abilities, standardized language scores, and cognitive abilities after a brief intervention focused on processing speed and sustained attention. However, this evidence is still preliminary and equivocal, and should be further investigated before it is considered as an intervention strategy.

### ***Relation to Working Memory and Language***

The secondary goal of the current research was to investigate the interrelations between sustained attention, working memory, and language performance across groups. Results revealed that sustained attention, working memory, and narrative language ability were all interrelated within the group of children with DLD, although working memory was no longer significantly correlated with narrative language after correcting for multiple comparisons. These results are consistent with theoretical models of attention and working memory (Baddeley, 2001; Cowan et al., 2005; Engle, 2002) that view visual-spatial working memory as dependent upon the ability to control and sustain attention. We hypothesize there may be a mediation effect underlying the relation between these three abilities. That is, individual differences in attention drive individual differences in working memory, which are in turn associated with language abilities. This hypothesis is supported by theoretical models and correlation results, but future research would be needed to confirm a mediation effect. Furthermore, performance on the narrative language task was dependent upon both sustained attention and working memory abilities. Researchers have suggested three possibilities for the causal nature of the relation between language and cognitive abilities: deficits in both are likely to co-occur, cognitive deficits cause language deficits, or language deficits cause cognitive deficits (Kapa & Plante, 2015). Although we cannot determine causation from correlations, our results suggest that the narrative task was difficult for children with DLD, in part, because it reached or succeeded children's attention and working memory capacity. In fact, we suggest that the relation may be a bidirectional one: Limitations in sustained attention and/or working memory result in delayed language development, and language deficits, in turn, result in reduced performance on domain-general cognitive tasks. This idea is consistent with cross-lagged correlation results on nonword repetition and vocabulary, which revealed reciprocal relations between these two abilities over time (Gathercole et al., 1992; Verhagen et al., 2019; but cf. Melby-Lervåg et al., 2012).

In contrast, no significant correlations between measures were observed for children with TLD. The fact that sustained attention and working memory were not related in the TLD group is somewhat surprising, based on evidence that individual differences in attentional control form the basis of individual differences in working memory (e.g., Kane et al., 2001). It is possible that, in the current study, the sustained attention task (even the heterogeneous condition) was not difficult enough for the children with TLD and that the associated reduced variance was insufficient to

detect a relation. If this is the case, the sustained attention task might not have been sufficiently difficult to result in an accurate estimation of individual differences in sustained attention abilities in this group. That the homogeneous Track-It condition yielded a restricted range of performance for children with TLD is a minor weakness of this study. That neither sustained attention nor working memory was associated with narrative language performance in the TLD group is consistent with evidence that relations between domain-general cognitive abilities and language performance is not always evident in typical groups, possibly because performance does not overly tax attention or working memory capacity (Montgomery, 2008; Montgomery et al., 2009). In other words, individual differences in performance on the narrative language task in children with TLD may be associated with abilities other than working memory and attention. Comprehending and producing narratives requires vocabulary knowledge, complex syntax, and the ability to verbalize a cause-and-effect relationship. It is possible that the narrative task, while not overly taxing working memory and attention, revealed limitations in TLD children's language abilities or vocabulary knowledge.

Finally, examination of correlations separately by narrative language comprehension and production yielded no significant associations, with the exception of sustained attention and narrative language production in the DLD group. We hypothesize this is due to the limited range of scores in the comprehension and production scores separately compared to the narrative language index overall, which reduced our power to find significant correlations. Additionally, nonverbal cognition was not associated with sustained attention, working memory, or narrative language in either group. This suggests that group differences in nonverbal cognition did not contribute to group differences in sustained attention.

### ***Directions for Future Research***

One strength of the present research is that we used visual-spatial tasks of both sustained attention and working memory, thus decreasing the chance that the performance of children with DLD is due to difficulties with auditory processing or language ability. However, we acknowledge that even in tasks that do not use auditory stimuli, children might still recruit their language abilities to improve task performance (e.g., Fatzner & Roebers, 2012). For example, in the heterogeneous condition of the Track-It task, children may use verbal labels to help them keep track of the target. Future research should utilize visual-spatial tasks with a manipulation that precludes the use of language to help performance (e.g., articulatory suppression) to confirm differential group performance is not a result of language ability per se.

Future research should also further investigate the causal relations between domain-general cognitive abilities and language. There are two approaches that would be useful here: longitudinal research and cross-lagged correlations or intervention research. Currently, there is a small body of work that preliminarily suggests improving attentional

control in children with DLD also improves their language abilities (Ebert et al., 2014; Ebert et al., 2012). However, these studies used small samples (Ebert et al., 2012) and/or no active control condition (Ebert et al., 2014, 2012) and thus firm conclusions cannot yet be drawn. Second, theoretical models of attention, working memory, and language suggest a mediation effect such that attention causes working memory, which in turn causes language. A mediation model was not possible in the current study due to small sample size and only single measures of attention and working memory. Future research should administer a battery of attention, working memory, and language measures to children with DLD and TLD to investigate the possibility of mediation.

### Contributions and Conclusions

In summary, this research extended prior work in important ways. The first was methodological: We used a visual-spatial task of sustained attention that enables us to assess sustained attention and memory retention for the target separately. This study confirms that deficits are due to group differences in attentional control rather than memory encoding or retention. Additionally, we documented relationships between attention, working memory, and language ability that may motivate research activity aimed at the development of assessments and interventions that address cognitive domains that extend beyond language.

### Acknowledgments

This work was supported by National Institute on Deafness and Other Communication Disorders Grants R01 DC011742-07 to the second author and T32 DC000013-39 to the first author. We acknowledge Anna Fisher who consulted with us on how best to set the options in Track-It for our first graders, Nancy Ohlmann for her work on recruitment and data collection, and all the families and participants who made this research possible.

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