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Word learning and verbal working memory in children with developmental language disorder

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Abstract

Background and aims: Previous research into word learning in children with developmental language disorder (DLD) indicates that the learning of word forms and meanings, rather than form-referent links, is problematic. This difficulty appears to arise with impaired encoding, while retention of word knowledge remains intact. Evidence also suggests that word learning skills may be related to verbal working memory. We aimed to substantiate these findings in the current study by exploring word learning over a series of days.

Methods: Fifty children with DLD (mean age 6; 11, 72% male) and 54 age-matched typically developing (TD) children (mean age 6; 10, 56% male) were taught eight novel words across a four-day word learning protocol. Day 1 measured encoding, Days 2 and 3 measured re-encoding, and Day 4 assessed retention. At each day, word learning success was evaluated using *Naming, Recognition, Description*, and *Identification* tasks.

Results: Children with DLD showed comparable performance to the TD group on the *Identification* task, indicating an intact ability to learn the form-referent links. In contrast, children with DLD performed significantly worse for *Naming* and *Recognition* (signifying an impaired ability to learn novel word forms), and for *Description*, indicating problems establishing new word meanings. These deficits for the DLD group were apparent at Days 1, 2, and 3 of testing, indicating impairments with initial encoding and re-encoding; however, the DLD and TD groups demonstrated a similar rate of learning. All children found the retention assessments at Day 4 difficult, and there were no significant group differences. Finally, verbal working memory emerged as a significant moderator of performance on the *Naming* and *Recognition* tasks, such that children with DLD and poor verbal working memory had the lowest levels of accuracy.

Conclusions: This study demonstrates that children with DLD struggle with learning novel word forms and meanings, but are unimpaired in their ability to establish new form-referent links. The findings suggest that the word learning deficit may be attributed to problems with encoding, rather than with retention, of new word knowledge; however, further exploration is required given the poor performance of both groups for retention testing. Furthermore, we found evidence that an impaired ability to learn word forms may only be apparent in children who have DLD and low levels of verbal working memory.

Implications: When working with children with DLD, speech-language pathologists should assess word learning using tasks that evaluate the ability to learn word forms, meanings, and form-referent links to develop a profile of individual word learning strengths and weaknesses. Clinicians should also assess verbal working memory to identify children at particular risk of word learning deficits. Future research should explore the notion of optimal intervention intensity for facilitating word learning in children with poor language and verbal working memory.

Keywords

Word learning, vocabulary, verbal working memory, developmental language disorder

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Introduction

Developmental language disorder (DLD) is a neurodevelopmental condition that affects approximately 1 in 14 children (Norbury et al., 2016; Tomblin et al., 1997). DLD is characterised by persistent language problems that cannot be attributed to a biomedical condition, such as autism spectrum disorder or intellectual disability; however, DLD may co-occur with conditions such as Attention Deficit-Hyperactive Disorder (ADHD; Bishop et al., 2017). DLD is heterogeneous, which results in varied profiles of impairment in oral language and cognitive skills (Bishop, 2006; Pennington, 2006). The study reported here focuses on word learning skills, which are often impaired in children with DLD and are shown to have a persistent and detrimental impact on academic, social-emotional, and vocational development (Kan & Windsor, 2010; Law et al., 2009; Spencer et al., 2017).

A problem with encoding or retention?

Word learning, or the ability to learn and establish new lexical items in vocabulary, is a critical component of language development (Beck et al., 2013). There are robust links between vocabulary and academic development, including literacy (Castles et al., 2018) and mathematics (Spencer et al., 2017), as well as social-emotional outcomes in adolescence and adulthood (Armstrong et al., 2017). Learning a novel word relies on the development of the word form (*phonological representation*), meaning (*semantic representation*), and the creation of an association between the two (*form-referent link*; Chiat, 2001). Deficits in the ability to establish these foundational representations during word learning can have an adverse impact on the ability to recognise, and therefore further refine, word knowledge in future instances (Gray et al., 2020). This can have a detrimental effect on the ability to establish syntactic, orthographic, and articulatory representations, all of which are required for effective use of words in spoken and written contexts (Castles et al., 2018).

The course of developing new word knowledge has been conceptualised as a process that centrally involves the establishment of new information in memory. Under this framework, word learning is described as involving *encoding, re-encoding,* and *retention* (McGregor et al., 2020; Storkel et al., 2019). Encoding involves several processes, including sensory perception of the novel word, recognition of the stimuli as novel, and the direction of attention to relevant environmental detail (Kane et al., 2001). Subsequently, an initial memory trace of the new form and referent is encoded (Suzuki, 2006). Following the initial encoding process, the memory trace may be forgotten (i.e., if insufficient information was stored) or retained in long-term memory (Wilhelm et al., 2012). Retention of new words relies on consolidation processes, whereby the encoded memory trace transfers to long-term memory without external input. Consolidation is driven by the passing of time, and is facilitated by sleep (Stickgold, 2005). Through consolidation, the retained memory of the novel word can become more stable, and integrates with existing information in vocabulary (Davis & Gaskell, 2009; McClelland et al., 1995). Retention of the word may be further strengthened (i.e., stored in more detail over a prolonged period of time) through re-encoding, whereby the word is encountered again and retrieved from long-term memory, making it susceptible to change (Desmottes et al., 2016). Through re-encoding, word knowledge can be refined in response to further input (McGregor et al., 2013a; Nader & Hardt, 2009).

It has been suggested that word learning deficits experienced by people with DLD may be attributed to impaired encoding (McGregor et al., 2013a). This likely results in problems with the retained word knowledge in long-term memory; however, the processes involved in retention itself may remain intact (i.e., in declarative memory; Bishop & Hsu, 2015). Evidence for this 'encoding deficit hypothesis' has been demonstrated in a series of studies with adolescents and adults with DLD (McGregor et al., 2013a, 2017a, 2017b). Across these studies, college students with DLD and their typically developing (TD) peers were trained on novel word forms and their associated referents. All students received an equal number of training exposures, and learning was tested via recall tasks immediately after training and one week later. McGregor et al. (2013a) found evidence of poor encoding of word forms and meanings for the DLD group, as indicated by poor performance on the immediate post-training assessment tasks. Retention of the word meanings at the one-week interval appeared intact; however, the DLD-TD gap widened over this time for word forms, indicating a potential problem with retaining phonological information. In their subsequent studies, McGregor et al. (2017a, 2017b, 2020) controlled for potential confounds on retention and demonstrated that word learning in the DLD group was characterised by poor encoding, yet intact retention. As a result, McGregor et al. (2020) concluded that "encoding of word forms is the primary bottleneck to word learning among people with DLD" (p. 14).

There is also evidence of an encoding deficit in children with DLD. Bishop and Hsu (2015) found that eight-year-olds with DLD were significantly worse than their TD peers at learning the names of novel animals. This deficit was observed immediately after training, yet the rate of learning over a two-week period was similar, supporting the notion of intact retention but impaired encoding. In Haebig et al. (2019) and Leonard et al. (2019), five-year-old children with and without DLD learned a set of new words through retrieval practice, whereby the new word and a definition were introduced, and learning was reinforced through repeated opportunities to retrieve the name and definition from memory. In comparison to the TD children, those with DLD demonstrated poor accuracy when naming the newly-learned words after a five-minute interval; however, their rate of learning after a one-week interval was similar to the TD group (Haebig et al., 2019; Leonard et al., 2019). While these findings point to an encoding deficit in word learning, this hypothesis requires further substantiation, as some research has failed to show a deficit for children with DLD across both encoding and retention.

For instance, Gray and colleagues measured encoding and retention of novel words that had either high or low phonotactic probability and neighbourhood density (Gray et al., 2012; Gray & Brinkley, 2011). The results of both studies showed no significant difference between the TD and DLD groups for either encoding or retention of word forms. It is possible that methodological differences contribute to the mixed findings from Gray and colleagues, and those from Haebig et al. (2019) and Leonard et al. (2019). In particular, in Gray and colleagues' studies, participants engaged in four consecutive days of word learning through a supported learning context, followed by a fifth day of retention testing. In contrast, in Leonard and Haebig's studies, the children were provided with novel word training over two consecutive days (during which time encoding was tested), followed by a post-test retention task one week later. It is possible that the more frequent learning sessions provided by Gray and colleagues allowed the children with DLD to effectively establish and refine their knowledge of the novel words (Gray et al., 2012; Gray & Brinkley, 2011). Furthermore, their administration of the post-tests at one day, instead of one week, after learning may have meant that novel word forms and meanings were subject to less decay and/or interference between each of the new memory traces (Haebig et al., 2019; Leonard et al., 2019; Mainela-Arnold et al., 2010).

Theoretically, encoding deficits in children with DLD may be underpinned by deficits within the working memory system. According to Baddeley (2003), working memory is a capacity-limited system of interacting components responsible for temporary storage and processing of verbal and visual information. This system is responsible for facilitating the transfer of new information into long-term memory, and as such is linked strongly to vocabulary development (Gathercole & Baddeley, 1989). Specifically, the encoding of novel words is thought to be supported by the components of working memory that are concerned with processing verbal information (for simplicity, we refer to this as 'verbal working memory'; Archibald & Gathercole, 2006). Verbal working memory (WM) is likely to support encoding by directing and maintaining attention to the novel phonological stimulus and refreshing the echoic memory in the phonological loop, while processing other sensory input (such as contextual information about the word, e.g., physical features; Kane et al., 2001). Deficits with verbal WM are therefore proposed to contribute to problems with encoding, which would be expected to have a subsequent impact on the ability to store an accurate memory trace in long-term memory. However, it is likely that the long-term memory system itself (i.e., declarative memory) may be unimpaired (Bishop & Hsu, 2015; Lum et al., 2015). While verbal WM is thought to be primarily occupied with the initial stage of word learning (encoding), it may also be implicated with later retrieval and monitoring of word knowledge from long-term memory; however, the link between these processes and verbal WM has not been empirically tested (Cabeza et al., 2002; Lum et al., 2015).

A problem with word forms, meanings, or form-referent links?

Understanding the nature of the word learning deficit in children with DLD is complicated by the fact that word learning requires the development of various aspects of knowledge. We focus our investigation on the processes involved in learning nouns as they are typically concrete and non-relational, and are usually imageable (Skipp et al., 2002). At a minimum, learning nouns includes establishing the *word form*, *word meaning* (such as details about the physical features of the item), and a link between the two (i.e., the *form-referent link*; Gray et al., 2020). Difficulties with learning the word form have been well-evidenced in children with DLD (Kan & Windsor, 2010). The methods for evaluating word form learning are varied, and differ in their degree of linguistic demand. Frequently, knowledge of the word form is assessed using a naming task, which involves retrieving the word form for spoken production in response to seeing the item (Jackson et al., 2019a). Recognition tasks are also commonly used, requiring identification of the target from similar-sounding foils (Alt & Suddarth, 2012). Using such measures, studies have consistently shown that children with DLD have significant deficits learning novel word forms in comparison to control groups (Kan & Windsor, 2010), and there is strong theoretical support for the notion that verbal WM deficits underlie this impairment (Archibald, 2016; Baddeley, 2003). However, only a handful of studies have directly explored this relationship (Montgomery et al., 2010).

For instance, Alt and Plante (2006), Gray (2006), and Jackson et al. (2016) showed that nonword repetition performance significantly predicted naming accuracy at encoding. Additionally, Gray (2004) highlighted a significant link between nonword repetition performance and naming accuracy across several days of word learning. This suggests that verbal WM performance may also predict retention of novel word forms, and may be important in the process of retrieving word forms from long-term memory, and holding them active, in order to complete a naming task in the days following initial learning (Baddeley, 2003; Lum et al., 2015). However, further investigation is required to understand whether impairments in encoding, re-encoding, and retention may be ascribed to deficits within the working memory system. In contrast, Gray (2006) and Hansson et al. (2004) failed to find a link between verbal WM (measured using nonword repetition) and performance on a naming task. In these two studies, naming was measured following a single session of learning, and as such was largely a measure of encoding (McGregor et al., 2013a). The inconsistency in findings may reflect the fact that nonword repetition performance varies among children; some children with DLD show unimpaired nonword repetition skills, and some TD children are impaired at nonword repetition (Archibald & Joanisse, 2009).

Evidence suggests that children with DLD are also impaired at learning novel word meanings, as demonstrated by poor performance on tasks that are expressive (e.g., describing the appearance of the item; Alt & Plante, 2006) and receptive in nature (e.g., answering 'Yes/No' questions about elements of meaning; Nash & Donaldson, 2005). These findings provide support for the notion that the word learning deficit in children with DLD is multifactorial, affecting the ability to develop new word forms and meanings (Nation, 2014). It is possible that verbal WM deficits contribute to problems with learning word meanings in children with DLD (Alt & Plante, 2006); however, previous research into this relationship is limited and the findings equivocal. For instance, Alt and Plante (2006) found a significant relationship, whereas Storkel et al. (2019) did not.

Finally, there is mixed evidence regarding the ability of children with DLD to learn form-referent links for novel words (McGregor et al., 2020). This aspect of word learning is usually evaluated using an identification task, which involves hearing the novel word and selecting the target from an array of items (Jackson et al., 2019a). While Gray (2004, 2005) and Rice et al. (1990, 1992, 1994) found that children with DLD performed poorly on this task, Gray (2006) and Rice et al. (2000) found comparable performance with control groups. Gray et al. (2020) highlighted that children may be able to perform accurately on identification tasks even if they have encoded and retained weaker phonological and semantic representations, because only partial knowledge is required to create a link between the word form and its appearance. The findings of previous research indicate that verbal WM is not associated with the ability to learn form-referent links (e.g., see Gray, 2004), which may reflect the assumption that learning form-referent links places minimal demands on the working memory system (Ullman et al., 2020). However, this relationship has been the subject of little previous research, warranting further exploration.

The current study

Overall, the literature suggests that the initial encoding stage of the word learning process is impaired in children with DLD, with retention remaining intact. However, this pattern of impairment requires further substantiation. Further evidence is also required to determine whether learning the word forms, word meanings, and/or form-referent links is problematic. Word learning deficits – especially those impacting the learning of the word form – are likely to be driven by deficits in verbal WM; however, further investigation into the nature of this relationship is required. Thus, the current study had two primary aims:

1. Using a four-day protocol, we aimed to identify whether a word learning deficit in children with DLD could be attributed to problems with initial encoding (Day 1), re-encoding (Days 2 and 3), or retention (Day 4). To determine whether learning the word forms, form-referent links, and/or word meanings is problematic for children with DLD, word learning was evaluated using four different outcome measures across the four-day protocol:
   - Knowledge of word forms was tested using *Naming* (an expressive task) and *Recognition* (a receptive task);
   - Knowledge of word meanings was evaluated using *Description*, and;
   - Knowledge of the form-referent links was evaluated using *Identification*.

Based on previous literature, we predicted that the children with DLD would exhibit deficits at *Naming*, *Recognition*, and *Description*, indicating an impaired ability to establish novel word forms and meanings.

In contrast, we predicted that these children would perform similarly to the TD group for *Identification*, indicating an intact ability to establish form-referent links. Furthermore, we hypothesised that deficits on the *Naming, Recognition*, and *Description* tasks would be apparent for the DLD group at Day 1, indicating deficits with initial encoding. Poor performance across Days 2 and 3 was also expected, which would reflect subsequent deficits in re-encoding as a result of poor initial encoding. We expected that the gap between the DLD and TD groups would not further widen at Day 4, which would indicate intact retention for the children with DLD (Bishop & Hsu, 2015; McGregor et al., 2020).

2. Verbal WM impairments may be a key factor contributing to the word learning deficits of children with DLD (Archibald, 2016; Baddeley et al., 1998). There is some evidence for this link with regards to the initial encoding of novel word forms, but the link between verbal WM to word meanings and form-referent links is unclear. Furthermore, to our knowledge very few studies have explored the influence of verbal WM across the stages of encoding, re-encoding, and retention (Gray, 2004; Montgomery et al., 2010). We predicted that verbal WM ability would moderate performance across the four days of word learning for the *Naming* and *Recognition* tasks, such that poor performance would only be observed in children who have impaired verbal WM; however, this was not expected for the *Description* and *Identification* tasks.

Method

Participants

The participants were involved in a broad programme of research that involved testing memory skills and word learning in TD children and those with DLD. The data regarding word learning are pertinent for this study and have not been previously reported. The data regarding the memory skills of this cohort are comprehensively reported in Jackson et al. (2020), and data regarding verbal WM skills are reported again in the current paper.

To qualify for this research programme, all children met the general criteria of speaking English as a primary language, with no significant history of hearing, articulation, or behavioural problems. No participant had a primary developmental condition that might account for their language disorder, such as Down syndrome or intellectual disability (Bishop et al., 2017). There were three children with DLD and one typically developing child who had a diagnosis of ADHD. All participants passed a hearing screen and the Diagnostic Evaluation of Articulation and Phonology (DEAP) Diagnostic Screen (Dodd et al., 2002). Children with DLD were recruited from two specialist language schools, and TD children attended three mainstream primary schools.

Children recruited from the specialist language schools had all been clinically diagnosed with DLD 12 to 18 months prior to recruitment, and so a full battery of oral language assessments was not required. Where the Clinical Evaluation of Language Fundamentals – 4th Edition, Australian and New Zealand standardisation (CELF-4^{AUZN}) had been administered in the past 12 months, those scores were obtained with parental permission (Semel et al., 2006). Otherwise, general oral language skills were reassessed to confirm eligibility for the DLD group, using the Core Language Score subtests of the CELF-4^{AUZN}. All participants with DLD obtained a Core Language Score of 85 or less ($\leq 1SD$ below the mean). The children recruited from the mainstream schools for the TD group were also assessed using the Core Language subtests and achieved a standard score of 86 or higher (i.e., within or above the average range). Summary statistics describing demographic details and scores on the participant selection assessments are presented in Table 1.

Additionally, all participants were assessed using the Primary Test of Nonverbal Intelligence (PTONI; Ehrler & McGhee, 2008) and achieved a standard score of above 70, ruling out the presence of an intellectual disability (Bishop et al., 2017). Participants were not excluded on the basis of low-range nonverbal intelligence (IQ) scores, in line with the CATALISE guidelines for the classification of DLD. Differences between groups for these variables were evaluated using independent samples t tests. As expected, the DLD group had significantly lower scores than the TD group on the measure of general oral language (Core Language Score). The DLD group was also significantly lower on the PTONI. In their meta-analysis, Kan and Windsor (2010) reported nonverbal IQ as a significant moderator of group differences in word learning performance. As such, we controlled for nonverbal IQ in our statistical analyses to ensure that any observed group differences on word learning were not the result of differences in nonverbal IQ.

Protocol

Data collection

Recruitment and testing followed procedures approved by the Jackson et al. (2020) ethics committees. All tests were completed individually in a quiet school room

Table 1. Demographic features, summary statistics, and group comparisons for participant selection measures.

	DLD ($n = 50$)		TD ($n = 54$)			
Domain	*M* (SD)	Range	*M* (SD)	Range	*p*	*d*
Age in months	83.54 (7.59)	71–104	82.04 (7.56)	70–98	.081	0.20
CLS[a]	64.16 (11.47)	40–85	101.26 (11.79)	86–134	<.001**	3.19
Nonverbal IQ[a]	87.40 (15.20)	70–141	102.93 (18.96)	76–140	<.001**	1.08
Nonword Repetition[b]	72.45 (10.54)	48.96–92.71	89.83 (5.05)	80.21–99.31	<.001**	2.10
Digit Recall[a]	84.26 (17.35)	56–121	102.63 (14.90)	73–137	.018*	1.14
Backwards Digit Recall[a]	73.84 (13.04)	56–104	95.61 (15.91)	67–141	.011*	1.50
Verbal WM factor	-0.74 (0.81)	-2.42–0.76	0.69 (0.57)	-0.71–2.21	<.001**	2.04

CLS: Core Language Score on the CELF-4; Nonverbal IQ: standard score on the PTONI; Verbal WM factor: verbal working memory factor, calculated using principal component analysis of scores on the Nonword Repetition, Digit Recall, and Backwards Digit Recall tasks.
[a]Scores are standardised to a mean of 100 and standard deviation of 15.
[b]Score is reported as percentage of phonemes correct (PPC).
*$p < .05$. **$p < .01$.

during normal school hours. As previously stated, participants in the current study completed a range of tests as part of a larger research protocol (details reported in Jackson et al., 2020). The tasks required for data collection reported here were administered across seven individual testing sessions distributed over two consecutive weeks. The first week involved administering the participant selection tasks and measures of verbal working memory in four 30-minute sessions, and the second week involved administration of the word learning task across four consecutive days (20-30 minute sessions).

Materials

The word learning stimuli were eight novel words (pseudowords) derived from English syllables. A large portion of English words are multisyllabic (Balota et al., 2007), and word learning success can differ depending on word length (Jackson et al., 2019b). Thus, to capture variation in performance the stimuli included two items at one, two, three, and four-syllable lengths (see Appendix 1). An additional two-syllable nonword was included as a practice item. Pseudowords were chosen to ensure there was no prior knowledge of the stimuli, and all had low phonotactic probability to reduce the possible bias of prior lexical knowledge on learning novel word forms (Gray et al., 2012). The stimuli did not include phonemes that the younger participants may not have developed by their chronological age, such as /x/,/θ/,/ð/,/v/, and /r/. There were no consonant clusters, to minimise articulatory complexity (Bowen, 2014). Each pseudoword was randomly assigned to a concrete referent (unfamiliar 'alien' creatures) made from coloured modelling clay (see Supplemental Materials). Thus, the stimuli were taught as proper nouns linked to the referent, which suited our aim of testing whether the word form, meaning, or form-referent link was problematic for children with DLD (McGregor et al., 2020). The referents were designed to be maximally different with regards to physical attributes: each item differed from the others in at least three physical features (body shape, body colour, leg colour, and number of eyes). Photos of each were integrated into an animated video using the Moovly online program (Moovly.com). A separate animation was created for each item and for each day of the protocol. The animations were narrated by a female Australian English speaker and administered individually via iPad. The procedures for training and administration of outcome measures are described below and detailed in the Supplemental Materials.

Word learning protocol

Encoding and re-encoding (days 1–3)

Day 1 (*encoding*) and Days 2 and 3 (*re-encoding*) all followed a similar procedure: the eight stimuli were presented in a training block, which was followed by the administration of four outcome measures (*Naming, Recognition, Description*, and *Identification*). The stimuli were presented in randomised order on each day for each participant. In the training block, the stimuli were presented one at a time. For each item, the word form was modelled four times in commenting phrases interleaved with semantic description about the body shape and colour of the legs. To ensure the participant was actively engaged, they were asked to imitate the word form, and regardless of their response, the examiner repeated the name to provide an additional exposure. Throughout the task, participants were not stopped from making extraneous comments, but were always redirected back to the task. At the start of Day 1, a practice item was presented to familiarise participants with the training procedure and outcome measures. A detailed description of the protocol is provided in Supplemental Materials.

Outcome measures. On Days 1, 2, and 3, the training task was followed by the administration of the four outcome measures. Each outcome measure inherently involves additional learning opportunities (i.e., through additional exposure and/or retrieval of the word); thus, the measures were administered in fixed order to ensure consistent learning opportunities prior to testing. The tasks were scored on-line within each session (using hard copy score forms) and were also voice recorded (using a Philips Audio Recorder) for later checking. Twenty percent of the tasks were later scored by an independent second scorer (an experienced speech-language pathologist) blind to groups. There was high inter-rater reliability for scoring of each outcome measure (Naming $r = .91$, Recognition $r = .98$, Identification $r = .99$, and Description $r = .95$).

For the practice item at the start of Day 1, specific feedback was provided to the child regarding the accuracy of their response on each of the four outcome measures (see script in Supplemental Materials). For the test items, only neutral feedback was provided (e.g., "You're working well"), with no feedback on accuracy.

Naming. Participants were asked to say the name of each item to test their ability to produce the word form. If no response was given, participants were prompted to "try and say any of the sounds in the name". Responses were phonetically transcribed, and accuracy was evaluated using the percentage of phonemes correct (PPC) method (Dollaghan & Campbell, 1998). To ensure that naming performance was not limited by restrictions in the child's phonetic inventory, the child's performance on the DEAP screener (Dodd et al., 2002) and observations of their spontaneous speech were considered to identify consistent errors in their speech. These errors were scored as correct in their *Naming* responses; any errors with producing phonemes that were in their phonetic inventories were marked as incorrect (Dollaghan & Campbell, 1998).

Recognition. A mispronunciation detection task involved identifying the correct word form from three phonologically-related foils. The foils differed from the target according to: 1) initial phoneme modification; 2) final phoneme modification; and, 3) syllable modification (i.e., transposition of syllables, or an added random syllable for one-syllable items). The target and foils were randomly ordered for each item and participants were not informed about the ratio of correct and incorrect choices. The participant was required to make a decision about each option as it was presented, and they pressed a green or red button if they judged the option to be correct or incorrect (Alt & Suddarth, 2012). No feedback was provided on each judgement made by the child. One point was allocated for each correct response, yielding a maximum score of 4 per item (and a total maximum score of 32), and a percentage of *Recognition* accuracy was calculated for use in the analyses.

Identification. Knowledge of the word-referent link was tested using a task in which participants saw all eight target items displayed on the screen and heard the target word in the phrase, "Point to ____". Participants made their selection by pointing to the item on the screen. Responses were scored as correct (1 point) or incorrect (0 points), yielding a total maximum score of 8. A percentage of *Identification* accuracy was calculated.

Description. Knowledge of the word meaning was evaluated by asking the child to describe the item's appearance ("What does ____ look like?"). During the practice task at the start of Day 1, participants were trained to provide four features in their descriptions. If an incomplete description was provided, the prompt "What else?" was given, until the description included four features or no further information could be provided. Responses were transcribed, and one point was allocated for each correct semantic feature, yielding a maximum of 4 for each item (maximum score of 32). A percentage of *Description* accuracy was calculated.

Retention (day 4)

Retention of the novel words was tested approximately 24 hours after the Day 3 session for each participant. The *Naming, Recognition*, and *Identification* tasks were administered, but not the *Description* task as retention testing of either the word form or meaning would require exposure to the target information, thus confounding assessment. Administration of the three outcome measures was counterbalanced for each item across participants. The same scoring procedures as above were used and no corrective feedback was provided.

Dosage

Previous studies have developed word learning protocols with the aim of training to mastery, or evaluating effective training intensities to facilitate comparable word learning among DLD and TD children (e.g., McGregor et al., 2020; Storkel et al., 2017). The purpose for the current study, however, was not intervention; we aimed to provide each participant with the same training opportunities in order to afford a controlled comparison of word learning abilities. On Days 1, 2, and 3 of the protocol, 8 exposures to the word form were provided (5 through training and 3 through outcome measure administration). Thus, prior to retention testing participants had received 24 verbal models for each item.

Verbal working memory

Three tasks were administered to evaluate verbal WM skills. Two subtests from the Working Memory Test Battery for Children (WMTB-C; Gathercole & Pickering, 2001) were administered: (1) Digit Recall, which requires hearing, temporarily storing, and recalling strings of digits; and, (2) Backwards Digit Recall, which requires hearing and temporarily storing strings of digits, and then recalling these in reverse order. Together, both tasks give a good indication of a child's verbal WM capabilities (Archibald & Gathercole, 2006). These subtests are standardised to a mean of 100 and SD of 15. The Nonword Repetition Test (Dollaghan & Campbell, 1998) was also administered, which requires the oral repetition of nonwords that increase in length. Guidelines for pronunciation and scoring outlined by Dollaghan and Campbell (1998) were followed. As with scoring of the word learning *Naming* task, responses were scored using the PPC method while taking into account each child's phonetic inventory. Responses on this task were audio recorded and 20% of the tasks were later scored by the independent second scorer, with high inter-rater reliability ($r = .93$).

Verbal WM for this cohort of children was reported as part of a large battery of memory measures in Jackson et al. (2020). The results showed that the DLD group scored significantly lower than the TD group on all three measures. Furthermore, scores were significantly correlated with each other (*r*s ranging from .52 to .69), indicating that these measures evaluated a similar construct. As such, principal components analysis was conducted to achieve data reduction and obtain a Verbal WM Factor (full details are provided in Jackson et al., 2020).

Results

Our first aim was to examine whether word learning impairments in children with DLD may be attributed to deficits in encoding or retention. As such, word learning was evaluated across a four-day protocol (Day 1: *encoding*, Days 2 and 3: *re-encoding*, Day 4: *retention*). Across the four days, we evaluated the word learning process using four outcome measures (*Naming, Recognition, Identification*, and *Description*) in order to identify whether children with DLD have deficits with learning the word form, meaning, or form-referent link. A series of four Generalised Linear Mixed Model (GLMM) analyses were run using IBM SPSS Statistics (Version 26; IBM Corp., 2019). For the *Naming, Recognition*, and *Identification* analyses, participant was included as a random effect (random intercept). Time (Day 1, Day 2, Day 3, and Day 4), Group (DLD, TD), and the interaction between Time and Group were included as fixed effects. As described in the Method, we noted significant group differences for nonverbal IQ (PTONI) abilities, so we adjusted for this. The fixed effects for the nonverbal IQ factor for each analysis are reported in Supplemental Materials. The *Description* analysis involved the same random and fixed effects; however, there were only three time points (Day 4 retention testing was not conducted for this outcome measure, as described in the Method).

The second study aim was to explore whether verbal WM abilities moderated performance on *Naming, Recognition, Identification*, and *Description* across the four-day protocol. To explore this aim, the same GLMM analyses as above were run, with the inclusion of the Verbal WM factor as an additional fixed effect, and the three-way interaction for Group $\times$ Verbal WM $\times$ Time.

There were low rates of missing data (<2% on all variables), and these data were missing completely at random, $\chi^2(52) = 40.91$, $p = .866$. Missing data were imputed using expectation maximisation. There were two univariate outliers but these were deemed genuine scores rather than errors in data entry (and were not more than 3*SD* away from their group mean). These data points were dropped and the analyses were re-run, but they did not have an impact on the results; therefore, the reported analyses used the full data set. Descriptive statistics for all analyses (disaggregated by group) are summarised in Table 2. Statistics for all follow-up contrasts are presented in Supplemental Materials.

Aim 1: Encoding, re-encoding, and retention of word forms, form-referent links, and meanings

Word forms: Naming

The main effect of time was significant, $F(3, 407) = 140.85$, $p < .001$, *partial* $\eta^2 = 0.51$. Follow-up contrasts for the DLD group revealed a significant increase in naming accuracy from Days 1 to 2, and from Days 2 to 3. This was followed by a significant decrease from

Table 2. Descriptive statistics for group performances on the naming, recognition, identification, and description tasks.

Measure	Group	M^a	M^b	SE^a	SE^b	95% CI[a]	95% CI[b]
Day 1 (encoding)							
Naming	DLD	49.59	60.80	2.81	2.28	44.06, 55.12	56.32, 65.28
	TD	75.05	69.47	2.29	3.57	70.55, 79.54	62.45, 76.50
Recognition	DLD	72.27	77.80	1.84	1.91	69.65, 76.90	74.05, 81.56
	TD	88.41	86.13	1.08	1.95	86.28, 90.54	82.29, 89.96
Identification	DLD	94.20	93.31	1.98	2.27	90.31, 98.09	88.85, 97.96
	TD	98.00	97.40	0.70	1.05	96.62, 99.39	95.34, 99.46
Description	DLD	69.99	72.53	2.44	2.76	65.19, 74.79	67.09, 77.96
	TD	80.38	79.91	1.70	2.41	77.03, 83.72	75.17, 84.64
Day 2 (re-encoding)							
Naming	DLD	56.75	66.03	2.81	3.09	51.24, 62.27	59.96, 72.10
	TD	84.72	79.71	2.22	3.08	80.36, 89.08	73.66, 85.77
Recognition	DLD	75.78	81.35	1.86	1.92	71.93, 79.23	77.57, 85.13
	TD	93.79	92.54	0.91	1.30	92.01, 95.57	89.98, 95.10
Identification	DLD	95.78	95.31	1.10	1.22	93.62, 97.94	92.91, 97.71
	TD	97.99	97.06	0.82	1.46	96.16, 99.39	94.19, 99.93
Description	DLD	70.32	75.12	2.16	2.22	66.07, 74.56	70.75, 79.49
	TD	79.57	81.25	1.92	2.52	75.78, 83.35	76.30, 86.21
Day 3 (re-encoding)							
Naming	DLD	67.28	78.13	3.06	2.71	61.26, 73.30	72.81, 83.46
	TD	88.53	84.61	1.94	2.81	84.71, 92.34	79.09, 90.13
Recognition	DLD	80.40	86.90	2.21	2.88	76.06, 84.74	91.23, 92.57
	TD	96.28	95.76	0.69	0.86	94.92, 97.64	94.07, 97.45
Identification	DLD	97.91	97.88	0.92	1.13	96.10, 99.71	95.30, 100.45
	TD	98.28	97.84	0.59	1.10	97.13, 99.44	95.65, 99.98
Description	DLD	74.19	78.97	2.10	3.12	70.06, 78.32	76.82, 85.11
	TD	84.23	84.35	1.41	1.82	81.47, 87.00	80.77, 87.94
Day 4 (retention)							
Naming	DLD	34.71	39.15	2.87	2.81	29.07, 40.35	31.54, 46.75
	TD	36.00	31.95	2.11	3.87	31.83, 40.14	25.42, 38.47
Recognition	DLD	73.96	81.16	2.51	3.05	69.02, 78.89	75.17, 87.15
	TD	92.81	92.15	0.89	1.44	91.05, 94.57	89.32, 94.98
Identification	DLD	43.41	45.98	3.88	5.50	35.78, 51.04	35.17, 56.79
	TD	51.34	46.87	2.99	4.47	45.45, 57.22	38.10, 55.65

95% CI: 95% confidence interval (upper, lower). All values indicate percentage of accuracy on the tasks.
[a]Values are from the first set of GLMM analyses, which included a fixed effect to control for nonverbal IQ.
[b]Values are from the second set of GLMM analyses, which included fixed effects to control for nonverbal IQ and verbal WM.

Day 3 to Day 4. The same pattern of results was observed for the TD group. Examination of the group averages at each day showed that by Day 3, the DLD group on average attained 67% accuracy and the TD children obtained 89%. At Day 4, both groups demonstrated evidence of some retention, with accuracy levels of 35% and 36% for the DLD and TD groups, respectively. It is noteworthy that there is no chance-level performance on this task given that naming requires retrieval of the word form from memory.

The main effect of group was significant, $F(1, 407) = 42.15$, $p < .001$, *partial* $\eta^2 = 0.09$. To determine whether the group effect could be attributed to problems with initial encoding (Day 1), re-encoding (Days 2 and 3), or retention (Day 4), LSD contrasts between the groups were examined at each time point. The DLD group had significantly lower naming accuracy than the TD group at Day 1 (initial encoding) and at Days 2 and 3 (re-encoding). At Day 4 (retention), there was no significant difference between any of the three groups. The Group × Time interaction was significant, $F(3, 407) = 12.40$, $p < .001$, *partial* $\eta^2 = 0.08$ (see Figure 1(a)); however, it appears that this interaction was driven by the accuracy score for the TD group significantly dropping at Day 4, resulting in no group difference at this point.

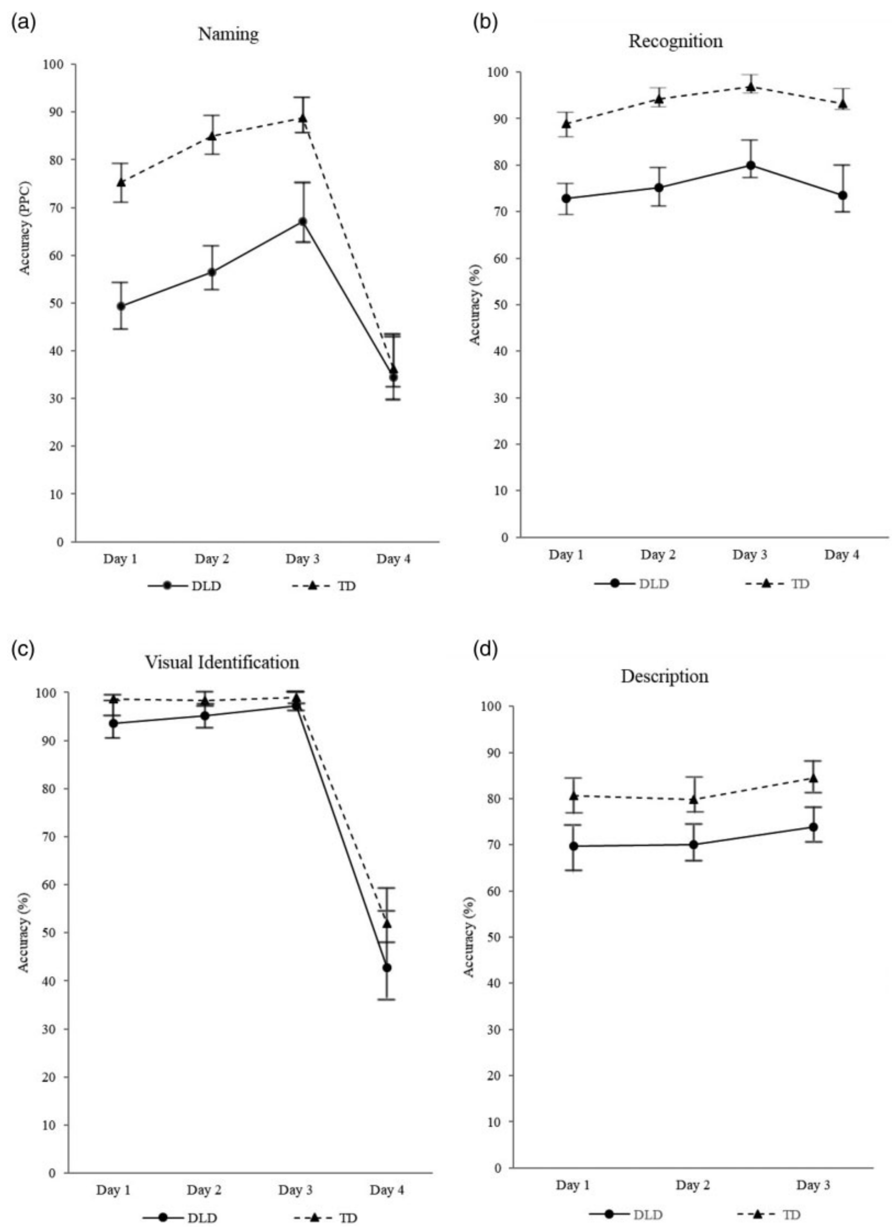

Figure 1. Performance on measures of naming, recognition, identification, and description. Panel A: Group × Time interaction on *Naming* ($p < .05$). Panel B: Group × Time interaction on *Recognition* ($p < .05$). Panel C: Group × Time interaction on *Visual Identification* ($p > .05$). Panel D: Group × Time interaction on *Description* ($p > .05$).

Word forms: Recognition

The main effect for time was significant, $F(3, 407) = 19.46$, $p < .001$, *partial* $\eta^2 = 0.13$. For the DLD group, there was a non-significant increase in average recognition accuracy from Days 1 to 2, and a significant increase from Days 2 to 3. However, accuracy declined significantly from Days 3 to 4. For TD, recognition accuracy increased significantly from Days 1 to 2, Days 2 to 3, and then declined significantly from Days 3 to 4. By Day 3, the DLD and TD groups obtained average accuracy levels of 80% and 96%, respectively. At Day 4, while there was a significant drop in accuracy (to 74% for the DLD group and 93% for the TD group), the groups were still performing above chance level (i.e., 50%, given that on each trial, the child was able to answer 'yes' or 'no'). As with the *Naming* task, both groups showed a similar pattern of linear increase in *Recognition* accuracy across the encoding and re-encoding phases; however, they had difficulty maintaining that level of accuracy at the retention test.

The group main effect was also significant, $F(1, 407) = 69.53$, $p < .001$, *partial* $\eta^2 = 0.15$, and follow-up contrasts showed a significant difference between the groups at all four time points. This indicates that the DLD group performed more poorly than the TD group across the tests of encoding, re-encoding, and retention. The Group × Time interaction was also significant, $F(3, 407) = 3.12$, $p = .026$, *partial* $\eta^2 = 0.02$ (see Figure 1(b)), which appeared to be driven by the DLD group dropping further in accuracy at Day 4 in comparison to the TD group.

Form-referent link: Identification

The main effect of time was significant, $F(3, 407) = 139.09$, $p < .001$, *partial* $\eta^2 = 0.51$. Follow-up contrasts for the DLD group showed no changes in accuracy across the first three days. At Day 4, however, there was a significant drop in accuracy. The TD group demonstrated the same pattern. This decline in performance at Day 4 for both groups appeared to drive the time effect. While the groups exhibited a significant drop in accuracy for the retention test, both still performed above chance level (which was 12.5%) by attaining accuracy levels of 43% and 51% (DLD and TD, respectively), indicating some degree of successful retention after the 24-hour delay. The main effect of group was significant, $F(1, 407) = 5.72$, $p = .017$, *partial* $\eta^2 = 0.01$. However, follow-up contrasts showed no significant differences between the groups at any of the four time points, suggesting comparable encoding, re-encoding and retention for the groups. The Group × Time interaction was also non-significant (see Figure 1(c)).

Word meanings: Description

There was a significant main effect for time, $F(2, 305) = 6.12$, $p = .002$, *partial* $\eta^2 = 0.04$. Follow-up contrasts for the DLD group showed a non-significant increase in description accuracy from Days 1 to 2, and a significant increase from Days 2 to 3. The TD group demonstrated the same pattern of growth. The group effect was significant, $F(1, 305) = 17.26$, $p < .001$, *partial* $\eta^2 = 0.05$. Follow-up contrasts revealed that the DLD group was significantly less accurate than the TD group across Days 1, 2, and 3, indicating deficits in encoding and re-encoding for semantic details. The Group X Time interaction was non-significant (see Figure 1(d)).

Aim 2: The relationship between word learning and verbal WM

Each of the four GLMM analyses were re-run with the addition of the Verbal WM factor as a fixed effect. Notable results are described below, and the findings for the fixed effects and interactions for each GLMM are presented in Tables 3, 4, 5, and 6.

Word forms: Naming

After controlling for verbal WM, there was a significant main effect of time (see Table 3). The main effect of group was no longer statistically significant. The interactions for Time × Verbal WM and Group × Verbal WM × Time were also non-significant. However, the main effect of verbal WM was significant, as was the Time × Group interaction. The Group × Verbal WM interaction was also significant, indicating that verbal WM had differential effects on naming in the two groups.

The interaction between group and verbal WM was probed by plotting the estimated values for the DLD and TD groups when verbal WM was at the mean level and at 1 *SD* below the mean. Figure 2(a) displays these estimated values for children with DLD and low verbal WM ('DLDlow'), children with DLD and verbal WM at the mean ('DLDav'), TD children with low verbal WM ('TDlow'), and TD children with average verbal WM ('TDav'). Examination of the confidence intervals indicates that children with DLD and low verbal WM performed significantly worse than TD children (with average and low verbal WM), as well as those with DLD and average verbal WM, across the first three time points. However, performance was similar between all groups at Day 4. None of the other

Table 3. Main effects and interactions for the GLMM analysis for naming (adjusted for nonverbal IQ and verbal working memory).

Fixed effect	*F*	Degrees of freedom	*p*	Partial η^2
Group	3.72	1, 399	.055	0.01
Time	63.02	3, 399	<.001**	0.32
Nonverbal IQ	0.40	1, 399	.526	0.001
Verbal WM	63.69	1, 399	<.001**	0.14
Group × Time	3.97	3, 399	.008**	0.03
Group × Verbal WM	4.41	1, 399	.036*	0.01
Time × Verbal WM	1.04	3, 399	.377	0.01
Group × Time × Verbal WM	0.74	3, 399	.526	0.01

Nonverbal IQ: nonverbal IQ, as measured on the PTONI; Verbal WM: verbal working memory factor.
$^{*}p < .05$. $^{**}p < .01$.

Table 4. Main effects and interactions for the GLMM analysis for recognition (adjusted for nonverbal IQ and verbal working memory).

Fixed effect	*F*	Degrees of freedom	*p*	Partial η^2
Group	17.48	1, 399	<.001**	0.04
Time	12.65	3, 399	<.001**	0.09
Nonverbal IQ	1.30	1, 399	.256	0.003
Verbal WM	20.74	1, 399	<.001**	0.05
Group × Time	0.88	3, 399	.451	0.007
Group × Verbal WM	8.30	1, 399	.004**	0.02
Time × Verbal WM	0.10	3, 399	.958	0.001
Group × Time × Verbal WM	1.05	3, 399	.370	0.007

Nonverbal IQ: nonverbal IQ, as measured on the PTONI; Verbal WM: verbal working memory factor.
$^{**}p < .01$.

Table 5. Main effects and interactions for the GLMM analysis for identification (adjusted for nonverbal IQ and verbal working memory).

Fixed effect	*F*	Degrees of freedom	*p*	Partial η^2
Group	0.67	1, 399	.413	0.002
Time	66.21	3, 399	<.001**	0.33
Nonverbal IQ	3.78	1, 399	.052	0.009
Verbal WM	2.37	1, 399	.125	0.006
Group × Time	0.76	3, 399	.518	0.006
Group × Verbal WM	1.01	1, 399	.316	0.003
Time × Verbal WM	0.72	3, 399	.542	0.005
Group × Time × Verbal WM	0.10	3, 399	.958	0.001

Nonverbal IQ: nonverbal IQ, as measured on the PTONI; Verbal WM: verbal working memory factor.
$^{**}p < .01$.

Table 6. Main effects and interactions for the GLMM analysis for description (adjusted for nonverbal IQ and verbal working memory).

Fixed effect	*F*	Degrees of freedom	*p*	Partial η^2
Group	4.97	1, 299	<.001**	0.01
Time	3.14	1, 299	.027*	0.01
Nonverbal IQ	0.39	2, 299	.532	0.002
Verbal WM	1.90	1, 299	.169	0.01
Group × Time	0.11	2, 299	.897	0.001
Group × Verbal WM	2.98	1, 299	.086	0.01
Time × Verbal WM	0.15	2, 299	.862	0.001
Group × Time × Verbal WM	1.91	2, 299	.149	0.01

Nonverbal IQ: nonverbal IQ, as measured on the PTONI; Verbal WM: verbal working memory factor.
$^{*}p < .05$; $^{**}p < .01$.

comparisons were significant, except for the DLDav group being significantly lower than the TDav group at Day 2 (confidence intervals are reported in Supplemental Materials).

Word forms: Recognition

There was a significant main effect of time, group, and verbal WM (see Table 4). The two-way interactions for Time × Group and Time × Verbal WM were non-significant, as was the three-way interaction for Group × Verbal WM × Time. However, the Group × Verbal WM interaction was significant, indicating differential effects of verbal WM on recognition accuracy in the two groups. As with the *Naming* analysis, to probe the Group × Verbal WM interaction, we plotted the estimated values for the DLD and TD children according to average and below-average verbal WM (i.e., DLDlow, DLDav, TDlow, TDav; see Figure 2 (b)). Examination of the confidence intervals (reported in Supplemental Materials) showed that, across Days 1, 2, and 3, children with DLD and low verbal WM had significantly poorer recognition accuracy in comparison to the DLDav, TDlow, and TDav children. At Day 4, children with DLDlow were significantly lower than the TDlow and TDav children. Finally, the children with DLD and average verbal WM were significantly lower than TD children with average verbal WM across all four days.

Form-referent link: Identification

The main effect for time was significant, which was likely driven by the significant drop in accuracy from Day 3 to 4 (see Table 5). The remaining main effects and interactions were all non-significant. The results

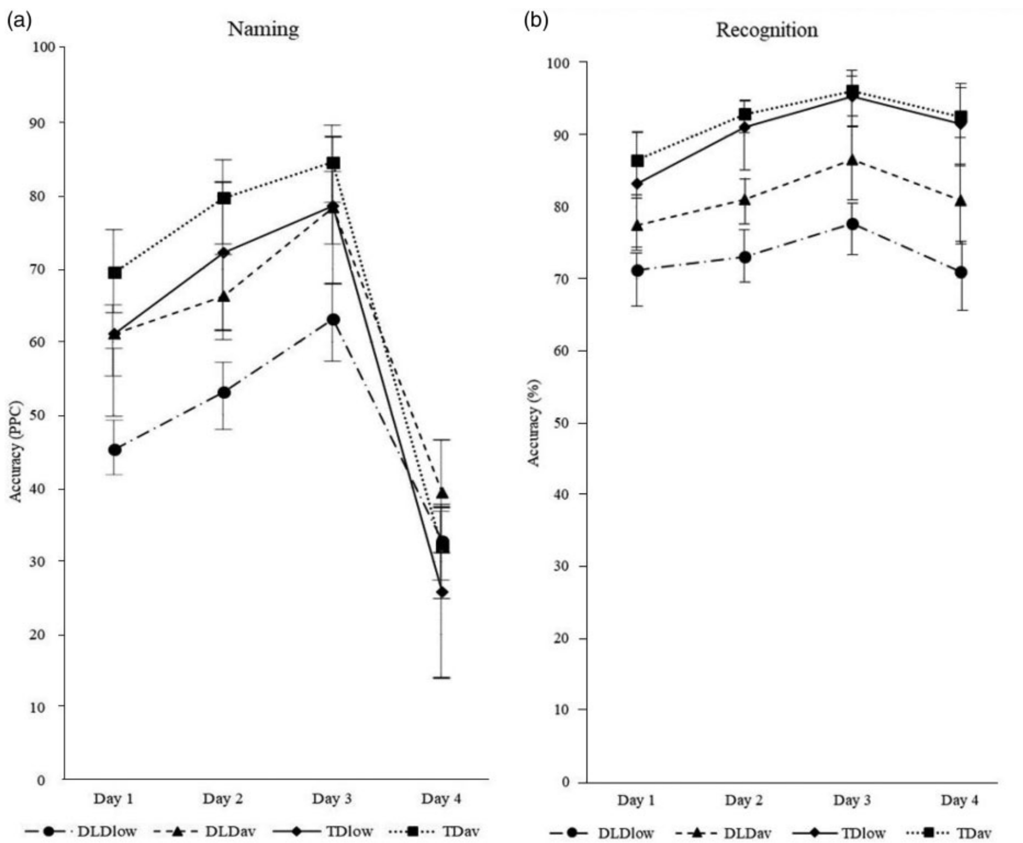

Figure 2. Estimated performance on naming and recognition for children with DLD and TD (low versus average verbal WM).

suggest that verbal WM does not moderate performance for *Identification*.

Word meanings: Description

The main effects of time and group were significant; however, the remaining main effects and interactions were all non-significant (see Table 6). The results suggest that verbal WM does not moderate performance for *Description* accuracy.

Discussion

In this study, we explored whether word learning in children with DLD is characterised by deficits in encoding, re-encoding, or retention. Across these stages, word learning was evaluated using four outcome measures that tested how well the children learned the novel word forms, form-referent links, and word meanings. Additionally, we explored verbal WM as a moderator of word learning performance. Overall, the children with DLD presented with an impaired ability to learn the word forms (*Naming* and *Recognition*) and meanings (*Description*) compared to their TD peers. These deficits were apparent across the stages of encoding and re-encoding. In contrast, children with DLD exhibited an intact ability to learn the form-referent links (*Identification*). Notably, both groups exhibited problems at the retention stage for all aspects of word learning. Verbal WM significantly moderated the ability to learn new word forms, such that poor performance on the *Naming* and *Recognition* tasks was only identified in children who had DLD and low verbal WM.

The encoding of word forms and meanings is problematic for children with DLD

Consistent with our predictions, the group of children with DLD appeared to have intact skills for learning form-referent links of novel words (McGregor et al., 2020). To create a link between the form and referent, the child needs to store only a partial representation of the word form in order to be able to identify the correct item upon hearing its label (Gray et al., 2020). Therefore, it seems that the children with DLD were able to store a sufficient level of phonological detail in order to create an association with the physical referent. This finding highlights the importance of evaluating word learning skills in children with DLD using a range of outcome measures, as *Identification* in isolation may fail to identify a deficit. It is also important to note that, if additional novel words were included, or if fewer exposures were presented, a group difference might become apparent. This may be further explored in the future to build an understanding of the nature of form-referent link learning.

Also in line with our hypothesis, the DLD group exhibited significant difficulties with learning novel word forms. These group differences were observed on both the *Naming* and *Recognition* tasks, indicating the deficit is apparent when assessing knowledge of the word form expressively and receptively (Jackson et al., 2019a). Furthermore, examination of *Naming* and *Recognition* performance showed a significant deficit for the DLD group at Day 1. Across Days 2 and 3, both groups showed a linear increase in accuracy on the tasks, with the between-groups gap remaining relatively stable. These findings indicate that difficulties with learning novel word forms originate at the initial encoding stage for children with DLD (Bishop & Hsu, 2015; McGregor et al., 2020). Following encoding, both groups appeared to improve their knowledge of word forms through re-encoding, whereby the initially-encoded memory trace of each phonological representation was retrieved from long-term memory and further refined throughout the training task (McGregor et al., 2013a; Nader & Hardt, 2009). However, while the children with DLD clearly improved their word form knowledge through re-encoding, they did not catch up to their TD peers at this level of training intensity (Cepeda et al., 2006; Leonard et al., 2019). Difficulty encoding novel word forms has also been documented in a body of literature concerning children, adolescents, and adults with DLD (e.g., see Bishop & Hsu, 2015; Haebig et al., 2019; McGregor et al., 2013a, 2017a, 2017b, 2020).

Notably, performance on the measures of *Naming, Recognition*, and *Identification* dropped significantly for both groups at retention testing (i.e., Day 4), and group differences disappeared. On each task, however, accuracy for each group was above chance level, indicating the retention of some new word knowledge in long-term memory (Dumay & Gaskell, 2007). It may be possible to interpret the low Day 4 scores as evidence that children with DLD have comparable retention skills to TD children. That is, while the children with DLD struggled to encode effectively, they managed to retain a similar level of knowledge about word forms and form-referent links as the TD children (Lukacs et al., 2017). However, it is also important to consider why performance of the TD group dropped dramatically at Day 4, to the point where the DLD-TD gap closed. We can infer that the TD children were able to most effectively take advantage of within-session opportunities to encode and re-encode across the three days of training. It is likely that stronger oral language skills facilitated their novel word learning within the training tasks, with previous evidence showing that children with typical language more effectively take advantage of strategies such as syntactic and semantic bootstrapping to learn novel words (Chiat, 2001; Eyer et al., 2002). Despite the effectiveness of within-session learning, the TD children had not retained as much information at Day 4 as training suggested. Perhaps what we observed was that training was advantageous for TD children; however, this did not necessarily translate into consolidated gains. That is, it seems that the children with and without DLD were similarly subject to memory decay after approximately 24-hours at this level of intensity (Lukacs et al., 2017).

While our findings may suggest ineffective retention across the groups, a higher degree of training intensity would likely have bolstered retention (Kan & Windsor, 2010). Recent research, such as Leonard et al. (2019) and Storkel et al. (2017) – published after the design of our word learning protocol – showed that children with and without DLD demonstrated high levels of retention accuracy when provided with a higher degree of exposures than here. Leonard et al. (2019) provided 48 exposures over four sessions and focused on training to mastery. It is perhaps unsurprising, therefore, that the children in our study did not demonstrate effective retention in response to the provision of 24 exposures over 3 training sessions. As noted in the Methods section, however, the intention of the word learning protocol in this research was not to provide intervention, nor to ensure training to mastery. Instead, we aimed to explore patterns of word learning across different tasks (and the relationship with verbal WM). Future research may adapt our word learning protocol to facilitate more effective retention. It would also be useful to evaluate retention after various interval periods (e.g. 24 hours, one week, one month) in order to further develop effective intervention strategies to ensure long-term retention of new vocabulary knowledge for children with DLD (McGregor et al., 2020).

Finally, in addition to problems learning novel word forms, we predicted that children with DLD would struggle with establishing word meanings. Performance on the *Description* task highlighted a significant deficit for the DLD group; however, the small to medium effect size (partial $\eta^2 = 0.05$) indicates that the deficit was more severe for learning novel word forms. This is consistent with a body of previous research (Alt & Plante, 2006; Nash & Donaldson, 2005) and supports the notion of multifactorial word learning deficits in children with DLD (Gray et al., 2020). These findings also align with those of

McGregor et al. (2013b), who found that children with DLD exhibit deficits in their vocabulary depth, such that their definitions of known words are sparser than those of children with typical language. While McGregor et al. (2013b) investigated semantic knowledge of already-established vocabulary, the findings from the present study highlight that these deficits in vocabulary depth likely originate with poor encoding of semantic knowledge in children with DLD. As a result of poor encoding, we found that there remained a significant gap in *Description* abilities between groups across Days 2 and 3, indicating that the children with DLD did not close the gap in semantic knowledge with this degree of training intensity (Storkel et al., 2019).

A key limitation of our study was the lack of inclusion of a retention test for *Description*, and so we are unable to comment on retention for either group with regards to learning word meanings. This should be the focus of future research. Additionally, the nature of the novel items were limited in range in that they were all proper nouns that differed by a few visual features. Future research should further explore a range of word types and use stimuli and outcomes measures that allow exploration into how well the children make connections in their semantic networks (Mainela-Arnold et al., 2010). These findings should also be substantiated in research tasks that more closely resemble everyday word learning situations, such as interactive book reading tasks (Storkel et al., 2019).

The influence of verbal working memory

The second aim of our study was to explore whether verbal WM moderated performance across the four measures of word learning. As predicted, verbal WM significantly moderated performance on the tasks measuring word-form learning (i.e., *Naming* and *Recognition*). Notably, poor performance was observed specifically for children with DLD who also had low verbal WM; this effect was magnified especially on the *Naming* task. These findings indicate that verbal WM is a key factor that drives the ability to learn novel phonological representations, supporting the theoretical claim that verbal WM acts as a 'gateway' for vocabulary development (Baddeley et al., 1998; Lum et al., 2015). Specifically, the pattern of moderation across the four-day protocol suggests that verbal WM facilitates the initial encoding of word forms (Gathercole & Baddeley, 1989), and may also play a role in supporting the retrieval and monitoring of phonological information from long-term memory, as required in re-encoding and retention (Lum et al., 2012). Despite there being a theoretical link between verbal WM and learning novel word forms, only a handful of past studies have provided empirical evidence in support of this relationship (e.g., see Gray, 2004; Jackson et al., 2016). Furthermore, Gray (2006) and Horohov and Oetting (2004) failed to find a relationship between verbal WM and word-form learning; however, this may have been the result of floor-level performances on naming tasks, resulting in a lack of variability among scores to yield a relationship (Kan & Windsor, 2010).

As predicted, verbal WM did not moderate performance on the *Identification* task. It seems that the act of establishing form-referent links bypasses weaknesses in verbal WM by placing minimal demands on phonological storage and retrieval (Gray et al., 2020). Notably, however, there was a lack of variability in performance across Days 1 to 3 that may have masked a potential association, which was due to both groups performing close to ceiling. Finally, verbal WM did not moderate learning of word meanings, which was consistent with our understanding of the theoretical contribution that verbal WM plays in the word learning process (Baddeley, 2003). Our findings indicate that stronger oral language skills (i.e., as in the TD group) facilitated better performance on the *Description* task. It is likely that existing vocabulary was used to establish new collections of semantic details for each item, and grammatical skills were drawn on to weave these details into descriptive sentences (Carr & Johnston, 2001).

Conclusions

The results of our study provide further evidence that word learning is a problematic aspect of language development for children with DLD, especially for those who have comorbid deficits in verbal WM. Our findings indicate that children with DLD are able to effectively establish novel form-referent associations. However, they exhibit significant difficulties with developing accurate, detailed knowledge of the word forms and meanings. The problem with establishing novel word forms is compounded by poor verbal WM skills in children with DLD. Additionally, our findings support the notion that "encoding is the bottleneck that limits word learning" (McGregor et al., 2020, p. 14) in this population. While our results suggest that retention may be a relative strength, this requires further substantiation using a task that overcomes the limitations of our word learning protocol. The relationship between nonverbal IQ and word learning should also be explored in future research, as Kan and Windsor (2010) found this to be a significant moderator of word learning performance in their meta-analysis. While we controlled for nonverbal IQ, we did not have sufficient power to include an additional interaction and therefore did not explore the nature of this relationship.

The findings of the current study are relevant for the assessment and treatment practices of children with DLD. Four specific implications emerge:

1. Word learning is a multifaceted process, and given the heterogeneous nature of DLD it is important for speech-language pathologists (SLPs) to consider that clients will likely present with an individual profile of word learning ability. SLPs should evaluate word learning using a range of outcome measures, and avoid using a single outcome measure such as *Identification*, which may give a false sense of word learning abilities. Understanding a child's word learning strengths and weaknesses would support the provision of individually-tailored intervention strategies (Storkel et al., 2019).
2. Children with DLD will require intervention that explicitly targets their ability to learn new word forms *and* meanings. Furthermore, they will likely benefit from a high degree of training intensity compared to their peers as a way of mitigating an encoding deficit (McGregor et al., 2013a), and long-term retention of word knowledge may be supported through the use of periodic review (McGregor et al., 2020). Further research should explore whether there is an ideal treatment intensity that benefits children with DLD who have comorbid deficits in verbal WM (Archibald & Gathercole, 2006). Various strategies and cues, such as the presence of orthography and gestural cues, may also prove useful for these children (Ricketts et al., 2015; Vogt & Kauschke, 2017).
3. A theoretically-informed assessment battery for children with DLD should include measures of verbal WM (such as nonword repetition and digit span tasks). This information may allow SLPs to identify which children are at greatest risk of word learning impairments.
4. The finding that within-session learning may not transfer to retention of learned information has important implications for teaching new vocabulary in the context of intervention and classroom teaching. SLPs and teachers should monitor how effectively children have learned new words within sessions but also after a delay (e.g., a day, week, and month) to determine whether effective retention has occurred.

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Supplemental material

Supplemental material for this article is available online.

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Appendix 1

Table A1. Word learning stimuli (pseudoword labels).

Word length	Training item	Experimental items
1-syllable	–	/nɔb/
		/lɜz/
2-syllable	/poʊdɔd/[a]	/doʊnug/
		/jugɔɪn/
3-syllable	–	/gɔnəpɛk/
		/gɪtəmoʊk/
4-syllable	–	/hɒʃətæjɪk/
		/gufəʃɜgʊs/

Note. Pseudowords were taken from Jackson et al. (2016) and Jusczyk et al. (1994). Two- and three-syllable stimuli were pronounced with stress on the first syllable, and the four-syllable items were pronounced with emphasis on the third syllable.

[a]Only one item (two-syllable nonword) was used for training, as pilot testing showed that training one item was sufficient for participants to understand the parameters of the task.