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Abstract

Purpose: To investigate factors that influence word learning in children with developmental language disorder (DLD).
Method: The participants were 23 children with DLD and 26 typically developing (TD) children, aged five. Participants completed a fast mapping task (assessed using a production measure), as well as tests of nonword repetition and receptive vocabulary. We explored the effect of word length on nonword repetition and fast mapping abilities while controlling for receptive vocabulary skills.
Results: The results indicate that children with DLD demonstrate significant difficulties accurately repeating nonwords of all lengths relative to their TD peers. Children with DLD also exhibited significant difficulties with fast mapping, especially when learning longer novel words.
Conclusions: Our findings indicate that children with DLD demonstrate an impaired capacity to encode phonological information; however, this differentially impacts their nonword repetition and fast mapping abilities. TD children may more effectively take advantage of receptive vocabulary to support performance on these tasks.
Learning outcomes: Readers will understand how phonological short-term memory and receptive vocabulary contribute to fast mapping in children with DLD and in TD children.

Keywords
Word learning, fast mapping, developmental language disorder, working memory, vocabulary

Introduction

1. Introduction

1.1. Developmental language disorder

Developmental language disorder (DLD) – formerly known as specific language impairment – affects around 3-7% of the school-aged population and is characterised by an impaired ability to acquire language in the absence of any other areas of significant impairment (Bishop, Snowling, Thomson, Greenhalgh, & CATALISE-2 Consortium, 2016). DLD may manifest as impairment in the ability to comprehend and/or produce language across one or more of the following domains: morphosyntax (i.e., grammar), phonology, semantics, and pragmatics; however, children with DLD represent a heterogeneous population, with the profile of language deficits varying widely (Leonard, 2014). We were particularly interested in word learning impairments in this population, generally thought to occur as a result of deficiencies in the storage, specification, and/or use of the phonology and semantics of words (Alt, Plante, & Creusere, 2004; Kan & Windsor, 2010). Specifically, we aimed to build understanding of the relationship between phonological short-term memory (STM) and word learning by exploring how accurately preschool children with and without DLD learn and encode the phonology of novel words of varied length.

1.2. Word learning

The ability to effectively learn new words is a fundamental skill, and usually occurs with relative ease for children with typical language development (Chiat, 2001; Ramachandra, Hewitt, & Brackenbury, 2011). Carey and Bartlett's (1978) *mapping theory* provides a framework which describes the typical process of word learning as occurring over two distinct yet overlapping phases (Chiat, 2001). First, *fast mapping* involves brief exposure to the novel word, during which representations of the phonology and semantics are stored to create a form-meaning 'map' (Carey & Bartlett, 1978). Initially, this fast-mapped word may be unstable, and contain sufficient detail only to distinguish the word from others. However, as the word is encountered in subsequent contexts, the phonological and semantic representations are further enriched and more accurately established in long-term memory (Bion, Borovsky, & Fernald, 2013). This process is referred to as *slow mapping*, and is thought to occur repeatedly as the word is encountered across linguistic contexts (Carey & Bartlett, 1978).

It has been hypothesised that impairments in the fast mapping stage have a cascading effect on slow mapping success, because an inaccurate form-meaning map may not be recognised, and therefore refined, in future encounters (Bion et al., 2013). Additionally, the quality with which a child fast maps phonological representations is suggested to influence how effectively the representations for semantic, syntactic, motor programming, and orthographic information may be stored for use in oral and written forms (Castles, Rastle, & Nation, 2018; Stackhouse & Wells, 1997). Thus, poor storage of phonological representations may affect learning across multiple aspects of language (Constable, 2001), and as such, the manner in which children with DLD learn the phonology of new words has been a major focus of word learning research.

1.3. Nonword repetition in children with developmental language disorder

Phonological STM plays a significant role in how the phonological form of the novel word is learned (Gathercole, Hitch, Service, & Martin, 1997; Montgomery, Magimairaj, & Finney, 2010). As such, this component of working memory has been widely explored in children with DLD, often using nonword repetition tasks (Dollaghan & Campbell, 1998; Estes, Evans, & Else-Quest, 2007). Numerous studies indicate that children with DLD exhibit significant difficulties with nonword repetition. For instance, a meta-analysis by Estes et al. (2007) showed that, across 23 studies, children with DLD performed on average 1.27 standard deviations below TD children (indicating a significant deficit). This substantial difficulty with repeating nonwords has supported the development of the *limited capacity processing account* for DLD, which posits that the language impairments experienced by these children may be largely explained by deficits in the processing, encoding, and storage of sound-based information (Chiat, 2001). It is suggested that this underlying deficit contributes considerably to problems learning new words, as the word learning process requires the temporary storage of novel phonological strings in short-term memory, before being transferred to long-term memory (Botting & Conti-Ramsden, 2001; Ramus, Marshall, Rosen, & van der Lely, 2013).

While the research consistently shows a deficit in nonword repetition performance in children with DLD (Archibald & Gathercole, 2007; Dollaghan & Campbell, 1998; Jones, Tamburelli, Watson, Gobet, & Pine, 2010) the magnitude of this deficit varies greatly, hypothesised to be a result of differing task characteristics across measures. Perhaps, most notably, the length of nonwords has been shown to considerably affect performance (Estes et al., 2007). Studies have found that children with DLD may show a similar level of accuracy to TD children when repeating short nonwords (i.e., one and two syllables; Coady & Evans, 2008; Gathercole & Baddeley, 1990); however, with longer nonwords (i.e., those with three or more syllables), an impaired phonological STM capacity in children with DLD is clearly shown (Jones et al., 2010). While Estes et al. (2007) found that children with DLD also struggled to repeat shorter nonwords in comparison to TD children (one and two-syllables), the magnitude of this deficit was considerably smaller than that seen for repetition of longer nonwords (three and four syllables). Thus, while children with DLD may struggle to repeat shorter nonwords, they generally reach their capacity limitation (and exhibit the greatest level of difficulty) for multisyllabic nonwords.

The phenomenon of declining repetition accuracy as nonword length increases is described as the *word length effect,* and what we glean from previous studies is that this effect differentially impacts children with DLD and TD children, presumably as a reflection of their differing phonological STM capacities (Baddeley, 2003). That is, children with DLD may generally reach the 'capacity limitation' at three syllables, while TD children may reach this at four and five syllables (Dollaghan & Campbell, 1998; Estes et al., 2007). The fact that children with DLD tend to exhibit greatest difficulty with longer nonwords supports the notion that their nonword repetition deficit largely reflects impaired phonological STM capacity, rather than general deficits in phonological perception, phonological encoding, articulation or motor programming, which would presumably impact repetition across nonwords of all lengths (Archibald & Gathercole, 2007).

The *word length effect* has numerous practical implications for how well children (especially those with phonological STM impairments, such as children with DLD) may cope with processing lengthy phonological strings, such as encoding multisyllabic novel words (Montgomery, 1995; Riches, 2012). Therefore, this effect is also expected to extend to performance in fast mapping given the similar processing requirements of nonword repetition and word learning (Gathercole, 2006). That is, both tasks require input processing of a novel phonological string, and temporary storage in phonological STM prior to transference into long-term memory (as in fast mapping) or formulation of an output representation (as in nonword repetition; Gathercole, 2006).

1.4. The relationship between phonological short-term memory and fast mapping

In light of the theoretical link between nonword repetition and fast mapping, a body of research has explored this relationship in TD children and found a robust association (e.g., Adlof & Patten, 2017; Montgomery et al., 2010). In earlier work, Gathercole et al. (1997) found that new word learning (of two- and three-syllable novel words) in five and six-year-old children was significantly associated with phonological STM abilities, as measured by both digit span and nonword repetition. A similar relationship was demonstrated in eight to ten-year-olds by Morra and Camba (2009), who introduced 24 novel words (two and four syllables in length) matched to pictures. Among other factors (e.g., phonological sensitivity and rehearsal efficiency), phonological STM significantly predicted their fast mapping production accuracy. This relationship was further reinforced in a group of TD children (aged five to 12), whose fast mapping of bisyllabic unfamiliar real words was strongly predicted by nonword repetition performance (Adlof & Patten, 2017). Taken together, these findings highlight the role of phonological STM in how TD children encode and store novel word forms and facilitate their transfer to long-term memory; thus reinforcing phonological STM as a core "language learning device" (Baddeley, Gathercole, & Papagno, 1998, p. 158). However, to our knowledge, there is a paucity of research investigating the nature of this relationship in TD children, such as whether performance differs across short versus long novel words.

A smaller body of research has investigated the relationship between phonological STM and fast mapping in children with DLD. Due largely to variations in methodology (particularly, the utilisation of different novel word lengths and different measures to assess learning in the fast mapping tasks), the findings of investigations in this population have been equivocal. Alt (2003) and Alt and Plante (2006) provided three exposures to novel words (two syllables in length) for five year olds in their respective studies, and found that those with DLD were significantly less accurate at fast mapping than the TD children. In this study, fast mapping was assessed with a semantic task (i.e., children had to recall semantic features of the novel items), and a recognition task that required them to identify the correct phonological label from three foils. Performance on both tasks correlated with nonword repetition performance (Alt, 2003; Alt & Plante, 2006). This supports the suggestion that fast mapping of the phonological form is facilitated by the ability to hold verbal information in phonological STM (Baddeley, 2003), and additionally suggests that phonological STM plays a role in establishing semantic representations. The fact that the novel words used by Alt (2003) and Alt and Plante (2006) were bisyllabic aligns to a degree with the *word length effect*, which states that nonword repetition (and by extension, word learning) may be especially difficult for children with DLD as nonword length increases (Dollaghan & Campbell, 1998). To further unpack this relationship, further research is required to explore how children with DLD and TD children learn novel words across different lengths.

In contrast, Gray (2006) found no association between phonological STM and fast mapping (of bisyllabic novel words) in children with DLD. While these null findings may seem to suggest that phonological STM did not constrain fast mapping in these children, it is noteworthy that, in their groups of three, four, five, and six-year-olds, fast mapping performance in the TD and DLD groups only differed at age five. Gray (2006) suggested that this may have occurred due to the increased severity of language deficits in this age group of children with DLD. Alternately, the lack of group differences might have reflected the nature of the fast mapping task and the outcome measures that were used to evaluate learning of the novel words. First, a comprehension task was used, which required children to identify the item when provided with its label from an array of all eight target items (Gray, 2006). Both groups of children performed well on this task and thus group scores were similar, reflecting the fact that comprehension tasks are less linguistically-demanding (that is, they require the storage of only enough phonological information that allows differentiation from the other items; Kan & Windsor, 2010). However, the second measure involved producing each novel word label – a task that requires storing the word's phonology in sufficient detail to support production (Stackhouse & Wells, 1997). This measure is considered linguistically demanding (Kan & Windsor, 2010), and was simply scored as correct or incorrect. As such, children in both groups tended to score close to basal on the production task. This resulted in a lack of variability in the group scores for both the comprehension and production measures of fast mapping, which may have contributed to a non-significant relationship between nonword repetition and fast mapping performance (Gray, 2006). The equivocal nature of the literature highlights the need for further investigation into the relationship between phonological STM and fast mapping in children with DLD.

Despite the theoretical link between phonological STM and fast mapping, to our knowledge only one study has explored the nature of this relationship by examining fast mapping accuracy in novel words of different lengths. Alt (2011) presented seven and eight-year-old children (with and without DLD) with either short (two-syllable) or long (four-syllable) novel words as a means of exploring whether the *word length effect* – observed in nonword repetition performance – would extend to fast mapping performance. Children with DLD produced and recognised the short novel words with similar accuracy to the TD children; however, accuracy was significantly worse for the longer stimuli. Alt (2011) proposed that children with DLD experienced this pattern of difficulty because the longer novel words exceeded the bounds of their phonological STM capacity; a finding that suggests the proposed *word length effect* may similarly affect both nonword repetition and fast mapping, and provides further support for theoretical claims that deficits in phonological STM may contribute to word learning impairments experienced by children with DLD (Alt, 2011; Baddeley et al., 1998).

1.5. The relationship between receptive vocabulary, phonological short-term memory, and fast mapping

A body of research demonstrates a strong link between nonword repetition and existing vocabulary knowledge in children with typical language (Alloway, Rajendram, & Archibald, 2009; Baddeley, 2003; Gathercole & Baddeley, 1990; Gathercole, Service, Hitch, Adams, & Martin, 1999). Existing vocabulary is suggested to support nonword repetition by providing a store of phonological patterns or templates to draw from in order to form new representations required for repetition (Bowey, 2001). This relationship has also been documented in children with DLD (Munson, Kurtz, & Windsor, 2005b; Vugs, Knoors, Caperus, Hendricks, & Verhoeven, 2016). While these findings support a link between vocabulary (i.e., static measures of word knowledge) and nonword repetition (arguably a dynamic task involving processing and encoding), findings regarding the influence of existing vocabulary during the dynamic process of word learning (i.e. fast mapping) are equivocal for both DLD and TD populations.

For instance, Gray (2006) explored the relationship between receptive vocabulary and fast mapping in TD children and those with DLD, and found it contributed to a small (non-significant) amount of variance. While it was suggested that receptive vocabulary was likely to be an important contributing factor, in this study the groups were not separated in the regression analysis, which may have resulted in the TD group scores masking a potential relationship (Gray, 2006). Similarly, Rice, Buhr, and Nemeth (1990), Rice, Buhr, and Oetting (1992), and Rice, Oetting, Marquis, Bode, and Pae (1994) found no association between receptive vocabulary and fast mapping comprehension scores. However, in these studies, children were sampled based on lower vocabulary performance, hence limiting the variability among scores. In contrast, Alt et al. (2004) and Gray (2004) explored the influence of receptive vocabulary on fast mapping in four to six-year old children with DLD and TD children, and found it correlated with fast mapping recognition, production, and comprehension performance in both groups. This aligns with theoretical expectation that the existing vocabulary store facilitates the establishment of novel phonological strings (Montgomery et al., 2010).

While previous research into the association between receptive vocabulary, nonword repetition, and fast mapping in children with DLD remains unclear, it seems that receptive vocabulary may similarly support both nonword repetition and fast mapping (Baddeley, 2003; Hick, Joseph, Conti-Ramsden, Serratrice, & Faragher, 2002; Montgomery et al., 2010), and this relationship requires further investigation in this group of children.

1.6. The current study

In a previous study by our research team, we examined fast mapping performance in five-year-old (preschool) children with DLD and TD children using novel words of varied lengths (two, three, and four syllables; Jackson, Leitão, & Claessen, 2016). The results indicated that overall, children with DLD were significantly less accurate at fast mapping the phonological label (measured by a production task that was scored according to the percentage of phonemes that were correctly produced) compared to TD children. Additionally, nonword repetition performance and receptive vocabulary were both significant predictors of fast mapping production accuracy (Jackson et al., 2016). However, in that study we did not examine nonword repetition and fast mapping performance at the different nonword lengths, which may have shed further light on the *word length effect* and how it affects accuracy on these two tasks. One previous study (Alt, 2011) found evidence of this effect on fast mapping performance in seven and eight-year-old children; however, we aimed to extend this research into younger (preschool) children. This is important given that working memory capacity is thought to considerably grow throughout the period of childhood (Gathercole & Hitch, 1993), and thus, if phonological STM capacity does in fact constrain word learning, this may impact how children of different ages learn novel words at different lengths (Gathercole & Baddeley, 1990).

Thus, the present study aimed to extend the findings of Jackson et al. (2016) by re-analysing the data to investigate the effect of word length on nonword repetition and fast mapping performance. Specifically, we aimed to compare performance of children with and without DLD on these tasks and examine whether performance on both tasks varies as a function of nonword length, after controlling for receptive vocabulary. If the *word length effect* is indeed found to constrain fast mapping performance in children with DLD, this will have implications for the development of intervention strategies that support these children to develop strong and accurate representations of novel words that are both short and long – an important skill given the high incidence of English words that are multisyllabic (Balota et al., 2007).

2. Method

2.1. Participants and measures

This research involved further analysis of data (collected within Australia) from Jackson et al. (2016). A total of 49 five-year-old children participated in the study (see Table 1 for participant characteristics). The project was approved by the Curtin University Human Research Ethics Committee. Following ethics approval, a specialist language development centre was approached to recruit children with DLD, and a mainstream school (matched to the language centre for socio-economic status) was approached regarding recruitment for the TD group. Following principal consent, teachers at the respective schools were informed of the general criteria for inclusion, and they then distributed information letters and consent forms to parents or caregivers of children who met these criteria. General criteria included: English as a primary or dominant language; no significant history of hearing or medical conditions; and no significant behavioural, pragmatic, or articulatory difficulties. Parents or caregivers provided informed written consent prior to their child's participation. At the language development school, 70% of the approached sample were consented to participate, and 58% consented from the mainstream school.

Twenty-three children diagnosed with DLD were recruited and formed the 'DLD group'. These children were enrolled at the centre on the basis of meeting the diagnostic criteria for DLD that were in effect at the time of recruitment: impaired oral language skills with unimpaired nonverbal cognitive skills (American Psychiatric Association, 2013). Their inclusion in the study was confirmed by meeting the following criteria: a Core Language Score of 85 or less (1 SD below the mean) on the Clinical Evaluation of Language Fundamentals, Preschool second edition (CELF-P2; Wiig, Secord, & Semel, 2006) and a raw score of 14 or more ('average range') on the Raven's Coloured Progressive Matrices (CPM; Raven, 2003). The CELF-P2 Core Language Score was selected because its diagnostic accuracy at the standard score cut-off of 85 has .85 sensitivity and .82 specificity (Wiig et al., 2006). While standard scores are not available for the Raven's CPM, a raw score of 14 or higher indicates non-verbal cognitive functioning in the average range for this age group. This assessment has acceptable internal consistency (Cronbach's α = .80) and test-retest reliability (r = .87; Raven, 2003).

Twenty-six children with normally developing language were recruited from a mainstream school to form the 'TD group'. Teachers at the school were asked to flag children with apparent typical language skills for potential participation, and inclusion in the group was confirmed by achieving a Core Language Score of 86 or above on the CELF-P2 and 14 or higher on the Raven's CPM. While the Core Language criteria of ≤ 85 for DLD and ≥ 86 for TD raises questions about the similarity of oral language skills between the groups, a *t*-test confirmed that the two groups differed significantly in their performance on the CELF-P2 Core Language Score (range: 63 to 84 in the DLD group; 100 to 134 in the TD group; see Table 1). In addition to having lower scores on this standardised test, the children included in the DLD group were enrolled at the language centre as they required ongoing specialist intervention and educational support for oral language difficulties, as determined by the team of specialist teachers and speech-language pathologists at the centre.

Additional descriptive measures of receptive vocabulary and phonological STM were administered for use in the analysis but had no bearing on group inclusion. To assess receptive vocabulary, the Peabody Picture Vocabulary Test, fourth edition (PPVT-IV; Dunn & Dunn, 2007) was administered according to the assessment guidelines. This task involves pointing to a named item from an array of four pictures and has high internal consistency (α = .93 to .95) and acceptable validity (.84; Dunn & Dunn, 2007). Standard scores were obtained to be used in the analyses (see Table 1 for group scores).

The Nonword Repetition Test, developed by Dollaghan and Campbell (1998), was administered to assess phonological STM and has an acceptable level of internal consistency (demonstrated by a split-half reliability coefficient of .85). The stimuli includes 16 nonwords – four each at four syllable lengths (one to four syllables). The syllable shapes at each length are: CVC, CVCVC, CVCVCVC, and CVCVCVCVC (Dollaghan & Campbell, 1998). Nonwords were constructed to be dissimilar to English words and exclude any of the 'late eight' consonants to minimise articulatory difficulty (Dollaghan & Campbell, 1998). Procedures for nonword pronunciation and administration were followed, and the task was delivered 'live voice' to participants. Responses were scored on-line using the percentage of consonants correct (PPC) method, and were audio recorded for later checking. A trained research assistant (a final-year speech-language pathology undergraduate student) later re-scored all nonword repetition tasks, and high reliability between scorers was found (r = .96). To ensure that performance on the task was not constrained by restrictions in participants' phonological inventories, in accordance with procedures outlined by Dollaghan and Campbell (1998), we examined each participant's nonword repetition performance and flagged any consonants that were repeated incorrectly at least once. In subsequent testing sessions, the spontaneous speech of participants was observed to look for evidence that those incorrectly repeated sounds were in the participant's phonological inventory. If so, these incorrect productions were marked as errors in scoring the nonword repetition task; if not, the sound was scored as correct (Dollaghan & Campbell, 1998).

Table 1
Participant Characteristics and Means and Standard Deviations on Standardised Assessments

	DLD (18 boys, 5 girls)		TD (10 boys, 16 girls)			
	M	*SD*	*M*	*SD*	*p*	*d*
Age in months	64.39	4.10	65.92	2.98	.148	0.43
CELF-P2 CLS[a]	80.39	5.70	108.54	8.74	**<.001**	3.82
Raven's CPM[b]	17.13	2.94	20.42	3.71	.079	0.20
PPVT-IV[a]	90.83	7.13	108.04	9.43	**<.001**	2.06
Nonword Repetition[c]	65.59	8.91	87.46	4.55	**<.001**	3.09

Note. CELF-P2 CLS = Clinical Evaluation of Language Fundamentals, preschool second edition – Core Language Score; CPM = Coloured Progressive Matrices; PPVT-IV = Peabody Picture Vocabulary Test, fourth edition.

[a]Standard score. [b]Raw score. [c]Percent phonemes correct score.
Values in boldface were significant at $p < .05$, two-tailed.

2.2. Fast mapping stimuli
The fast mapping task (also described in Jackson et al., 2016) was designed to assess participants' ability to fast map the phonological label for nine unfamiliar 'alien' objects. The objects were hand-constructed from coloured modelling clay and were designed to be visually dissimilar (see Appendix A). The nine objects were paired with nonword labels ranging in length (3 x two-syllable, 3 x three-syllable, and 3 x four-syllable nonwords). Phonotactic probability (the frequency with which sounds and sound segments occur within a word position; Munson et al., 2005b) of the nonwords was considered, as this can significantly impact word learning performance (Alt & Plante, 2006; Gray, Pittman, & Weinhold, 2014). First, a randomised list of 227 real words were processed using the N-Watch algorithm (Davis, 2005) and the mean and standard deviation phonotactic probabilities of real words at two, three, and four syllables were calculated. Following that, 29 nonwords were selected from previous nonword repetition and fast mapping studies (Gathercole, Willis, Baddeley, & Emslie, 1994; Gupta, 2003; Munson, Edwards, & Beckman, 2005a) and the N-Watch algorithm was used to calculate their phonotactic probabilities. All those with probabilities that were less than one standard deviation below the mean for that syllable length (calculated from the real word sample) were considered to have low phonotactic probability (Davis, 2005). Previous research shows that children with DLD may not take advantage of high phonotactic probabilities to the same extent as TD children (Gray et al., 2014); thus, nonwords with low phonotactic probabilities were selected as stimuli (see Appendix B).

The articulatory complexity of the nonwords was also considered: we selected nonwords if they contained phonemes that are considered to typically develop before the age of five. Some consonant clusters were included, as the use the cluster reduction phonological process generally resolves by this age (Bernthal, Bankson, & Flipsen, 2009). Participants' phonological errors (such as cluster reductions) were taken into account when scoring the fast mapping task (see *Section 2.5*). The selection of nonwords with low phonotactic probability and developmentally appropriate phonemes was prioritised; thus, the nonwords varied in syllable shape. All two-syllable nonwords were CVCVC; the three-syllable stimuli were CVCVCVC, CVCVCVCC, and CVCCVCVC; and four-syllable nonwords were CVCVCCVCV, CVCVCVCVC, and CVCVCVCVC. An additional two nonwords were selected for training purposes: one two-syllable (CVCVC) and one three-syllable nonword (CVCVCVCC). The novel names were arranged into three sets, each set consisting of a two, three, and four-syllable nonword (see Appendix B).

2.3. Fast mapping training phase
The fast mapping task involved presenting the novel objects and their nonword labels in an interactive task using coloured blocks. To familiarise participants with the task requirements, the two training items were presented, one at a time. First, the participant was encouraged to build a farm scene using the coloured blocks (see Appendix A). They were then instructed that they would be learning the names of some aliens and that they had to try their best to remember the names.

Both training items (aliens) were inside a toy rocket, and the examiner pretended to land the rocket on the farm. The participant was instructed to select an item from the rocket without looking (to ensure random presentation). Over a period of approximately 60 seconds, the examiner modelled the nonword label for the alien three times within simple commenting or instructional phrases (e.g., "You picked out /poʊdɔd/… Put /poʊdɔd/ on the horse… /Poʊdɔd/ likes the horse."). Following this exposure phase, a production probe was administered to assess how accurately participants had fast mapped the phonological label (i.e., "What is its name?"). Participants were provided with feedback regarding their production accuracy in the training task. Training proceeded identically with the second item in the training set.

2.4. Fast mapping experimental phase
The experimental phase proceeded similarly to the training phase. The three sets were presented one at a time in randomised order. To present the first set, the farm setting was used, as in the training phase. All three items (the aliens with the two, three, and four-syllable labels) in the first set were placed inside the rocket, and the examiner 'landed' the rocket on the farm. As in the training phase, the participant randomly selected one item, and the examiner provided three verbal exposures to the nonword label within

simple sentences. The production probe was then administered, and neutral feedback was provided. This procedure was followed for the remaining two items in the set.

After all items had been administered in a set, participants were given up to three minutes to use the blocks to construct a different setting (such as a park or backyard). This was to provide a break from the task and maintain interest. The examiner placed the second set of three items into the rocket, and the items were individually presented and production was assessed. Participants then changed the blocks to create a different setting, and the third set was presented following the same procedure.

2.5. Scoring

Responses on the production task were scored on-line using the PPC method. They were also audio recorded for score checking, and all productions were double scored by a trained research assistant (final year speech pathology undergraduate student). There was high inter-rater reliability (r = .93) and internal consistency (α = .84). As with the nonword repetition scoring (see *Section 2.1*), observations of participants' spontaneous speech were used to examine phonological inventories, and any consistent errors in their speech production were taken into account when assigning a PPC score (Dollaghan & Campbell, 1998).

2.6. General procedures

Following approval from relevant committees, participant recruitment commenced. Each participant took part in four short sessions over two days in consecutive weeks. In their first week of participation, the CELF-P2 Core Language subtests and Raven's CPM were administered in two sessions (15-20 minutes each) on the same day. The following week, participants took part in the data collection measures in two 20-minute sessions: the first session involved administering the nonword repetition and PPVT-IV tasks, and the second was for the fast mapping task (the training and experimental task were administered in succession).

2.7 Analysis

The current study involved the use of two mixed model analyses of covariance (ANCOVA) with appropriate post-hoc tests. The first ANCOVA was a 2 (group) x 4 (word length) design, selected to explore the impact of word length on nonword repetition accuracy amongst children with DLD and TD children, while controlling for receptive vocabulary. The second ANCOVA was a 2 (group) x 3 (word length) design to examine the influence of word length on fast mapping production accuracy in the two groups (with receptive vocabulary as a covariate).

3. Results

3.1. Fast mapping and nonword repetition

As reported in Jackson et al. (2016), the children with DLD were significantly less accurate overall at producing the fast-mapped words than the TD children and also performed significantly worse on the nonword repetition task. Furthermore, both nonword repetition and PPVT-IV scores accounted for a significant proportion of variance in fast mapping production performance when collapsing scores across the groups.

3.2. Nonword repetition and word length

Given that previous research indicates a strong relationship between receptive vocabulary and nonword repetition (e.g., see Alloway et al., 2009; Gathercole et al., 1999), we explored correlations between these measures and found that PPVT-IV scores correlated significantly with nonword repetition across all nonword lengths (r values ranged from .49 to .64, all p values < .001). Therefore, a mixed model ANCOVA with a 2 (group) x 4 (word length) design was used to investigate the impact of word length (number of syllables) on the nonword repetition accuracy of children with DLD and TD children, after controlling for receptive vocabulary. All assumptions were tested and met, and the results of the ANCOVA are summarised in Table 2. The main effect of nonword length was not statistically significant [$F(3, 132) = 1.04$, $p = .379$, partial $\eta^2 = .02$]. However, there was a significant main effect of group [$F(1, 44) = 48.79$, $p < .001$, partial $\eta^2 = .53$], with nonword repetition scores in the TD group (M = 87.34 PPC, SE = 1.74 PPC) being significantly higher than the DLD group (M = 66.29 PPC, SE = 1.89 PPC). There was also a significant interaction between nonword length and group [$F(3, 132) = 5.44$, $p < .001$, partial $\eta^2 = .11$]. This suggests that after controlling for receptive vocabulary, nonword repetition performance does not decline as the word length increases for TD children. However, children with DLD exhibit increased difficulty as nonword length increases (see Figure 1a).

Table 2
ANCOVA Results for Nonword Repetition by Group and Word Length

Source	*Sum of Squares*	*df*	*Mean Square*	*F*	*p*	*Partial η²*
Group	9352.04	1	9352.04	48.79	**< .001**	.53
Length	289.15	3	96.38	1.04	.379	.02
Group × length	1519.70	3	506.57	5.44	**< .001**	.11
PPVT	.90	1	.90	.005	.946	.00
Error	144.53	29	4.98			

Note. Reported values are percent phonemes correct; values in boldface were significant at $p < .05$.

To further analyse the interaction between nonword length and group, we conducted post-hoc ANCOVA comparisons for each nonword length (controlling for receptive vocabulary). In comparison to the children with DLD, TD children were significantly more accurate at repeating nonwords at all four syllable lengths, with medium to large effect sizes (see Table 3). When examining performance across the nonword lengths in the DLD group, there was no significant difference in performance for repetition of two and three-syllable nonwords. However, their performance dropped significantly from three to four syllables. In contrast, in the TD group, there was no significant difference in performance at any of the nonword lengths.

Table 3
Results of the Post-hoc ANCOVAs for Nonword Repetition and Fast Mapping

	DLD			TD					
	M	*SE*	95% CI	*M*	*SE*	95% CI	*F*	*p*	*Partial η²*
Nonword repetition									
1-syllable	84.48	2.85	78.74 – 90.22	94.66	2.61	89.40 – 99.92	5.05	**.030**	.10
2-syllable	74.23	2.26	69.68 – 78.78	90.91	2.07	86.75 – 95.07	21.63	**< .001**	.33
3-syllable	62.94	2.75	57.40 – 68.94	87.44	2.52	82.36 – 92.52	31.27	**< .001**	.42
4-syllable	43.53	3.81	35.86 – 51.20	76.36	3.49	69.34 – 83.39	29.41	**< .001**	.40
Fast mapping									
2-syllable	52.91	5.72	41.39 – 64.42	70.80	5.39	59.93 – 81.66	3.74	0.059	.08
3-syllable	33.64	4.61	24.36 – 42.91	73.43	4.35	64.68 – 82.19	28.52	**< .001**	.39
4-syllable	21.96	4.68	12.53 – 31.39	55.80	4.42	46.90 – 64.70	19.95	**< .001**	.31

Note. Estimated marginal means are reported; reported values are percent phonemes correct; values in boldface were significant at $p < .05$.

3.3. Fast mapping and word length

In light of research suggesting that receptive vocabulary may influence fast mapping (Alt et al., 2004; Gray, 2004), correlations were run, and PPVT-IV standard scores significantly correlated with fast mapping production performance across all novel word lengths (*r* values ranged from .47 to .68, all *p* values < .001). Therefore, we conducted a mixed model ANCOVA with a 2 (group) x 3 (length) design, to investigate the influence of novel word length on fast mapping performance while controlling for receptive vocabulary. The assumptions for a mixed model ANCOVA were tested and were not violated. The results of the ANCOVA are summarised in Table 4.There was no significant main effect of length on fast mapping performance after controlling for receptive vocabulary [$F(2, 90) = .14$, $p = .869$, partial $\eta^2 = .003$], indicating that overall fast mapping accuracy does not significantly change as the length of novel words increases. However, a significant main effect of group on fast mapping was found [$F(1, 45) = 24.73$, $p < .001$, partial $\eta^2 = .36$], with TD children (*M* = 66.68 PPC, *SE* = 3.58 PPC) showing significantly higher fast mapping production performance than children with DLD (*M* = 36.17 PPC, *SE* = 3.79 PPC).

Table 4
ANCOVA Results for Fast Mapping by Group and Word Length

Source	*Sum of Squares*	*df*	*Mean Square*	*F*	*p*	*Partial* η^2
Group	14822.48	1	14822.48	24.73	**< .001**	.36
Length	64.13	2	32.06	.14	.869	.003
Group × length	1361.83	2	680.91	3.00	.055	.06
PPVT	798.45	1	798.45	1.32	.254	.01
Error	26969.43	45	599.32			

Note. Reported values are percent phonemes correct; values in boldface were significant at $p < .05$.

We did not find a significant interaction between word length and group in their effects on fast mapping performance [$F(2, 90) = 3.00$, $p = .055$, partial $\eta^2 = .06$]. However, the effect size was small to medium; therefore, exploratory post-hoc ANCOVAs were conducted to explore between-group differences at each syllable length while controlling for receptive vocabulary (see Table 3). There was no significant between-groups difference for fast mapping two-syllable novel words, but TD children were significantly more accurate at producing fast mapped novel words of three and four syllables in comparison to children with DLD (with large effect sizes;). The (non-significant) interaction between word length and group is plotted in Figure 1b.

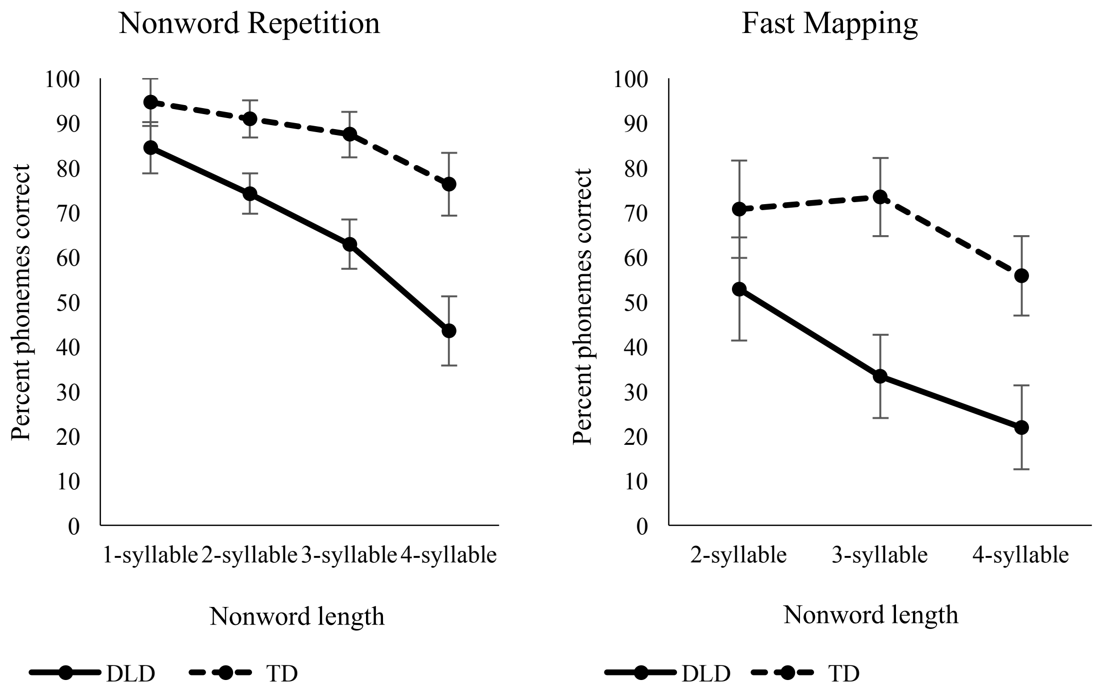

Figure 1a. Significant interaction between word length and group on nonword repetition, after controlling for receptive vocabulary.
Figure 1b. Non-significant interaction between word length and group on fast mapping, after controlling for receptive vocabulary.
Error bars represent 95% confidence intervals.

4. Discussion

4.1. The impact of word length on nonword repetition and fast mapping

Extensive evidence of a phonological STM deficit in children with DLD has been provided by studies exploring their nonword repetition abilities (e.g., see Archibald & Gathercole, 2007; Gathercole & Baddeley, 1990; Edwards & Lahey, 1998). The findings of our previous paper aligned with this research (Jackson et al., 2016), with our group of preschool children with DLD overall performing significantly worse on a nonword repetition task (Dollaghan & Campbell, 1998) relative to their TD peers. To further explore the nature of the nonword repetition deficit in children with DLD, previous research has examined performance at different nonword lengths, with the results generally indicating that shorter nonwords are produced with greater accuracy (and sometimes at an accuracy comparable to TD children; Coady & Evans, 2008; Gathercole & Baddeley, 1998; Weismer et al., 2000); however, the deficit increases when faced with longer words. Thus, the first aim of the current paper was to further investigate the proposed *word length effect* for nonword repetition (Dollaghan & Campbell, 1998; Jones et al., 2010).

The results of our investigation diverged somewhat from those of previous studies. In line with the predictions of the *word length effect*, we were expecting that children with DLD would be comparable to TD children when repeating one and two-syllable nonwords, but show significantly poorer performance for three and four-syllable nonwords (i.e., at the point where they reach their ‘capacity limit’; Dollaghan & Campbell, 1998; Jones et al., 2010). However, our group of children with DLD were significantly worse at repeating nonwords of all lengths compared to their TD peers. It is noteworthy, however, that while all effect sizes for the between-groups differences were large, the largest effect sizes were obtained at three and four syllables (partial η^2 = .42 and .40, respectively). This aligns with the findings of Estes et al. (2007) and suggests that the magnitude of the deficit experienced by children with DLD is greater when they are faced with lengthier phonological strings that place a greater strain on their reduced phonological STM capacities.

A factor that may explain the global difficulty our children with DLD had with repeating both short and long nonwords might be that our participants were considerably younger (5;0 – 5;11) than those in previous studies. For instance, Dollaghan and Campbell’s (1998) participants (in the DLD and TD groups) were aged 6;0 to 9;9, and significant between groups diffferences were not found at one and two syllables, but only at three and four syllables. The poorer performance across all syllable lengths exhibited by our group of children with DLD may therefore be a reflection of developmental differences in phonological STM capacity size (Gathercole & Hitch, 1993). Another possible interpretation is one which challenges the suggestion that the nonword repetition deficit in children with DLD is largely a reflection of reduced phonological STM capacity (Estes et al., 2007). For instance, Weismer et al. (2000) also found that older children with DLD (mean age 7;11) struggled to repeat short nonwords, and suggested that broader issues regarding phonological processing (such as general difficulties encoding phonological stimuli, phonological analysis, or motor programming) may affect the capacity of some children with DLD to repeat novel words above and beyond a phonological STM deficit (Bishop, 1997; Nash & Donaldson, 2005). While previous studies have specifically explored these factors, and suggested they do not significantly contribute to nonword repetition deficits in children with DLD (e.g., Edwards & Lahey, 1998), the heterogeneity of the DLD population may mean that our relatively small sample comprised children with deficits in these broader phonological processing skills (Kamhi & Catts, 1986; Metsala, 1999; Tallal et al., 1996). We attempted to exclude participants with deficits in hearing and articulation; however, specific and comprehensive assessment of areas such as hearing, phonological discrimination, and articulation were not administered. Future research should consider measuring and controlling for these factors in nonword repetition performance, with larger sample sizes.

Examination of the within-groups performance for nonword repetition showed greater consistency with the proposed *word length effect*. In relation to their own performance, children with DLD performed similarly when repeating one and two-syllable nonwords; however, their repetition accuracy dropped significantly from two to three-syllables and then again from three to four-syllables. These findings support the predictions of the *word length effect* in that longer nonwords pose a greater challenge for processing capacity than shorter ones (Dollaghan & Campbell, 1998; Estes et al., 2007). On the other hand, in the TD group, nonword repetition performance declined non-significantly as nonword length increased. Based on previous research, it was expected that the TD children may have exhibited a considerable drop in accuracy when faced with the longest words (e.g., four-syllables; Dollaghan & Campbell, 1998). This pattern of performance suggests that our particular group of TD children may have had greater phonological STM capacities (Gathercole & Adams, 1993). Alternately, given that receptive vocabulary was used as a covariate in the analyses, these findings may indicate that for TD children, vocabulary knowledge may work to offset difficulties with nonword repetition as the task becomes more difficult and the nonwords exceed the bounds of phonological STM capacity (Alt et al., 2004; Gray, 2004, 2006; Hick et al., 2002; Vugs et al., 2016).

Given that phonological STM is thought to constrain fast mapping abilities (Baddeley et al., 1998; Gathercole & Baddeley, 1990; Kan & Windsor, 2010), we expected a similar pattern of performance in nonword repetition and fast mapping accuracy across the groups. However, our results showed that word length affected fast mapping differently to nonword repetition. Examination of the between-group differences of fast mapping accuracy at the different word lengths revealed that there was not a statistically significant difference between the groups for fast mapping of the shortest (two-syllable) novel words. However, there was a moderate effect size ($\eta^2 = .08$). Post-hoc testing also revealed that children with DLD were significantly worse at fast mapping both three and four-syllable novel words relative to the TD children (and large effect sizes were observed). These findings seem to differ from those of a previous study by Alt (2011), in which the DLD and TD groups fast mapped two-syllable novel words with comparable accuracy. These contrasting findings may be attributable to age differences in participants (children were aged seven and eight in Alt, 2011); thus, the children with DLD may have had greater phonological STM capacities than our five-year-olds, which facilitated their successful fast mapping of the shorter novel words. While our findings provide preliminary insight into the impact of word length on fast mapping, the results need to be interpreted with caution given that the overall interaction was not significant. This may have occurred due to the relatively small sample size; we were potentially underpowered to find statistically significant effects. These findings should be replicated and extended using a larger sample.

Finally, on examination of the general accuracy of the children's nonword repetition and fast mapping (as indicated by their PPC scores on both tasks), we can see that at each nonword length these scores were higher for nonword repetition than fast mapping (see Table 3). These results suggest that both groups of children were more successful at learning phonological forms in a nonword repetition context. We had expected that, overall, the children may have achieved greater PPC scores in the fast mapping task compared to nonword repetition, because our fast mapping procedure involved processes that should facilitate phonological learning. For instance, the novel words were heard three times (instead of just once, as in nonword repetition). Based on previous research that indicates increased input frequency facilitates learning (e.g., Rice et al., 1994), this factor was expected to result in greater accuracy, given that the children had increased opportunities to refine the phonological representation before production was required (Kan & Windsor, 2010). The items were also given as labels for tangible objects, which would presumably facilitate the establishment of a semantic representation (Zens, Gillon, & Moran, 2009), and were presented in simple sentence frames, which should allow the child to use implicit syntactic and semantic bootstrapping processes that generally work to strengthen representations for unfamiliar words (Horohov & Oetting, 2004).

Yet, the lower fast mapping scores may have resulted from the nature of the learning context for fast mapping, with the multiple linguistic cues placing a greater load on cognitive resources (Alloway et al., 2009). This was perhaps detrimental to learning the phonological form. It is also possible that attention resources were directed towards engagement in the play-based aspects of the fast mapping task, whereby children could interact with the setting while hearing the novel word forms. In contrast, nonword repetition is highly specified and designed to primarily require phonological processing, with minimal demands placed on other areas of processing (such as semantics; Dollaghan & Campbell, 1998), thus supporting the establishment of the phonological representations.

While the idea of teaching new words in an isolated, phonological manner does not seem particularly useful (given the need for children to develop multiple representations to be able to understand and use a new word in context; Stackhouse & Wells, 1997), this consideration raises some possibilities around how we initially introduce novel words to children. For instance, it may be the case that children are able to achieve greater success with word learning if they are first introduced to the phonology of a new word in relative isolation, before bringing in additional information regarding other components (i.e. building up a complete 'map' of a new word progressively). This could be the focus of further research.

4.2. Clinical implications

In summary, the results showed that children with DLD exhibited an impaired capacity to encode incoming phonological information, but this differentially affected their nonword repetition and fast mapping abilities. In the fast mapping task, the children with DLD achieved relatively more success laying down an accurate phonological representation if the words were shorter. This has implications for informing targeted intervention strategies for word learning for children with DLD, such as ensuring the provision of visual information to facilitate development of a semantic representation that supports the establishment of a more stable form-meaning map (Alt & Plante, 2006). Additionally, given that children with DLD struggled most with longer novel words, strategies need to be trialled that support their success for establishing multisyllabic words that exceed the bounds of their phonological STM capacity. This could include scaffolding a child into a new concept by first teaching a shorter word to build understanding (Alt, 2011). Previous research also suggests that children with DLD benefit from a greater number of exposures to a novel word to effectively learn it (Rice et al., 1994), and investigation into whether this strategy may assist with offsetting phonological STM weaknesses would be beneficial.

Our findings also reinforce the utility of the nonword repetition task as a clinical marker of the disorder (Bishop, North, & Donlan, 1996; Botting & Conti-Ramsden, 2001); however, differential performance across the word lengths should be considered, and performance should be carefully interpreted in light of other areas of potential impairment that may contribute to global difficulties repeating nonwords of all lengths (Weismer et al., 2000). Given the general similarities in performance on both nonword repetition and fast mapping in the children, we suggest that nonword repetition has predictive value in understanding a child's potential word learning capabilities, and is therefore a helpful tool in devising directions for therapy (Conti-Ramsden, Botting, & Faragher, 2001).

4.3. Limitations and future directions

A key limitation in the study was our use of a single outcome measure to assess fast mapping (i.e., a production task). Previous research suggests that production is the most difficult task for children to complete, as it requires the establishment of an output representation, which involves a "fine-grained knowledge of the phonemic structure of words" (Alt, 2011, p. 181). However, a different pattern of performance may emerge when using tasks that assess input processing, such as comprehension or recognition (Kan & Windsor, 2010); therefore, future research should include a range of assessments to measure fast mapping success. Another methodological limitation is that we did not include a one-syllable novel word in the fast mapping task, making it difficult to make a direct and comprehensive comparison between all word lengths on the fast mapping and nonword repetition tasks. Future investigations should modify the fast mapping methodology to allow for this. An additional consideration for future use of the fast mapping task is that the four-syllable stimuli included later-acquired fricatives (e.g. /s/ and /ʃ/; Bernthal et al., 2009). While we considered each child's phonological inventory in scoring these items, in future use of the task these items may be replaced by those that contain only earlier-developing phonemes to avoid the potential confound of delayed phonological acquisition.

While our research focused on short-term learning of novel words, in line with mapping theory it would be expected that deficits with initial encoding of novel word forms would adversely impact slow mapping (i.e., long-term word learning; Carey & Bartlett, 1978; Nash & Donaldson, 2005). However, to verify these assumptions, the trajectory of the word learning process should be explored longitudinally, which would further add to understanding of potential points of breakdown in this process in children with DLD (Bion et al., 2013). Further, our findings highlight the specific deficit in phonological learning experienced by children with DLD; however, it is conceivable that this would extend to their difficulty in establishing detailed semantic representations (Stackhouse & Wells, 1997). Future studies should therefore investigate factors that additionally impact semantic learning, and consider broader ramifications of poor phonological fast mapping on the establishment of other aspects of lexical development (Chiat, 2001).

5. Conclusions

Our findings reinforce the notion that phonological STM is an area of core deficit in children with DLD, and provides evidence that this factor considerably impacts their ability to establish phonological representations in the early stages of learning new words (Baddeley et al., 1998; Gathercole, 2006). Thus, the results help to clarify the nature of word learning problems in children with DLD, and provide additional support for the *limited capacity processing account* of DLD – that these children experience an inherent deficit in the processing, encoding, and storage of verbal information, and this affects broader aspects of their language development (Gathercole, 2006; Conti-Ramsden et al., 2001). In contrast to previous findings, however, our results suggest that the deficit experienced by children with DLD in nonword repetition may not be fully ascribed to a deficit in phonological STM capacity, as they experienced breakdown at all word lengths relative to their TD peers. Thus, these findings likely reflect the heterogeneity of the DLD population, and suggest that performance on nonword repetition and fast mapping tasks in children with DLD may be adversely affected by more general deficits in phonological encoding, phonological representations and/or poor perception, which warrants further investigation (Archibald & Joanisse, 2009).

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Appendix A
Examples of Fast Mapping Materials

Figure 1. Images of hand-constructed clay objects for fast mapping stimuli. Set 1 shown: /doʊnug/, /gɔnəpek/, and /jelæntɪfɜ/.

Figure 2. Images of play-based settings that were constructed by participants for the fast mapping task.

Appendix B
Nonword Stimuli for Fast Mapping Task

Item Length	Training	Set One	Set Two	Set Three
2-syllable	/poʊdɔd/	/doʊnug/	/jugɔɪn/	/boʊgib/
3-syllable	/kɜdəwəmb/	/gɔnəpek/	/fɪkətæmp/	/tʌgnədit/
4-syllable[a]		/jelæntɪfɜ/	/gufeʃɜgʊs/	/jɔfeʃɜged/

Note. Participants were not penalised in the scoring of this task if they produced a schwa sound instead of the final 'ɜ' in /jelæntɪfɜ/.

[a]No four-syllable word item was included in the training set, to aid familiarisation with the task requirements without the increased cognitive load of learning a longer phonological label.