Research Article

Spoken Word Learning Differences Among Children With Dyslexia, Concomitant Dyslexia and Developmental Language Disorder, and Typical Development

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Purpose: The purpose of our study was to test the hypotheses (a) that children with dyslexia have spoken word learning deficits primarily related to phonology and (b) that children with dyslexia and concomitant developmental language disorder (DLD) have word learning deficits related to both phonology and semantic processing when compared to peers with typical development (TD).

Method: Second-graders with dyslexia ($n = 82$), concomitant dyslexia and DLD (dyslexia + DLD; $n = 40$), and TD ($n = 167$) learned names and semantic features for cartoon monsters in 5 carefully controlled word learning tasks that varied phonological and semantic demands. The computer-based tasks were played in 6 different word learning games. We analyzed results using Bayesian statistics.

Results: In general, the dyslexia + DLD group showed lower accuracy on tasks compared to the dyslexia and TD groups. As predicted, word learning tasks that taxed phonology revealed deficits in the dyslexia group, although there were some exceptions related to visual complexity. Word learning deficits in the dyslexia + DLD group were present in tasks that taxed phonology, semantic processing, or both.

Conclusions: The dyslexia + DLD group demonstrated word learning deficits across the range of word learning tasks that tapped phonology and semantic processing, whereas the dyslexia group primarily struggled with the phonological aspects of word learning.

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One debate in the literature is the extent to which children with dyslexia and those with developmental language disorder (DLD)¹ share the same type of phonological and semantic processing deficits. Historically, people have questioned whether these disorders were distinct (Catts, Adlof, Hogan, & Ellis Weismer, 2005; Kamhi &

Catts, 1986) or overlapping (Bishop & Snowling, 2004). Broadly, we would expect children with dyslexia to have problems primarily with word reading, children with DLD to have problems primarily with oral language, and children with dyslexia and concomitant DLD (dyslexia + DLD) to have problems with both word reading and oral language.

Although there are different models of the relation between dyslexia and DLD, the current consensus is that these disorders frequently co-occur but have distinct etiologies (e.g., Adlof & Hogan, 2018; Pennington & Bishop, 2009; Ramus, Marshall, Rosen, & van der Lely, 2013; Wong, Kidd, Ho, & Au, 2010). Despite the focus on poor word reading in children with dyslexia, studies of children with

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¹There has been a recent consensus within the field to use the term *DLD* to refer to children who were previously labeled as having specific language impairment (e.g., Bishop, Snowling, Thompson, Greenhalgh, & the CATALISE-2 Consortium, 2017). We will use the term *DLD* throughout this article for consistency but want to make sure the historical link to work on specific language impairment is clear.

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dyslexia and children with DLD show that both of these groups have poor oral word learning (Alt & Plante, 2006; Alt et al., 2017; Gray, 2004; McGregor, Newman, Reilly, & Capone, 2002; Oetting, Rice, & Swank, 1995; Thomson & Goswami, 2010; Voelmle & Storkel, 2015). However, studies of both groups often fail to account for the high rate of comorbidity of dyslexia and DLD (Adlof & Hogan, 2018), making it difficult to know the source of these difficulties.

The purpose of our study was to test the hypotheses that children with dyslexia have spoken word learning deficits primarily related to phonology and that children with dyslexia + DLD have word learning deficits related to both phonology and semantic processing when compared to peers with typical development (TD). Due to these proposed deficits, we further hypothesize that those with dyslexia + DLD will have more broad-based word learning deficits compared to their peers with dyslexia. We test these hypotheses using carefully controlled word learning tasks that varied phonological and semantic demands. If there are differences between these groups, it would be helpful for clinicians and educators to know what to expect and potentially how to inform practice-based research on individualized word learning instruction.

Word Learning in Children With Dyslexia

Children with dyslexia are typically diagnosed using exclusionary criteria. After ruling out intellectual or sensory problems or neurodevelopmental syndromes, these children are characterized primarily by their difficulty in decoding written words (e.g., Adlof & Hogan, 2018), difficulty in processing phonological information (Snowling, 2001), and deficits in phonological form learning (Litt & Nation, 2014). Taken together, decades of work point to a phonological core deficit in children with dyslexia that manifests primarily in word reading (see Vellutino, Fletcher, Snowling, & Scanlon, 2004, for a review). Although a diagnosis of dyslexia only (without comorbid DLD) should verify age-appropriate grammar and vocabulary, many studies of children with dyslexia do not test oral language skills (Adlof & Hogan, 2018).

Presumably due to their primary phonological deficit, children with dyslexia have difficulty learning new words (Thomson & Goswami, 2010) and foreign languages (Downey, Snyder, & Hill, 2000), although somewhat paradoxically, their problems with phonology do not appear to significantly negatively affect oral language, as demonstrated by test scores within normal limits on tests of oral language or vocabulary (Alt et al., 2017; Catts et al., 2005). However, children with dyslexia also have difficulty with visual processing. Visual deficits in the literature include reduced visual attention span (e.g., Lobier, Zoubrinetzky, & Valdois, 2012), reduced visual short-term storage capacity (Bogon et al., 2014), and visual resolution deficits (Huestegge, Rohrßen, van Ermingen-Marbach, Pape-Neumann, & Heim, 2014). As this list shows, these problems are related to basic visual processing, visual memory, or both. In terms

of word learning, problems processing visual information could potentially translate to problems with learning visually accessible semantic information (e.g., Alt, Meyers, & Alt, 2013; Alt & Plante, 2006), such as color, texture, or details of the physical makeup of an object. Alt et al. (2017) tested the word learning skills of a large group of children with dyslexia compared to their peers with TD using carefully controlled word learning tasks that manipulated phonological and visual-semantic processing. Their results confirmed the hypothesis that children with dyslexia were weak in word learning tasks that taxed phonology compared to their peers with TD, and there were a few areas of weakness associated with visual complexity. This study was particularly informative because it included children with dyslexia who had typical language skills, eliminating the potential confound of concomitant DLD in past studies.

Word Learning in Children With Dyslexia + DLD

Similar to children with dyslexia, children with DLD are diagnosed using exclusionary criteria, ruling out intellectual disability, sensory loss, and other neurodevelopmental disorders, but they are characterized by notable difficulty with oral language skills (e.g., Adlof & Hogan, 2018), including phonology (e.g., Leonard, 1982), morphosyntax (e.g., Leonard, 1989), semantics (e.g., Alt & Plante, 2006), and pragmatics (e.g., Marton, Abramoff, & Rosenzweig, 2005). They have also been noted to have difficulty with phonological (e.g., Montgomery, Majimairaj, & Finney, 2010) and visuospatial (Alt, 2013; Vugs, Cuperus, Hendriks, & Verhoeven, 2013) working memory. Their skills with word reading may or may not be assessed, so studies of children with DLD may include those with DLD only and those with comorbid dyslexia + DLD. One might assume that, absent a problem with reading written words, children with DLD would not have difficulty with semantic processing. However, in addition to the visuospatial working memory weaknesses noted above, which are outside the realm of word learning, children with DLD have well-documented difficulty learning visually presented semantic features of novel words (e.g., Alt & Plante, 2006; Alt, Plante, & Creusere, 2004). Due to these weaknesses, it is not surprising that children with DLD have word learning deficits associated with both phonological and semantic processing impairments.

There is substantial comorbidity between children with DLD and dyslexia ranging from 17% to 71% for English-speaking children (Adlof & Hogan, 2018). In a study of Cantonese-speaking children, Wong et al. (2010) found comparable rates of comorbidity, classifying 13 of 30 (43%) children with a previous diagnosis of DLD only as actually having dyslexia + DLD. The current consensus is that these disorders frequently co-occur but have distinct etiologies; dyslexia is not considered to be a milder form of DLD (e.g., Adlof & Hogan, 2018; Pennington & Bishop, 2009; Ramus et al., 2013; Wong et al., 2010).

One problem with understanding these disorders is that most researchers do not evaluate their study participants

to determine which participants have dyslexia, which have DLD, and which have both (Adlof & Hogan, 2018). Studies of children with dyslexia are particularly susceptible to unknowingly including children with dyslexia who have concomitant DLD because DLD is notoriously underdiagnosed (upward of 70%), making it unlikely that children with dyslexia will have a documented concomitant DLD (e.g., Norbury et al., 2016; Tomblin et al., 1997). Therefore, studies that find visuospatial processing problems in children with dyslexia may unintentionally be describing children with dyslexia + DLD rather than children with dyslexia. Alternatively, some suggest that phonological deficits are primarily related to dyslexia and not DLD (e.g., Catts et al., 2005). So studies that report phonological problems in children with DLD that have not evaluated their participants for dyslexia may be attributing difficulties to DLD that are actually associated with dyslexia. Word learning experiments offer the opportunity to better understand the phonological and semantic deficits of each group.

As noted, there is evidence that both children with dyslexia (e.g., Alt et al., 2017) and children with DLD (e.g., Kan & Windsor, 2010) have poor word learning, although only children with dyslexia + DLD tend to have poor vocabularies. Word learning research provides an excellent context for examining the nature of the deficits associated with each disorder because, to learn new words, children must create, store, and link phonological and visually based semantic representations.

Alt et al. (2017) showed that children with dyslexia had word learning deficits primarily related to phonology with a few deficits for both phonological and visually based semantic tasks when the learning condition increased the visual complexity of the stimuli. In this study, we extend that work using the same carefully controlled word learning tasks, to test the hypothesis that word learning deficits in children with dyslexia + DLD are related to both phonological and visually based semantic deficits. We defined *deficit* as significantly poorer performance compared to peers with TD in the same grade.

We classified children using a methodological approach that mirrors the fully distinct hypothesis (Catts et al., 2005; as described by Adlof & Hogan, 2018) or the component model (as described by Ramus et al., 2013). These commonly used approaches characterize participants using the two components that determine a diagnosis of either dyslexia or DLD—word reading skills and oral language ability. Thus, in this study that included children with dyslexia who did or did not have concomitant DLD, dyslexia is characterized by “good” oral language skills combined with poor reading skills. Dyslexia + DLD, in contrast, is defined by “poor” oral language skills combined with poor reading skills. Given this contrast, we hypothesize that children with dyslexia will perform poorly on word learning tasks that tax phonology, as phonological deficits are the hallmark of dyslexia (e.g., Snowling, 2001). We hypothesize that children with dyslexia + DLD will perform poorly on tasks that tax phonology or visually based semantic processing,

which will result in broad-based word learning deficits compared to peers with dyslexia and TD.

Method

Participants

Participants were second-graders, ages 7–9 years, who completed tasks as part of a larger study of word learning and memory.² There were 167 monolingual English-speaking children with TD (95 girls, 72 boys), 82 monolingual English-speaking children with dyslexia (46 girls, 36 boys), and 44 monolingual English-speaking children with dyslexia + DLD (17 girls, 27 boys). Table 1 contains details about the demographics of these groups, including their scores on inclusionary and descriptive measures.

After obtaining institutional review board approval for the study, we recruited participants from schools in Arizona, Massachusetts, and Nebraska. After receiving parental consent, we tested children to ensure they met inclusionary criteria. To be included, parents had to report that their child had no history of neuropsychiatric disorders, special education services for nonqualifying categories (e.g., intellectual disability or autism), or significant exposure to languages other than English. All children were required to pass a bilateral hearing screening, near vision acuity screening, and color vision screening. They had to achieve a standard score of 75 or higher on the Kaufman Assessment Battery for Children, Second Edition (Kaufman & Kaufman, 2004) to rule out intellectual disability.

To qualify for the TD group, children were required to demonstrate age-appropriate oral language, reading, and articulation skills. To measure oral language skills, we used the core language component of the Clinical Evaluation of Language Fundamentals–Fourth Edition (CELF-4; Semel, Wiig, & Secord, 2003). Children needed to achieve a standard score of 88 or higher (1 *SD* below the normative sample mean of 85 + 1 *SE* of measure). For reading, children needed to achieve a grade-level standard score of 96 or higher on the Test of Word Reading Efficiency–Second Edition (Torgesen, Wagner, & Rashotte, 2012). This is the 40th percentile. For speech, children were required to score above the 31st percentile on the Goldman-Fristoe Test

²Participants in this article represent a portion of the participants from a larger sample in the Profiles of Working Memory and Word Learning (POWVER) study, funded by National Institute on Deafness and Other Communication Disorders Grant R01 DC010784. The POWVER study includes the groups reported, as well as bilingual children with TD. Participants in the POWVER study completed a total of six word learning games and a comprehensive battery of working memory tasks (see Cabbage et al., 2017), completed over the course of at least 6 days. Data on a subset of the groups with TD and dyslexia were reported in Alt et al. (2017) and Baron et al. (2018). Data on a subset of all three groups were reported in Cowan et al. (2017). POWVER word learning results have also been published in Arizmendi et al. (2018), Erikson et al. (2018), Gray et al. (2017), and Green et al. (2016).

Table 1. Participant demographics.

Variable	Typical development (<i>n</i> = 167; 95 girls, 72 boys)	Dyslexia (<i>n</i> = 82; 46 girls, 36 boys)	Dyslexia + developmental language disorder (<i>n</i> = 44; 17 girls, 27 boys)	Bayes factor	Interpretation	Group differences
Age in months	92.82 (4.96) 82–110	94.19 (5.39) 85–107	94.61 (5.66) 84–109	0.78	Null (anecdotal)	
MLE	15.38 (1.65) 12–17	14.83 (1.96) 9–17	14.18 (2.11) 10–17	74.27	Alternative (strong)	TD > DYS + DLD
K-ABC2	117.60 (15.52) 78–160	106.80 (13.39) 82–141	97.20 (14.46) 76–141	5.597e +12	Alternative (extreme)	TD > DYS > DYS + DLD
CELF-4	108.75 (9.58) 88–130	100.30 (8.61) 88–126	73.29 (8.32) 48–82	8.059e +61	Alternative (extreme)	TD > DYS > DYS + DLD
TOWRE-2	109.44 (8.40) 96–145	80.61 (6.23) 55–88	79.27 (7.08) 62–88	2.488e +93	Alternative (extreme)	TD > DYS = DYS + DLD
WRMT	108.22 (9.85) 82–144	93.89 (10.66) 55–115	82.11 (11.79) 55–111	9.328e +37	Alternative (extreme)	TD > DYS > DYS + DLD
EVT-2	112.38 (10.95) 90–137	103.34 (10.84) 79–137	89.18 (9.57) 55–113	5.156e +26	Alternative (extreme)	TD > DYS > DYS + DLD
GFTA-2 %ile	50.89 (8.53) 7–62	41.33 (15.96) 3–62	33.5 (18.53) 3–62	4.092e +12	Alternative (extreme)	TD > DYS > DYS + DLD
ADHD	10.19 (2.76) 0–41	13.01 (9.02) 0–40	15.17 (12.10) 0–44	2.91	Alternative (anecdotal)	
Race	3 American Indian/ Alaskan Native 3 Asian 4 Black/African American 135 White 20 More than one race 2 Not reported	3 American Indian/ Alaskan Native 2 Black/African American 61 White 12 More than one race 4 Not reported	3 American Indian/ Alaskan Native 5 Black/African American 29 White 3 More than one race 4 Not reported			
Ethnicity	145 Non-Hispanic 20 Hispanic 2 Not reported	64 Non-Hispanic 16 Hispanic 2 Not reported	30 Non-Hispanic 12 Hispanic 2 Not reported			

Note. Values are means (*SD*s) and ranges. MLE = mother's level of education; TD = typical development; DYS = dyslexia; DLD = developmental language disorder; K-ABC2 = Kaufman Assessment Battery for Children, Second Edition (Kaufman & Kaufman, 2004); CELF-4 = Clinical Evaluation of Language Fundamentals–Fourth Edition (Semel et al., 2003); TOWRE-2 = Test of Word Reading Efficiency–Second Edition (Torgesen et al., 2012); WRMT = Woodcock Reading Mastery Test, Paragraph Comprehension Subtest (Woodcock, 2011); EVT-2 = Expressive Vocabulary Test–Second Edition (Williams, 2007); GFTA-2 = Goldman-Fristoe Test of Articulation–Second Edition (Goldman & Fristoe, 2000); ADHD = parental rating of attention-deficit/hyperactivity disorder behaviors using the ADHD Rating Scale–IV Home Version (DuPaul et al., 1998).

of Articulation–Second Edition (Goldman & Fristoe, 2000). If they scored lower, they could still be included if they evidenced only one consistent articulation error that would not affect scoring on any experimental production measure.

Children in the dyslexia group were required to demonstrate good oral language skills and poor reading skills. Like the TD group, they needed a standard score of 88 or better on the CELF-4 Core Language score. For reading, they needed to receive a standard score of 88 or below ($\leq$ 20th percentile) on the Test of Word Reading Efficiency–Second Edition. We chose to use a 20th percentile cutoff score because the diagnostic criterion for dyslexia varies widely across studies, ranging from the seventh percentile (Badian, McAnulty, Duffy, & Als, 1990) to the 30th percentile (Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996), and the 20th percentile is one of the most common cut-points used in the literature on school-age children with dyslexia. Children with dyslexia had to score above the 31st percentile of the Goldman-Fristoe Test of Articulation–Second Edition. If their score was lower but they could produce all phonemes on each experimental

production measure correctly, they were still included. We used these slightly different criteria because children with dyslexia often have comorbid speech sound disorders (e.g., Peterson & Pennington, 2015).

Children with dyslexia + DLD needed to demonstrate poor oral language and reading skills. For oral language, we defined this as a standard score on the CELF-4 Core Language component of 82 or less (1 *SD* below the mean plus 1 *SE* of measure). These children had the same criteria for poor language and appropriate speech as the children in the dyslexia group.

In addition to these inclusionary criteria, we also collected descriptive data for maternal level of education and parental ratings of attention and administered a non-word repetition task (Dollaghan & Campbell, 1998), an expressive vocabulary test (Expressive Vocabulary Test–Edition; Williams, 2007), and a reading comprehension test (Woodcock Reading Mastery Test, Paragraph Comprehension; Woodcock, 2011). Means and standard deviations for all inclusionary and descriptive assessments can be found in Table 1.

Procedures, Games, and Tasks

After completing inclusionary assessments described above, children took part in six word learning games, each of which manipulated a different aspect of word learning (see Table 2). Each game took place on a different day to reduce the risk of interference. While there was variation given children's different schedules, most children met with research staff either two or three times per week (e.g., Tuesdays and Thursdays, or Mondays, Wednesdays, and Fridays), thus taking 2–3 weeks to complete all games. The order was randomized across participants by the computer. Each game had the same premise: Children were to learn the names (lexical label) and semantic features (visual appearance) of four novel sea monsters. Trained research assistants administered the games via touchscreen computer.

Each game included five tasks (see Table 3). The first task of each game was the fast mapping component that utilized a phonological–visual linking task. Children saw four monsters on screen, heard a name, and touched the image of the monster that matched the name. They had to discover which name matched which monster based on feedback (a coin for a correct answer, a rock for an incorrect response). During the fast mapping component, children were exposed to each monster's name two times. Then, there were three additional blocks of the phonological–visual linking task, with each block providing 15 exposures to each name. Thus, by the end of the game, children had heard each monster's name 47 times (i.e., $2 + 15 + 15 + 15$). The computer scored each response for accuracy.

After each block of the phonological–visual linking task was completed, four remaining tasks were presented in random order. Two of the tasks taxed phonological skills. The naming task showed a monster and required children to recall and produce the name of the monster. They were asked to produce each monster's name one time at each block, for a total of four productions for each monster. Responses were audio-recorded and postscored for percent consonants correct.

The second task taxing phonological skills was the mispronunciation detection task. Children saw a monster and heard either the correct name or a foil requiring four decisions per monster. They pressed a button to indicate whether the name they heard was accurate or not. The

computer registered their response. The dependent variable for this task was adjusted percent accuracy that utilized the following formula to adjust scores for potential guessing: $(\% \text{ of correct number of hits}) - (1 - \% \text{ correct for foils})$.

The remaining two tasks mirrored the phonological tasks but taxed visually based semantic skills. In the visual feature recall task, children were asked to recall and correctly select visual features of a monster, including its color, eyes, head covering, and arms. They saw the outline of a monster and had to choose the visual features from a field of four. Once selected, the computer filled in the outline of the monster (e.g., if they pressed the blue button, the monster would turn blue). This allowed them to review their selection (see Figure 1). Once a child was satisfied with their selection, they pressed a button to indicate that they were done. They did this once each block for each monster, for a total of four decisions per monster. The computer registered responses and calculated percent accuracy.

In the visual difference decision task, children saw an image of the target monster or a foil monster. The foils were versions of the trained image, but that differed by one to three semantic features. They pressed a button to indicate whether the image was an accurate representation of the monster they had seen or not. They did this once for each monster for each block, resulting in four decisions per monster. As with the mispronunciation detection task, the computer registered responses, and we calculated adjusted percent correct for the dependent variable using the same formula noted above.

While each word learning game had the same general structure, we created six different manipulations. The word length game taught two-syllable and four-syllable words. The phonological similarity game taught phonologically similar and dissimilar words. The visual similarity taught names of referents that were visually similar or dissimilar. The location game taught the names for referents that stayed in the same location or moved to a different location during the game. The orthography game taught the names and features of monsters when orthography was present and when orthography was absent. Finally, the verb game taught children to name four different patterns of movement demonstrated by a single monster. These different manipulations were created to mirror conditions known to tax word learning for children with word learning difficulties.

Table 2. Description of games, conditions, and type of working memory and word learning skills taxed.

Game	Conditions	Type of working memory taxed	Word learning skill taxed
Word length	Two-syllable nonwords Four-syllable nonwords	Phonological working memory capacity (length)	Phonology
Phonological similarity	Phonologically dissimilar nonwords Phonologically similar nonwords	Phonological working memory (discrimination)	Phonology
Visual similarity	Visually dissimilar referents Visually similar referents	Visual working memory (discrimination)	Semantics
Location	Referents remain stationary Referents change location	Spatial working memory	Semantics
Orthography	Orthography present Orthography absent	Visual working memory (capacity)	Addition of orthography could affect both phonology and semantics
Verbs	Actions present (no manipulation)	Spatial working memory	

Table 3. Description of tasks, stimuli, and word learning processes.

Task	Stimuli tested	Type of word learning process assessed
Naming (see monster/action, name it, positive feedback for trying)	Noun/verb nonwords	Create, retrieve, and produce phonological form
Mispronunciation detection (see monster/action, hear correct label or foil, decide if correct label, receive immediate feedback)	CVC syllable structure; no phonological neighbors (low neighborhood density); low biphone phonotactic probability (1.00–1.01)	Create, store, and access phonological form
Visual feature recall (select correct color, eyes, arms, and head covering for monster; for verbs, select correct speed, direction, nature, and special effect of action; feedback based on number of correct selections)	Noun referents	Create, retrieve, and recreate semantic representation
Visual difference decision (see monster/action, decide if monster/action shown is an accurate depiction of one of the learned monsters/actions, receive immediate feedback)	or Verb referents	Create, store, and access semantic representation
Phonological–visual linking (hear label, choose one of four monsters/actions, receive immediate feedback)	Identical virtual sea monsters performing four different, unique actions	Link phonological form and semantic representation
	Nonwords and referents	

Stimuli

Each game had a unique set of four nonwords. The same names for sea monsters were presented for each game, but names were randomly assigned to each referent by the computer. Names were CVCCVC structures (except for the four-syllable names, which were CVCCVCCVCCVC

structures) with low English phonotactic probability and no phonological neighbors in English. The Appendix has a full list of the names, the foils for the names, and their phonotactic probabilities (Alt et al., 2019).
Each game had its own set of sea monsters. We created monsters to lack resemblance to any nameable

Figure 1. Example of visual feature recall response screen.

animal or object. For each game, monsters differed from each other in at least four dimensions, including shape, color, eyes, arms, feet, mouth, and head covering (see Figure 2 for an example). In the visual similarity game, two monsters were highly similar and differed by only two visual characteristics (e.g., arms, feet). The other two monsters differed on all seven features. In the verb game, children saw the same monster perform four different actions within the same block. Those same actions were performed by a different monster in another block.

Analytic Approach

To answer our research questions about potential differences between groups with dyslexia, dyslexia + DLD, and TD, we used Bayesian repeated-measures analyses of variance (ANOVAs) for all tasks except the verb game where we utilized a Bayesian ANOVA. The between-groups factor was group (dyslexia, dyslexia + DLD, TD), and the within-group factor was condition (e.g., number of syllables). We used Bayesian analyses because Bayesian statistics allow for interpretation of both null and alternative hypotheses (Kruschke, 2013). We conducted post hoc tests in JASP Version 0.9.1.0 (JASP Team, 2018) to follow up interactions. All Bayes factors were interpreted according to the guidelines in Wagenmakers et al. (2018), which range from anecdotal to extreme evidence in favor of either the null or alternative hypothesis, which for our study meant no between-groups differences in performance (null) or differences between groups (alternative). The JASP

Figure 2. Example of a set of monsters in a typical word learning game.

program specified that the default testing for effect sizes was a zero-centered Cauchy distribution of 0.707. However, for post hoc tests with multiple comparisons, posterior odds were corrected for multiple testing by using a prior probability of .5, following Westfall, Johnson, and Utts (1997).

Analyses of our inclusionary test means using Bayesian ANOVAs showed a significant, unexpected, between-groups difference in nonverbal IQ between the TD group and the dyslexia group (see Table 1 and Figure 3). Although this was unexpected, we did expect the dyslexia + DLD group to have lower nonverbal IQ scores than the other groups (Gallinat & Spaulding, 2014). Therefore, we also ran Bayesian repeated-measures analyses of covariance (ANCOVAs)—and an ANCOVA for verbs—with nonverbal IQ scores as the covariate. Although nonverbal IQ differed between groups, it did not have a substantial influence on the conclusions. We have included the ANCOVAs in Supplemental Material S1.

Results

Group Differences for Phonologically Taxing Tasks

There were two games that primarily taxed phonology: naming and mispronunciation detection. Table 4 and Figure 4 give detailed results for the naming task. Key findings for naming were that the dyslexia group was less accurate than the TD group for all games except those involving verbs. There was one Group $\times$ Condition interaction in that the dyslexia group was less accurate than the TD group for the orthography-present condition, but not the orthography-absent condition. Similarly, the dyslexia + DLD group was less accurate than the TD group on all games. When comparing the two disordered groups, the dyslexia + DLD group was less accurate than the dyslexia group on the word length and verbs games.

Figure 3. Violin plot of standard scores on the nonverbal intelligence measure by group. KABCstd = Standard nonverbal intelligence score on the Kaufman Assessment Battery for Children; DLD = developmental language disorder; TD = typical development.

Table 4. Results of Bayesian repeated-measures analyses of variance (ANOVAs), post hoc tests, descriptive means, and Hedges' *g* effect sizes for the naming task.

Group	Word length	Phonological similarity	Visual similarity	Location	Orthography	Verbs
Group ANOVA results						
	Groups differ (extreme; $BF_{Inc} = 142,177.23$)	Groups differ (extreme; $BF_{Inc} = 60,230.65$)	Groups differ (extreme; $BF_{Inc} = 21,384.57$)	Groups differ (extreme; $BF_{Inc} = 745.37$)	Groups differ (extreme; $BF_{Inc} = 49,215.73$)	Groups differ (extreme; $BF_{Inc} = 289,532.10$)
Group post hoc test results						
TD vs. dyslexia	Groups differ (moderate; $BF_{10} = 7.17$)	Groups differ (extreme; $BF_{10} = 6,683.53$)	Groups differ (extreme; $BF_{10} = 412.57$)	Groups differ (very strong; $BF_{10} = 83.18$)	Ortho+ = groups differ (extreme; $BF_{10} = 1,467.51$); Ortho- = groups tend not to differ (anecdotal; $BF_{10} = 0.97$)	Groups tend not to differ (anecdotal; $BF_{10} = 0.60$)
TD vs. dyslexia + DLD	Groups differ (extreme; $BF_{10} = 160,497.33$)	Groups differ (extreme; $BF_{10} = 739,261.82$)	Groups differ (extreme; $BF_{10} = 91,237.78$)	Groups differ (extreme; $BF_{10} = 4,260.74$)	Ortho+ = groups differ (extreme; $BF_{10} = 12,823.44$); Ortho- = groups differ (moderate; $BF_{10} = 6.02$)	Groups differ (extreme; $BF_{10} = 1.970e + 6$)
Dyslexia vs. dyslexia + DLD	Groups differ (very strong; $BF_{10} = 62.96$)	Groups tend to differ (anecdotal; $BF_{10} = 2.21$)	Groups tend to differ (anecdotal; $BF_{10} = 1.53$)	Groups tend not to differ (anecdotal; $BF_{10} = 0.75$)	Ortho+ = groups tend not to differ (anecdotal; $BF_{10} = 0.84$); Ortho- = groups tend not to differ (anecdotal; $BF_{10} = 0.44$)	Groups differ (extreme; $BF_{10} = 1,712.37$)
Group means (SDs) and effect sizes						
TD	25.19 (11.61)	28.03 (15.88)	25.47 (12.92)	29.67 (14.83)	42.88 (21.06); 27.31 (15.79)	19.80 (11.67)
Dyslexia	20.75 (9.42)	20.27 (11.10)	19.05 (11.34)	24.47 (12.58)	29.25 (16.45); 22.75 (13.76)	16.93 (11.47)
Dyslexia + DLD	14.13 (7.57)	16.02 (9.69)	14.90 (9.06)	20.98 (12.46)	23.21 (15.88); 19.02 (14.55)	7.24 (6.27)
TD vs. dyslexia	0.40	0.53	0.51	0.36	0.68; 0.30	0.24
TD vs. dyslexia + DLD	1.00	0.80	0.85	0.60	0.97; 0.50	1.15
Dyslexia vs. dyslexia + DLD	0.74	0.39	0.38	0.27	0.36; 0.26	0.95
Condition ANOVA results						
	Extreme; $BF_{Inc} = 2.587e + 38$	Moderate (null); $BF_{Inc} = 0.13$	Extreme; $BF_{Inc} = 594.27$	Anecdotal; $BF_{Inc} = 2.61$	Extreme; $BF_{Inc} = 6.361e + 14$	
Group × Condition results						
					Extreme; $BF_{Inc} = 181.28$	
Condition means (SDs) and effect size						
	Short	Similar	Similar	Change	Orthography	
	33.31 (18.51)	24.51 (16.38)	20.19 (14.73)	25.59 (16.47)	36.12 (20.70)	
	Long	Dissimilar	Dissimilar	No change	No orthography	
	17.16 (10.62)	23.72 (16.45)	24.50 (15.55)	28.43 (17.08)	24.79 (15.33)	
	1.06	0.04	-0.28	-0.16	0.62	

Note. Results include Bayes factors (BFs) and interpretations of those factors based on the guidelines of Wagenmakers et al. (2018) and Hedge's *g* for significant differences. Interactions are reported only when there was more than anecdotal evidence for a Group × Condition interaction. TD = typical development; DLD = developmental language disorder.

Figure 4. Accuracy on the naming task by group, with group differences with at least moderate evidence noted. DLD = developmental language disorder; TD = typical development.

Results were similar for the mispronunciation detection task (detailed results can be found in Table 5 and Figure 5). The dyslexia group scored lower than the TD group for three of the six games (phonological similarity, visual similarity, orthography). Similarly, the dyslexia + DLD group scored lower than the TD group for five of the six games (all but verbs). When comparing the disordered groups, the dyslexia + DLD group was less accurate than the dyslexia group for the location game. As expected, both disordered groups scored lower than the TD group on the majority of games within these phonologically taxing tasks.

Group Differences for Visually Based Semantically Taxing Tasks

There were two tasks that tapped visually based semantic processing: visual feature recall and visual difference decision. Detailed results for the visual feature recall task may be found in Table 6 and Figure 6. The key findings for the visual feature recall task were that the dyslexia and TD groups were equivalent on all games. In contrast, the dyslexia + DLD group scored lower than the TD group on half of the games (word length, visual similarity, orthography). In comparing the two disordered groups, the dyslexia + DLD group scored lower than the dyslexia group on the word length and orthography games.

For the visual difference decision game, detailed results can be found in Table 7 and Figure 7. The dyslexia and TD groups were equivalent on all games. In comparison, the dyslexia + DLD group was less accurate than the TD group on all games except location. Finally, when comparing the two disordered groups, the dyslexia + DLD

group was less accurate than the dyslexia group for the word length and visual similarity games. As predicted, children with dyslexia showed relative strengths in semantic learning; that is, they were equivalent to their peers with TD. In contrast, children with dyslexia + DLD evidenced more difficulties with semantic learning when compared to children with TD or those with dyslexia only.

Group Differences for Phonological–Visual Linking Task

The phonological–visual linking task relied on both phonological and visually based semantic skills. Detailed results can be found in Table 8 and Figure 8. Key findings for the phonological–visual linking tasks were that the dyslexia group was less accurate than the TD group for the visual similarity and orthography games. In contrast, the dyslexia + DLD group was less accurate than the TD group on all games. When comparing the disordered groups, the dyslexia + DLD group was less accurate than the dyslexia group for the word length, phonological similarity, and location games. A summary of the between-groups differences on the ANOVA is illustrated in Figure 9.

Summary of Differences

In summary, the main findings are that the dyslexia group scored lower than the TD group most often with the phonological tasks. They were less accurate than the TD group on eight of 12 phonological tasks/games. The effect sizes for these differences ranged from small to medium. In contrast, on the tasks that tasked visually based semantic

Table 5. Results of Bayesian repeated-measures analyses of variance (ANOVAs), post hoc tests, descriptive means, and Hedges' *g* effect sizes for the mispronunciation detection task.

Group	Word length	Phonological similarity	Visual similarity	Location	Orthography	Verbs
Group ANOVA results						
	Groups differ (extreme; $BF_{Inc} = 103.24$)	Groups differ (extreme; $BF_{Inc} = 147.68$)	Groups differ (extreme; $BF_{Inc} = 1,115.86$)	Groups differ (extreme; $BF_{Inc} = 158.55$)	Groups differ (extreme; $BF_{Inc} = 3,373.63$)	Groups tend to differ (anecdotal; $BF_{Inc} = 1.68$)
Group post hoc test results						
TD vs. dyslexia	Groups tend to differ (anecdotal; $BF_{10} = 2.88$)	Groups Differ (Strong; $BF_{10} = 24.36$)	Groups differ (extreme; $BF_{10} = 521.32$)	Groups tend <u>not</u> to differ (anecdotal; $BF_{10} = 0.79$)	Groups differ (extreme; $BF_{10} = 3,164.78$)	Groups tend to differ (anecdotal; $BF_{10} = 1.07$)
TD vs. dyslexia + DLD	Groups differ (extreme; $BF_{10} = 2,877.68$)	Groups differ (extreme; $BF_{10} = 480.36$)	Groups differ (extreme; $BF_{10} = 1,157.03$)	Groups differ (extreme; $BF_{10} = 11,615.70$)	Groups differ (extreme; $BF_{10} = 1,505.01$)	Groups tend to differ (anecdotal; $BF_{10} = 2.51$)
Dyslexia vs. dyslexia + DLD	Groups tend to differ (anecdotal; $BF_{10} = 1.39$)	Groups tend <u>not</u> to differ (anecdotal; $BF_{10} = 0.38$)	Groups do <u>not</u> differ (moderate; $BF_{10} = 0.21$)	Groups differ (strong; $BF_{10} = 10.27$)	Groups do <u>not</u> differ (moderate; $BF_{10} = 0.19$)	Groups do <u>not</u> differ (moderate; $BF_{10} = 0.27$)
Group means (SDs) and effect sizes						
TD	49.14 (28.65)	32.33 (27.15)	45.14 (26.33)	44.37 (31.81)	49.62 (30.54)	38.71 (30.61)
Dyslexia	41.23 (27.21)	21.15 (27.28)	30.91 (29.13)	36.82 (30.40)	31.55 (25.88)	29.79 (31.02)
Dyslexia + DLD	29.17 (23.36)	14.33 (28.85)	26.83 (27.61)	21.73 (26.78)	28.04 (29.52)	25.00 (33.00)
TD vs. dyslexia	0.27	0.40	0.51	0.24	0.61	0.28
TD vs. dyslexia + DLD	0.71	0.65	0.68	0.73	0.70	0.43
Dyslexia vs. dyslexia + DLD	0.45	0.24	0.14	0.51	0.12	0.15
Condition ANOVA results						
	Extreme; $BF_{Inc} = 2.155e + 6$	Strong (null); $BF_{Inc} = 0.09$	Moderate (null); $BF_{Inc} = 0.27$	Strong (null); $BF_{Inc} = 0.12$	Anecdotal (null); $BF_{Inc} = 0.40$	
Condition means (SDs) and effect sizes						
	Short	Similar	Similar	Change	Orthography	
	53.90 (33.8)	26.6 (36.07)	36.82 (33.41)	39.95 (38.15)	43.64 (37.87)	
	Long	Dissimilar	Dissimilar	No change	No orthography	
	44.30 (34.9)	26.6 (34.42)	40.43 (36.16)	37.86 (37.93)	38.90 (36.68)	
	0.41	0.00	-0.10	-0.05	0.12	

Note. Results include Bayes factors (BFs) and interpretations of those factors based on the guidelines of Wagenmakers et al. (2018). Interactions are reported only when there was more than anecdotal evidence for a Group $\times$ Condition interaction. TD = typical development; DLD = developmental language disorder.

Figure 5. Adjusted accuracy on the mispronunciation task by group, with group differences with at least moderate evidence noted. DLD = developmental language disorder; TD = typical development.

processing, there was no difference between the TD and dyslexia groups for eight of the 12 tasks/games, with inconclusive evidence for the remaining four tasks/games. In the linking task that combined phonological and visually based semantic processing, the dyslexia group was less accurate than the TD group on games that included more visual processing (orthography, visual similarity with small effect sizes) but equally accurate on games that included more spatial processing (location, verbs).

However, the group with dyslexia + DLD evidenced lower accuracy than the TD group on both phonological and visually based semantic tasks. Of the 30 potential comparisons (five tasks across six games), the dyslexia + DLD group was less accurate than the TD group in 25 of those comparisons (83%), spanning both phonological and visually based semantic tasks and games. The dyslexia + DLD group was less accurate than the TD group for 11 of 12 phonological tasks/games and eight of 12 visually based semantic tasks/games. They were less accurate than the TD group on all six games for the phonological–visual linking task, which required both phonological and visually based semantic processing.

Thus, when comparing the dyslexia and dyslexia + DLD groups, the dyslexia + DLD group performed less accurately than the TD group more often than the dyslexia group. In contrast to the dyslexia group, who performed equivalently to the TD group, they also demonstrated lower performance on semantic learning tasks when compared to the TD group. Direct comparisons between the groups showed that the group with dyslexia + DLD was less accurate than the dyslexia group in 10 of 30 potential comparisons

(30%) with the differences spread across phonological, semantic, and combination tasks.

Discussion

We tested the hypothesis that children with dyslexia have word learning deficits primarily related to phonology and that children with dyslexia + DLD have word learning deficits related to both phonology and semantic processing when compared to their peers with TD. We tested this hypothesis through carefully controlled word learning tasks that varied phonological and visually based semantic demands. As predicted, on average, the dyslexia + DLD group demonstrated word learning deficits across the range of word learning tasks that tapped phonology and semantic processing, whereas the dyslexia group primarily demonstrated word learning deficits in the phonological aspects of word learning.

Word Learning Deficits in Children With Dyslexia

Children with dyslexia have difficulty learning new spoken words, although as a group they tend to score within normal limits on tests of vocabulary. In this study, we showed that their deficits in word learning were primarily related to phonological learning, with a relative strength in semantic learning. We see this clearly in Figure 9, in which children with TD outperformed children with dyslexia for most of the phonologically demanding tasks (yellow), but children with TD had equivalent performance to children

Table 6. Results of Bayesian repeated-measures analyses of variance (ANOVAs), post hoc tests, descriptive means, and Hedges' *g* effect sizes for the visual feature recall task.

Group	Word length	Phonological similarity	Visual similarity	Location	Orthography	Verbs
Group ANOVA results						
	Groups tend to differ (anecdotal; $BF_{Inc} = 2.16$)	Groups do not differ (moderate; $BF_{Inc} = 0.22$)	Groups differ (moderate; $BF_{Inc} = 7.33$)	Groups do not differ (moderate; $BF_{Inc} = 0.26$)	Groups differ (moderate; $BF_{Inc} = 5.59$)	Groups do not differ (strong; $BF_{Inc} = 0.08$)
Group post hoc test results						
TD vs. dyslexia	Groups do not differ (moderate; $BF_{10} = 0.13$)		Groups do not differ (moderate; $BF_{10} = 0.28$)		Groups do not differ (moderate; $BF_{10} = 0.12$)	
TD vs. dyslexia + DLD	Groups differ (very strong; $BF_{10} = 57.86$)		Groups differ (extreme; $BF_{10} = 403.12$)		Groups differ (very strong; $BF_{10} = 77.77$)	
Dyslexia vs. dyslexia + DLD	Groups differ (moderate; $BF_{10} = 4.65$)		Groups tend to differ (anecdotal; $BF_{10} = 2.52$)		Groups differ (very strong; $BF_{10} = 42.91$)	
Group means (SDs) and effect sizes						
TD	64.02 (14.99)	66.99 (16.17)	68.38 (14.18)	68.63 (14.57)	63.56 (13.29)	42.72 (14.26)
Dyslexia	62.84 (14.80)	64.80 (15.89)	65.96 (16.74)	69.31 (14.52)	63.92 (12.64)	43.75 (10.63)
Dyslexia + DLD	56.13 (15.09)	62.69 (18.37)	59.38 (17.99)	64.21 (14.51)	55.87 (13.53)	40.68 (11.10)
TD vs. dyslexia	0.07	0.13	0.16	-0.04	-0.02	-0.07
TD vs. dyslexia + DLD	0.52	0.25	0.59	0.30	0.57	0.14
Dyslexia vs. dyslexia + DLD	0.44	0.12	0.38	0.34	0.61	0.28
Condition ANOVA results						
	Strong (null); $BF_{Inc} = 0.10$	Strong (null); $BF_{Inc} = 0.10$	Extreme; $BF_{Inc} = 350.22$	Anecdotal; $BF_{Inc} = 1.40$	Moderate (null); $BF_{Inc} = 0.107$	
Condition means (SDs) and effect sizes						
	Short	Similar	Similar	Change	Orthography	
	62.44 (17.03)	65.67 (18.88)	68.63 (18.72)	66.84 (17.32)	62.20 (15.58)	
	Long	Dissimilar	Dissimilar	No Change	No Orthography	
	62.73 (17.81)	65.85 (18.49)	64.18 (17.42)	69.46 (17.11)	62.62 (16.44)	
	0.01	-0.00	0.24	-0.15	0.102	

Note. Results include Bayes factors (BFs) and interpretations of those factors based on the guidelines of Wagenmakers et al. (2018). Interactions are reported only when there was more than anecdotal evidence for a Group $\times$ Condition interaction. TD = typical development; DLD = developmental language disorder.

Figure 6. Accuracy on the visual feature recall task by group, with group differences with at least moderate evidence noted. DLD = developmental language disorder; TD = typical development.

with dyslexia for the majority of the semantically demanding tasks (blue).

While some argue that children with dyslexia have deficits in visual processing (Bogon et al., 2014; Lobier et al., 2012), the majority of studies point to phonological skills as their primary weakness (e.g., Snowling, 2001). Our results support this position. However, it is noteworthy that, in our study, children with dyslexia were less accurate than their peers with TD on two word learning games that taxed visually based semantic processing: visual similarity and orthography.

Group differences for the visual similarity game could be attributed to the additional visually based semantic processing demands of that game. Children had the usual demands of learning the phonological representation of the label and the semantic representation of the referent; however, this game also required children to make distinctions between two visually similar monsters. Thus, to be successful, children needed to attend to specific visual details about each referent (e.g., head covering, feet) and could not rely on gross visual differences (e.g., color, shape) that would suffice in other games. This result provides support for research reporting basic visual processing difficulties in children with dyslexia (Bogon et al., 2014; Lobier et al., 2012).

We could attribute group differences for the orthography game to lower word reading abilities in the children with dyslexia. Importantly, it was not necessary for children to read the labels to learn all the relevant information about the monsters and their names. Instead, the orthographic cue provided additional information, but if children expended cognitive resources on decoding the words, this could have reduced resources available for storing the semantic characteristics of the monsters. Alternatively, it may simply have been too demanding for children with

dyslexia to attend to both phonological and visual information, given their phonological deficit. This could be the case for both the orthography and the visual similarity games.

Interestingly, a word learning deficit was not found for the two games that involved spatial manipulations even though these relied on visually based semantic processing. This suggests that children with dyslexia are more challenged by visual than spatial discrimination. The relative strength in processing visual movement provides some nuance to the evidence for difficulty with visual processing in some children with dyslexia (e.g., Bogon et al., 2014; Lobier et al., 2012).

As in Alt et al. (2017), we found a word learning deficit in children with dyslexia who had oral language skills scores within normal limits on norm-referenced, standardized assessments. This finding represents a paradox in which children with dyslexia have learned words well enough to score within normal limits on static language assessments but demonstrate deficits on our dynamic word learning tasks. This is not something we would expect given their standardized test scores. It may be the case that children with dyslexia have compensatory strategies that allow them to gain as many vocabulary terms as their typically developing peers over time, despite some initial difficulty with certain word learning tasks. Explaining this discrepancy in performance is an important goal for future research. These findings also highlight that the relative strengths and weaknesses children with dyslexia demonstrate in phonological, visual, or semantic processing do not exist in isolation but depend on overall task demands.

Word Learning in Children With Dyslexia + DLD

We asked how children with dyslexia who have comorbid DLD learn new words compared to their peers

Table 7. Results of Bayesian repeated-measures analyses of variance (ANOVAs), post hoc tests, descriptive means, and Hedges' *g* effect sizes for the visual difference decision task.

Group	Word length	Phonological similarity	Visual similarity	Location	Orthography	Verbs
Group ANOVA results						
	Groups tend to differ (anecdotal; $BF_{Inc} = 1.60$)	Groups differ (moderate; $BF_{Inc} = 5.59$)	Groups differ (extreme; $BF_{Inc} = 94,477.05$)	Groups tend not to differ (anecdotal; $BF_{Inc} = 0.40$)	Groups differ (moderate; $BF_{Inc} = 4.68$)	Groups differ (strong; $BF_{Inc} = 13.58$)
Group post hoc test results						
TD vs. dyslexia	Groups do not differ (moderate; $BF_{10} = 0.17$)	Groups tend not to differ (anecdotal; $BF_{10} = 0.33$)	Groups tend not to differ (anecdotal; $BF_{10} = 0.57$)		Groups tend not to differ (anecdotal; $BF_{10} = 0.33$)	Groups tend not to differ (anecdotal; $BF_{10} = 0.39$)
TD vs. dyslexia + DLD	Groups differ (moderate; $BF_{10} = 4.44$)	Groups differ (extreme; $BF_{10} = 160.54$)	Groups differ (extreme; $BF_{10} = 7.55e + 7$)		Groups differ (extreme; $BF_{10} = 165.21$)	Groups differ (very strong; $BF_{10} =$ 60.38)
Dyslexia vs. dyslexia + DLD	Groups differ (strong; $BF_{10} = 26.77$)	Groups tend to differ (anecdotal; $BF_{10} = 1.36$)	Groups differ (extreme; $BF_{10} = 255.43$)		Groups tend to differ (anecdotal; $BF_{10} = 1.19$)	Groups tend to differ (anecdotal; $BF_{10} =$ 1.58)
Group means (SDs) and effect sizes						
TD	68.24 (25.73)	72.07 (22.01)	77.39 (18.77)	61.80 (22.96)	80.21 (20.72)	52.02 (25.74)
Dyslexia	71.10 (19.89)	67.79 (26.84)	72.80 (20.83)	66.61 (18.99)	75.99 (24.93)	46.75 (27.64)
Dyslexia + DLD	57.37 (28.06)	57.62 (33.53)	54.57 (34.88)	56.55 (28.46)	66.89 (23.97)	34.03 (32.27)
TD vs. dyslexia	-0.11	0.18	0.23	-0.21	0.18	0.19
TD vs. dyslexia + DLD	0.41	0.58	0.99	0.21	0.61	0.66
Dyslexia vs. dyslexia + DLD	0.59	0.34	0.67	0.43	0.36	0.43
Condition ANOVA results						
	Moderate (null); $BF_{Inc} = 0.22$	Moderate (null); $BF_{Inc} = 0.16$	Extreme; $BF_{Inc} = 5.144e + 6$	Moderate (null); $BF_{Inc} = 0.12$	Moderate (null); $BF_{Inc} = 0.103$	
Condition means (SDs) and effect sizes						
	Short	Similar	Similar	Change	Orthography	
	66.09 (30.47)	69.84 (30.84)	78.61 (28.08)	63.09 (28.20)	77.16 (28.50)	
	Long	Dissimilar	Dissimilar	No change	No orthography	
	68.91 (30.68)	67.70 (30.84)	66.97 (28.49)	61.45 (29.99)	76.72 (23.36)	
	0.09	0.06	0.41	0.05	0.01	

Note. Results include Bayes factors (BFs) and interpretations of those factors based on the guidelines of Wagenmakers et al. (2018). Interactions are reported only when there was more than anecdotal evidence for a Group $\times$ Condition interaction.

Figure 7. Adjusted accuracy on the visual difference decision task by group, with group differences with at least moderate evidence noted. DLD = developmental language disorder; TD = typical development.

with dyslexia. We predicted that those with concomitant DLD would perform lower on word learning tasks than their peers with dyslexia or TD and that their word learning would be negatively impacted by phonological and semantic deficits. Evidence supporting these predictions was found across all of the word learning tasks (indicating difficulties with all aspects of word learning), although not across all of the games. Figure 9 shows that comparisons between the TD and dyslexia + DLD groups are dominated by the TD > dyslexia + DLD findings. Comparisons between the dyslexia and dyslexia + DLD groups favored the dyslexia group but lacked a clear pattern of results.

The pattern of results when comparing the dyslexia + DLD group to the TD group clearly shows deficits for all the tasks involving phonology (see the yellow and green parts of Figure 9). Processing phonological information during word learning is unambiguously a weakness for children with dyslexia + DLD. Semantic deficits were present in 75% of the games, and there was no clear pattern as to which 25% of the games were likely to be easier, with the exception of the location games, on which the dyslexia + DLD group performed equivalently to the TD group for both semantic tasks. Even if children with dyslexia + DLD have a relative strength in processing visually presented locations, this strength only appears in the semantically demanding tasks (blue on Figure 9) and does not compensate for the challenges found in the phonologically taxing tasks.

When comparing the dyslexia + DLD group to the dyslexia group, one pattern emerged: The game in which children with dyslexia + DLD were less accurate than their peers with dyslexia was the word length game. By varying word length, we were able to tax phonological working memory. In this game, children with dyslexia + DLD

showed poorer performance than the dyslexia-only group for four of the five tasks (except mispronunciation detection). These results provide support for the Ramus et al. (2013) hypothesis that children with dyslexia and DLD demonstrate different types of phonological processing deficits and that children with dyslexia + DLD do not simply have a more pronounced phonological impairment. If that were the case, they should have performed less accurately on the phonological similarity game. However, there was only one difference between these groups on the phonological similarity game. By varying phonological similarity, we were able to tax phonological discrimination. Although both groups were less accurate than the TD group for the word length game, the group with dyslexia + DLD was less accurate than the group with dyslexia for most tasks on the word length game, suggesting that the group with dyslexia + DLD had even more difficulty with phonological working memory than their peers with dyslexia only. This type of deficit would be predicted by Alt (2011), who found that children with DLD had the most difficulty encoding longer words but were able to perform as well as their peers on shorter words.

The other trend in the difference between the groups with dyslexia + DLD and dyslexia is that the dyslexia + DLD group was less accurate than the dyslexia group on half of the phonological-visual linking tasks (word length, phonological similarity, location). It is difficult to make a clear statement about the precise additive problems of the dyslexia + DLD group, as the other areas of difference that we have not already commented upon were wide ranging (i.e., verbs game for naming, location game for mispronunciation detection, orthography game for visual feature recall, and visual similarity for visual difference decision).

Table 8. Results of Bayesian repeated-measures analyses of variance (ANOVAs), post hoc tests, descriptive means, and Hedges' *g* effect sizes for the phonological–visual linking task.

Group	Word length	Phonological similarity	Visual similarity	Location	Orthography	Verbs
Group ANOVA results						
	Groups differ (moderate; $BF_{Inc} = 7.27$)	Groups differ (strong; $BF_{Inc} = 24.23$)	Groups differ (strong; $BF_{Inc} = 22.62$)	Groups differ (very strong; $BF_{Inc} = 45.91$)	Groups differ (extreme; $BF_{Inc} = 237.99$)	Groups tend to differ (anecdotal; $BF_{Inc} = 1.75$)
Group post hoc test results						
TD vs. dyslexia	Groups do not differ (moderate; $BF_{10} = 0.23$)	Groups tend not to differ (anecdotal; $BF_{10} = 0.68$)	Groups differ (very strong; $BF_{10} = 56.63$)	Groups do not differ (moderate; $BF_{10} = 0.16$)	Groups differ (very strong; $BF_{10} = 41.06$)	Groups do not differ (moderate; $BF_{10} = 0.23$)
TD vs. dyslexia + DLD	Groups differ (extreme; $BF_{10} = 880.53$)	Groups differ (extreme; $BF_{10} = 9,574.81$)	Groups differ (extreme; $BF_{10} = 193.17$)	Groups differ (extreme; $BF_{10} = 6,022.99$)	Groups differ (extreme; $BF_{10} = 76,593.62$)	Groups differ (moderate; $BF_{10} = 8.19$)
Dyslexia vs. dyslexia + DLD	Groups differ (moderate; $BF_{10} = 5.61$)	Groups differ (strong; $BF_{10} = 21.40$)	Groups do not differ (moderate; $BF_{10} = 0.23$)	Groups differ (very strong; $BF_{10} = 44.39$)	Groups tend to differ (anecdotal; $BF_{10} = 1.62$)	Groups tend to differ (anecdotal; $BF_{10} = 1.06$)
Group means (SDs) and effect sizes						
TD	69.42 (14.89)	61.13 (18.29)	62.63 (18.00)	62.96 (17.53)	69.83 (15.75)	53.69 (18.08)
Dyslexia	67.38 (16.35)	57.57 (16.88)	55.84 (17.83)	61.22 (18.00)	63.29 (16.23)	51.23 (18.71)
Dyslexia + DLD	60.26 (18.75)	49.81 (14.42)	53.27 (18.74)	51.87 (19.33)	57.05 (20.31)	43.96 (18.70)
TD vs. dyslexia	0.13	0.19	0.37	0.09	0.40	0.13
TD vs. dyslexia + DLD	0.58	0.64	0.51	0.61	0.75	0.53
Dyslexia vs. dyslexia + DLD	0.41	0.47	0.14	0.50	0.34	0.38
Condition ANOVA results						
	Extreme; $BF_{Inc} = 1.381e + 10$	Extreme; $BF_{Inc} = 360.01$	Anecdotal; $BF_{Inc} = 2.99$	Moderate (null); $BF_{Inc} = 0.11$	Extreme; $BF_{Inc} = 22,827.21$	
Condition means (SDs) and effect sizes						
	Short	Similar	Similar	Change	Orthography	
	70.09 (16.39)	57.09 (19.43)	58.41 (19.02)	60.65 (19.50)	68.14 (18.51)	
	Long	Dissimilar	Dissimilar	No change	No orthography	
	65.02 (17.75)	59.96 (17.89)	60.45 (19.94)	60.97 (19.01)	63.83 (18.31)	
	0.29	−0.15	−0.10	−0.01	0.23	

Note. Results include Bayes factors (BFs) and interpretations of those factors based on the guidelines of Wagenmakers et al. (2018). Interactions are reported only when there was more than anecdotal evidence for a Group × Condition interaction. TD = typical development; DLD = developmental language disorder.

Figure 8. Accuracy on the phonological–visual linking task by group, with group differences with at least moderate evidence noted. DLD = developmental language disorder; TD = typical development.

One distinct possibility is that linking is more difficult without more detailed semantic and phonological representations in long-term memory. So since they were poorer in both of these aspects than their peers, they were likely poorer at linking, although it is not clear why some linking tasks were more difficult than others for each group.

Another way to compare the dyslexia and dyslexia + DLD groups is to consider on how many of the 30 measures (five tasks over six games) they scored lower than the TD group. The group with dyslexia was equivalent to the TD group on 11 of these measures (36%), including all of the games for the visual feature recall task. They were less accurate on 10 measures (33%), with eight of those coming from the phonologically taxing tasks of naming and mispronunciation detection. There was inconclusive information on the remaining nine tasks (30%). In contrast, the group with dyslexia + DLD was equivalent to the TD group on only four measures (13%), most in the visual feature recall task. They were less accurate on a full 25 measures (83%), including all the naming and phonological–visual linking tasks and all but one of each of the decision tasks. There was inconclusive evidence for only one task (3%). Based on these results, having dyslexia + DLD leads to more pervasive word learning deficits across the entire word learning spectrum (i.e., creating, storing, linking, and recalling both visual and phonological components of words) than having dyslexia alone. There was no task in which the dyslexia + DLD group performed better than the dyslexia or TD group.

Clinical Implications

Results of this study show that diagnostic testing for children with dyslexia or DLD is important to determine whether children have a concomitant disorder. If so, this

suggests a different word learning profile than either disorder alone. Children with dyslexia + DLD are more likely to have significant word learning challenges than their peers with dyslexia. In contrast, children with dyslexia may learn new words (i.e., bind a label to a referent), as well as their peers with TD, although they are likely to struggle more with accurate naming or precision of their phonological representations. Additionally, situations that tax semantic learning, such as those involving discrimination of similar visual stimuli (e.g., when learning chemical structures that often look quite similar: circle, lines, and hexagons), may be more challenging. In addition to considering the level of support children with different diagnoses need, the information in Figure 9 may help clinicians choose contexts that facilitate word learning. For example, when learning the new phonological representation for a word and linking it to a new semantic representation (i.e., phonological–visual linking), a child with dyslexia would likely learn best when the visual representations of concepts contrast visually. When teaching shape names to a child with dyslexia, it would be best to teach “pentagon” and “circle” together rather than “circle” and “oval.” In terms of phonological difficulties, children with dyslexia and dyslexia + DLD are likely to need additional supports. Adding orthography can improve learning for children with dyslexia; however, they do not benefit as much as their peers with TD (Baron et al., 2018). Additional supports could include more exposures to novel words. In our study, all children showed improvement in learning across the blocks (i.e., with more exposures). This finding mirrors work in word learning research, showing that children with DLD can learn words but often need more exposure to a word than their peers with TD do so (e.g., Gray, 2004; Rice, Oetting, Marquis, Bode, & Pae, 1994; Storkel et al., 2017).

Figure 9. Summary of between-groups differences from analysis of variance (ANOVA) results. TD = typical development; DLD = developmental language disorder.

Tasks	Games	TD vs. dyslexia	TD vs. dyslexia + DLD	Dyslexia vs. dyslexia + DLD
Naming (Create, retrieve and produce phonological form)	Word Length	TD > dyslexia	TD > dyslexia + DLD	Dyslexia > dyslexia + DLD
	Phonological Similarity			Inconclusive
	Visual Similarity			
	Location			
	Orthography +	Inconclusive		Dyslexia > dyslexia + DLD
	Orthography –			
	Verbs	TD = dyslexia		
Mispronunciation Detection (Create, store, and access phonological form)	Word Length	Inconclusive	TD > dyslexia + DLD	Inconclusive
	Phonological Similarity	TD > dyslexia		Dyslexia = dyslexia + DLD
	Visual Similarity			Dyslexia > dyslexia + DLD
	Location	Inconclusive		Dyslexia = dyslexia + DLD
	Orthography	TD > dyslexia		
	Verbs	Inconclusive	Inconclusive	Dyslexia = dyslexia + DLD
	Visual Feature Recall (Create, retrieve and recreate semantic representation)	Word Length	TD = dyslexia	TD > dyslexia + DLD
Phonological Similarity		TD = dyslexia + DLD		Dyslexia = dyslexia + DLD
Visual Similarity		TD > dyslexia +DLD		Inconclusive
Location		TD = dyslexia + DLD		Dyslexia = dyslexia + DLD
Orthography		TD > dyslexia + DLD		Dyslexia > dyslexia + DLD
Verbs		TD = dyslexia + DLD		Dyslexia = dyslexia + DLD
Visual Difference Decision (Create, store, and access semantic representation)	Word Length	TD = dyslexia	TD > dyslexia + DLD	Dyslexia > dyslexia + DLD
	Phonological Similarity	Inconclusive		Inconclusive
	Visual Similarity			Dyslexia > dyslexia + DLD
	Location	TD = dyslexia	TD = dyslexia + DLD	Dyslexia = dyslexia + DLD
	Orthography	Inconclusive	TD > dyslexia + DLD	Inconclusive
	Verbs			
Phonological Visual Linking (Link phonological form and semantic representation)	Word Length	TD = dyslexia	TD > dyslexia + DLD	Dyslexia > dyslexia + DLD
	Phonological Similarity	Inconclusive		Dyslexia = dyslexia + DLD
	Visual Similarity	TD > dyslexia		Dyslexia > dyslexia + DLD
	Location	TD = dyslexia		
	Orthography	TD > dyslexia		
	Verbs	TD = dyslexia		Inconclusive

Limitations

By comparing groups with dyslexia and dyslexia + DLD, we were able to examine the potential additive role of DLD and dyslexia. Although we feel that this is a valuable comparison, some people have criticized Bishop and Snowling's (2004) additional deficit model because, as Ramus et al. (2013) pointed out, it makes an assumption that all children with DLD will have dyslexia, which is not the case (e.g., Adlof & Hogan, 2018; Ramus et al., 2013). Thus, in future work, it would be interesting to add a group with DLD only for comparison. Having this group would allow us to directly examine differences in the three groups rather than inferring the effect of DLD in addition to dyslexia. It could also help us examine more closely differences in semantic learning observed primarily in the dyslexia + DLD group and whether this may be associated with having the concomitant disorder of DLD itself. These problems could be differentially related to attention or executive function (e.g., Gray et al., 2017, 2019), which may differ in children with DLD and dyslexia + DLD.

Some researchers might choose to examine groups matched on abilities in an attempt to control for variables hypothesized to directly impact the outcome variables. We chose not to do this because this type of matching often leads to uninterpretable conclusions. Often, ability matches lead to comparisons with younger typically developing children, and age difference creates a confound in interpreting results (e.g., Plante, Swisher, Kiernan, & Restrepo, 1993). Alternatively, matching on characteristics known to be low in children with impairments means that the age-equivalent peers who are chosen as matches are likely not representative of the larger sample of typically developing children.

Another potential limitation is that, although we comprehensively examined the early stages of word learning, we did not examine later stages that accrue over time. Additional between-groups differences may emerge as phonological and semantic representations are elaborated with more exposures to newly learned words in different contexts.

Conclusion

In our comprehensive study of word learning in children with TD, dyslexia, and dyslexia + DLD, children with dyslexia primarily had difficulty with phonological tasks; however, results suggested that, in two instances when learning taxed the visual system, children with dyslexia performed lower than their peers with TD. Children with dyslexia + DLD had difficulty with both phonological and semantic word learning tasks.

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Appendix

Nonword Stimuli Characteristics

Condition of interest	Nonword in Klattese ^a	Condition manipulation	Duration (ms) with means and standard deviations in bold ^b	Biphone frequency with means and standard deviations in bold ^c	Summed biphone probability with means and standard deviations in bold ^d	Similar foils ^e	Dissimilar foils ^f
Phonological similarity	<i>n^dwef</i>	Similar	845	0.0008	0.0039	<i>nudwev</i>	<i>nudweg</i>
	<i>w^gyed</i>	Similar	825	0.0009	0.0043	<i>w^gyet</i>	<i>w^gyef</i>
			835.00 (14.14)	0.0009 (0.0001)	0.0041 (0.0002)		
	<i>hWktcf</i>	Dissimilar	1,111	0.0012	0.0050	<i>hWktcv</i>	<i>hWktcg</i>
Word length	<i>gomp@v</i>	Dissimilar	873	0.0028	0.0140	<i>gomp@f</i>	<i>gomp@p</i>
			992.00 (168.29)	0.0020 (0.0011)	0.0095 (0.0063)		
	<i>kYmtUp</i>	Short	867	0.0004	0.0022	<i>kYmtUb</i>	<i>kYmtUz</i>
	<i>dUdtif</i>	Short	850	0.0012	0.0061	<i>dUdtiv</i>	<i>dUdtig</i>
Visual similarity			858.50 (12.02)	0.0008 (0.0006)	0.0041 (0.0027)		
	<i>wefyUktughcd</i>	Long	1,600	0.0015	0.0162	<i>wefyUktughcn</i>	<i>wefyUktughcf</i>
	<i>nUdfegdYnyup</i>	Long	1,585	0.0004	0.0044	<i>nUdfegdYnyub</i>	<i>nUdfegdYnyun</i>
			1,592.50 (10.61)	0.0010 (0.0008)	0.0103 (0.0083)		
Grid location	<i>dofwig</i>	†	875	0.0004	0.0022	<i>dofwik</i>	<i>dofwim</i>
	<i>b^vdep</i>		736	0.0012	0.0059	<i>b^vdeb</i>	<i>b^vden</i>
	<i>yitgYm</i>		772	0.0007	0.0034	<i>yitgYn</i>	<i>yitgYk</i>
	<i>fugbOn</i>		917	0.0003	0.0015	<i>fugbOd</i>	<i>fugbOk</i>
Orthography			825.00 (85.04)	0.00065 (0.0004)	0.0032 (0.0019)		
	<i>t^pwib</i>	†	958	0.0006	0.0032	<i>t^pwim</i>	<i>t^pwin</i>
	<i>tughWt</i>		783	0.0006	0.0028	<i>tughWd</i>	<i>tughWv</i>
	<i>kYmyeg</i>		904	0.0006	0.0028	<i>kYmyek</i>	<i>kYmyen</i>
Verbs	<i>yiktuf</i>		999	0.0015	0.0077	<i>yiktuv</i>	<i>yiktug</i>
			911.00 (93.78)	0.00083 (0.0004)	1.0041 (0.0023)		
	<i>banfep</i>	†	830	0.0038	0.0188	<i>banfeb</i>	<i>banfen</i>
	<i>m^bglk</i>		1,057	0.0041	0.0204	<i>m^bglg</i>	<i>M^bglf</i>
Verbs	<i>dimbYg</i>		931	0.0018	0.0090	<i>dimbYk</i>	<i>dimbYm</i>
	<i>duftcg</i>		902	0.0009	0.0044	<i>duftck</i>	<i>duftcf</i>
			930.00 (94.72)	0.0026 (0.0016)	0.0131 (0.0077)		
Verbs	<i>buviyid</i>	†	900	0.0004	0.0020	<i>buviyp</i>	<i>buviyk</i>
	<i>hOtgyYm</i>		939	0.0002	0.0010	<i>hOtgyYn</i>	<i>hOtgyYk</i>
	<i>kibtUp</i>		840	0.0003	0.0017	<i>kibtUb</i>	<i>kibtUz</i>
	<i>yevhWt</i>		915	0.0004	0.0020	<i>yevhWd</i>	<i>yevhWv</i>
Verbs			898.50 (42.18)	0.0003 (0.0001)	0.0017 (0.0005)		

Note. † denotes the computer randomly assigned two nonword–monster pairs to each condition for all participants.

^aKlattese is a computer-readable interface for the International Phonetic Alphabet. See Vitevitch and Luce (2004) for more information. ^bExcluding the “long” phonological manipulation, there was no significant effect of duration on condition of interest when using multiple *t* tests for independent samples and a Bonferroni correction for multiple comparisons ($p < .005$). ^cAll phonotactic probabilities were calculated using the phonotactic probability calculator (Vitevitch & Luce, 2004). There was no difference between biphone frequency means for any condition when using multiple *t* tests for independent samples and a Bonferroni correction for multiple comparisons ($p < .003$). ^dThere was no difference between summed biphone probabilities for any condition when using multiple *t* tests for independent samples and a Bonferroni correction for multiple comparisons ($p < .005$). Long words were not included in this comparison because they have more phonemes and thus higher biphone probabilities. ^eSimilar foils differed from the target word by a single consonant feature in the word-final phoneme (12 differed in voicing, three differed in manner, one differed in place). Foils were only presented during the mispronunciation decision task. ^fDissimilar foils primarily differed from the target word by all three consonant features in the word-final phoneme (three differed by two consonant features only). Foils were only presented during the mispronunciation decision task.