Research Article

Word Learning Deficits in Children With Dyslexia

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Purpose: The purpose of this study is to investigate word learning in children with dyslexia to ascertain their strengths and weaknesses during the configuration stage of word learning.

Method: Children with typical development ($N = 116$) and dyslexia ($N = 68$) participated in computer-based word learning games that assessed word learning in 4 sets of games that manipulated phonological or visuospatial demands. All children were monolingual English-speaking 2nd graders without oral language impairment. The word learning games measured children's ability to link novel names with novel objects, to make decisions about the accuracy of those names and objects, to recognize the semantic features of the objects, and to produce the names of the novel words.

Accuracy data were analyzed using analyses of covariance with nonverbal intelligence scores as a covariate.

Results: Word learning deficits were evident for children with dyslexia across every type of manipulation and on 3 of 5 tasks, but not for every combination of task/manipulation. Deficits were more common when task demands taxed phonology. Visuospatial manipulations led to both disadvantages and advantages for children with dyslexia.

Conclusion: Children with dyslexia evidence spoken word learning deficits, but their performance is highly dependent on manipulations and task demand, suggesting a processing trade-off between visuospatial and phonological demands.

Word learning is a dynamic process that can be described in three overlapping stages: (a) *triggering*—recognizing that a word is new and needs to be learned, (b) *configuration*—forming lexical and semantic representations and a link between them, and (c) *engagement*—the dynamic stage of learning where the representations formed during configuration interact with and affect the existing lexicon (Gray, Pittman, & Weinhold, 2014; Hoover, Storkel, & Hogan, 2010; Leach & Samuel, 2007). The purpose of this study is to investigate spoken word learning in children with dyslexia to ascertain their strengths and weaknesses during the configuration stage of word learning. Word learning is relatively understudied in the dyslexic population despite documented deficits in language learning and the fact that word learning competence is crucial for academic success (Protopapas, Mouzaki, Sideridis, Kotsolakou, & Simos,

2013; Tunmer & Chapman, 2012). Word learning experiments provide an opportunity to examine the range of proposed deficits in this population in a situation that involves both visually and phonologically based processing and learning.

Dyslexia traditionally has been viewed as a phonologically based deficit (e.g., Vellutino, Fletcher, Snowling, & Scanlon, 2004) associated with poor word reading abilities (e.g., Melby-Lervåg, Lyster, & Hulme, 2012). The nature of the deficits underlying dyslexia recently has been shown to extend beyond phonological deficits to procedural learning (e.g., Nicolson & Fawcett, 2011) and to visuospatial deficits (e.g., Vidyasagar & Pammer, 2010). These deficits have the potential to affect children's word learning. For example, children with visuospatial deficits are likely to have difficulty forming visually based semantic representations. In other words, they may not be registering the visual cues that inform the semantic representation of a word (e.g., the shape of the face of a dog versus a cat). Difficulties with either the phonological or semantic component of word learning could cause problems with linking a new word's label and object referent, given that it would be difficult to link fuzzy or absent representations. By determining the word learning strengths and weaknesses of children with dyslexia, we can further our understanding of the disorder and provide a research base for evidence-based treatments.

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Paired Associate Learning by Children With Dyslexia

Paired associate learning is a paradigm in which participants must learn pairs of stimuli, which mirrors the configuration stage of word learning in which people must link new words' labels and object referents. Across studies of paired associate learning, school-aged children with dyslexia are less accurate at visual-verbal paired associate learning than their peers with typical reading skills (e.g., Litt & Nation, 2014; Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003, 2006; Thomson & Goswami, 2010; Vellutino, Steger, Harding, & Phillips, 1975), but this depends on the characteristics of words used in the study. Mayringer and Wimmer (2000) and Messbauer and de Jong (2006) reported conditions for visual-verbal paired associate learning in which children with dyslexia performed as well as their peers with typical reading skills. These conditions involved short words (three to four phonemes) that were familiar names. In contrast, children with dyslexia evidenced a paired association learning deficit for longer words (six phonemes) that were pseudonyms. Thus, the nature of the words to be learned influenced performance. The fact that children with dyslexia were more successful with shorter words suggests that phonological working memory could affect their paired associate learning. Messbauer and de Jong (2003) hypothesized that better performance on familiar names versus pseudonyms also suggested stronger, better specified phonological representations for the former. Although children with dyslexia demonstrated visual-verbal paired learning deficits in these studies, results also suggested that children with dyslexia did not have a general paired associate learning deficit because they could perform as well as their peers with typical reading skills on tasks that were primarily visual (i.e., visual-visual) in nature (Litt & Nation, 2014; Messbauer & de Jong, 2003, 2006).

Results from paired associate learning studies also suggest that the primary source of difficulty, when children with dyslexia are asked to link new labels with referents in word learning studies, is likely to be phonological rather than visual. However, many studies using paired associate learning tasks have asked children to pair new words with familiar images, which reduces visuospatial processing load (e.g., Bonner, Burton, Jenkins, McNeill & Bruce, 2003). In these paradigms children did not need to create new semantic representations for referents; they were only required to create a link between a stored representation and a new word. Further, tasks that required children to pair novel images with new words tended to include fairly simple images, typically monochromatic symbols. Not all simple mappings were successful for children with dyslexia. When asked to pair novel short words with shapes, children with dyslexia were significantly less successful than typically developing peers (Thomson & Goswami, 2010). Regardless, whether using symbols that are representative of letters or simple shapes, none of these tasks represent the type of visuospatial processing load required to learn names for most referents in the real world.

Studies of word learning or paired associate learning by children with dyslexia suggest that children with dyslexia have difficulty with phonological processing, whereas findings from paradigms other than paired associate learning have suggested that children with dyslexia could have visuospatial processing difficulties. Given the consistent findings related to phonological deficits in children with dyslexia, we would expect to see word learning deficits in acquiring labels, particularly for longer novel words, and as a consequence difficulty pairing labels and referents. We also expect to see difficulty creating and storing representations of visually complex referents (i.e., not monochromatic symbols) and with pairing labels and these complex referents due to hypothesized difficulties with visuospatial processing.

The Current Study

Our study was designed to assess children's success in the configuration stage of spoken word learning when they create phonological and semantic representations and link them. One strength of this study is that we used stringent selection criteria for our dyslexic sample to ensure that participants did not also have oral language impairment. It is unfortunate that studies of children with dyslexia frequently include (or do not explicitly exclude) children with oral language deficits, which affects the interpretation of study results. Dyslexia commonly co-occurs with language impairment, a disorder that is associated with poor word learning (Kan & Windsor, 2010). The reported rates of comorbidity vary widely. For example, McArthur, Hogben, Edwards, Heath, and Mengler (2000) found that roughly half of the children in their study who were classified as having a specific language or reading disability should have been classified as having disabilities in both areas. In contrast, rates for comorbidity were 20%–25% in a study by Catts, Adlof, Hogan, and Weismer (2005). Without careful dissociation of these disorders, researchers could draw conclusions about children with dyslexia that, in reality, only apply to children with comorbid dyslexia and oral language impairment. A case in point is a study by Ramus, Marshall, Rosen, and van der Lely (2013), who found distinct sources of variance in individual performance on language tasks depending upon whether an individual had language impairment or dyslexia. It may be that the inclusion of children with dyslexia who have comorbid language impairment is a source of equivocal findings related to phonological and visual impairments in groups of children with dyslexia.

We examined word learning using four different games with multiple tasks assessing different visual, spatial, and phonological aspects of word learning. Because phonological similarity (e.g., Papagno & Vallar, 1992) and word length (e.g., Alt, 2011) have been shown to influence word learning in adults and children, we manipulated these variables in our study. Decreased accuracy on items with phonological similarity might point to difficulty with establishing clear phonological representations, whereas difficulty with longer words could point to limited phonological working memory capabilities.

We also examined the effects of the visual similarity of referents and changing their spatial location to assess the impact on the creation and storage of semantic representations. Research suggests that adults attend to spatial location and process information in a stable location faster than information presented in an unexpected location (e.g., Awh & Jonides, 2001). In addition, eye movements have been found to decrease adults' spatial span. Location changes are associated with increased eye movements (Pearson & Sahraie, 2003) and visually similar referents are more difficult for adults to discriminate than visually dissimilar referents (e.g., Palmer, 1978). Thus, decreased performance compared with peers on items that are visually similar or that change location could point to difficulty with visuospatial processing.

Our primary research question was whether children with dyslexia evidence word learning deficits compared with their peers with typical development (TD) under tasks and conditions that require the linking of labels and referents or that tax phonology or visuospatial processing. We specifically asked:

1. Do children with dyslexia perform less accurately than peers with typical reading skills on word learning tasks that require them to link phonological and visual representations (i.e., labels and referents)?
 - a. If there are differences related to linking labels and referents, would they be influenced by the demands of the learning context (i.e., phonological or visuospatial)?
2. Do children with dyslexia perform less accurately than peers with typical reading skills on word learning tasks with high phonological demands (i.e., creating and storing phonological representations)?
 - a. If there are differences related to phonology, do they emerge in all learning contexts or only those that tax phonology (i.e., phonologically similar vs. phonologically dissimilar words; long vs. short words).
3. Do children with dyslexia perform less accurately than peers with typical reading skills on word learning tasks that tax visuospatial processing (i.e., creating and storing detailed visuospatial representations)?
 - a. If there are differences related to visuospatial processing, do they emerge in all learning contexts or only those that tax visuospatial processing (i.e., visually similar referents vs. visually dissimilar referents; referents that appear in a stable location vs. referents that change location)?

Findings have the potential to inform hypotheses about deficits underlying dyslexia and to identify specific word learning problems in these children.

Method

Participants

Participants were second graders, ages 7–9 years, who completed tasks as part of a larger study of word

learning and working memory.¹ There were 116 monolingual English-speaking children with TD (73 girls; 43 boys) and 68 monolingual English-speaking children with dyslexia (41 girls; 27 boys). For the group with TD, three children were American Indian/Alaskan Native, two were Asian, three were Black/African American, 93 were White, 13 were more than one race, and two did not report a race. For ethnicity, 100 children were non-Hispanic, 14 were Hispanic, and two did not report this information. For the children in the dyslexia group, three were American Indian/Alaska Natives, two were Black/African American, 51 were White, 10 were more than one race, and two did not report a race. For ethnicity, 53 identified as non-Hispanic, 13 as Hispanic, and two did not report ethnicity. Descriptive information can be found in Table 1.

Participants were recruited from Arizona, Massachusetts, and Nebraska, primarily through school districts. After receiving parental consent, children were tested 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 (K-ABC-2; Kaufman & Kaufman, 2004), which is a measure of non-verbal intelligence, to rule out intellectual disability. We also disqualified children with a standard score of 125 or higher on the K-ABC-2 to exclude children in the gifted range. All children were also required to achieve a standard score equivalent of 88 or higher on the core language measures of the Clinical Evaluation of Language Fundamentals–Fourth Edition (Semel, Wiig, & Secord, 2003), which is 1 *SD* below the mean, plus 1 *SEM*. This helped to ensure that we did not include children with oral language disorders in our sample.

To qualify for the TD group, children were required to achieve a grade level standard score of 96 or higher on the Test of Word Reading Efficiency–Second Edition (Torgesen, Wagner, & Rashotte, 2012) and score above the 31st percentile on the Goldman–Fristoe Test 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 ($N = 3$). Children in

¹Participants in this article represent a portion of the participants in a larger sample from the POWWER study, funded by National Institute on Deafness and Other Communication Disorders Grant R01 DC010784. The POWWER study includes the groups reported, as well as TD bilingual children, children with oral language impairment, and children with comorbid dyslexia and oral language impairment. Participants in the POWWER study completed a total of six word learning games and a comprehensive battery of working memory tasks, completed over the course of at least 6 days.

Table 1. Means and standard deviations for standard scores on inclusionary and descriptive assessments.

Parameter	TD	Dyslexia	<i>p</i> value*
N	116	68	n/a
Age	7;8 (0;4)	7;10 (0;5)	.08
MLE	15.22 (1.69)	14.74 (1.94)	.08
TOWRE-2	108.82 (8.77)	80.58 (6.19)	<.001
K-ABC-2	109.24 (9.27)	103.57 (10.83)	<.001
CELF-4	106.18 (8.46)	99.61 (8.75)	<.001
GFTA-2**	50.87 (7.81)	42.57 (17.46)	<.001
EVT-2	110.22 (10.39)	103.00 (11.08)	<.001
WRMT	106.56 (9.61)	92.69 (10.47)	<.001
ADHD	10.18 (8.88)	13.04 (9.21)	.08
NWR % CC	85.47% (8.51)	82.61% (10.74)	.06

TD = typical development; MLE = mother's level of education; TOWRE-2 = Test of Word Reading Efficiency–Second Edition (Torgesen, Wagner, & Rashotte, 2012); K-ABC-2 = Kaufman Assessment Battery for Children–Second Edition (Kaufman & Kaufman, 2004); CELF-4 = Clinical Evaluation of Language Fundamentals–Fourth Edition (Semel, Wiig, & Secord, 2003); GFTA-2 = Goldman–Fristoe Test of Articulation–2 (Goldman & Fristoe, 2000); EVT-2 = Expressive Vocabulary Test–Second Edition (Williams, 2007); WRMT = Woodcock Reading Mastery Test, Paragraph Comprehension Subtest (Woodcock, 2011); ADHD = parental rating of attention-deficit/hyperactivity disorder behaviors using the ADHD Rating Scale–IV Home Version (DuPaul et al., 1998); NWR % CC = Nonword Repetition task, percent consonants correct (Dollaghan & Campbell, 1998).

*Between group differences were tested using *t* tests. **Percentile, rather than standard score.

the dyslexia group were required 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 it is roughly midway between the wide range of diagnostic criteria for dyslexia in the literature, ranging from the 7th percentile (Badian, McAnulty, Duffy, & Als, 1990) to the 30th percentile (Manis et al., 1997). Children with dyslexia also had to score above the 31st percentile on 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 ($N = 16$). We used these slightly different criteria due to the fact that children with dyslexia often have comorbid speech sound disorders (e.g., Peterson & Pennington, 2015) that might still be resolving in second grade. With the criteria for speech sound production, none of the children included in the study had articulation errors on three or more late-developing sounds.

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

Procedures

The word learning games described here are part of Comprehensive Assessment Battery for Children–Word Learning (Alt, Hogan, Gray, Green, & Cowan, 2017), a computer-based, pirate-themed adventure in which children travel to different virtual islands to help their pirate solve problems. Each set of games manipulates a different variable known to affect word learning and contains five separate tasks. The entire battery, which also included working memory games from the Comprehensive Assessment Battery for Children–Working Memory (Cabbage et al., in press), required an average of six to eight research sessions, each of which lasted roughly 1 hr and 15 min. Most children averaged two sessions for assessments, with the remaining sessions dedicated to word learning and memory games that were presented each session.

The games were presented in random order within and across sessions and a child never played more than one set of word learning games per day. Children were seated at a touchscreen computer that ran the pirate adventure game format. This format was designed to keep children motivated and engaged across multiple days of research. They were able to choose a pirate avatar, buy virtual presents for their pirate that they retained across sessions, and were often rewarded with virtual coins and animations.

A trained research assistant (RA) monitored the child's progress and advanced the games when necessary. RA training consisted of several steps. After being provided with an overview of the pirate adventure, potential RAs were given a written manual that described the operating procedures for each game and were instructed to practice the games multiple times with other people. After practice, they were required to pass a quiz that outlined general principles of the games (e.g., do not elaborate on the standardized instructions presented on the computer). If they passed the quiz, they took an in-lab fidelity test, where they had to administer the games to a lead data collector who had a checklist of procedures that were to be followed. If they passed that check, they had to pass a live fidelity check in the field with an actual participant.

The instructions for the experimental procedures were presented by the computer and the RAs were trained not to provide extra help or commentary to ensure standardization of procedures. With the exception of the Naming task, which was scored offline from audio recordings, all data collection was automated by the computer. After each session children were rewarded with trips to a virtual pirate store where they could purchase virtual items for their pirate with the coins they had earned. They were also given small prizes and stickers at the conclusion of each session. Once they completed all sessions they were given a \$15 gift card.

Stimuli

Nonwords

The nonwords followed a consonant–vowel (CV) or consonant–vowel–consonant (CVC) syllable structure (e.g.,

gompav, nudwef) and contained no later-developing speech sounds (i.e., /r/, /θ/, or /s/). Nonwords had no phonological neighbors, thus were low in neighborhood density. Phonotactic probabilities were equal across conditions ($M = 1.0046$) and were low on the basis of the ranges found in other studies using summed biphone probabilities for two-syllable nonwords (range of means for low phonotactic probability: 1.0039–1.009; Alt, 2011; Alt, Meyers, & Figueroa, 2013; Alt & Plante, 2006). Please see Appendix A for a list of the nonwords and their characteristics.

Referents

The referents that children learned to name were all virtual sea monsters created on a computer. They were all the same size, but varied in body shape, color, limb shape, head covering, and facial features.

The Word Learning Games

Within the pirate adventure children completed four word learning islands, or sets of games, each on a different day. They learned names for four sea monsters for each set of games. Teaching and testing occurred across four blocks that each contained five tasks. Each set of games targeted a different construct (i.e., phonological working memory or visuospatial working memory). In order to target that construct, we manipulated a subconstruct for each set of games (e.g., word length), thus creating two conditions for each set of games (e.g., two- vs. four-syllable words), and those conditions were present in all five tasks. The conditions varied depending upon the set of games. Please see Figure 1 for an overview of the experiment and Table 2 for an overview of each task and its requirements.

For each set of games children had to learn the names and semantic features for four different sea monsters. The names and semantic features were distinct across each set of games to minimize the possibility of interference. Each set of games was divided into four blocks with two exposures to each word and referent pair in Block 1 (triggering stage of word learning), and 15 exposures each in Blocks 2, 3, and 4 (configuration stage of word learning). Children were not explicitly told which referents paired with which words. Rather, they learned the word-referent pairs during the Phonological–Visual Linking task, through the feedback that was provided within that task. Each block consisted of the exposure to the word-referent pairs (i.e., Phonological–Visual Linking task) and was followed, in random order, by the other tasks. The randomization was important to reduce the risk of order effects. Each task is explained in detail below.

Phonological–Visual Linking

During this linking task children saw four monsters on the computer screen, heard the name of one monster, and had to select the monster that was linked to that name by touching the screen. They received immediate feedback for each selection in the form of a virtual coin in the bottom of the screen for a correct selection and a virtual rock

for an incorrect selection. The dependent variable was accuracy for each block.

Mispronunciation Detection

This task measured phonology. In the Mispronunciation Detection task we presented children with one of the referents they had seen in the Phonological–Visual Linking task and they heard either the correct label for that referent or a foil. Children were asked to make an explicit decision about the phonological composition of a lexical label and whether or not it matched the label they had been learning by pressing a large Yes or No button on the touchscreen (examples in Supplemental Material S1). They received immediate feedback of a coin for a correct answer or a rock for an incorrect response. Children completed four Mispronunciation Detection trials (one for each word) during each block, for a total of 16 trials in each set of games' Mispronunciation Detection task. Half of the trials presented foils and half presented the actual targets (see Appendix A for details).

Given that children had a 50% chance of guessing the correct answer, the dependent variable was the adjusted number of correctly identified target nonwords per word learning condition. To get this score, we calculated the proportion of hits (correct recognition on trials when the real target was presented) minus the proportion of false alarms (incorrect Yes response on trials containing foils).

Naming

The second phonological task was the Naming task, so called because children were asked to produce the name for a referent, which requires them to recall the stored phonological representation and output it. A child was presented with the image of a sea monster and was asked to name it. If the child attempted to name the monster, regardless of accuracy, the RA pressed a coded key on the keyboard to indicate that an attempt was made. If the child did not attempt a name, or gave a general name that applied to all trials (e.g., “monster”), the RA pressed a coded key to indicate the child did not attempt a response. Children received a virtual coin for any verbal attempt or received a virtual rock if no verbal naming attempt was made. Children named each of the four monsters every block, though the order of presentation was randomized across blocks, for a total of 16 trials across four testing blocks. The child's response was recorded via a microphone–headset combination and transcribed offline by trained phonetic transcribers using Klattese, a computer-based representation of the International Phonetic Alphabet (see Vitevitch & Luce, 2004 for a full description of Klattese).

The dependent variable for this task was the total consonants correct by condition (e.g., similar vs. dissimilar nonwords) as measured by the number of consonants that correctly aligned with the consonants in the nonwords in a phoneme-by-phoneme analysis. This measure was chosen given that we did not have theoretically based hypotheses related to vowels and because reliability is typically higher for consonants than for vowels (e.g., Shriberg, Austin,

Figure 1. Overview of experiment. (a) Description of constructs, manipulations, and conditions. Note: for each set of games the manipulation (e.g., short vs. long words) was imposed within each of the five tasks (i.e., Phonological–Visual Linking, Naming, Visual Difference Decision, Visual Feature Recall, and Mispronunciation Detection). (b) Description of research tasks administered for each set of games.

A								
Construct	Phonological working memory				Visuospatial working memory			
Name of set of games & manipulation	Ice Cream Island Word Length		Dinosaur Island Phonological Similarity		Sports Island Location		Lost Treasure Island Visual Similarity	
Randomization	(Sets of games were presented in random order with one set completed per research session)							
Conditions	2-syllable	4-syllable	Phonologically dissimilar nonwords	Phonologically similar nonwords	Referent in stationary position	Referent changes position	Visually dissimilar referent	Visually similar referent

B					
Blocks	Task 1	Task 2	Task 3	Task 4	Task 5
	(Always first; children learn nonword/referent pairs)	(Tasks 2, 3, 4, & 5 administered in random order for each block after Task 1; order below is one possible example)			
Block 1	Phonological–Visual Linking 2 exposures	Naming	Visual Difference Decision	Visual Feature Recall	Mispronunciation Detection
Block 2	Phonological–Visual Linking 15 exposures	Visual Difference Decision	Visual Feature Recall	Mispronunciation Detection	Naming
Block 3	Phonological–Visual Linking 15 exposures	Visual Feature Recall	Mispronunciation Detection	Naming	Visual Difference Decision
Block 4	Phonological–Visual Linking 15 Exposures	Mispronunciation Detection	Naming	Visual Difference Decision	Visual Feature Recall

Lewis, McSweeny, & Wilson, 1997). Overall accuracy scores could range from 0 to 64 for most conditions, although the scores could range from 0 to 96 for the condition in the set of games that included four-syllable nonwords. To

calculate reliability a second trained transcriber rescored a minimum of 20% of the sample and scores were compared. Point-to-point agreement ranged from .90 to .93 on the four naming tasks.

Table 2. Details of tasks by construct.

Domain	Task name	Task description and requirements
Linking	Phonological–Visual Linking	See four referents and hear one lexical label. Choose the referent to which the label refers. Receive immediate feedback. Data available for four time points.
Phonology	Mispronunciation Detection	See a referent. Hear a lexical label. Decide if the lexical label is accurate or not. This is never an issue of a legal name being paired with the wrong image. The judgment is about the phonology of the label. Requires metalinguistic knowledge. Data from four decisions collapsed into a single accuracy score.
	Naming	See a referent. Recall lexical label from memory and produce the label that matches that image. Data available for four time points.
Visuospatial	Visual Difference Decision	See a referent. Decide if the referent is the same as the referent child has been learning. This is never an issue of a legal referent from a different set of games being presented in the current set of games. The judgment is about the accuracy of the semantic representation. Requires metalinguistic knowledge. There is no overt phonological component to this task. Data from four decisions collapsed into a single accuracy score.
	Visual Feature Recall	See an outline of a referent. Recall four semantic features from memory and choose, from fields of four, the correct features for the referent. There is no overt phonological component to this task. Data available for four time points.

Visual Difference Decision

The tasks that tapped visuospatial semantic knowledge included the Visual Difference Decision task and the Visual Feature Recall task. The Visual Difference Decision task was much like the Mispronunciation Detection task. In this case, the child saw an image of a monster and had to decide if it was an accurate depiction of the monster the child had been learning. There was no phonology involved. Decisions were indicated by pressing a Yes or No button on the screen. Much like the lexical foils (see Appendix A), one foil differed by only one semantic feature, whereas one foil differed by three semantic features. Children made a decision about each monster in each block. By the end of the task, they had made four decisions about each monster's name. Trials (correct or foil presentations) were randomly presented across the four blocks. We used the same formula as in the Mispronunciation Detection task to determine the adjusted number of correctly identified referents, which served as the dependent variable.

Visual Feature Recall

The Visual Feature Recall task was thus named because it required children to recall fine-grained stored visual representations of visual features and suppress any potential interference from competing choices. This task allowed children to demonstrate their memory of visual features without taxing their expressive language skills. In this task, children were asked to recall a monster's color, eyes, arms, and head covering. They were provided with an outline of the monster, and four choices for each semantic feature. When they made a selection (by touching the screen) for a feature, that feature appeared on the outline, so children could try out the feature on the monster, and were not making a purely abstract choice removed from its original context. Once the selection was made, children pressed the Next button and received feedback about the accuracy of their choices via a gold coin for each correctly selected feature or a rock for incorrect selections. Children recalled visual features about each monster in each block. By the end of the set of games, they had engaged in four visual feature recall sessions about each monster. The dependent variable was the percentage of features correctly identified across blocks. See Supplemental Material S2.

Analytic Approach

To answer our research questions we conducted both analyses of variance (ANOVAs) and analyses of covariance (ANCOVAs). The ANOVA analyses allow us to look at the groups as they presented and the results can be found in Appendix B. An ANOVA alone, however, would not allow us to determine whether or not group differences on the dependent variables were only due to the between-groups differences in nonverbal intelligence. Thus, the ANCOVAs (presented below) used nonverbal intelligence (from the K-ABC-2) as the covariate. As you will see in Table 1, the groups differed on other measures besides nonverbal intelligence. However, this was the only variable that was not

expected to differ between groups, and thus the one we chose to covary. Children who are poor readers are likely to have lower scores than peers on anything related to language and reading (e.g., Catts et al., 2005). However, the role of nonverbal intelligence as a feature of dyslexia is unclear. We could not determine if the differences between groups in nonverbal intelligence were a fair representation of the population or an artifact of subject selection. Thus, we chose to covary nonverbal intelligence to get a clearer picture of between-groups differences related to word learning, independent of intelligence.

To begin, we ran a separate repeated measures ANOVA for each dependent variable of each task (i.e., Phonological–Visual Linking, Naming, Mispronunciation Detection, Visual Difference Decision, Visual Feature Recall) within each set of games (i.e., word length, phonological similarity, location, visual similarity) for a total of 20 ANOVAs. The between-groups factor was group (TD, dyslexia) and the within-group variable was the manipulation (e.g., two-syllable vs. four-syllable). Each analysis was followed by post hoc testing to clarify significant interactions.

However, below, we only report the analyses using ANCOVA with nonverbal intelligence as a covariate.² We used a centered covariate, and when an interaction was present, we used a difference score in the ANCOVA to reflect the interaction.

Results

Linking

Phonological–Visual Linking Task

This task was designed to illustrate how well children were able to link phonological labels and visual referents across time under different conditions known to affect word learning. For this task, we conducted an ANCOVA for accuracy. The between-groups factor was group and the within-group factors were condition (e.g., two-syllable, four-syllable) and block (i.e., 1, 2, 3, 4). Across all conditions, there were differences related to block, with children generally improving across blocks.

Word Length Manipulation

There was a significant interaction between group and condition. Children with dyslexia had a trend towards lower means ($M = 63.92\%$, $SEM = 2.12\%$) than children in the TD group ($M = 65.62\%$, $SEM = 1.69\%$) for long words, but the pattern was reversed for short words. Children with dyslexia had a trend towards higher means ($M = 71.73\%$, $SEM = 1.95\%$) than children in the TD group ($M = 69.40\%$, $SEM = 1.55\%$) for short words. However, post hoc tests

²In the covariate analyses, there was a main effect for nonverbal intelligence for 12 out of the 20 tasks (five tasks across four sets of games) as noted in Tables 3–7. There was a main effect for nonverbal intelligence: for four of five tasks for both of the visuospatial manipulations, for three of five tasks for the phonological similarity manipulations, and for one task for the word length manipulation.

did not find either of these differences to be statistically significant (see Table 3 and Supplemental Material S3).

Phonological Similarity Manipulation

There were no significant main effects or interactions related to group for this manipulation.

Location Manipulation

There were no significant main effects or interactions related to group for this manipulation.

Visual Similarity Manipulation

There were no significant main effects or interactions related to group for this manipulation.

Phonology

Mispronunciation Detection Task

For this task we used adjusted percent accuracy scores (defined earlier) as the dependent variable in the ANCOVA with group as the between-groups measure and condition as the within-group measure. Details for the results of all the manipulations are found in Table 4.

Word Length Manipulation

There was an interaction between group and length such that the dyslexia group was significantly less accurate than the TD group, but only for the longer, four-syllable words.

Phonological Similarity Manipulation

Results for phonological similarity were similar. The dyslexic group was significantly less accurate than the TD group only for phonologically similar words.

Location Manipulation

There were no significant main effects or interactions related to group for this manipulation.

Visual Similarity

For visual similarity the dyslexic group was significantly less accurate than the TD group.

Naming Task

This task required children to produce the correct lexical label when provided with a referent. We conducted a separate ANCOVA for Accuracy $\times$ Block, with group as the between-groups measure and block and condition as the within-group measures. Details for all the manipulations can be found in Table 5 (see Supplemental Material S4).

Word Length Manipulation

There were no significant main effects or interactions related to group for this manipulation.

Phonological Similarity Manipulation

The dyslexia group was significantly less accurate than the TD group.

Location Manipulation

The dyslexia group was significantly less accurate than the TD group.

Visual Similarity Manipulation

The dyslexia group was significantly less accurate than the TD group.

Visuospatial

Visual Difference Decision Task

For this task we completed an ANCOVA with group as the between-groups variable and for each condition as the within-group variable using the adjusted percent accuracy score as the dependent variable, as with the Mispronunciation Detection task. Summaries of the findings are available in Table 6.

Table 3. Adjusted means and standard errors for accuracy on the fourth block of the Phonological–Visual Linking task by condition.

Condition	Phonology				Visuospatial			
	Word length ^{a,b}		Phonological similarity ^{b,c}		Location ^c		Visual similarity ^{b,c}	
	4 syllables	2 syllables	Similar	Dissimilar	Variable	Stable	Similar	Dissimilar
TD	82.16 (2.10)	87.72 (1.79)	71.84 (2.61)	73.89 (2.57)	76.18 (2.52)	78.28 (2.39)	72.34 (2.56)	78.48 (2.65)
<i>N</i>		109		111		109		111
DYS	81.12 (2.65)	85.43 (2.25)	71.52 (3.31)	76.50 (3.25)	75.24 (3.27)	75.06 (3.10)	70.65 (3.33)	72.32 (3.44)
<i>N</i>		68		68		64		65
ANCOVA								
<i>F</i>	(1, 174) = 5.62		(1, 176) = 0.00		(1, 170) = 0.16		(1, 173) = 2.46	
<i>p</i>	.01		.98		.68		.11	
η^2_{partial}	.03		<.01		<.01		.01	

Note. Nonverbal IQ added as covariate. TD = Children with typical development; DYS = Children with dyslexia; ANCOVA = Analysis of covariance.

^aIndicates an interaction between group and condition. ^bIndicates a main effect of condition. ^cIndicates a main effect for nonverbal intelligence.

Table 4. Adjusted means and standard errors for accuracy on the Mispronunciation Detection task by condition.

Condition	Phonology				Visuospatial			
	Word length ^{a,b}		Phonological similarity ^{b,c}		Location		Visual similarity ^c	
	4 syllables	2 syllables	Similar	Dissimilar	Variable	Stable	Similar	Dissimilar
TD	41.42 (3.37)	47.36 (3.36)	32.60 (3.26)	25.79 (3.31)	41.44 (3.69)	38.66 (3.87)	41.73 (3.17)	43.99 (3.42)
<i>N</i>		109		111		109		111
DYS	29.82 (4.24)	49.78 (4.22)	17.94 (4.10)	24.64 (4.16)	41.51 (4.78)	36.02 (5.02)	30.77 (4.12)	33.03 (4.44)
<i>N</i>		68		69		64		65
ANCOVA								
<i>F</i>	(1, 174) = 4.84		(1, 177) = 4.57		(1, 170) = 0.05		(1, 173) = 6.21	
<i>p</i>	.02 .02		.03		.80		.01	
η^2_{partial}			.02		<.01		.03	

Note. Nonverbal IQ added as covariate. TD = Children with typical development; DYS = Children with dyslexia; ANCOVA = Analysis of covariance.

^aIndicates a main effect for condition. ^bIndicates interaction between condition and group. ^cIndicates a main effect for nonverbal intelligence.

Word Length Manipulation

There were no significant main effects or interactions related to group for this manipulation.

Phonological Similarity Manipulation

There were no significant main effects or interactions related to group for this manipulation.

Location Manipulation

There was a significant main effect for group for location with the dyslexia group being more accurate than the TD group.

Visual Similarity

There was an interaction between group and condition such that the dyslexia group ($M = 64.25\%$, $SEM = 3.22$) was significantly less accurate than the TD group ($M = 71.94\%$, $SEM = 2.48$), but only for referents that were visually dissimilar ($t = 2.29$, $p = .02$, $d = 0.34$).

Visual Feature Recall Task

This task allowed us to examine the effect of visuospatial manipulations on word learning. We conducted ANCOVAs for accuracy with group as the between-subjects measure and block and condition as the within-subjects measures. Details for all manipulations can be found in Table 7. There were no significant main effects or interactions related to group for any of the manipulations for this task. For a summary of all group differences on all tasks with nonverbal intelligence run as a covariate, please see Supplemental Material S5.

Discussion

Using a word learning task allowed us to examine some of the potential sources of weakness for children with dyslexia (i.e., phonological and visuospatial processing). It is important to note that we could contrast these sources within the same task, and within the same children. Not only is it important to understand the nature of dyslexia

Table 5. Adjusted means and standard errors for accuracy on the fourth block of the Naming task by condition.

Condition	Phonology				Visuospatial			
	Word length ^{a,b}		Phonological similarity ^b		Location ^b		Visual similarity ^{a,b}	
	4 syllables	2 syllables	Similar	Dissimilar	Variable	Stable	Similar	Dissimilar
TD	22.59 (1.61)	45.16 (2.49)	35.53 (2.41)	35.56 (2.53)	36.03 (2.39)	40.51 (2.44)	30.78 (2.01)	37.27 (2.11)
<i>N</i>		111		109		106		157
DYS	20.68 (2.03)	39.77 (3.14)	30.35 (3.08)	25.17 (3.24)	27.80 (3.16)	31.52 (3.23)	21.70 (3.04)	29.33 (3.20)
<i>N</i>		66		66		60		66
ANCOVA								
<i>F</i>	(1, 167) = 1.36		(1, 172) = 7.02		(1, 163) = 5.71		(1, 162) = 10.51	
<i>p</i>	.24		<.01		.01		<.01	
η^2_{partial}	<.01		.03		.03		.06	

Note. Nonverbal IQ added as covariate. TD = Children with typical development; DYS = Children with dyslexia; ANCOVA = Analysis of covariance.

^aIndicates a main effect for condition. ^bIndicates a main effect for nonverbal intelligence.

Table 6. Adjusted means and standard errors for accuracy on the Visual Difference Decision task by condition.

Condition	Phonology				Visuospatial			
	Word length		Phonological similarity		Location ^{a,c}		Visual similarity ^b	
	4 syllables	2 syllables	Similar	Dissimilar	Variable	Stable	Similar	Dissimilar
TD	65.62 (3.13)	62.80 (3.00)	70.57 (3.03)	69.62 (2.88)	61.94 (2.80)	56.91 (2.93)	79.55 (2.33)	71.94 (2.48)
<i>N</i>		109		111		109		111
DYS	72.48 (3.95)	69.24 (3.77)	68.26 (3.81)	66.27 (3.62)	69.71 (3.64)	65.34 (3.80)	83.15 (3.03)	64.25 (3.22)
<i>N</i>		68		69		64		65
ANCOVA								
<i>F</i>	(1, 174) = 2.59		(1, 177) = 0.49		(1, 170) = 5.14		(1, 173) = 5.52	
<i>p</i>	.10		.48		.02		.01	
η^2_{partial}	.01		<.01		.02		.03	

Note. Nonverbal IQ added as a covariate. TD = Children with typical development; DYS = Children with dyslexia; ANCOVA = Analysis of covariance.

^aIndicates a main effect for group. ^bIndicates an interaction between group and condition. ^cIndicates a main effect for nonverbal intelligence.

theoretically, it is important to take a closer look at word learning in this population, as it is a critical academic skill.

Our first research question was about the potential word learning performance of children with dyslexia when asked to link phonological and visual representations. Our Phonological–Visual Linking task, which tested this ability, is the most like many of the paired-associate tasks reported in the literature. The children with dyslexia were as accurate as peers with TD across all four sets of games and their manipulations. Thus, there does not seem to be a fundamental deficit in paired-associate learning. Our findings line up well with the conclusions of Litt and Nation (2014), who also did not find deficits in associative learning, but found more primary deficits with phonological form learning.

Our next question about word learning in children with dyslexia was whether or not they would perform less accurately than peers with typical reading skills on tasks with high phonological demands. In our study, we assessed this with the Mispronunciation Detection and Naming tasks. Indeed, when they were asked to create and store detailed

phonological representations, they were less accurate than peers with typical reading for three of four sets of games for the Naming task and for three of four sets of games for the Mispronunciation Detection task. Thus, this provides evidence for phonological deficits in children with dyslexia, but it is important to note that there are some situations that tax phonological processing in which children with dyslexia could perform as well as peers. Phonology has long been reported to be a central deficit of children with dyslexia, so it is not surprising to find that the children in our study struggled with phonologically demanding tasks. That said, the phonological deficit in dyslexia is often tied to written language, and these findings highlight that those deficits need not be limited to phonological–orthographic linking.

An additional consideration related to phonology is that we found deficits in tasks that required output (Naming) as well as those that did not (Mispronunciation Detection). This finding is counter to expectations from views of dyslexia that posit that the phonological deficits

Table 7. Adjusted means and standard errors for accuracy on the fourth block of the Visual Feature Recall task by condition.

Condition	Phonology				Visuospatial			
	Word length		Phonological similarity		Location ^b		Visual similarity ^{a,b}	
	4 syllables	2 syllables	Similar	Dissimilar	Variable	Stable	Similar	Dissimilar
TD	71.07 (2.22)	71.90 (2.10)	74.55 (2.08)	72.81 (2.25)	74.49 (2.01)	76.88 (1.86)	82.00 (2.05)	74.87 (2.09)
<i>N</i>		109		111		109		111
DYS	70.70 (2.79)	75.98 (2.64)	75.44 (2.62)	73.93 (2.83)	75.76 (2.61)	82.30 (2.41)	81.45 (2.66)	72.38 (2.72)
<i>N</i>		68		69		64		65
ANCOVA								
<i>F</i>	(1, 174) = 1.10		(1, 177) = 0.00		(1, 170) = 1.63		(1, 173) = 0.01	
<i>p</i>	.29		.95		.20		.91	
η^2_{partial}	<.01		<.01		<.01		<.01	

Note. Nonverbal IQ added as covariate. TD = Children with typical development; DYS = Children with dyslexia; ANCOVA = Analysis of covariance.

^aIndicates a main effect of condition. ^bIndicates a main effect for nonverbal intelligence.

in children with dyslexia are actually problems with output, or access to the representation (e.g., Hulme & Snowling, 1992; Ramus & Szenkovits, 2008; Truman & Hennessey, 2006), and thus we should not see deficits in tasks such as Mispronunciation Detection. One potential confound for our findings is the fact that these tasks have the potential to influence one another (e.g., a child could produce foils heard in the Mispronunciation Detection task or could have their judgment of a foil influenced by their own misproduction). This is the reason that these tasks were presented in random order for each block for each child. Thus, any effect of one task on the other would be nullified by the randomized order. Our data set unfortunately will not allow us to provide definitive evidence for or against an output/access account of dyslexia.

Our second question about phonology was related to manipulation. We were curious if the sets of games that manipulated phonology (i.e., word length and phonological similarity) would result in deficits for children with dyslexia. Let us begin with phonological similarity in which newly learned phonological labels comprised either similar sounds or dissimilar sounds. Children with dyslexia were less accurate than peers with TD on two out of five tasks (i.e., Naming and Mispronunciation Detection) for this manipulation. Given that the children with dyslexia were only less accurate than peers with TD on phonologically based tasks, the driving factor may have been the task rather than the manipulation. This case is made stronger by the fact that, despite a hypothesis that similar words would be more difficult, there were actually no differences related to condition for phonological similarity on most of the tasks. A difference did emerge for the Phonological–Visual Linking task, but its effect was consistent across groups. This suggests that children with dyslexia did not have particular difficulty processing phonologically similar sounds in our study, but they did struggle with tasks that asked them to assess the phonology of a newly learned word.

The second phonological manipulation was word length—that is, the phonological labels to be learned were either long or short. Children with dyslexia were less accurate than their peers with TD on only one of the five tasks in this learning context: Mispronunciation Detection for the long words. From this one task that revealed difficulty with longer words, we cannot assume that children with dyslexia have a clear phonological working memory capacity limitation, as might be predicted. Although their weak performance on four-syllable words in the Mispronunciation Detection task would support this hypothesis, their adequate performance on the other four tasks argues against this interpretation.

Our finding that shorter words were easier for children with dyslexia to learn than longer words is in line with Mayringer and Wimmer (2000) and Messbauer and de Jong (2006). However, it may be the case that “short” is a relative term. Our short words were six phonemes long, which is the same length of the troublesome “long” words in previous research. Thus, context may influence learning more than word length, meaning that relative length might be

more important than absolute length. This further suggests that phonological challenges in children with dyslexia are not related to an absolute phonological working memory capacity limitation, at least not for words that are six phonemes in length.

Given suggestions in the literature that difficulties with visuospatial processing or attention may be central to dyslexia, we were interested to see if tasks that required children to create and store visual representations (i.e., Visual Difference Decision and Visual Feature Recall) would lead to word learning deficits in the participants with dyslexia. Out of eight opportunities, there was only one situation in which a deficit emerged: Children with dyslexia had difficulty making visual difference decisions when the items to be learned were visually dissimilar. In fact, in one of the eight opportunities, Visual Difference Decision, in which location was manipulated, children with dyslexia were actually more accurate than children with TD.

To better understand this finding, it would be helpful to consider the manipulation under which the advantage occurred. Children with dyslexia were more accurate than peers with TD when the location of the referent was manipulated. It is possible that the children with dyslexia were using a particular strategy in this situation. For example, perhaps the movement cued them to focus their attention more keenly, which allowed them to be successful. However, this particular manipulation (e.g., stable vs. moving location) that was a strength for children with dyslexia was not powerful enough to overcome the inherent challenges of the task demands for the other tasks within that manipulation. When task demands were phonological, children with dyslexia were either equivalent to or less accurate than peers with typical reading skills for this manipulation.

This single metric of superior spatial processing in the Visual Difference Decision task clearly does not point to a primary spatial processing deficit in children with dyslexia. However, it would also be premature to interpret visuospatial skills as an unmitigated strength for children with dyslexia. If this were the case, we would expect no deficits in the visuospatial tasks that manipulated visuospatial factors. In fact, when children with dyslexia were asked to learn in a condition that manipulated visual similarity, they were less accurate than peers on the majority (three of five) of the tasks. In all the tasks with visual similarity manipulations, all children were actually more accurate for the visually similar referents, which presumably should be more difficult to recall. Although this at first appears counterintuitive, we may be seeing the effects of engagement. This sort of engagement is not equivalent to interest in the task, but rather reflects the fact that increased cognitive resources are necessary for a certain task. Examples of this phenomenon are present in many types of tasks, including the effects of background babble on working memory in young adults (e.g., Neidleman, Wambacq, Besing, Spitzer, & Koehnke, 2015). In our experiment, the more similar the monsters appeared, the more effort the participants had to put into the task to be successful. The trade-off is that the performance on the visually dissimilar

monsters was slightly less accurate, and for the children with dyslexia, this difference was much greater than for the peers with TD for the Visual Difference Decision task. Our study was not set up to test different theories of specific types of visuospatial deficits noted in the literature for children with dyslexia (e.g., Bosse, Tainturier, & Valdois, 2007, vs. Facoetti, Lorusso, Paganoni, Umiltà, & Mascetti, 2003). However, the point is that our data do support at least a limited visuospatial deficit in children with dyslexia, with the locus of the problem likely being more visually than spatially based.

Nature of Learners

Our findings show several group difference for components of word learning between children who differ on reading skills. It is important to note that all of the children in this experiment had age-appropriate oral language skills. Thus, differences in word learning skills in children with dyslexia cannot be directly related to oral language deficits.

Children with dyslexia notably had lower scores on many measures than their peers in the TD groups. All of the children were recruited from the same environments. Given that dyslexia is a brain-based developmental disorder, it is not surprising to find some of these differences. Just as specific language impairment is notoriously nonspecific in terms of deficits (e.g., lower IQ; Gallinat & Spaulding, 2014), it is not surprising to find evidence of other mild cognitive and learning differences in children with dyslexia. However, that does not make it easy to interpret how these differences may play a role in performance on different tasks children with dyslexia encounter daily. For example, although the group with dyslexia had lower nonverbal intelligence scores than the TD group, their overall mean was still well within normal limits. The between-groups difference for nonverbal intelligence we found could be related to a skewed sample of peers with TD (despite recruiting from identical schools) or a manifestation of a real cognitive difference in children with dyslexia. It is important to understand if lower, but still typical, nonverbal intelligence is a feature of dyslexia, although that is not a question this study can answer.

In terms of interpreting our task we can feel fairly confident noting that the word learning differences we found are likely related to word-reading differences: The primary feature on which we selected our groups—that is, our use of a covariate for nonverbal intelligence—suggests that any word learning differences between the groups were likely not due to any differences in nonverbal intelligence between the groups. This is especially true given that the results with and without the covariate were similar for 18 of the 20 tasks.

In addition, both groups of children showed a relatively wide range of variability in their performance on most tasks. It is clear that additional work addressing individual differences in learners is called for. This is especially important in light of Peyrin et al.'s (2012) suggestion that

the root cause of dyslexia may be different for different individuals.

Summary

Our data support the conclusion that children with dyslexia have spoken word learning deficits in the configuration stage of word learning that can be attributed primarily to phonological deficits as evidenced by the difficulties with tasks that required children to create and store detailed phonological representations. However, visual processing deficits, particularly when visual similarity is manipulated, likely play a role as well. Yet, children with dyslexia showed a word learning advantage when the location of the referent was manipulated and the task demand was visuospatial. Thus, between-groups differences manifested depending on task and condition demands and may reflect unique learning strategies, be they implicit or explicit, for children with dyslexia. To be specific, it is possible that children with dyslexia may be using more cognitive resources to process certain types of visuospatial information at the expense of phonological information, although this hypothesis will need to be explicitly tested in future research.

It is also important to note that visuospatial information both helped and hindered word learning, depending on the type of information presented. Manipulations of visual similarity were detrimental for children with dyslexia in three of five tasks, and manipulations of location were detrimental for children with dyslexia for naming. However, the one task/condition in which children with dyslexia were more accurate than peers with TD was when they were asked to make a decision about a referent's appearance and they had learned about the referent in the location manipulation condition. These findings have implications for the types of materials instructors may use to assess or support word learning for children with dyslexia. To be specific, educators should not assume that all visual supports will be helpful or will override the phonological deficits found in many children with dyslexia. Adding visual information to a spoken learning task actually has the potential to result in less accurate outcomes for children with dyslexia. We will need more research to determine the ideal learning approach (e.g., staggered introduction of stimuli in different modalities, capitalization of more effective learning contexts) to recommend specific strategies to educators.

We see these deficits (and strengths) as the result of learning, rather than a problem with access to the representations as might be suggested by Ahissar's (2007) perceptual anchoring hypothesis, which suggests that people with dyslexia may not have strong perceptual anchors, and thus treat all incoming sounds as novel items, rather than linking them to existing categories. We make this distinction for two reasons. First, we have evidence that all of these participants had the sensory abilities to access the information. Second, participants with dyslexia had equivalent performance to their peers for every task in at least one learning condition. The most telling learning context relative to the

perceptual anchoring hypothesis would be the similarity conditions (both visual and perceptual). Although participants with dyslexia did show weaknesses in these learning contexts, they were not across-the-board deficits. If people with dyslexia truly have no perceptual anchor, they should not be able to effectively “anchor” in any situation. These results demonstrate that children with dyslexia do have the ability to learn as effectively as peers, even in these challenging learning contexts. Thus, our interpretation is that there is an interaction between learning context, task demand, and learning strategies that leads to this less-than-clean set of results. When working with children with dyslexia, it is important to note that spoken word learning can be a challenge, that tasks that tap phonology are likely to be the most challenging, and that the manipulation of visual similarity can also lead to decreased learning accuracy.

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Appendix A

Nonword stimuli characteristics

Condition of interest	Nonword in Klattese ^a	Condition manipulation	Duration in ms ^b	Biphone frequency ^c	Summed biphone probability ^d	Similar foils ^e	Dissimilar foils ^f
Phonological similarity	<i>n^dwef</i>	Similar	845	.0008	.0039	<i>nudwev</i>	<i>nudweg</i>
	<i>w^gyed</i>	Similar	825	.0009	.0043	<i>w^gyet</i>	<i>w^gyef</i>
<i>M</i> (SD)			835.00 (14.14)	.0009 (.0001)	.0041 (.0002)		
	<i>hWktcf</i>	Dissimilar	1111	.0012	.0050	<i>hWktcv</i>	<i>hWktcg</i>
<i>M</i> (SD)	<i>gomp@v</i>	Dissimilar	873	.0028	.0140	<i>gomp@f</i>	<i>gomp@p</i>
			992.00 (168.29)	.0020 (.0011)	.0095 (.0063)		
Word length	<i>kYmtUp</i>	Short	867	.0004	.0022	<i>kYmtUb</i>	<i>kYmtUz</i>
	<i>dUdtif</i>	Short	850	.0012	.0061	<i>dUdtiv</i>	<i>dUdtig</i>
<i>M</i> (SD)			858.50 (12.02)	.0008 (.0006)	.0041 (.0027)		
	<i>wefyUktughcd</i>	Long	1600	.0015	.0162	<i>wefyUktughcn</i>	<i>wefyUktughcf</i>
<i>M</i> (SD)	<i>nUdfegdYnyup</i>	Long	1585	.0004	.0044	<i>nUdfegdYnyub</i>	<i>nUdfegdYnyun</i>
			1592.50 (10.61)	.0010 (.0008)	.0103 (.0083)		
Visual similarity	<i>dofwig</i>	†	875	.0004	.0022	<i>dofwik</i>	<i>dofwim</i>
	<i>b^vdep</i>		736	.0012	.0059	<i>b^vdeb</i>	<i>b^vden</i>
<i>M</i> (SD)	<i>yitgYm</i>		772	.0007	.0034	<i>yitgYn</i>	<i>yitgYk</i>
	<i>fugbOn</i>		917	.0003	.0015	<i>fugbOd</i>	<i>fugbOk</i>
Grid location	<i>t^pwib</i>	†	825.00 (85.04)	.00065 (.0004)	.0032 (.0019)		
	<i>tughWt</i>		958	.0006	.0032	<i>t^pwim</i>	<i>t^pwin</i>
<i>M</i> (SD)	<i>kYmyeg</i>		783	.0006	.0028	<i>tughWd</i>	<i>tughWv</i>
	<i>yiktuf</i>		904	.0006	.0028	<i>kYmyek</i>	<i>kYmyen</i>
<i>M</i> (SD)			999	.0015	.0077	<i>yiktuv</i>	<i>yiktug</i>
			911.00 (93.78)	.00083 (.0004)	.0041 (.0023)		

^aKlattese is a computer-readable interface for the International Phonetic Alphabet. See Vitevitch & 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.

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

Appendix B

Results for accuracy analyses without covariates.

Table B1. Means and standard errors for accuracy on the fourth block of the Phonological–Visual Linking task by condition.

Condition	Phonology				Visuospatial			
	Word length ^a		Phonological similarity ^b		Location		Visual similarity ^b	
	4 syllables	2 syllables	Similar	Dissimilar	Variable	Stable	Similar	Dissimilar
TD	82.90 (2.09)	88.25 (1.74)	72.97 (2.70)	74.95 (2.59)	77.37 (2.56)	79.60 (2.36)	73.42 (2.51)	79.36 (2.47)
<i>N</i>		109		111		109		111
DYS	80.39 (2.63)	84.90 (2.30)	70.39 (3.02)	75.44 (3.10)	74.06 (3.20)	73.75 (3.25)	69.53 (3.45)	71.43 (3.75)
<i>N</i>		68		68		64		65
ANOVA								
<i>F</i>	(1, 175) = 7.80		(1, 177) = 0.41		(1, 171) = 0.10		(1, 174) = 4.66	
<i>p</i>	<.01		.51		.75		.03	
η^2_{partial}	.04		<.01		<.01		.02	

Note. TD = Children with typical development; DYS = Children with dyslexia; ANOVA = Analysis of variance.

^aIndicates an interaction between group and condition. ^bIndicates a main effect of condition.

Table B2. Means and standard errors for accuracy on the Mispronunciation Detection task by condition.

Condition	Phonology				Visuospatial			
	Word length ^{a,b}		Phonological similarity		Location		Visual similarity	
	4 syllables	2 syllables	Similar	Dissimilar	Variable	Stable	Similar	Dissimilar
TD	42.20 (3.33)	48.62 (3.35)	32.43 (3.22)	27.25 (3.24)	43.11 (3.82)	38.76 (3.80)	42.11 (3.06)	45.49 (3.41)
<i>N</i>		109		111		109		111
DYS	29.04 (4.17)	48.52 (4.18)	18.11 (3.96)	23.18 (4.23)	39.84 (4.47)	35.93 (4.94)	30.38 (4.19)	31.53 (4.46)
<i>N</i>		68		69		64		65
ANOVA								
<i>F</i>	(1, 175) = 4.44		(1, 178) = 4.77		(1, 171) = 0.34		(1, 174) = 8.79	
<i>p</i>	.03		.03		.55		< .01	
η^2_{partial}	.02		.02		<.01		.04	

Note. TD = Children with typical development; DYS = Children with dyslexia; ANOVA = Analysis of variance.

^aIndicates a main effect for condition. ^bIndicates an interaction between condition and group.

Table B3. Means and standard errors for accuracy on the fourth block of the Naming task by condition.

Condition	Phonology				Visuospatial			
	Word length ^a		Phonological similarity ^{b,d}		Location ^{b,c}		Visual similarity ^{a,b}	
	4 syllables	2 syllables	Similar	Dissimilar	Variable	Stable	Similar	Dissimilar
TD	23.27 (1.65)	46.66 (2.68)	36.15 (2.51)	36.12 (2.71)	37.38 (2.57)	41.62 (2.64)	31.77 (2.51)	39.11 (2.66)
<i>N</i>		105		109		106		107
DYS	20.00 (1.91)	38.26 (2.79)	29.73 (2.74)	24.62 (2.67)	26.45 (2.85)	30.41 (2.76)	19.61 (2.62)	25.86 (2.78)
<i>N</i>		65		66		60		58
ANOVA								
<i>F</i>	(1, 168) = 3.85		(1, 173) = 10.00		(1, 164) = 8.40		(1, 163) = 14.57	
<i>p</i>	.051		<.01		<.01		<.01	
η^2_{partial}	.02		.05		.04		.08	

Note. TD = Children with typical development; DYS = Children with dyslexia; ANOVA = Analysis of variance.

^aIndicates a main effect for condition. ^bIndicates a main effect for group. ^cIndicates an interaction between Group × Block (i.e., group differences were apparent in all blocks, except Block 1). ^dIndicates an interaction between Group × Block (i.e., group differences were apparent in all blocks, except Block 2).

Table B4. Means and standard errors for accuracy on the Visual Difference Decision task by condition.

Condition	Phonology				Visuospatial			
	Word length		Phonological similarity		Location		Visual similarity ^a	
	4 syllables	2 syllables	Similar	Dissimilar	Variable	Stable	Similar	Dissimilar
TD	66.05 (3.41)	63.30 (3.04)	70.72 (2.76)	69.59 (2.79)	63.30 (2.99)	57.79 (3.12)	80.40 (2.27)	72.74 (2.29)
<i>N</i>		109		111		109		111
DYS	72.05 (3.12)	68.75 (3.52)	68.11 (4.12)	66.30 (3.60)	68.35 (3.21)	64.45 (3.23)	82.30 (3.13)	63.46 (3.55)
<i>N</i>		68		69		64		65
ANOVA								
<i>F</i>	(1, 175) = 2.02		(1, 178) = 0.57		(1, 171) = 2.71		(1, 174) = 5.72	
<i>p</i>	.15		.44		.10		.01	
η^2_{partial}	.01		<.01		.01		.03	

Note. TD = Children with typical development; DYS = Children with dyslexia; ANOVA = Analysis of variance.

^aIndicates an interaction between group and condition.

Table B5. Means and standard errors for accuracy on the fourth block of the Visual Feature Recall task by condition.

Condition	Phonology				Visuospatial			
	Word length		Phonological similarity		Location ^a		Visual similarity ^a	
	4 syllables	2 syllables	Similar	Dissimilar	Variable	Stable	Similar	Dissimilar
TD	71.55 (1.99)	72.70 (2.23)	75.00 (2.04)	73.19 (2.21)	75.45 (1.99)	77.75 (1.83)	82.88 (1.83)	75.33 (1.90)
<i>N</i>		109		111		109		111
DYS	70.22 (3.12)	75.18 (2.32)	75.00 (2.59)	73.55 (2.78)	74.80 (2.69)	81.44 (2.50)	80.57 (3.10)	71.92 (3.04)
<i>N</i>		68		69		64		65
ANOVA								
<i>F</i>	(1, 175) = 0.63		(1, 178) = 0.13		(1, 171) = 0.26		(1, 174) = 0.17	
<i>p</i>	.42		.70		.61		.68	
η^2_{partial}	<.01		<.01		<.01		<.01	

Note. TD = Children with typical development; DYS = Children with dyslexia; ANOVA = Analysis of variance.

^aIndicates a main effect of condition.