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Research Article

Children With Dyslexia Benefit From Orthographic Facilitation During Spoken Word Learning

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Purpose: Orthographic facilitation describes the phenomenon in which a spoken word is produced more accurately when its corresponding written word is present during learning. We examined the orthographic facilitation effect in children with dyslexia because they have poor learning and recall of spoken words. We hypothesized that including orthography during spoken word learning would facilitate learning and recall.
Method: Children with dyslexia and children with typical development (n = 46 per group), 7–9 years old, were matched for grade and nonverbal intelligence. Across 4 blocks of exposure in 1 session, children learned pairings between 4 spoken pseudowords and novel semantic referents in a modified paired-associate learning task. Two of the pairings were presented with orthography present, and 2 were presented with orthography absent. Recall of newly learned spoken words was assessed using a naming task.
Results: Both groups showed orthographic facilitation during learning and naming. During learning, both groups paired pseudowords and referents more accurately when orthography was present. During naming, children with typical development showed a large orthographic facilitation effect that increased across blocks. For children with dyslexia, this effect was present initially but then plateaued.
Conclusions: We demonstrate for the first time that children with dyslexia benefit from orthographic facilitation during spoken word learning. These findings have direct implications for teaching spoken vocabulary to children with dyslexia.

The ability to learn new words is essential for successful spoken and written communication across the life span. Written words may provide critical support for spoken word learning in children with and without reading impairments. Children with typical development produce a new spoken word more accurately when the corresponding written word is present during learning (Ehri & Wilce, 1979; Reitsma, 1983). This phenomenon is dubbed "orthographic facilitation" (Ricketts, Bishop, & Nation, 2009; Rosenthal & Ehri, 2008). No studies have examined the orthographic facilitation effect in children with dyslexia, who are characterized by difficulty with phonological decoding of orthography (Lyon, Shaywitz, & Shaywitz, 2003; Snowling, 1980; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Children with dyslexia also have weak word learning (Vellutino et al., 2004), especially for the recall of newly learned spoken words (Alt et al., 2017; Thomson & Goswami, 2010). In the present study, we examined whether the orthographic facilitation effect occurs in children with dyslexia. We hypothesized that children with dyslexia would show orthographic facilitation because this effect has been shown in children with a wide range of skills. However, it is also possible that the poor word reading skills of children with dyslexia could interfere with their ability to benefit from orthography.

Orthographic Facilitation

Word learning is a dynamic process involving the formation and storage of mental representations. Spoken words comprise two mental representations. There is a *phonological representation*, or the sounds in a word, and a *semantic representation*, or the word's meaning (Carey, 1978; Perfetti & Hart, 2002). A novel spoken word is learned once the phonological and semantic representations are connected or linked in the mental lexicon. For example, a child has learned the word "elevator" when he can recall

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the sounds /ɛləvetɚ/ (the phonological representation) upon seeing the mechanical lift in a building (the semantic representation). Literate individuals create and link a third mental representation: an *orthographic representation*, which contains the written letters or word that symbolizes a specific phonological representation. *Orthographic knowledge* is the combination of stored orthographic representations with an understanding of patterns and rules for letter–sound correspondence (Apel, 2011).

"Orthographic facilitation" describes a phenomenon in which the presence of the orthographic representation increases the specificity of a new phonological representation. Said another way, orthographic facilitation is the experience of producing a new word more accurately when it is paired with its written counterpart during learning. For example, when a child hears the word /ɛləvetɚ/, he might store the phonological representation in a slightly incorrect form, such as /ɛləbetɚ/. Upon recognition that the written word "elevator" (the orthographic representation) contains a letter "v," he may then correct the error in his initial phonological representation. Of note, it is not necessary to explicitly draw attention to an orthographic representation for orthographic facilitation to occur (e.g., Jubenville, Sénéchal, & Malette, 2014; Ricketts, Dockrell, Patel, Charman, & Lindsay, 2015). The prevailing explanation for orthographic facilitation is that the presence of orthography increases the specificity of a newly learned spoken word through letter–sound correspondences, which provide clues to accurate production (i.e., a more fully specified phonological representation; Ricketts et al., 2009; Rosenthal & Ehri, 2008). The general premise that linked mental representations will influence one another is in line with the lexical quality hypothesis (Perfetti, 1992; Perfetti & Hart, 2002). Additionally, letters may serve as salient symbols of a transient speech signal when learning new spoken words (Ricketts et al., 2009).

Orthographic facilitation is well documented in children and adults with typical development (Ehri & Wilce, 1979; Jubenville et al., 2014; O'Leary, 2017; Rastle, McCormick, Bayliss, & Davis, 2011; Reitsma, 1983; Ricketts et al., 2009; Rosenthal & Ehri, 2008; Saletta, Goffman, & Brentari, 2016; Saletta, Goffman, & Hogan, 2016). For example, Rosenthal and Ehri (2008) exposed 7- and 10-year-old children to unfamiliar vocabulary words while manipulating the presence or absence of orthography. Children produced words more accurately when they were exposed to orthography during learning. Likewise, Ricketts and colleagues (2009) trained 8- to 9-year-old children with typical development to pair spoken pseudowords with photographs of novel objects while also manipulating the presence or absence of orthography. The children named the novel objects more accurately when orthography was present during training compared to when it was absent.

Orthographic Facilitation in Children With Dyslexia

Orthographic facilitation has not been studied in children with dyslexia; however, it has been observed in other children with atypical development, including those with specific language impairment (Ricketts et al., 2015), autism spectrum disorder (Lucas & Norbury, 2014; Ricketts et al., 2015), and Down syndrome (Mengoni, Nash, & Hulme, 2013). These populations generally have weak oral language with a relative strength in word reading (although abilities ranged from low to high). Thus, orthographic facilitation was examined as a means of improving weak oral language skills. In these populations, the magnitude of orthographic facilitation was moderately and positively correlated with word reading ability, even when controlling for age and nonverbal intelligence (Mengoni et al., 2013; Ricketts et al., 2009; Rosenthal & Ehri, 2008). Orthographic facilitation has also been observed in typically developing preschool children with emerging word reading abilities and partial knowledge of letter–sound correspondences (O'Leary, 2017). Even though emerging reading ability is qualitatively different from the impaired reading ability of children with dyslexia (Goswami & Bryant, 1989), this finding provides evidence that an orthographic facilitation effect may be possible for children with a wider distribution of reading skills than first noted in studies of school-age children with typical development.

Dyslexia is a specific word reading impairment prevalent in 5%–10% of school-age children (Shaywitz, Shaywitz, Fletcher, & Escobar, 1990). Dyslexia is most commonly attributed to a biologically based core deficit in phonological processing (Lyon et al., 2003; Vellutino et al., 2004). Due to this core phonological deficit, children with dyslexia have difficulty in creating and storing phonological representations (Boada & Pennington, 2006; Messbauer & de Jong, 2003) and often have poor working memory (de Jong, 1998; Smith-Spark & Fisk, 2007; Vellutino et al., 2004). These deficits result in poor performance on phonologically based tasks such as nonword repetition (Catts, Adlof, Hogan, & Ellis Weismer, 2005), phonological awareness (Swan & Goswami, 1997), and spoken word learning (Alt et al., 2017; Thomson & Goswami, 2010). In addition to poor phonological processing, children with dyslexia also have weak orthographic knowledge, which manifests in difficulties with spelling and further contributes to impaired letter–sound correspondences (Manis, Custodio, & Szeszulski, 1993).

To the extent that orthographic facilitation is reliant on accurate letter–sound correspondences, it seems unlikely that children with dyslexia could leverage orthography while learning new spoken words. There is some evidence, however, that children with dyslexia may use relative strengths in orthographic knowledge to compensate for weak phonological processing (Cassar, Treiman, Moats, Pollo, & Kessler, 2005; Olson, 1985; Siegel, Share, & Geva, 1995; Stanovich, Siegel, & Gottardo, 1997; van der Leij & van Daal, 1999). For example, Siegel and colleagues (1995) asked school-age children with dyslexia and their peers with typical reading skills to complete an orthographic awareness task, in which they selected between a pair of pseudowords (e.g., filv vs. filk), the one that "could be a word or looks like a word" (p. 251). Compared to reading-matched peers, children with dyslexia were significantly more accurate at selecting the correct pseudoword. That is, children with dyslexia paid more attention to orthography to circumvent their weak phonological processing. If children with dyslexia are particularly attuned to orthography, perhaps they will benefit from its presence, even without necessarily having to decode. Considering both perspectives and the presence of orthographic facilitation across a wide range of language and reading abilities, we predicted that children with dyslexia would show an orthographic facilitation effect. If revealed, an orthographic facilitation effect on spoken word learning could lead to more effective methods for teaching spoken vocabulary to children with dyslexia.

Orthographic Facilitation During Learning

In past studies of orthographic facilitation, a paired-associate learning task was used to teach an explicit verbal–visual pairing, with or without orthography present (see Messbauer & de Jong, 2003). For example, Ricketts and colleagues (2009, 2015) taught pseudoword–picture pairs via alternating repetition and production trials. During repetition trials, children saw a picture with or without orthography, heard a pseudoword, and then had to repeat that pseudoword until any incorrect pronunciations were corrected. During production trials, children saw a picture and had to produce the corresponding pseudoword. They were provided feedback—regardless of whether their response was correct or incorrect—that included additional exposure to the correct pseudoword–picture pairing, with and without orthography. Note that the pairing was explicitly taught, but no attention was drawn to the presence of orthography. Similar training procedures with feedback were used by Ehri and Wilce (1979), Jubenville and colleagues (2014), and Rosenthal and Ehri (2008).

No studies have examined orthographic facilitation effects during paired-associate learning. This may be due to how orthographic facilitation has been defined—the influence of orthography on the recall of newly learned spoken words, as measured by repetition or production. Thus, paired-associate learning has been the vehicle to teach words, not an outcome to be measured. Of note, Jubenville and colleagues (2014) observed that, in their learning task, which mirrored Ricketts and colleagues' (2009) repetition trials, that pseudowords were repeated more accurately during pairing of those pseudowords to novel referents when orthography was present; however, they did not statistically test this finding. In this study, we used a modified paired-associate learning paradigm to examine orthographic facilitation effects during learning, separate from repetition or production. Our unique paradigm required children to discover the link between pseudowords and novel referents through trial and error with no verbal output (see Gray, Pittman, & Weinhold, 2014). We provided children with visual feedback indicating whether they pointed to the correct referent after hearing a pseudoword; however, we never explicitly provided the correct pseudoword-referent link. We created this paradigm to simulate incidental word learning, in which a child hears an unfamiliar word and has to link that new word to the correct referent. In our study, the child confirmed their pairing through multiple exposures with feedback.

Past studies of paired-associate learning have found that children with dyslexia learn pairings less accurately than their peers when those pairings required a verbal response (Alt et al., 2017; Litt & Nation, 2014; Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003, 2006; Thomson & Goswami, 2010). The necessity of a verbal response, which involves phonological processing, may have confounded learning for children with dyslexia who have a marked impairment in phonological processing. In fact, children with dyslexia do not have a general paired-associate learning deficit (Litt & Nation, 2014; Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003), and moreover, the word learning abilities of children with dyslexia vary based on task demands (Alt et al., 2017). Our modified paired-associate learning paradigm, which allowed us to measure a child's accuracy during learning without repetition or production, offered us a unique opportunity to examine orthographic facilitation, independent of production-based naming. We hypothesized that the presence of orthography would boost paired-associate learning in children with dyslexia and their peers.

The Current Study

The current study adds to the literature by examining orthographic facilitation (a) in children with dyslexia during recall of a newly learned spoken word and (b) in a paired-associate learning task that requires no immediate verbal output. We compared the performance of school-age children with dyslexia to a control group of children with typical development. All children had age-appropriate oral language skills and were matched on grade and nonverbal intelligence. Over the course of four experimental blocks, we measured word learning using a modified paired-associate learning paradigm in which the child discovered the link between phonological representations (spoken pseudowords) and semantic representations (visually based novel referents). Two of the pairings had orthography present during learning, whereas the other two did not. We then assessed the accuracy of the newly learned phonological forms during spoken naming.

Based on converging evidence from past studies, we predicted that the children with typical development would show an orthographic facilitation effect indicated by more accurate learning and naming for pseudowords learned with orthography present. We predicted that the effect would increase across blocks with accumulated exposures during learning (Ricketts et al., 2015). Given the robust evidence for orthographic facilitation across both typical and atypical development, we predicted that children with dyslexia would also show an orthographic facilitation effect during paired-associate learning and naming tasks, despite their impaired word reading ability.

Method

Participants

This study included 92 children who participated in a larger investigation of working memory and word learning[1] in Arizona, Massachusetts, and Nebraska. With informed parental consent, participants completed a comprehensive assessment battery to determine study eligibility and group assignment. All children spoke English as their primary language and were currently enrolled in or had just completed second grade. Exclusion criteria included (a) parent report of an attention deficit hyperactivity disorder diagnosis, (b) history of neuropsychiatric disorders, (c) special education services for nonqualifying categories (e.g., autism spectrum disorder or intellectual disability), or (d) intellectual disability as measured by a standard score of less than 75 on the nonverbal index of the Kaufman Assessment Battery for Children–Second Edition (KABC-II; Kaufman & Kaufman, 2004). Inclusion criteria were passing scores on (a) a bilateral pure-tone hearing screening; (b) a near vision acuity screening wearing corrective lenses, if necessary; (c) a color vision screening; (d) a measure of speech articulation, the Goldman–Fristoe Test of Articulation–Second Edition (Goldman & Fristoe, 2000); and (e) a measure of oral language, the Clinical Evaluation of Language Fundamentals–Fourth Edition (CELF-4; Semel, Wiig, & Secord, 2003). All children had to achieve a standard score of 88 or higher on the CELF-4, which is 1 *SD* below the normative mean, plus 1 *SEM*.

Many studies of children with dyslexia do not assess for oral language ability despite the fact that up to 50% of children with dyslexia have co-occurring language impairment (Catts et al., 2005; McArthur, Hogben, Edwards, Heath, & Mengler, 2000). Without careful dissociation of these disorders, one could make conclusions about orthographic facilitation during word learning in children with dyslexia that only apply to a subset of these children with or without co-occurring language impairment. We have no evidence for orthographic facilitation in children with dyslexia and thus chose to exclude children with co-occurring language impairment to investigate children with relatively "pure" cases of dyslexia, that is, a specific word reading disability in the presence of typical spoken language skills.

Group Assignment and Matching

Once children qualified as having typical development in speech, oral language, and cognition, we assessed their word reading ability using the Test of Word Reading Efficiency–Second Edition (TOWRE-2; Torgesen, Wagner, & Rashotte, 2012) to determine group assignment. This assessment has two subtests: Sight Word Efficiency, which uses real words, and Phonemic Decoding Efficiency, which uses pseudowords. During each subtest, children are required to read as many words or pseudowords as possible in 45 s. Scores are based on the number of accurately read items in that 45-s period. TOWRE-2 scores are determined more by the accuracy of a child's reading than by speed, unless the child reads all words within the 45-s time limit, which is uncommon for children in second grade (Torgesen et al., 2012). Measures of timed word reading, such as the TOWRE-2, capture the full range of word reading differences in older elementary children, and as such, they are commonly used to identify children with dyslexia in second grade (e.g., Alt et al., 2017; Litt & Nation, 2014).

Children who received a composite standard score of 88 or below (≤ 20th percentile) using the grade-based norms on the TOWRE-2 were categorized as having dyslexia. We chose the 20th percentile cutoff because it is one of the most common cut-points used in the literature on school-age children with dyslexia (Badian, McAnulty, Duffy, & Als, 1990; Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996). Children who received a standard score of 96 or higher (≥ 40th percentile) on the TOWRE-2 were categorized as having typical development in word reading. Children who received a standard score between 89 and 95 on the TOWRE-2 were excluded from the study. These stringent criteria and cutoffs accommodated measurement error in the TOWRE-2, thus ensuring the classification of children into correct subgroups. We did not consider any existing dyslexia diagnoses as part of our inclusionary procedures because criteria for dyslexia diagnosis and enrollment in special education or intervention services vary across and within states (Elliott & Grigorenko, 2014; Gabriel & Woulfin, 2017).

Initially, 58 children with dyslexia and 128 peers with typical development qualified for and participated in this study. Preliminary analyses of KABC-II scores revealed that nonverbal intelligence scores were significantly higher for children with typical development (M = 118.00, SD = 15.62) compared to the children with dyslexia (M = 105.98, SD = 13.49), $t(184) = 5.06$, $p < .001$. The average score for each group was well within the normal range of nonverbal intelligence, and the total range of scores was comparable (78–160 for children with typical development; 84–141 for children with dyslexia). We decided to match the participants to ensure that any significant effects could be attributed to differences in word reading rather than nonverbal intelligence. We matched pairs of children across groups with a maximum difference of two standard score points on the KABC-II. Twelve of the children with dyslexia could not be matched to a peer with typical development because there were more children with dyslexia at the lower end of the sample distribution compared to children with typical development. There were 23 children with dyslexia and only 14 children with typical development who had nonverbal intelligence standard scores of 101 or lower. When applying the matching criteria described above, there were not enough children

[1]Participants described in this article represent a portion of the participants in a larger sample from the Profiles of Working Memory and Word Learning for Educational Research (POWWER) project, funded by NIH NIDHC Grant R01 DC010784. The POWWER study includes the groups reported, as well as bilingual children with typical development, children with co-occurring dyslexia and language impairment, and children with specific language impairment only.

with typical development to create matched pairs in this range of scores. Therefore, 12 children with dyslexia were excluded from this study.

Table 1 reports the results of assessments for each group and paired-samples *t* tests. We used dependent *t* tests to account for dependency (Kenny & Judd, 1986) because children with dyslexia and children with typical development were individually matched on nonverbal intelligence. The final sample included 92 children: 46 with dyslexia and 46 with typical development. There was a 3-month age difference between groups that was statistically significant. However, it is unlikely that substantial developmental changes related to orthographic facilitation and word learning would occur in this relatively short time span, especially because the children were all in the same stage of their education. Furthermore, the children with dyslexia were older than their peers with typical development, which, if anything, would likely engender a performance advantage for these children. Therefore, we did not include age as a covariate in the analyses.

Oral language scores were in an age-appropriate range for all children but were significantly different between groups. On average, children with dyslexia scored 3 standard score points lower than their peers with typical development on the CELF-4. It is not uncommon for language to be impacted by word reading ability when compared to typically developing peers (Catts et al., 2005). However, these children with dyslexia have language abilities that are solidly within the average range on the CELF-4 (M = standard score of 102). As such, we did not control for oral language in the analyses.

Finally, nonverbal intelligence, which was the basis for participant matching, was equal across groups. Word reading, which was the basis for group assignment, was significantly lower for the children with dyslexia compared to their peers with typical development.

Of the 46 children with dyslexia, 21 were boys and 25 were girls; of the 46 children with typical development, 19 were boys and 27 were girls. For children with dyslexia, 35 reported being White, nine reported more than one race, one reported a minority race (e.g., American Indian or Eskimo, Asian, or Black or African American), and one did not report race. Eleven also identified as Hispanic. Of the children with typical development, 36 reported being White, five reported more than one race, four reported another minority race, and one did not report race. Seven also identified as Hispanic.

Materials

In this study, we administered the Comprehensive Assessment Battery for Children–Word Learning (see Alt et al., 2017). The battery was designed to be an engaging, age-appropriate series of pirate-themed word learning games. There were six games with identical tasks and procedures but different phonological or visual learning conditions. The objective of each game was to learn the spoken names of four monsters. By the end of all six word learning games, children would have learned 24 unique monster names. In this study, we present the results from one word learning game that included four monster names and manipulated the presence of orthography during the learning phase. Further details about the orthography game are provided below. Additional games are described by Alt and colleagues (2017).

Equipment and Standardization Protocols

The word learning game was programmed using Adobe Flash software and administered to each child individually on a Toshiba DX1210-ST4N22 desktop computer with a 21.5-in. touchscreen monitor and a standard keyboard. Children wore headphones with an attached microphone to hear all auditory output and to record the child's verbal responses. A research assistant, who passed multiple stages of fidelity training (see Alt et al., 2017, for details), was present and wearing headphones for the duration of the research session. He or she did not give verbal instructions during the research session but was responsible for setting up the equipment, facilitating use of the computer, and collecting live behavioral data.

Stimuli

Table 2 contains the pseudowords and their characteristics. Pseudowords were created using a database from the

Table 1. Participant characteristics.

	Dyslexia (n = 46)			Typical development (n = 46)					
Characteristic	M	SD	Range	M	SD	Range	$t(45)$	p	d_z
Age in months	93.07	5.8	85–107	90.74	4.5	84–106	2.02	.050*	0.211
Nonverbal IQ[a]	109.43	12.8	84–141	109.52	12.9	84–141	−0.03	.987	−0.003
Oral language[b]	102.07	8.9	88–126	106.61	8.6	93–124	−2.67	.011*	−0.278
Word reading[c]	80.87	5.7	65–88	106.74	7.8	96–124	−17.39	< .001**	−1.813

Note. Effect size is Cohen's d_z, which accounts for correlation between variables in the matched group design (Lakens, 2013).

[a]Nonverbal IQ or intelligence is a standard index score from the Kaufman Assessment Battery for Children–Second Edition (Kaufman & Kaufman, 2004). [b]Oral language is a standard score from the core language index on the Clinical Evaluation of Language Fundamentals–Fourth Edition (Semel et al., 2003). [c]Word reading is a standard score from the Test of Word Reading Efficiency–Second Edition (Torgesen et al., 2012).

*p < .05, **p < .001.

Table 2. Pseudoword stimuli characteristics.

Pseudoword spelling	Pseudoword in Klattese[a]	Duration in milliseconds	Mean biphone frequency	Summed biphone probability
bonfape	banfep	830	0.0038	0.0188
mubgik	m^bglk	1,057	0.0041	0.0204
deembieg	dimbYg	931	0.0018	0.0090
dooftog	duftcg	902	0.0009	0.0044
		M = 930.00 (*SD* = 94.72)	*M* = 0.00265 (*SD* = 0.0016)	*M* = 0.01315 (*SD* = 0.0077)

[a]Klattese is a computer-readable interface for the International Phonetic Alphabet. See Vitevitch and Luce (2004) for more information.

Word and Sound Learning Lab at the University of Kansas directed by Holly Storkel. The database, created by Storkel and Hogan, contains all legal English consonant–vowel–consonant (CVC) nonwords. We randomly selected eight CVC nonwords using only early developing speech sounds. Nonwords containing later developing speech sounds such as /r/, /θ/, or /s/ were excluded. The selected CVC nonwords were combined to make four 2-syllable (CVCCVC) pseudowords.

All phonotactic probabilities were calculated using the Phonotactic Probability Calculator (Vitevitch & Luce, 2004). Each pseudoword had zero phonological neighbors and, therefore, was low in neighborhood density (Storkel & Morrisette, 2002; Vitevitch & Luce, 1998). The average pseudoword biphone frequency was 0.00265, which is considered low phonotactic probability compared to ranges found in other studies (Alt, 2011; Alt, Meyers, & Figueroa, 2013; Alt & Plante, 2006). Each pseudoword had a similar duration and spondaic stress pattern as audio-recorded by a male, native speaker of English.

The orthographic spelling for each of the four pseudowords was determined using the most frequent feedback mappings of the phonological rime (Ziegler, Stone, & Jacobs, 1997). The spelling options were then selected to balance the numbers of letters within each syllable across words. When present, spellings were shown in black Arial font, scaled to fit an 800 × 50 pixel textbox.

The visual referents were full-color, two-dimensional line drawings of monsters. Each of the four monsters was equal in size, differed in shape, and had four primary, visual-semantic features: color, head covering, eyes, and arms (see Figure 1).

Tasks and Procedure

The word learning game took approximately 30 min and included three phases: training, learning, and assessment. The learning and assessment phases together constituted an experimental block. There was one training phase followed by four experimental blocks. Figure 2 illustrates the game sequence.

Training Phase

The training phase provided an opportunity for children to learn the task instructions and practice using the touchscreen. A pirate-themed narrator presented verbal instructions, visual demonstrations, and practice trials for each assessment task in the game. Children were required to correctly complete all practice trials to proceed to the first experimental block. If children could not pass a practice task after five attempts, the entire word learning game was discontinued. In this study, all children passed the training phase.

Experimental Blocks

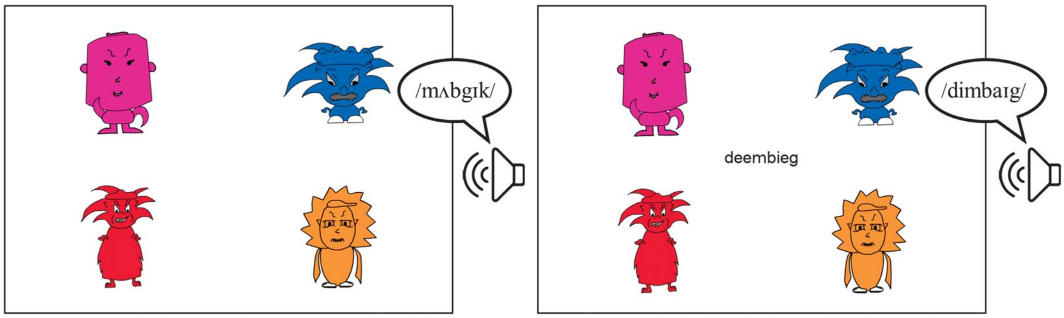
This study contained four experimental blocks, each with a learning and assessment phase. In Block 1, the learning phase contained eight trials total (i.e., 2 exposures × 4 pseudowords) and simulated the fast mapping phase of word learning. Fast mapping is the initial encoding process or quick incidental learning of new words (Carey, 1978). In Blocks 2, 3, and 4, each learning phase contained 60 trials in total (i.e., 15 exposures × 4 pseudowords) to simulate the configuration phase of word learning. Configuration refers to the long-term storage and retrieval of words that occurs after repeated exposures (Leach & Samuel, 2007). Based on these different constructs, we analyzed the learning and assessment data from Block 1 separately from Blocks 2, 3, and 4. The assessment phase always contained one trial per pseudoword in each task.

Learning Phase

Phonological–visual linking task. The learning phase contained a phonological–visual linking task in which children had to discover the links between four pseudowords and four individual monsters by integrating feedback about accuracy from each response. This task is illustrated in Figure 1. The monsters were presented simultaneously in a two-by-two grid on the computer monitor. The pseudowords were presented in one of two conditions. In the *orthography-absent* condition, the pseudoword was presented in its spoken form only. In the *orthography-present* condition, the pseudoword was presented in spoken and written forms simultaneously. The written word appeared in the center of the screen for the duration of the trial. Children touched the screen to select the monster corresponding to each pseudoword, which advanced the program to the next trial.

When children linked the pseudoword with the correct monster, they immediately saw a gold coin and heard a jingling noise. When the children selected the wrong

Figure 1. Learning phase: Phonological–visual linking task screenshots. Left, orthography-absent condition; right, orthography-present condition.



monster, they immediately saw a rock and heard a dull thud. At the end of the game, children could use their coins to purchase virtual prizes. These coins and rocks were the only information provided to the children about the pseudoword–monster links. In this learning paradigm, children were not alerted to the presence of the written word, similar to past studies of "incidental" orthographic facilitation (Jubenville et al., 2014; Ricketts et al., 2015). Children were allowed as much time as necessary to make their selection and then the next trial was presented. The monster's grid location remained constant within a single block but was randomized across blocks. The condition, monster, and pseudoword combinations were randomized across children, but they were held constant across all experimental blocks for each child.

The dependent variable for the phonological–visual linking task was the proportion of correct pseudoword–monster pairs selected for each condition (i.e., orthography-absent, orthography-present) in each block. This score was recorded by the computer.

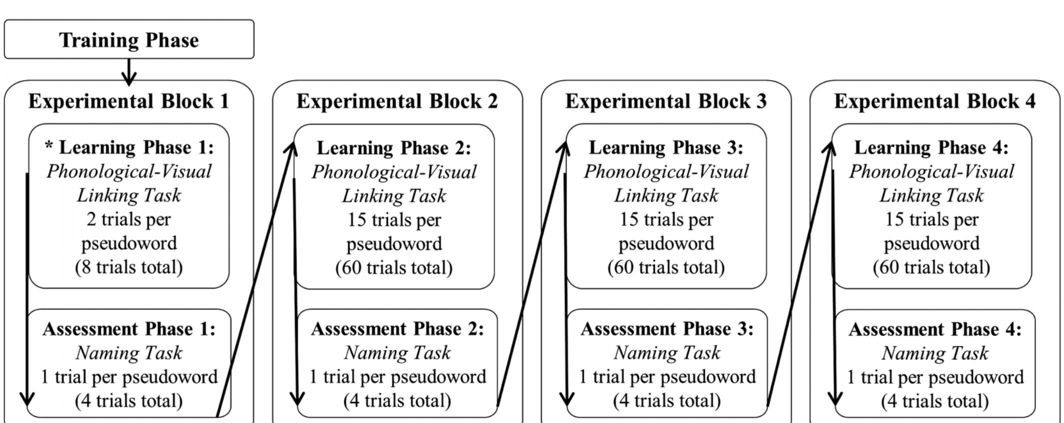
Assessment Phase

Each learning phase was followed by an assessment phase in which children completed four tasks: naming, mispronunciation detection, visual feature recall, and visual difference decision. From this assessment phase, we only report results of the naming task in this study, which is in line with past studies of orthographic facilitation.

Naming task. The naming task measured recall and production of phonological representations. Children heard the question, "What is this monster's name?" once and then saw each monster, one at a time, in the center of the computer screen. The orthography was not present for any of the monsters during this task. If the child attempted to speak the pseudoword, regardless of accuracy, the research assistant pressed the coded key on the keyboard to indicate that an attempt was made. If the child did not produce any sounds or said "I don't know," the research assistant pressed the coded key to indicate the child did not attempt a response. Once all four monsters were presented, children received summative feedback (i.e., total amount of coins and rocks) corresponding to participation attempts. The order of monster presentation was randomized across blocks. Children named each monster one time per block.

The dependent variable for the naming task was the proportion of consonants produced correctly in each pseudoword per learning condition. Given four pseudowords (with four consonants per pseudoword), there were 16 total

Figure 2. Diagram of game sequence. *Pseudowords were presented in either the orthography-absent or orthography-present condition during the phonological–visual linking task.



consonants per block and eight consonants in each learning condition. The proportion of consonants correct was obtained using the following protocol: The child's spoken response was audio-recorded and transcribed offline by trained phonetic transcribers using the International Phonetic Alphabet. A phoneme-by-phoneme analysis was used to determine the number of consonants correct for each pseudoword. Transcribers were blind to group membership and pseudoword condition. Interrater transcription reliability was 92%.

Results

We used analyses of variance (ANOVAs) to determine if orthography influenced spoken word learning for children with dyslexia compared to children with typical development matched on grade and nonverbal intelligence.[2] First, we employed a 2 (group) × 2 (condition) repeated measures ANOVA for Block 1 for the phonological–visual linking task and for the naming task. Recall that the phonological–visual linking task in Block 1 simulated fast mapping and contained only two exposures per pseudoword. Next, we employed a 2 (group) × 2 (condition) × 3 (block) repeated measures ANOVA for Blocks 2, 3, and 4 for the phonological–visual linking task and for the naming task. The phonological–visual linking task in Blocks 2, 3, and 4 simulated another phase of word learning, configuration, and contained 15 exposures per pseudoword in each block.

The Huynh–Feldt correction was applied to the degrees of freedom for all analyses to prevent violations of the sphericity assumption (Huynh & Feldt, 1976) and is commonly used for repeated measures analyses. All effect sizes were interpreted using Richardson's (2011) guidelines for partial eta squared (η_p^2), where a value of less than .01 was considered small, .06 was considered medium, and .14 was considered large. For significant interactions, we conducted simple effects analyses with Bonferroni corrections for multiple comparisons.

Performance During Block 1

Phonological–Visual Linking Task

First, we examined the ability to link spoken pseudowords to visual monsters. Recall that orthography was present for two of the four pseudowords during this task. In Block 1, the main effect of group was not significant, $F(1, 45) = 0.063$, $p = .803$, $\eta_p^2 = .001$. Children with dyslexia ($M = .40$, $SEM = .03$) linked pseudowords to monsters as accurately as their peers with typical development ($M = .40$, $SEM = .03$). The main effect of condition—or the orthographic facilitation effect—was also not significant, $F(1, 45) = 0.626$, $p = .433$, $\eta_p^2 = .014$. With only two exposures, children linked pseudowords to monsters with similar accuracy when orthography was absent ($M = .39$, $SEM = .03$) and when it was present ($M = .42$, $SEM = .03$). The interaction between group and condition was not significant, $F(1, 45) = 0.119$, $p = .732$, $\eta_p^2 = .003$.

Naming Task

Next, we examined the ability to recall and produce the pseudoword names associated with each monster. In Block 1, the main effect of group was not significant, $F(1, 45) = 1.36$, $p = .250$, $\eta_p^2 = .029$. Children with dyslexia ($M = .15$, $SEM = .02$) and children with typical development ($M = .13$, $SEM = .02$) produced similar and very low proportions of consonants correct when generating the pseudoword names for each monster. Again in Block 1, the orthographic facilitation effect was not significant, $F(1, 45) = 0.005$, $p = .941$, $\eta_p^2 < .001$. Children were equally accurate when producing the pseudowords learned with orthography present ($M = .14$, $SEM = .02$) as when producing those learned with orthography absent ($M = .14$, $SEM = .02$). The interaction between group and condition was not significant, $F(1, 45) = 1.65$, $p = .205$, $\eta_p^2 = .035$.

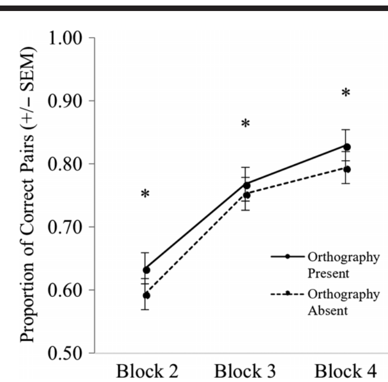
Performance During Blocks 2, 3, and 4

Phonological–Visual Linking Task

During Blocks 2, 3, and 4, the main effect of group was not significant, $F(1, 45) = 0.066$, $p = .798$, $\eta_p^2 = .001$. Children with dyslexia ($M = .72$, $SEM = .03$) linked pseudowords to monsters as accurately as their peers with typical development ($M = .73$, $SEM = .03$). Thus, results for both groups are combined when presented in Figure 3.

For all children, there was a significant orthographic facilitation effect, $F(1, 45) = 4.87$, $p = .032$, $\eta_p^2 = .098$, in which they were more accurate at linking pseudowords to monsters when orthography was present ($M = .74$, $SEM = .02$) than when it was absent ($M = .71$, $SEM = .02$). On average, the presence of orthography improved the overall accuracy of pseudoword–monster pairings by 3 percentage points. There was also a significant main effect of block, $F(1.9, 83.8) = 67.73$, $p < .001$, $\eta_p^2 = .601$, such that the proportion of correct pseudoword–monster pairs increased

Figure 3. Results for the phonological–visual linking task for both groups combined. Asterisks indicate a significant orthographic facilitation effect.



[2]Analyses were also completed using the full, unmatched data set. We observed a similar pattern of results; however, we report only the results of matched analyses to assess groups based on differences in reading ability.

successively (Block 2: $M = .61$, $SEM = .02$; Block 3: $M = .76$, $SEM = .03$; Block 4: $M = .81$, $SEM = .02$; all $ps < .004$). This increase in accuracy over time or learning is expected given repeated exposures to the pseudoword–monster pairings. No two- or three-way interactions were significant.

Naming Task

During Blocks 2, 3, and 4, the main effect of group was not significant, $F(1, 45) = 0.86$, $p = .359$, $\eta_p^2 = .019$. Overall, children with dyslexia ($M = .30$, $SEM = .02$) and children with typical development ($M = .33$, $SEM = .03$) produced similar proportions of consonants correct when producing the pseudoword names for each monster. There was a significant orthographic facilitation effect, $F(1, 45) = 30.51$, $p < .001$, $\eta_p^2 = .404$, in which all children were more accurate when producing the pseudowords learned with orthography present ($M = .37$, $SEM = .02$) than when producing the pseudowords learned with orthography absent ($M = .26$, $SEM = .02$). For both groups, overall, orthographic facilitation improved pseudoword naming accuracy by an average of 11 percentage points. There was a significant main effect of block, $F(2, 90) = 14.39$, $p < .001$, $\eta_p^2 = .242$, in which correct pseudoword productions increased and then leveled off. Specifically, correct pseudoword productions increased in Block 3 ($M = .33$, $SEM = .02$) compared to Block 2 ($M = .26$, $SEM = .02$; $p = .002$) but stayed statistically the same in Block 4 ($M = .36$, $SEM = .02$; $p = .223$) compared to Block 3. Overall, pseudoword productions in Block 4 were significantly more accurate than in Block 2 ($p < .001$).

Main effects were qualified by a significant three-way interaction between group, condition, and block, $F(2, 90) = 3.22$, $p = .045$, $\eta_p^2 = .067$. We decomposed the three-way interaction in two steps. First, we analyzed data by group. These results are summarized in Table 3. We then examined the interaction of condition and block for each group; these results are presented in Figure 4. Pairwise analyses with Bonferroni corrections allowed us to test our hypothesis that children would show increased learning over time. For children with dyslexia, there were significant orthographic facilitation effects in Block 2 ($p = .031$, $\eta_p^2 = .099$) and Block 3 ($p = .021$, $\eta_p^2 = .113$), but not in Block 4 ($p = .055$, $\eta_p^2 = .079$). For children with typical development, there were significant orthographic facilitation effects in Block 3 ($p = .002$, $\eta_p^2 = .187$) and Block 4 ($p < .001$, $\eta_p^2 = .364$), but not in Block 2 ($p = .148$, $\eta_p^2 = .046$).

In summary, orthographic facilitation occurred in both groups but to varying degrees. Children with dyslexia showed a modest but significant orthographic facilitation effect in Block 2 ($\eta_p^2 = .099$) followed by a strong effect in Block 3 ($\eta_p^2 = .113$) that plateaued in Block 4 ($\eta_p^2 = .079$). Their peers with typical development did not show a significant orthographic facilitation effect in Block 2 ($\eta_p^2 = .046$). However, a strong orthographic facilitation effect emerged in Block 3 ($\eta_p^2 = .187$) and Block 4 ($\eta_p^2 = .364$).

Discussion

Our study is the first to demonstrate that children with dyslexia show an orthographic facilitation effect in which they produced newly learned spoken words more accurately when orthography was present during learning compared to when it was absent. We chose to examine orthographic facilitation in children with dyslexia because these children have difficulty in recalling newly learned spoken words (Alt et al., 2017; Thomson & Goswami, 2010) and others with poor spoken word recall—children with language impairment (Ricketts et al., 2015), autism (Lucas & Norbury, 2014; Ricketts et al., 2015), and Down syndrome (Mengoni et al., 2013)—have improved recall when orthography was present during learning. We also reasoned that, despite poor word reading ability, children with dyslexia might show an orthographic facilitation effect by using relative strengths in orthographic knowledge to compensate for poor phonological skills as demonstrated by Siegel and colleagues (1995).

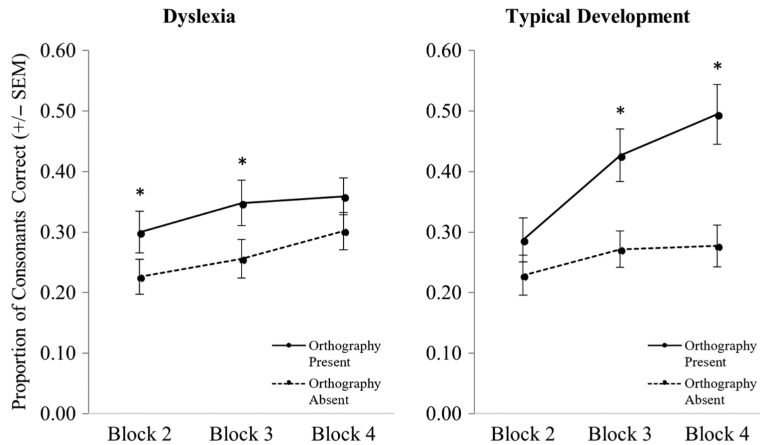
We examined orthographic facilitation using a modified paired-associate learning paradigm in which children paired spoken pseudowords with novel semantic referents. Children were required to learn and then recall the names of four monsters in a game format. In the earliest phase of the game, which represented fast mapping, orthographic facilitation did not occur. This may be due to the limited number of trials, indicating that the effect only occurs after a certain amount of exposure or after the child has stored a stable phonological representation. Alternatively, floor effects may have masked orthographic facilitation effects during this phase of word learning. In later phases of the game, following larger number of exposures, children with dyslexia showed an orthographic facilitation effect during learning and naming, similar to their peers with typical

Table 3. Results of decomposing the three-way interaction on the naming task by group.

	Dyslexia				Typical development			
Group	*df*	*F*	*p*	η_p^2	*df*	*F*	*p*	η_p^2
Condition	1, 45	7.97	.007**	.151	1, 45	20.03	< .001***	.308
Block	2, 90	3.33	.040*	.069	1.89, 84.93	9.5	< .001***	.174
Condition × Block	2, 90	0.46	.634	.010	1.89, 84.93	4.84	.011*	.097

*$p < .05$. **$p < .01$. ***$p < .001$.

Figure 4. Results for the naming task. Asterisks indicate a significant orthographic facilitation effect.



development. Overall, our results align with previous findings from children with typical development (Ehri & Wilce, 1979; Jubenville et al., 2014; Reitsma, 1983; Ricketts et al., 2009; Rosenthal & Ehri, 2008) and atypical development (Lucas & Norbury, 2014; Mengoni et al., 2013; Ricketts et al., 2015) and have direct theoretical and clinical implications.

Children With Dyslexia Benefit From Orthographic Facilitation

Prior to this study, it was unclear whether children with dyslexia would benefit from orthographic facilitation in word learning because hallmark characteristics of children with dyslexia include weak orthographic knowledge and poor letter–sound correspondences (Manis et al., 1993). These weaknesses, in addition to poor working memory (de Jong, 1998; Smith-Spark & Fisk, 2007), make it plausible that children with dyslexia would not benefit from the presence of orthography during spoken word learning. However, we predicted that they might show orthographic facilitation effects because (a) other children with potentially poor word reading show orthographic facilitation effects (Lucas & Norbury, 2014; Mengoni et al., 2013; Ricketts et al., 2015) and (b) some children with dyslexia pay special attention to orthography, which appears to help circumvent their weak phonological processing (Cassar et al., 2005; Olson, 1985; Siegel et al., 1995; Stanovich et al., 1997; van der Leij & van Daal, 1999).

How can children with dyslexia who, by definition, have impaired word reading, use written words to facilitate spoken word learning? One possibility is that some children with dyslexia have enough knowledge of letter–sound correspondences needed to provide clues to accurate production, such that stronger reading ability might be associated with larger orthographic facilitation effects. In support of this idea, past studies have found that word reading was positively correlated with orthographic facilitation effects in children with typical development (Mengoni et al., 2013; Ricketts et al., 2009; Rosenthal & Ehri, 2008). Our study was not designed to accurately evaluate the relation between word reading and orthographic facilitation because our sample was selected to represent typical versus low word reading abilities. Correlational analyses to examine individual groups would result in an artificially restricted range of scores and low statistical power. Alternatively, combining the groups might lead to the discovery of spurious or noncausal relationships (Bishop, 2012). Future research should investigate the causal mechanism for orthographic facilitation effects and the relationship with word reading ability using large, unselected samples. We posit that orthographic knowledge, as measured by word reading, varies among children with dyslexia and may provide clues to individual differences in spoken word learning.

A complementary idea is that weak phonological representations may be stabilized by the presence of letters, which serve as salient symbols of a transient speech signal when learning new spoken words (Ricketts et al., 2009). The idea that orthography increases the specificity of phonological representations is in line with the lexical quality hypothesis (Perfetti & Hart, 2002), which posits that linked mental representations will influence each other (e.g., Perfetti, 1992). Our study provides evidence that, in children with dyslexia, the presence of an orthographic representation increases the specificity of phonological representations. Of note, whereas there was a boost in accuracy in spoken word recall when orthography was present during learning, children with dyslexia had less accurate spoken word recall compared to their peers with typical development, in line with past studies. Moreover, their orthographic facilitation effect was initially robust and then plateaued indicating that orthography could only improve phonology to a certain point. In fact, the largest orthographic facilitation effect in children with dyslexia was 2.5 times smaller than the largest effect in children with typical development.

In summary, our findings could apply to instruction for children with dyslexia. Educators may shy away from including written words when teaching spoken vocabulary to children with dyslexia because the hallmark of dyslexia is difficulty in reading written words. Thus, the inclusion of written words may be perceived as distracting or as a source of anxiety that could impede spoken word learning. Our results suggest that, in fact, children with dyslexia can learn and remember spoken words more accurately when those words are taught with their written counterpart present. In our paradigm, we did not instruct children to pay attention to or read the written word, a procedure in line with most studies of orthographic facilitation. Even so, the positive effect of the written word was strong on spoken word learning. We tentatively conclude then that an easy and inexpensive way to improve spoken word learning in children with dyslexia is to merely have the word's written form present during instruction.

Orthographic Facilitation Occurs During Learning

Our study is the first to measure orthographic facilitation effects during a paired-associate learning task. Our learning task was unlike those in past studies of orthographic facilitation for two reasons: (a) In our study, learning itself served as an outcome, and (b) our learning task did not require a verbal response. Children with dyslexia learned pseudoword-referent pairs with greater accuracy when orthography was present than when it was absent. They did not differ in learning accuracy from their typically developing peers. Similar to our naming results, the orthographic facilitation effect on learning did not appear with only a few exposures. Overall, our findings are in line with past studies showing that children with dyslexia do not have paired-associate learning deficits when no verbal response is required (Alt et al., 2017; Litt & Nation, 2014; Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003). Importantly, we show that orthographic facilitation impacts not only the recall and production of newly learned phonological representations but the linkage between phonological and semantic representations.

Alternatively, one could hypothesize that the influence of orthography on paired-associate learning is not an orthographic effect per se but, instead, is explained by the dual coding theory (Sadoski, 2005), which proposes that storage and recall are improved when information is learned through multiple modalities. Using this reasoning, one could conclude that all children in the study, regardless of reading and language abilities, benefited from the presence of three modalities (or representations: semantic, phonological, and orthographic) when learning pseudoword-referent pairings compared to two modalities (semantic, phonological). However, Mengoni and colleagues (2013) provide contrasting evidence to this theory: a nonlinguistic visual cue or an "alien orthography" was not as effective as the matching English orthography at facilitating spoken word learning in children with Down syndrome. Therefore, the visual cue must provide phonological information about the new word, further strengthening the idea that letter–sound correspondences are driving orthographic facilitation.

Limitations

Our study involved learning four pseudoword-referent pairings in a highly controlled computer-based environment. Three limitations are worth noting and should inform future work. First, time constraints within our larger word learning battery did not allow us to measure orthographic facilitation beyond one learning session. However, Lucas and Norbury (2014) found that orthographic facilitation remained 1 day posttraining in children with autism and their typically developing peers. Similarly, Messbauer and de Jong (2003) found that long-term retention (1 week posttraining) of newly learned visual–verbal pairings was not impaired in children with dyslexia. Taken together, these findings suggest that, for spoken word learning, children with dyslexia may retain the benefit of orthographic facilitation beyond the one session included in our study.

Second, our low number of pseudowords limits the ability to generalize our findings to the innumerable amount of diverse words children encounter. Four items have been commonly used in past work on paired-associate learning and word learning in children with dyslexia, likely due to that fact that learning more than four items in one word learning session could be overly difficult, resulting in floor effects (Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003; Thomson & Goswami, 2010). Future work should examine whether orthographic facilitation makes a lasting impact on a larger variety of words in multiple learning contexts.

Third, when designing pseudowords, we carefully controlled phonotactic neighborhood density and probability and then selected the most common spelling to match. We randomized which pseudowords were shown in the orthography present condition across children to limit systematic error. It is possible that the magnitude of orthographic facilitation may be influenced by orthographic characteristics such as orthographic consistency (e.g., Ricketts et al., 2015) and orthotactic probability (e.g., Wolter & Apel, 2010). Future work should include pseudoword stimuli that vary by orthographic as well as phonological characteristics.

Conclusions

The current study extends previous research by showing that orthographic facilitation occurs not only for children with typical development but also for children with dyslexia despite weaknesses in phonological skills that typically impair spoken word learning. The incidental presence of orthography had a positive effect on learning as well as on the production of newly learned spoken words. We encourage teachers and clinicians to include written words when introducing new spoken vocabulary to children with dyslexia—during vocabulary lessons as well as outside the specific context of reading or writing instruction.

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References

Alt, M. (2011). Phonological working memory impairments in children with specific language impairment: Where does the problem lie? *Journal of Communication Disorders, 44*(2), 173–185. https://doi.org/10.1016/j.jcomdis.2010.09.003

Alt, M., Hogan, T., Green, S., Gray, S., Cabbage, K., & Cowan, N. (2017). Word learning deficits in children with dyslexia. *Journal of Speech, Language, and Hearing Research, 60*(4), 1012–1028. https://doi.org/10.1044/2016_JSLHR-L-16-0036

Alt, M., Meyers, C., & Figueroa, C. (2013). Factors that influence fast mapping in children exposed to Spanish and English. *Journal of Speech, Language, and Hearing Research, 56*(4), 1237–1248. https://doi.org/10.1044/1092-4388(2012/11-0092)

Alt, M., & Plante, E. (2006). Factors that influence lexical and semantic fast mapping of young children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 49*(5), 941–954. https://doi.org/10.1044/1092-4388(2006/068)

Apel, K. (2011). What is orthographic knowledge? *Language, Speech, and Hearing Services in Schools, 42*(4), 592–603. https://doi.org/10.1044/0161-1461(2011/10-0085)

Badian, N. A., McAnulty, G. B., Duffy, F. H., & Als, H. (1990). Prediction of dyslexia in kindergarten boys. *Annals of Dyslexia, 40,* 152–169. https://doi.org/10.1007/BF02648146

Bishop, D. (2012, June 24). *Causal models of developmental disorders: The perils of correlational data [Blog post]*. Retrieved from http://deevybee.blogspot.com.au/2012/06/causal-models-of-developmental.html

Boada, R., & Pennington, B. F. (2006). Deficient implicit phonological representations in children with dyslexia. *Journal of Experimental Child Psychology, 95*(3), 153–193. https://doi.org/10.1016/j.jecp.2006.04.003

Carey, S. (1978). The child as word learner. In J. Bresnan, G. Miller, & M. Halle (Eds.), *Linguistic theory and psychological reality* (pp. 264–293). Cambridge, MA: MIT Press.

Cassar, M., Treiman, R., Moats, L., Pollo, T. C., & Kessler, B. (2005). How do the spellings of children with dyslexia compare with those of nondyslexic children? *Reading and Writing, 18*(1), 27–49. https://doi.org/10.1007/s11145-004-2345-x

Catts, H. W., Adlof, S. M., Hogan, T. P., & Ellis Weismer, S. E. (2005). Are specific language impairment and dyslexia distinct disorders? *Journal of Speech, Language, and Hearing Research, 48*(6), 1378–1396. https://doi.org/10.1044/1092-4388(2005/096)

de Jong, P. F. (1998). Working memory deficits of reading disabled children. *Journal of Experimental Child Psychology, 70*(2), 75–96.

Ehri, L. C., & Wilce, L. S. (1979). The mnemonic value of orthography among beginning readers. *Journal of Educational Psychology, 71*(1), 26–40. https://doi.org/10.1037/0022-0663.71.1.26

Elliott, J. G., & Grigorenko, E. L. (2014). *The dyslexia debate (No. 14)*. Cambridge, United Kingdom: Cambridge University Press.

Gabriel, R. E., & Woulfin, S. (2017). Reading and dyslexia legislation: Analytic techniques and findings on the framing of dyslexia. In J. N. Lester, C. R. Lochmiller, & R. E. Gabriel (Eds.), *Discursive perspectives on education policy and implementation* (pp. 197–217). London, United Kingdom: Palgrave Macmillan, Cham.

Goldman, R., & Fristoe, M. (2000). *Goldman–Fristoe Test of Articulation–Second Edition (GFTA-2)*. Circle Pines, MN: AGS.

Goswami, U., & Bryant, P. (1989). The interpretation of studies using the reading level design. *Journal of Reading Behavior, 21*(4), 413–424.

Gray, S., Pittman, A., & Weinhold, J. (2014). Effect of phonotactic probability and neighborhood density on word-learning configuration by preschoolers with typical development and specific language impairment. *Journal of Speech, Language, and Hearing Research, 57*(3), 1011–1025. https://doi.org/10.1044/2014_JSLHR-L-12-0282

Huynh, H., & Feldt, L. S. (1976). Estimation of the box correction for degrees of freedom from sample data in randomized block and split-plot designs. *Journal of Educational Statistics, 1*(1), 69–82.

Jubenville, K., Sénéchal, M., & Malette, M. (2014). The moderating effect of orthographic consistency on oral vocabulary learning in monolingual and bilingual children. *Journal of Experimental Child Psychology, 126,* 245–263. https://doi.org/10.1016/j.jecp.2014.05.002

Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman Assessment Battery for Children–Second Edition (KABC-II)*. Circle Pines, MN: AGS.

Kenny, D. A., & Judd, C. M. (1986). Consequences of violating the independence assumption in analysis of variance. *Psychological Bulletin, 99*(3), 422–431. https://doi.org/10.1037/0033-2909.99.3.422

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for *t*-tests and ANOVAs. *Frontiers in Psychology, 4,* 1–12. https://doi.org/10.3389/fpsyg.2013.00863

Leach, L., & Samuel, A. G. (2007). Lexical configuration and lexical engagement: When adults learn new words. *Cognitive Psychology, 55*(4), 306–353. https://doi.org/10.1016/j.cogpsych.2007.01.001

Litt, R. A., & Nation, K. (2014). The nature and specificity of paired-associate learning deficits in children with dyslexia. *Journal of Memory and Language, 71*(1), 71–88. https://doi.org/10.1016/j.jml.2013.10.005

Lucas, R., & Norbury, C. F. (2014). Orthography facilitates vocabulary learning for children with autism spectrum disorders (ASD). *Quarterly Journal of Experimental Psychology, 67*(7), 1317–1334. https://doi.org/10.1080/17470218.2013.859714

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). Defining dyslexia, comorbidity, teachers' knowledge of language and reading: A definition of dyslexia. *Annals of Dyslexia, 53,* 1–15. https://doi.org/10.1007/s11881-003-0001-9

Manis, F. R., Custodio, R., & Szeszulski, P. A. (1993). Development of phonological and orthographic skill: A 2-year longitudinal study of dyslexic children. *Journal of Experimental Child Psychology, 56*(1), 64–86.

Manis, F. R., Seidenberg, M. S., Doi, L. M., McBride-Chang, C., & Petersen, A. (1996). On the bases of two subtypes of development dyslexia. *Cognition, 58*(2), 157–195. https://doi.org/10.1016/0010-0277(95)00679-6

Mayringer, H., & Wimmer, H. (2000). Pseudoname learning by German-speaking children with dyslexia: Evidence for a phonological learning deficit. *Journal of Experimental Child Psychology, 75,* 116–133. https://doi.org/10.1006/jecp.1999.2525

McArthur, G. M., Hogben, J. H., Edwards, V. T., Heath, S. M., & Mengler, E. D. (2000). On the "specifics" of specific reading disability and specific language impairment. *Journal of Child Psychology and Psychiatry, 41*(7), 869–874. https://doi.org/10.1111/1469-7610.00674

Mengoni, S. E., Nash, H., & Hulme, C. (2013). The benefit of orthographic support for oral vocabulary learning in children with Down syndrome. *Journal of Child Language, 40*(1), 221–243. https://doi.org/10.1017/S0305000912000396

Messbauer, V. C., & De Jong, P. F. (2006). Effects of visual and phonological distinctness on visual -verbal paired associate learning in Dutch dyslexic and normal readers. *Reading and Writing, 19*(4), 393–426.

Messbauer, V. C. S., & de Jong, P. F. (2003). Word, nonword, and visual paired-associate learning in Dutch dyslexic children. *Journal of Experimental Child Psychology, 84*(2), 77–96. https://doi.org/10.1016/S0022-0965(02)00179-0

O'Leary, R. (2017). *Do spellings of words and phonemic awareness training facilitate vocabulary learning in preschoolers?* (Doctoral dissertation). Retrieved from http://academicworks.cuny.edu/gc_etds/2137

Olson, R. K. (1985). Disabled reading processes and cognitive profiles. In D. B. Gray & J. F. Kavanagh (Eds.), *Biobehavioral measures of dyslexia* (pp. 215–244). York, United Kingdom: YPS Publishing.

Perfetti, C. A. (1992). The representation problem in reading acquisition, In P. B. Gough, L. C. Ehri, & R. Treiman (Eds.), *Reading Acquisition* (pp. 145–174). Hillsdale, NJ: Erlbaum.

Perfetti, C. A., & Hart, L. (2002). The lexical quality hypothesis. In L. Verhoeven, C. Elbro, & P. Reitsma (Eds.), *Precursors of functional literacy* (Vol. 11, pp. 67–86). Amsterdam, the Netherlands: John Benjamins.

Rastle, K., McCormick, S. F., Bayliss, L., & Davis, C. J. (2011). Orthography influences the perception and production of speech. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*(6), 1588–1594. https://doi.org/10.1037/a0024833

Reitsma, P. (1983). Printed word learning in beginning readers. *Journal of Experimental Child Psychology, 36*(2), 321–339. https://doi.org/10.1016/0022-0965(83)90036-X

Richardson, J. T. (2011). Eta squared and partial eta squared as measures of effect size in educational research. *Educational Research Review, 6*(2), 135–147. https://doi.org/10.1016/j.edurev.2010.12.001

Ricketts, J., Bishop, D. V. M., & Nation, K. (2009). Orthographic facilitation in oral vocabulary acquisition. *Quarterly Journal of Experimental Psychology, 62*(10), 1948–1966. https://doi.org/10.1080/17470210802696104

Ricketts, J., Dockrell, J. E., Patel, N., Charman, T., & Lindsay, G. (2015). Do children with specific language impairment and autism spectrum disorders benefit from the presence of orthography when learning new spoken words? *Journal of Experimental Child Psychology, 134,* 43–61. https://doi.org/10.1016/j.jecp.2015.01.015

Rosenthal, J., & Ehri, L. C. (2008). The mnemonic value of orthography for vocabulary learning. *Journal of Educational Psychology, 100*(1), 175–191. https://doi.org/10.1037/0022-0663.100.1.175

Sadoski, M. (2005). A dual coding view of vocabulary learning. *Reading & Writing Quarterly, 21*(3), 221–238. https://doi.org/10.1080/10573560590949359

Saletta, M., Goffman, L., & Brentari, D. (2016). Reading skill and exposure to orthography influence speech production. *Applied Psycholinguistics, 37,* 411–434. https://doi.org/10.1017/S0142716415000053

Saletta, M., Goffman, L., & Hogan, T. P. (2016). Orthography and modality influence speech production in adults and children. *Journal of Speech, Language, and Hearing Research, 59*(6), 1421–1435. https://doi.org/10.1044/2016_JSLHR-L-15-0242

Semel, E., Wiig, E. H., & Secord, W. A. (2003). *Clinical Evaluation of Language Fundamentals–Fourth Edition (CELF-4)*. Circle Pines, MN: AGS.

Shaywitz, S. E., Shaywitz, B. A., Fletcher, J. M., & Escobar, M. D. (1990). Prevalence of reading disability in boys and girls: Results of the Connecticut longitudinal study. *JAMA, 264*(8), 998–1002. https://doi.org/10.1001/jama.1990.03450080084036

Siegel, L. S., Share, D., & Geva, E. (1995). Evidence for superior orthographic skills in dyslexics. *Psychological Science, 6*(4), 250–254. https://doi.org/10.1111/j.1467-9280.1995.tb00601.x

Smith-Spark, J. H., & Fisk, J. E. (2007). Working memory functioning in developmental dyslexia. *Memory, 15*(1), 34–56.

Snowling, M. J. (1980). The development of grapheme-phoneme correspondence in normal and dyslexic readers. *Journal of Experimental Child Psychology, 29*(2), 294–305. https://doi.org/10.1016/0022-0965(80)90021-1

Stanovich, K. E., Siegel, L. S., & Gottardo, A. (1997). Converging evidence for phonological and surface subtypes of reading disability. *Journal of Educational Psychology, 89*(1), 114–127.

Storkel, H. L., & Morrisette, M. L. (2002). The lexicon and phonology: Interactions in language acquisition. *Language, Speech, and Hearing Services in Schools, 33*(1), 24–37. https://doi.org/10.1044/0161-1461(2002/003)

Swan, D., & Goswami, U. (1997). Phonological awareness deficits in developmental dyslexia and the phonological representations hypothesis. *Journal of Experimental Child Psychology, 66*(1), 18–41. https://doi.org/10.1006/jecp.1997.2375

Thomson, J. M., & Goswami, U. (2010). Learning novel phonological representations in developmental dyslexia: Associations with basic auditory processing of rise time and phonological awareness. *Reading and Writing, 23,* 453–473. https://doi.org/10.1007/s11145-009-9167-9

Torgesen, J., Wagner, R., & Rashotte, C. (2012). *Test of Word Reading Efficiency–Second Edition (TOWRE–2)*. Circle Pines, MN: AGS.

van der Leij, A., & van Daal, V. H. (1999). Automatization aspects of dyslexia: Speed limitations in word identification, sensitivity to increasing task demands, and orthographic compensation. *Journal of Learning Disabilities, 32*(5), 417–428.

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry, 45*(1), 2–40. https://doi.org/10.1046/j.0021-9630.2003.00305.x

Vitevitch, M. S., & Luce, P. A. (1998). When words compete: Levels of processing in perception of spoken words. *Psychological Science, 9*(4), 325–329.

Vitevitch, M. S., & Luce, P. A. (2004). A web-based interface to calculate phonotactic probability for words and nonwords in English. *Behavior Research Methods, Instruments, & Computers, 36*(3), 481–487. https://doi.org/10.3758/BF03195594

Wolter, J. A., & Apel, K. (2010). Initial acquisition of mental graphemic representations in children with language impairment. *Journal of Speech, Language, and Hearing Research, 53*(1), 179–195.

Ziegler, J. C., Stone, G. O., & Jacobs, A. M. (1997). What is the pronunciation for -ough and the spelling for /u/? A database for computing feedforward and feedback consistency in English. *Behavior Research Methods, 29*(4), 600–618.