Annals of Dyslexia (2020) 70:259–274
https://doi.org/10.1007/s11881-020-00198-7

Sight word acquisition in first grade students at risk for reading disabilities: an item-level exploration of the number of exposures required for mastery

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Received: 22 April 2019 / Accepted: 5 May 2020 / Published online: 17 June 2020

The purpose of this study was to examine word learning efficiency in at-risk first grade students ($N = 93$) participating in a yearlong study evaluating a multicomponent intervention targeting word reading and decoding skills. As part of each intervention lesson, students participated in a 1 to 3-min sight word reading activity in which high-frequency words were read from a list until mastered, at which point the word dropped off the list. This study explored factors predicting the number of exposures required for item reading mastery ($N = 145$ words). Specifically, we explored how the number of word exposures required to reach mastery varied as a function of linguistic features of the words and cognitive characteristics of the students. Using item-level crossed-random effects models, we found students required an average of 5.65 exposures for mastery, with word features representing word length, vocabulary grade, and imageability being significant predictors of learning efficiency. We also found a significant interaction between pretest word reading skill and imageability of a word, with this semantic feature being especially important for the poorest readers. Results indicate that in the absence of typical word recognition skills, poor readers tend to rely on other sources of information to learn words, which tend to be related to the semantic features of words.

Keywords Dyslexia · Efficiency · High-frequency words · Imageability · Intervention · Reading disabilities · Word reading

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Approximately one-third of fourth grade students in the USA struggle to read at a basic level (National Center for Education Statistics, 2015). A number of factors contribute to poor reading outcomes in developing readers suggesting that students with reading difficulties represent a heterogeneous group (see Scarborough, Neuman, & Dickinson, 2009). One important factor contributing to poor word reading, and consequently poor reading comprehension, is the lack of automatic word recognition (LaBerge & Samuels, 1974). Automaticity of word reading frees up cognitive resources for higher level processes that contribute to reading comprehension (see Perfetti, 1985). In light of the importance of automaticity, efficiency of word learning is an important aspect of reading instruction. The purpose of the present study was to explore child and word factors related to word acquisition efficiency by examining the number of exposures required for mastery of high-frequency words in a structured sight word reading activity within the context of a broader decoding intervention for at-risk first grade children.

Introduction

Development of the orthographic lexicon

As children learn to read, they construct an autonomous orthographic lexicon that allows for automatic word recognition (Perfetti, 1992). The lexicon expands through an increase in the absolute number of orthographically addressable entries, referred to as “word-specific” representations (Castles & Nation, 2006; Compton, 2002; Ehri, 2014; Perfetti & Stafura, 2014). A typically developing reader’s orthographic lexicon contains approximately 10,000 word-specific representations (excluding inflectional forms) by 8th grade (Ehri, 2005; Harris & Jacobson, 1982). This requires a lexical system that can quickly establish and reliably retrieve word-specific spellings that activate pronunciation and meaning. There are multiple factors that contribute to individual differences in the number and quality of word-specific representations formed by developing readers (see Perfetti, 2007). First, as children learn more words through aural exposure, the number of available semantic and phonological representations grows. These oral language–based representations are then available to form connections with the orthographic form of the word (see Ouellette, 2006), allowing readers to access pronunciation and meaning directly from spelling (Perfetti, 1992; Share, 1995). Second, as children learn decoding rules, the number of orthographic entries that can be associated with existing semantic and phonological representations increases generatively. Application of decoding rules by children supports the establishment of subword connections between orthographic and phonological codes that quickly evolve into a set of abstract relationships that are “implicit, numerous, and very fast” (Gough, Juel, & Griffith, 1992). Developing readers use these subword associations to decode unknown words, which allows new words to be added as word-specific representations in the evolving orthographic lexicon (see Share, 1995). Third, the number of entries increases due to exposure to specific words that children acquire as whole words.

Individual differences in the efficiency with which children add word-specific orthographic representations in English are likely dependent on other child-level factors that include, orthographic processing, phonological procesing, rapid automatized naming, and print experience (see Cunningham, Perry, & Stanovich, 2001; Harm & Seidenberg, 2004; Keenan & Betjemann, 2008; Nation & Snowling, 1998; Plaut, McClelland, Seidenberg, & Patterson, 1996). In addition, word-level features (e.g., frequency, length, decodability, and imageability) likely affect the ease and efficiency with which words are added to the orthographic lexicon (see Coltheart, Laxon, & Keating, 1988; Wang, Nickels, Nation, & Castles, 2013; Waters, Bruck, & Seidenberg, 1985; Waters, Seidenberg, & Bruck, 1984).

The role of exposure in word learning

One way of exploring efficiency of word learning in students with and without reading difficulties (RD) is to examine the number of times they need to be exposed to words (with feedback) to master the words or reliably read them independently. Reitsma (1983) found that students required on average between 4 and 6 exposures to nonwords to accurately identify them using sight. Ehri and Saltmarsh (1995) found that high-performing readers require approximately 4.4 exposures for mastery of nonwords while disabled and lower performing readers require approximately 9.3 exposures. Ehri (2014) suggests that sight vocabulary is developed through a "connection-forming process" whereby developing readers gradually form connections based on their knowledge of grapheme-phoneme correspondences. By focusing on the sub-lexical features of the words on multiple occasions, they gradually build up their sight vocabulary in memory. According to Ehri, the meaning of the word is also bonded to the representation and the word can then be retrieved from memory upon the next exposure.

The role of lexical feedback in word reading

One factor contributing to the building of the autonomous lexicon and automatic word retrieval may be lexical properties of the words. Growing evidence suggests that student awareness of word meanings (see Taylor, Duff, Woollams, Monaghan, & Ricketts, 2015 for review) and word familiarity (e.g., Kearns et al., 2016) contribute to word reading accuracy. Students are more likely to read a word correctly if they are familiar with the word or they have knowledge of the meaning of the word. Connectionist models of word reading posit that the semantic properties of words directly affect how students learn and process mappings between the written (orthographic) and spoken (phonological) forms of words. These models suggest that meaning is particularly important when the process of mapping the phonological and orthographic forms of the words is difficult, particularly for words with complex spelling patterns or for students who are poor readers (Taylor et al., 2015).

Present study

In the current study, we were interested in exploring three separate but interconnected research questions focusing on factors related to how children learn high-frequency words: (1) on average, how many exposures to mastery are required for beginning readers at risk for reading difficulties (RD)?; (2) what child cognitive skills and word properties are related to efficiency of learning?; and (3) how does initial reading skill interact with word properties to predict the number of exposures required for mastery of the target words? This study extends the current word reading literature by exploring individual differences in how children add entries to their orthographic lexicons using a diverse set of child- and word-level predictors.

Method

Participants

The participants in this study (N = 93) received 63 sessions of a decoding and fluency intervention program. The overall program targeted skills related to word recognition: phonological awareness, sight words, letter sounds, decodable words, reading sentences, reading fluency, and sight word challenge. All students in this study were at risk for RD at the outset of the study. Students were identified as "at risk" by their classroom teachers. They were then given a battery of reading measures (timed and untimed tests of rapid letter naming, phonemic decoding, and word recognition) by the research team and assigned a factor score. Children were rank-ordered based on the factor score (derived from the timed and untimed tests of letter naming, phonemic decoding, and word recognition) and the top 50% were excluded from the study. Students who achieved a score below the 10th percentile on the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) were also excluded from the study.

Sight word challenge activity

This study focuses specifically on a timed sight word reading activity (referred to as the "sight word challenge"). This word recognition activity was based on 500 high-frequency sight words, presented as lists of words and ordered by their frequency of use. The words selected were the 500 most frequent words based on the Educator's Word Frequency Guide (Zeno, Ivens, Millard, & Duvvuri, 1995). Students had 1 min to read as many words as they could. The tutor corrected errors by providing the correct pronunciation of the word. No semantic feedback was provided. When a student reads a word correctly on three consecutive days, the word was removed from the student's list. The tutor then reviewed as many as 3 words missed or not mastered over the previous three days. The tutor tracked the student's progress and awarded a certificate when the student met an arbitrary benchmark (10, 50, or 200 words mastered). The sample used for this study includes 93 students who mastered the same 145 words. Tutors in the larger intervention study were full-time graduate students in education policy, special education, and teaching and learning. All tutors had experience working with young children. This was a one-on-one intervention that took place in public schools. All sessions occurred in a quiet space outside of the students' classroom. Tutoring sessions were approximately 30–45 min. The sight word challenge activity was 1 to 3 min of the instructional time.

Measures

Child measures

Dependent measure The dependent measure of interest in this study was the number of exposures required for mastery on the sight word challenge activity. Mastery was defined as three consecutive exposures correct. Therefore, the minimum number of exposures required for mastery was three. [1]

[1] Please note that this measure was developed based on word frequency. It was not developed to explore specific questions related to the acquisition of specific grapheme-phoneme correspondences, specific vowel patterns, or multisyllabic words.

Word reading To test students' real word reading fluency, the Sight Word Efficiency subtest of the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999) was used. The student was presented with a series of words in order of increasing difficulty. The child was asked to read aloud as many words as possible in a 45-s time period. The student's score was the number of words read correctly.

Decoding The Phonemic Decoding Efficiency subtest of the TOWRE was used to measure students' decoding skills (Torgesen et al., 1999). The student was presented with a series of pseudowords in order of increasing difficulty. The child was asked to read aloud as many nonwords as possible in a 45-s time period. The student's score was the number of words read correctly.

Rapid letter naming The rapid letter naming task (Fuchs et al., 2001) requires students to name an array of 52 letters (all 26 letters upper and lower case) in random order in 1 min. The score for this task was the number of letters correctly identified in 1 min.

Rapid sound naming The rapid letter sound naming task (Fuchs et al., 2001) requires students to rapidly name letter sounds. After four practice items in which the tester modelled how to name the sounds of the letters, students were given 1 min to name an array of 26 letter sounds in random order. The score for this task was the number of sounds correctly identified in one minute.

Vocabulary The vocabulary subtest from the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) was used to measure expressive vocabulary. The test asked students to identify pictures and define words.

Phonological awareness Phonological awareness was assessed using the Sound Matching subtest of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999). We presented the students with four pictures: one stimulus and three response options. The students were required to state which of three response options begins or ends with the same phoneme as the stimulus.

Working memory To assess WM, we used the Listening Recall subtest from the *Working Memory Test Battery for Children* (WMTB-C; Pickering & Gathercole, 2001). For this task, the child listens to a series of short sentences, judges the veracity of each by responding "yes" or "no," and then recalls the final word of each of the sentences in sequence. There are six trials at each set size (1 to 6 sentences per set). The score is the number of trials recalled correctly. To lower the floor of this assessment for first graders, we modified its administration. Testing was discontinued when the child incorrectly answered four items within a set, rather than the standard three incorrect items. In addition, we gave feedback to the children on the first three test items. The score was the total number of items correct.

Word measures

Frequency The metric used for word frequency was the standard frequency index (SFI) from the *Educator's Word Frequency Guide* (Zeno et al., 1995). SFI represents a logarithmic transformation of the frequency of word type per million tokens within a corpus of over 60, 000 samples of texts from various sources. These sources range from textbooks to popular literature. The range of SFI within the corpus is 3.5 to 88.3. Words in our sample ranged from 67.10 to 88.30.

Word length To account for differences in word length across items, the number of letters in each word was used as a word-level covariate.

Number of phonemes Words were coded for the number of phoneme units in each word.

Vocabulary grade The words on the dependent measure were coded according to the EDL Reading Core Vocabulary List (Taylor et al., 1989). This variable represents the grade at which a given word is typically introduced in vocabulary instruction.

Orthographic and phonological Levenshtein distance (OLD and PLD) OLD and PLD were used as measures of orthographic and phonological neighborhood size and density. For these measures, low values indicate a denser neighborhood. OLD and PLD are calculated by taking the mean of the closest 20 Levenshtein distance neighbors for a given word. The Levenshtein distance between two words is the minimum number of substitution, insertion, or deletion operations (orthographic or phonological) required to turn one word into the other. For example, the distance from smile to similes is 2 (two insertions) while the distance from chance to strand is 5 (three substitutions, an insertion, and a deletion; see Yarkoni, Balota, & Yap, 2008 for a detailed overview). These values were retrieved from the English Lexicon Project database for this study (Balota et al., 2007).

Imageability Imageability is a word-specific feature referring to the ease with which a word can elicit a mental image in the reader (Paivio, Yuille, & Madigan, 1968). Adults were asked to rate the difficulty of bringing about a mental image for the words. The instructions included in the original paper by Paivio et al. (1968): "The words that arouse mental images most readily for you should be given a rating of 7; words that arouse images with the greatest difficulty or not at all should be rated 1; words that are intermediate in ease or difficulty of imagery, of course, should be rated appropriately between the two extremes." These values were retrieved from the MRC Psycholinguistic database for this study (Coltheart, 1981). Within the sample of words on the dependent measure in this study, high imageability words (imageability ratings greater than 5.50) included *water*, *house*, *man*, and *world.* Low imageability words (imageability ratings less than 2.10) included *an*, *any*, *could*, and *then.*

Decodability Decodability was coded using a 9-point rating scale based on the 7-point coding system by Menton and Hiebert (1999), with two added categories by Compton, Appleton, and Hosp (2004). The 9-point scale ranged from single letter words (e.g., *a*, *I*) to multisyllabic and nondecodeable monosyllabic words. The nine categories were as follows: (1) A, I, C-V words (e.g., *me*, *no)*; (2) C-V-C, V-C words (e.g., *man*, *it*); (3) C-C-V, V-C-C-[C], C-C-[C]-V-C, C-V-C-C-[C], C-C-[C]-V-C-C-[C] (e.g., *such*, *than*); (4) [C]-[C]-[C]-V-C-e words (e.g., *came*, *place*); (5) C-[C]-V-V-[C]-[C] including vowel digraphs, V-V-C-[C] including vowel digraphs (e.g., *been*, *great*); (6) C-[C]-V-r, [C]-[C]-V-r-C, [C]-[C]-V-ll, C-[C]-V-l-C, C-[C]-V-V-l-C (e.g., *about*, *work*); (7) diphthongs (e.g., *down*); (8) multisyllabic words (e.g., *because*, *water*); and (9) nondecodable monosyllabic words (e.g., *have*, *know*, *what*).

Procedure

Test examiners were graduate research assistants who had been trained on tests until procedures were implemented with 90% fidelity using fidelity checklists for each assessment. These fidelity checklists were based on the standardized administration outlined in the test manuals. All tests were given individually, audio recorded for reliability/fidelity purposes, and scored by the original examiner. Children received small school-related prizes for participating in each testing session. All tests were double-scored and double-entered; discrepancies were resolved by a third examiner.

Data analysis

A series of crossed-random effects models (De Boeck, 2008; Van den Noortgate, De Boeck, & Meulders, 2003) were used to answer the research questions outlined above. These models allowed us to include both child- and word-level predictors in the same model as well as address interactions between the two. These item response theory-based models are cross-classification multilevel models that allow variance to be partitioned across the person and item level and allow for responses to be predicted by both person and item level effects. These models go by many names in the literature including explanatory item response models, random item effects models, cross-classified random effects, generalized linear mixed models, and random effects item response theory. We conducted these analyses using Laplace approximation available through the lmer function (Bates & Maechler, 2009) from the lme4 library in R (R Development Team, 2012). The default for estimation is Restricted Maximum Likelihood (REML). The analyses included 93 children and 145 words. For these models, words and persons are assumed to be random samples from a population of words and a population of persons. Since words are not nested within persons, these models are not strictly hierarchical models, but instead cross-classified. Words and persons are on the same level and crossed in the design and responses are nested within persons and within words. Power for these analyses has been addressed through simulation studies (see Cho, Partchev, & De Boeck, 2012). Various methods for examining model parameters indicate little difference in fixed effect estimates across methods with precision being relatively robust to sample size and number of items (Cho et al., 2012). We estimated the variability explained by calculating the reduction in child and word variance from the base model using the formula $(r_{010\ (\text{Base model})} - r_{010(\text{Model}\ n)})/r_{010(\text{Base model})}$, where n represents the model to which the base model was compared (Bryk & Raudenbush, 1992). The dependent measure of these models is a continuous measure of the number of exposures required for mastery. All child and word predictors were grand mean centered to aid interpretation.

Results

Descriptive statistics for the tests administered to the children in this study are provided in Table 1. Descriptive statistics for the word characteristics are provided in Table 2. The minimum and maximum values provided are from our sample at pretest. The zero-order correlations are provided in Table 3 for the child measures and Table 4 for the word measures.

Table 1 Child-level descriptive statistics (N = 93)

Variable	M	SD	Min	Max
Rapid letter naming	39.70	11.29	0	67
Rapid sound naming	28.53	9.37	12	52
Sight word efficiency	11.22	4.30	0	21
Phonemic decoding	2.73	2.83	0	10
Vocabulary	17.06	5.62	1	29
Working memory	1.78	2.68	0	12
Phonological awareness	11.06	3.97	4	19

All values represent raw scores

We present three models in Table 5 to answer our research questions. The unconditional model (model 0) indicated that there was variance associated with both person ($\sigma^2 r_{010j}$ = 1.604) and word ($\sigma^2 r_{020i}$ = 3.891). The unconditional model had an intercept of 5.65, indicating that the average student required 5.65 exposures for mastery on the average word. In model 1, we included predictors for both person and word. This model indicated that general word reading (SWE; $\gamma_{000} = -.155$, $p < .001$) was a significant child predictor of number of exposures required for mastery. Students who were 1SD above average on SWE required 4.98 exposures for mastery while students who were 1SD below average on SWE required 6.32 exposures for mastery, setting all other variables to their mean value. Length, vocabulary grade, and imageability were significant word predictors of number of exposures required for mastery. Words that were 1SD above the mean for length required an average of 6.16 exposures for mastery while words that were 1SD below the mean for length required an average of 5.14 exposures for mastery. Words that were 1SD above the mean for vocabulary grade required an average of 6.23 exposures for mastery while words that were 1SD below the mean required 5.07 exposures for mastery. Words that were 1SD above the mean on the imageability scale required an average of 5.08 exposures for mastery while words that were 1SD below the mean on the imageability scale required an average of 6.22 exposures for mastery. To further illustrate the significant main effect for imageability, we created an interactive data visualization shiny application, which can be found at the following link: https://wordreadinggrowth.shinyapps.io/exposures_to_mastery/. This data visualization technique illustrates how learning occurs across exposures and how this learning differs for low vs. high imageability words.

In model 2, we included three interaction terms to explore interactions between initial word reading skill and relevant word properties: vocabulary grade, imageability, and Orthographic

Table 2 Word-level descriptive statistics (N = 145)

Variable	M	SD	Min	Max
Frequency (SFI)	72.60	3.89	67.10	88.30
Length	3.79	1.26	1.00	9.00
Number of phonemes	3	.89	1.00	7.00
Vocabulary grade	.87	.67	0	3.00
OLD	1.51	.36	1.00	2.80
PLD	1.28	.36	1.00	2.70
Imageability	323.42	95.47	195	632
Decodability	5.09	2.64	1.00	9.00

OLD, Orthographic Levenshtein Distance; *PLD*, Phonological Levenshtein Distance; *SFI*, standard frequency index

Table 3 Zero-order correlations between child variables

	1	2	3	4	5	6	7	8
1. Mean number of exposures	–							
2. Rapid letter naming	*− .19*	–						
3. Rapid sound naming	*− .07*	*.33*	–					
4. Sight Word Efficiency	*− .56*	*.30*	*.33*	–				
5. Phonemic Decoding Efficiency	*− .29*	*.21*	.20	.20	–			
6. WASI vocabulary	*− .10*	− .06	.05	.11	.16	–		
7. Working memory	*.02*	− .01	− .04	− .10	.02	.04	–	
8. Phonological awareness	*− .26*	.16	− .01	.19	*.26*	.14	− .01	–

$p < .05$ for all variables in italics

Levenshtein Distance. We specifically included these interactions because we were interested in the interaction between initial word reading skill and semantic properties of the words (i.e., vocabulary grade and imageability) and were interested in exploring whether students with better reading skills might be more likely to extract orthographic similarities between words and use that knowledge to learn new words (i.e., OLD). Two of the three interactions were significant: imageability and vocabulary grade. Graphs of these interactions are provided in Figs. 1 and 2. Overall, the imageability interaction indicates that for low imageability words (words for which it is harder to conjure a mental image), students who begin the intervention with very low word reading skills (2 standard deviations below the mean) require nearly 4 more exposures to those words, on average, than students who begin the intervention with relatively good word reading skills (2 standard deviations above the mean). Similarly, the vocabulary interaction (Fig. 2) indicates that for words that have a higher vocabulary grade, students who begin the intervention with very low word reading skills require more than twice as many exposures than students who begin the intervention with relatively good word reading skills.

Discussion

The results from this study suggest that there are a number of child and word factors related to how quickly students add words to their orthographic lexicons as they learn to read. These

Table 4 Zero-order correlations: word variables

	1	2	3	4	5	6	7	8	9
1. Mean number of exposures	–								
2. Frequency (SFI)	*− .26*	–							
3. Length	*.45*	*− .47*	–						
4. Number of phonemes	*.31*	*− .43*	*.81*	–					
5. EDL vocabulary grade	*.46*	*− .33*	*.40*	*.40*	–				
6. OLD	*.33*	*− .20*	*.66*	*.55*	*.36*	–			
7. PLD	*.36*	*− .17*	*.61*	*.67*	*.31*	*.74*	–		
8. Imageability	*− .20*	*− .40*	.14	.07	− .02	− .02	− .06	–	
9. Decodability	.26	− .13	*.50*	*.32*	.15	*.33*	*.37*	.08	–

OLD, Orthographic Levenshtein Distance; *PLD*, Phonological Levenshtein Distance

$p < .05$ for all variables in italics

Table 5 Main effects models for person ($N = 93$) and word ($N = 145$)

	Model 0				Model 1				Model 2			
Fixed effects												
Variable	**Coefficient**	**SE**	**t**	**p**	**Coefficient**	**SE**	**t**	**p**	**Coefficient**	**SE**	**t**	**p**
Intercept	5.65	.21	26.72	.001*	5.65	.171	33.053	.001*	5.653	0.171	32.968	.001*
Child factors												
SWE					− .155	.027	5.611	.001*	− .155	0.028	5.561	.001*
PDE					− .071	.041	1.711	.088	− .071	.042	1.689	.091
Working memory					− .015	.041	.373	.709	− .016	.042	.375	.708
PA					− .041	.029	1.423	.155	− .042	.030	1.414	.157
RLN					.001	.010	.123	.902	.001	.011	.129	.897
Word factors												
SFI					− .080	.044	1.811	.070	− .080	0.044	1.811	.070
OLD					− .508	.607	.847	.402	− .508	.607	0.837	.403
PLD					.602	.576	1.045	.296	.604	.576	1.049	.294
Length					.408	.178	2.283	.022*	.409	.179	2.387	.022*
Vocabulary grade					.871	.229	3.806	.001*	.871	.229	3.806	.001*
Imageability					− .006	.002	3.898	.001*	− .006	0.002	3.898	.001*
Decodability					.059	.060	.988	.323	.059	0.060	.987	.324
Interactions												
SWE*vocab									− 0.058	.010	5.800	.001 *
SWE*imageability									.001	.001	4.753	.001*
SWE*OLD									− 0.033	.019	1.782	.075
Random effects												
Source	**Variance**				**Variance**		**Variance explained**		**Variance**		**Variance explained**	
Person (intercept)	1.604				1.056		34.16%		1.070		33.29%	
Word (intercept)	3.891				2.492		36.72%		2.494		35.90%	

SWE, Sight Word Efficiency; *PDE*, Phonemic Decoding Efficiency; *PA*, Phonological Awareness; *RLN*, Rapid Letter Naming; *SFI*, Standard Frequency Index; *OLD*, Orthographic Levenshtein Distance; *PLD*, Phonological Levenshtein Distance; an assumption was made that the random effects were not correlated with one another in order to perform significance tests using a MCMC simulation method

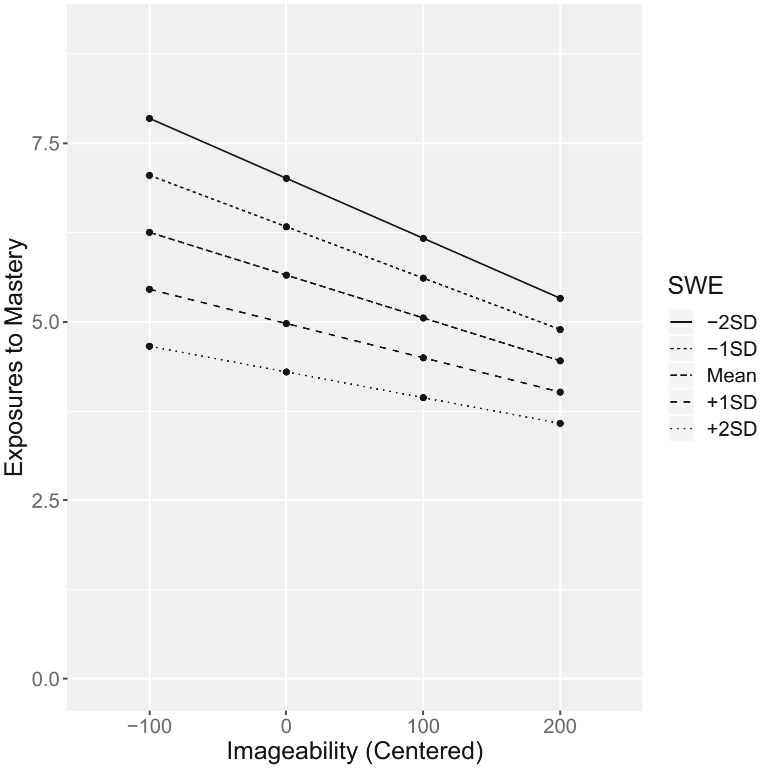

Fig. 1 Interaction between initial SWE and imageability

results implicate semantic properties of words (i.e., imageability and vocabulary grade) as important factors related to this efficiency of learning, particularly for students with poor word reading skills. In the present study, we found that both vocabulary grade (the grade when the word is introduced into formal vocabulary instruction) and imageability (the ease of bringing about a mental image to go with a word) are particularly important for students with the most need in the area of word reading. The results suggest that students with poor word reading skills may rely more heavily on the semantic properties of words while learning high-frequency words.

Word predictors of number of exposures for mastery

Our models indicated that the only significant predictor at the child level was initial word reading skill. This finding is not surprising given that the dependent measure is word reading and initial word reading skill is likely to account for the majority of variance, leaving little variance for other predictors. There were several word features that accounted for unique variance in the number of exposures required for mastery. The first was length, with longer words requiring more exposures for mastery than shorter words. This finding is consistent with other findings that longer words are typically more difficult to read, especially for younger students and students with dyslexia (e.g., Marinus & de Jong, 2010). The findings from our study provide further support that word length is related to both word difficulty and how efficiently children learn specific words.

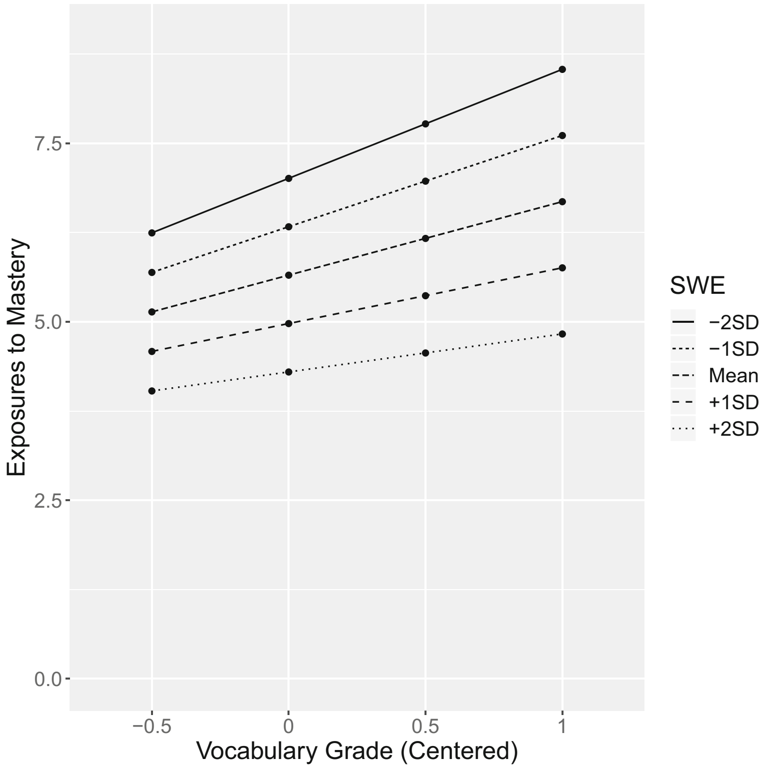

Fig. 2 Interaction between initial SWE and vocabulary grade

Our analyses indicated that two semantic features of words were significantly related to the number of exposures required for mastery. The first was word imageability, the ease with which a word elicits a mental image in the reader. The main effect for imageability and the significant interaction with initial word reading skill indicates that imageability is an important word feature, particularly for students who started the intervention with poor word reading skills. These findings are consistent with other findings that suggest that imageability is related to word difficulty (e.g., Steacy et al., 2017; Strain, Patterson, & Seidenberg, 1995) and word learning efficiency (Steacy & Compton, 2019). The second semantic feature that was significantly related to word learning efficiency was vocabulary grade according to the EDL Vocabulary List. As mentioned above, this variable indicates the grade in which the target words are typically introduced in formal vocabulary instruction. As such, it serves as a semantic feature of the words. This proxy was a significant predictor even after controlling for frequency, length, imageability, and decodability. Interpreted within a connectionist model of word reading (Seidenberg & McClelland, 1989), where lexical feedback is required to assist in the mapping of the phonological and orthographic forms of words, the significance of imageability and vocabulary grade in these models supports a hypothesis that students with RD are relying heavily on the semantic processor in word learning efficiency. We do not, however, have the correct data to make any causal inferences about this relationship. Words that are introduced earlier in vocabulary instruction and words that more easily elicit a mental image appear to be learned faster than words that are more advanced from a semantic standpoint. Taken together, these results indicate that semantic features of words may be important components of adding words to the orthographic lexicon.

Word reading × word feature interactions

In addition to the main effects we found for imageability and vocabulary grade, we conducted an exploratory interaction analysis to examine whether the effect of word imageability and vocabulary grade varied depending on word reading skill. These interactions were both significant. Among children who were at risk due to initial poor reading skills, words that were low on the imageability scale (i.e., it is more difficult to elicit a mental image for the word) were particularly difficult for students who began the intervention with the poorest word reading skills and required significantly more exposures for mastery than words that were higher on the imageability scale. The same pattern was found for vocabulary grade, with words introduced later in vocabulary instruction requiring significantly more exposures for mastery in students who began the intervention with the poorest word reading skills than students who began the intervention with higher word reading skills. Taken together, the results of the interaction models suggest that students with the poorest word reading skills may rely more on the semantic properties of words than students who start the intervention with better word reading skills. Within the triangle model of reading outlined above, these results may indicate that poor readers rely more on semantic feedback to "clean up" mismatches between phonology and orthography than stronger readers. Students with good word reading skills may rely less on these semantic properties because their connections between phonology and orthography are stronger (see Siegelman et al., in press). This may be particularly important for irregular words, many of which are taught as sight words in early word reading instruction. For poor readers, when there is less semantic feedback available (i.e., words are less imageable and/or they do not know the meanings of the words yet), their word reading growth slows down.

Taken together, the results from this study provide some insight into how students with poor word reading skills acquire words across the course of an intensive multicomponent intervention. Furthermore, these results suggest that the semantic properties of words play an important role in how efficiently these students learn words and how quickly they add them to their orthographic lexicons.

Limitations and future directions

There are limitations to this study that are worth noting. Firstly, the experimental design provided some indication of learning over time. We could not, however, experimentally control the number of times students encountered the target words in the sight word challenge in other instructional activities or in their broader experiences. Since these data were collected within the context of an intervention that spanned the entire first grade year, it is not possible to quantify these other experiences with the words. Additionally, the results from this study apply only to the target words outlined above. These data are also from a sample of poor readers, which limits generalizability to a typically developing sample. Caution should be exercised when generalizing to other words and children. Furthermore, the experimental measure employed in this study was based on frequency, which limited the word-level predictors that could be explored. Future work using controlled experimental designs would help to address some of these remaining questions. Furthermore, work on maintenance of word representations over time and number of exposures required for maintenance of learning is warranted.

Acknowledgments We thank the teachers, principals, and administrators of the Metro Nashville Public Schools for their interest and cooperation.

Funding information This research was financially supported in part by grant R01HD056109 and grant P20HD091013 from the Eunice Kennedy Shriver National Institute of Child Health & Human Development (NICHD).

Compliance with ethical standards

Disclaimer The authors are responsible for the paper's content, which does not necessarily represent the views of the NICHD or the National Institutes of Health.

Appendix

Table 6 Sight word challenge target word list ordered by frequency

Target word			
the	we	see	used
of	about	its	go
and	what	made	work
to	up	first	any
a	said	new	use
is	would	my	things
that	out	very	look
it	some	also	well
was	people	down	another
for	so	now	around
you	other	make	great
he	them	each	man
on	more	way	same
as	will	called	came
are	your	did	should
they	which	just	come
be	into	after	right
his	do	water	small
at	many	through	old
or	then	know	think
had	these	because	take
from	no	get	place
not	been	little	still
this	who	back	find
have	time	where	off
but	like	such	different
by	could	much	world
were	has	even	us
one	him	must	found
all	how	our	away
she	than	good	help
when	two	too	went
an	only	before	here
their	may	me	house
there	most	day	food
her	over	years	looked
can			

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