Testing mechanisms underlying children's reading development: The power of learning lexical representations.

Submitted February 26, 2024

Abstract

Prominent theories of reading development have separately emphasised the relevance of children's skill in learning (Share, 2008) and lexical representations (Perfetti & Hart, 2002). Integrating these ideas, we examined whether skill in learning lexical representations is a mechanism that might explain children's reading development. To do so we conducted a longitudinal study, following 139 children from Grades 3 to 5. In Grade 3 children completed measures of word reading and reading comprehension and again at Grade 5. In Grade 4, children read short stories containing novel words; they were later tested on their memory for the spellings and meanings of these new words, capturing orthographic and semantic learning, respectively. Using multiple-mediation path analysis, we tested whether children's skill in learning orthographic and semantic dimensions of new words was a mediator of individual differences in each of word reading and reading comprehension. In models controlling for nonverbal ability, working memory, vocabulary and phonological awareness, we found two clear effects: individual differences in orthographic learning at Grade 4 mediated the gains that children made in word reading between Grades 3 and 5 and individual differences in semantic learning at Grade 4 mediated gains in reading comprehension over the same time period. These findings suggest that children's ability to learn lexical representations is a mechanism in reading development, with orthographic effects on word reading and semantic effects on reading comprehension. These findings show the power and the specificity of children's capacity to learn in determining their progress in learning to read.

Keywords: lexical representations, learning, self-teaching, orthographic learning, word reading, reading comprehension

Public significance statement

Reading is one of the most important skills that children can acquire in elementary school, with its successful achievement enabling full societal engagement across the lifespan. This study suggests that children's capacity to learn targeted aspects of words—their spellings and meanings—is a mechanism that drives their reading development. These findings point to the need to incorporate the power of children's learning into theories of and instruction in reading.

Testing mechanisms underlying children's reading development: The power of learning lexical representations.

Learning to read is one of the most important goals for elementary school education. Early in the elementary years, the focus is, quite rightly, on word reading (e.g., Chall, 1983; Snow & Matthews, 2016). Individual differences in phonological skills have been reliably linked to children's progress in learning to read words (Bradley & Bryant, 1983; Perfetti et al., 1987). Children's skill in word reading is, in turn, a core foundation for learning to understand texts. The centrality of word reading to reading comprehension is captured in the Simple View of Reading (Gough & Tunmer, 1986) wherein word reading and language comprehension are each considered essential to reading comprehension success. More recently, the limitations of these influential ideas have been highlighted (e.g., Catts, 2018; Francis et al., 2018; Nation, 2019), encouraging openness to other factors that might be important for reading success. The self-teaching hypothesis has pointed to the need to consider children's capacity to learn, rather than just their "crystallised" knowledge (Share, 2008; see also Deacon et al., 2012). And the lexical quality hypothesis reminds us to consider both semantic and orthographic features of the lexical representations that children acquire (Perfetti & Hart, 2002; see also Perfetti & Stafura, 2014). Connecting these relatively siloed ideas leads us to speculate that the ability to learn lexical representations could be a mechanism that drives children's reading development. We report here on a longitudinal study designed to test this idea.

We conduct this research in middle-elementary school, a crucial point in the transition from learning to read to reading to learn (Chall, 1983; Semingson & Kerns, 2021). The elementary school years is a clear period of growth in children's word reading and reading comprehension skills. In the later elementary school years and beyond, children also appear to be remarkably stable in the pace of this development, with relative steadiness in the rank order of individual children (e.g., Bornstein et. al., 2017; Ricketts et al., 2020). High levels of stability are reflected, for instance, in high correlations between earlier and later reading skill (Deacon & Kirby, 2004; Parrila et al., 2005; Torgesen et al., 1997). Stability in word reading is high by late elementary school (Hulslander et al., 2010; Little et al., 2021), and by early adolescence for reading comprehension (Ricketts et al., 2020). The question that we ask here is what explains individual differences in reading development, beyond this incredible stability, and we turn to individual differences in ability to learn lexical representations as a potential answer.

We reflect on two key aspects of the ability to learn lexical representations as we consider its potential to explain individual differences in reading development. The first lies in a focus on *lexical representations* and a second is an emphasis on *learning.* We unpack each of these in turn.

It is well-established that skilled reading is founded on high quality representations—ones that include the sounds, spellings, and meanings of words (Perfetti & Hart, 2002). The lexical quality hypothesis (Perfetti & Hart, 2002) puts forward that high-quality representations free cognitive resources that are needed for reading comprehension. This makes sense; children need to know words to understand texts that are made up of words and richer and more detailed knowledge of individual words will allow the reader to divert cognitive resources to other aspects of text comprehension (e.g., making inferences), enabling deeper text comprehension. However, the lexical quality hypothesis does not posit a mechanism for the acquisition of lexical representations. When children encounter a new word in text, it is likely that the representations accessed will vary across children. Certainly, evidence to date suggests that, as children come across a new word such as *feap* in a text (Ouellette & Fraser, 2009), there are clear differences in the extent to which they learn its spelling and meaning (e.g., Authors et al., 2018, Ricketts et al., 2011; Shakory et al., 2021). Here we are interested in the role of individual differences in learning these two aspects of lexical representations in mediating children's progress in learning to read.

The value in exploring individual differences in learning comes in part from the self-teaching hypothesis (Share, 2008), which is well-known for turning the field of reading towards the capacity to learn (Verhoeven & Perfetti, 2021). This emphasis on learning is in keeping with a long-standing push to attend to both dynamic and crystallised knowledge, a distinction akin to fluid and crystallised intelligence (Cattell, 1963). Specific to the field of reading, there have been repeated calls over the last two decades to include learning in models of and instruction for reading development (Deacon & Kieffer, 2018; Grigorenko, 2009; Kilpatrick, 2018; Share, 2008; Steacy et al., 2017), in part because of evidence that crystallised knowledge might be an outcome of word reading (e.g., Deacon et al., 2012; Pasquarella et al., 2014). This emphasis on learning is at odds with traditional models of reading development that have focused on skill rather than learning. For instance, Perfetti and Hart (2002) write that " skill in reading comprehension rests to a considerable extent on knowledge of words" (p. 189). As such, the widely cited lexical quality hypothesis is centered clearly around word knowledge and not word learning. Similarly though on an educational level, Kilpatrick (2018) articulated that "neither of the two dominant reading approaches used in schools over the last 40 years properly distinguishes between *reading* words and *learning* words. They focus on the former without adequately addressing the latter." (p. 948). To explore the potential raised by these ideas, we need to test whether facility with learning words might, in turn, propel children's progress in learning to read words and to understand texts.

Children’s capacity to learn is a potentially powerful and, to this point, underleveraged resource. For instance, we know that struggling readers are likely to have fewer opportunities for learning both about words and the world because they spend less time reading (Stanovich, 1986; van Bergen et al., 2020); these Matthew effects are likely to be compounded by challenges in learning during those limited experiences. Delineating the power of children’s capacity to learn in enabling strong reading trajectories is a key first step towards fully exploiting its impacts. Towards this end, we examine whether the ability to learn lexical representations mediates individual differences in children’s reading development, with hypotheses specific to aspects of learning most likely to predict each of word reading versus reading comprehension.

Our first hypothesis is that the ability to learn the orthographic form of lexical representations is a mechanism in children’s word reading development. Orthographic learning is considered the “…child’s dynamic ability to form these [orthographic] representations” (Deacon, Pasquerella, et al., 2019, page 510). The self-teaching hypothesis puts forward orthographic learning as a secondary mechanism, beyond the role of phonological decoding, supporting efficient word reading (Share, 1995; Share, 2008). Traditionally, orthographic learning has been operationalised as the extent to which children acquire orthographic representations through a self-teaching paradigm, which requires independent reading (Share, 1995). The idea is that children learn new orthographic forms through their word reading. This relationship is likely reciprocal, such that skill in word reading drives orthographic learning, which, in turn, drives word reading. As such, when modeled empirically, orthographic learning should mediate gains in word reading made over time.

Several empirical studies provide preliminary empirical support for orthographic learning as a mechanism explaining gains in word reading. Studies with mid-elementary school aged children show correlations at a single point in time between levels of orthographic learning and word reading (Deacon et al., 2012; Authors et al., 2018; Ricketts et al., 2011; Wang et al., 2013). Deacon, Pasquarella et al. (2019) demonstrated that individual differences in children's orthographic learning accounts for gains in word reading over time, after controls for phonological awareness and non-verbal ability. In that study, children read short stories containing new words, such as "The new word is Laif. The coldest town in the world is Laif. Laif is in Greenland. The people who live in Laif need very hot houses." (based on Byrne et al., 2008). Children were supplied with the non-word if they could not read it on their own (see also Byrne et al., 2008) to isolate effects of orthographic learning from phonological decoding. Children's ability to learn orthographic representations for these new words (i.e., performance on an orthographic choice task such as *laif-lafe-laip-lape*) was related to individual differences in gains in word reading over the course of a year. Similarly, Authors et al. (2022) showed effects of orthographic learning on word reading and reading comprehension a year later, though these effects did not remain beyond the autoregressor. Intriguingly, effects of orthographic learning on word representations a year later did remain after autoregressor. Here we test the mechanistic effects of orthographic learning on gains in word reading in a different way, examining whether orthographic learning mediates individual differences in gains in word reading across several years. This approach tests more directly the capacity of orthographic learning as a mechanism, acknowledging the likely bidirectional effects between word reading and the capacity to learn orthographic representations (e.g., Conrad & Deacon, 2023).

Our second hypothesis is that the ability to learn the meanings of new words—or what is known as semantic learning—is a mechanism in the development of reading comprehension. This idea builds on the centrality of meaning in the high-quality representations advocated to be important for reading comprehension (Ouellette, 2006; Perfetti & Hart, 2002). In short, one needs to know words to read with understanding. This suggestion is confirmed empirically by the well-established role of children's knowledge of words, or their vocabulary, in their reading comprehension (e.g., Verhoeven & Van Leeuwe, 2008). And yet we are interested here in more than children's knowledge of word meaning; we turn here to their facility with acquiring word meaning. Our emphasis on learning resonates with suggestions that children learn vocabulary through their reading comprehension and that the vocabulary they learn in turn contributes to understanding what they read (Nation, 2017; Ricketts et al., 2011; Wagner & Meros, 2010). These ideas were recently articulated by Nation who advocated that, the "text is the substrate that allows the reader to pull in relevant information, including, for example, the meanings of words…This information is then processed to make connections, draw inferences and construct intended meaning." (Nation, 2019, p. 50-51). We build on these ideas to make the explicit prediction that children's semantic learning—beyond vocabulary knowledge alone-- will operate as a mechanism supporting the development of reading comprehension.

Several studies provide beginning support for this idea. Specifically, findings now show relations at a single point in time between children's ability to learn words through their reading—or semantic learning—and their reading comprehension (Mimeau et al., 2018; Ricketts et al., 2011). For instance, in a study with 8-year-old children, Mimeau et al. (2018) showed relations between semantic learning and reading comprehension after controls for age, nonverbal reasoning, working memory, phonological awareness, and vocabulary. That study in fact tested individual differences in the ability to acquire both the orthographic and semantic forms of new words that children read in stories. For example, children read, "Ben was at the pet shop and the fish tank looked dirty. Ben picked up the veap. The veap is used to clean fish tanks. Ben placed the veap in the fish tank. When the fish tank was clean, Ben put away the veap." (from Wang et al., 2011). Children were later tested on their ability to recognise and produce both the spelling and meaning of the new words, measuring the extent of orthographic and semantic learning, respectively. Structural equation modeling showed that individual differences in semantic learning were related to children's reading comprehension, and orthographic learning was related to word reading. These correlational findings confirm the relevance of semantic learning to reading comprehension, along with those of orthographic learning to word reading. Follow-up analyses of data to Grade 4 showed that semantic learning contributed to later levels of reading comprehension, just as orthographic learning contributed to later levels of word reading (Authors et al., 2022); these effects did not survive autoregressors though, suggesting that we do indeed need to take on board the potential origins of semantic learning in reading comprehension. Here we test semantic learning as a mechanism in the development of reading comprehension by modeling of its role as a mediator across three waves of data.

We report a longitudinal study testing the hypotheses that orthographic learning will be a mechanism by which children make gains in word reading and that semantic learning is a mechanism by which they make gains in reading comprehension. We work with children from Grades 3 to 5, a time in which word reading is likely to be more separable from reading comprehension, compared to younger children (Lonigan & Burgess, 2017). We expect that individual differences in orthographic learning will mediate gains in word reading and that individual differences in semantic learning will mediate gains in reading comprehension. For a schematic of this modeling see Figures 2 and 3.

Our modeling of three wave data is designed to directly test these predictions. Questions of mediation, in effect of mechanisms, are often tested with data collected at a single timepoint (e.g., Kim et al., 2020; Levesque et al., 2017). And yet, in its truest sense, mediation is meant to implicate causal relationships that unfold over time (Selig & Preacher 2009). A three-timepoint longitudinal study provides an optimal way to test mechanisms, by examining whether proposed mechanisms assessed at Time 2 mediate the development of the predicted outcome skill, such as reading, between Times 1 and 3. Within the field of reading, this approach provides a novel way to take on the challenging conceptual description of "text as the substrate" (Nation, 2019, p. 50), or the very foundation, of learning. Including levels of reading skill at Time 1 addresses the fact that children acquire skills through their reading, just as they bring skills to the task of learning to read. This reality is an ongoing critique of research and theory (e.g., Conrad & Deacon, 2023; Nation et al., 2022), and this modeling approach embraces the bidirectional and developmental nature of learning to read.

This statistical approach also embeds autoregressive controls, a highly conservative analytic approach (Gollob & Reichardt, 1987) that gets to the heart of what explains development over time. Conducting this research across several years allows room for individual differences to emerge, beyond the very high stability in both word reading and reading comprehension (e.g., Hulslander et al., 2010; Little et al., 2021; Ricketts et al., 2020). Layered on top of this, we use a multiple-mediation path analysis approach to test the unique effects of each of semantic and orthographic learning on the development of word reading and reading comprehension, respectively. To summarise, we test the effects of orthographic and semantic learning at Grade 4 as mediators in the gains that children make in word reading and reading comprehension between Grades 3 and 5; this evaluates each of orthographic and semantic learning as potential mechanisms responsible for this change over time.

Our methods add further stringency to answering these questions. We use a modification of a self-teaching paradigm. Children independently read short stories containing novel words. As in several prior studies (e.g., Byrne, 2008; Deacon et al., 2019; Mimeau et al., 2018), we gave children the pronunciation of the novel word if they could not read it on their own (in contrast to Share, 1999); this isolated effects of orthographic learning from skill in decoding, in line with the suggestion that orthographic learning is indeed a secondary source of variance beyond phonological decoding (e.g., Share, 1995). Following on their reading of the short stories, they complete tests of their learning of both the spellings and meanings of these new words, or orthographic and semantic learning, respectively. Modeling effects of performance on parallel learning measures of orthographic and semantic aspects of the same novel words learned within the same experience offers a stringent test of unique effects of each of orthographic and semantic learning.

We also measure key control variables. Given our interest in the effects of learning of lexical representations, we control for children's nonverbal ability and working memory; both are likely to be implicated in learning generally, including reading (e.g., Deacon & Kirby, 2004) and so controlling for them enables us to isolate effects for facility with learning orthographic and semantic features of new words. Both phonological awareness and vocabulary are well-demonstrated correlates of word reading and reading comprehension (National Reading Panel, 2000; Snow et. al., 1998; Verhoeven & Van Leeuwe, 2008), and so controlling for them enables us to isolate effects that emerge beyond these established relations.

Method

The present study was part of a larger investigation on reading development. In a previous report, we described the relation of orthographic and semantic learning at Grade 3 with reading skills measured at Grade 3 (Authors et al., 2018) and Grade 4 (Authors et al., 2022). Here we report on relations across a three-year longitudinal time span, focusing on measures of orthographic and semantic learning at Grade 4 as mediators in gains in reading levels between Grade 3 and 5. University-level ethics approval (#2014-3328) for this study was obtained from the authors' institution, as well as from the appropriate school boards.

Participants

We recruited Grade 3 children from six urban and five rural public schools in in eastern North America. The area in which we recruited is largely Caucasian (6 % of the population is Aboriginal and another 6% is non-Caucasian or non-white; Statistics Canada, 2019). The mean household income for the areas surrounding the schools was $77,740 (*SD* = $13,145), similar to the provincial average (Statistics Canada, 2019). We recruited from whole classrooms, with no restrictions on eligibility. We obtained parental consent for 139 children (74 boys and 65 girls). We followed up with 124 of the children in Grade 4, on average 11.71 months later (*SD* = 0.43), and then with 108 of the children in Grade 5, on average 11.98 months later (*SD* = 0.46). Attrition was explained by participants moving away (*n* = 14 at Grade 4; *n* = 13 at Grade 5) or withdrawing from the study (*n* = 1 at Grade 4; *n* = 3 at Grade 5). The mean age of participants was 8;09 years (*SD* = 3.5 months) at Grade 3, 9;09 years (*SD* = 3.5 months) at Grade 4, and 10;09 years (*SD* = 3.5 months) at Grade 5. Mean scores on standardised measures of word reading and reading comprehension at Grades 3 and 5 suggest that the children are typically developing in terms of word reading development (see Table 1).

Data for all 139 children was included in analysis, with the use of full maximum likelihood with robust parameter estimation as an appropriate way to handle missing data (Enders, 2012). The sample size of 139 exceeded that needed (*n* = 90) for structural equation modeling with two latent variables and 13 observed variables based on estimated effect size of .3 and desired power of .8 (Soper, 2022; see also Westland, 2010).

Materials

Word Reading

At Grades 3 and 5, we measured word reading with the Sight Word Efficiency subtest of the Test of Word Reading Efficiency (Torgesen et al., 1999). This age-appropriate test is well-developed to capture individual differences in word reading. Form A of the subtest was used at both grades. Participants were asked to read as many words as possible from a list of 104 words ordered in increasing difficulty. The task was discontinued after 45 seconds.

Reading Comprehension

At Grades 3 and 5, we measured reading comprehension with the Comprehension subtest of the fourth edition of the Gates-MacGinitie Reading Tests. Grade appropriate forms were used at each grade: Level 3 (Form T) at Grade 3 (MacGinitie et al., 2000a) and Level 5 (Form S) at Grade 5 (MacGinitie et al., 2000b). This developmentally appropriate test is well-scaled for each grade level that we report on here. Following on the manual protocol, participants were given 35 minutes to read short texts silently and answer 48 multiple-choice questions assessing comprehension.

Learning Task

Based on previous studies (e.g., Deacon, Mimeau et al., 2019; Authors et al., 2018; Ricketts et al., 2011; Share, 1999; Wang et al., 2011), we measured orthographic and semantic learning with a typical learning task with an exposure phase followed by orthographic and semantic learning post-tests. As noted earlier, the children completed a similar learning task at Grade 3 (see Authors et al., 2018); the stories and non-words were different at Grade 4, and so the orthographic and semantic learning post-tests were too. These two versions of the learning task were initially piloted with a separate group of 37 children in Grades 2 to 4. The children in this pilot study completed both versions of the task in two separate individual sessions, with the order of the versions counterbalanced across sessions. Based on the children's performance on each item, we switched some items from one version to the other to make the two versions of each task as equivalent in difficulty as possible. The corrected versions of each task, which we used in the present study, generated comparable performance scores (*p*s $\leq$ .64). Further, based on Authors et al.'s (2018) factor loadings, we used a spelling task as well as immediate and delayed orthographic choice tasks to capture orthographic learning and an immediate and delayed semantic choice task to measure semantic learning. Author et al. (2018) reports on the inclusion of a recall measure (i.e., producing a correct definition) for the semantic learning task, but this did not load well on semantic learning measures. We report here then on analyses in which orthographic learning was assessed with both recognition and recall, while semantic learning was assessed only with a recognition task.

Exposure Phase.

***Stories*.** Participants were asked to read out loud 12 stories, each about a new invention (e.g., a sock sorter; see Appendix A for an example). The stories were based on those created by Wang et al. (2011). Each story contained between 37 and 52 words, including four repetitions of one non-word that represented the invention. The stories were divided into five sentences describing a problem, introducing the invention, describing the function of the invention, describing the use of the invention to solve the problem, and concluding with the solving of the problem. The stories were presented in sets of three in the same pre-randomised order for all participants. As participants read the stories, the experimenter provided feedback every time a word or non-word was mispronounced, skipped, or added. This feedback was intended to allow participants to fully understand the stories and know the correct pronunciation of the non-words, which was particularly important since the experimenter referred to them in the orthographic and semantic learning post-tests. Participants were not required to repeat the words or non-words for which they received feedback.

Non-Words. The creation of the non-words followed strict criteria. The non-words were four letters long and both started and ended with a consonant sound. All 12 non-words began with a different letter. The non-words had regular grapheme-phoneme correspondences. Indeed, each grapheme was intended to be pronounced as the single phoneme listed in Rastle and Coltheart's (1999) rules (e.g., the regular pronunciation of "ee" is /i/). None of the non-words were listed in the Children's Printed Word Database (http://www.essex.ac.uk/psychology/cpwd), confirming their status as non-words for participants. Finally, each non-word contained a target sound that could be spelled in at least two ways (e.g., /i/, which can be spelled "ee" or "ea"), as per Fry's (2004) list of phoneme-grapheme correspondences. Each target sound was presented in two non-words, with a different spelling in each non-word (e.g., "feep" and "weaf"). To control for any spelling preference, half of participants were given an alternative spelling of the non-words (e.g., "feap" and "weef"; see Appendix B for the complete list of non-words, including the frequencies of each spelling of the target sounds).

Orthographic Learning Post-Tests. After reading each set of three stories, participants completed a spelling post-test. The experimenter read each of the three non-words from the set and asked participants to spell them on a sheet of paper (e.g., "Spell 'feep'"). Testing was implemented after each set of three (see also Byrne, 2008) to reduce memory load in this demanding learning task. No feedback was provided. Answers had to be identical to the non-words presented in the stories to be considered as correct. Within each set, the non-words were presented in the same pre-randomised order for all participants. Cronbach's alpha for this post-test was .75.

After reading the 12 stories, participants completed two orthographic choice post-tests: an immediate one right after the exposure phase to measure immediate recall and a delayed one a few days later to measure delayed retention (see the Procedure for more details). The two orthographic choice post-tests were identical. They were also designed to have the same structure as the semantic learning post-tests described below. For each non-word, the experimenter showed four spellings to participants and asked them to choose the correct one (e.g., "Show me the spelling of 'feep'"). No feedback was provided. The non-words and the choices were presented in the same pre-randomised order for all participants. The distractors were the alternative spelling of the non-word (e.g., "feap") and two non-words that varied by one letter (e.g., "veep" and "veap"). None of the distractors had been presented during the exposure phase. The phonological cue alone (e.g., "Show me the spelling of 'feep'") was not sufficient to find the correct answer, given that two of the choices could be read similarly (e.g., "feep" and "feap"). Reliability of the immediate and delayed orthographic choice post-tests were .51 and .40, with a correlation between the two at .58. Our analyses relied on latent variables calculated across these indices, attenuating any concerns about task reliability by analyzing the shared variance and covariance of the indicators, while excluding components of error (Kline, 2016).

Semantic Learning Post-Tests. After reading the 12 stories, participants also completed two semantic choice post-tests: an immediate one and a delayed one, as for the orthographic choice post-tests. The two semantic choice post-tests were identical. They were designed to have the same structure as the orthographic learning post-tests described above. For each non-word, the experimenter showed four pictures to participants and asked them to choose the correct one (e.g., "Show me the picture of a feep"). No feedback was provided. Some of the pictures came from Wang et al.'s (2011) work. The non-words and the choices were presented in the same pre-randomised order for all participants. The distractors were an invention that used the same object as the non-word (e.g., a sock fixer, whereas the invention from the story was a sock sorter) and two inventions that used another object (e.g., a snow melter and a snow sculptor). None of the distractors had been described in the stories during the exposure phase. Reliability of the immediate and delayed semantic choice post-tests were .53 and .50. The correlation between the immediate and the delayed semantic choice post-tests was .65. As with the orthographic choice task, latent variables were used to analyse shared variance and covariance of indicators, reducing concerns re reliability (Kline, 2016).

Control Variables

We included four control variables measured at Grade 3: nonverbal ability, working memory, vocabulary, and phonological awareness. To measure nonverbal ability, we used the Matrix Reasoning subtest of the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999), in which participants chose the missing pieces to complete 32 pictures. To measure working memory, we used the Digit Span subtest of the fourth edition of the Wechsler Intelligence Scale for Children (Wechsler, 2003), in which participants repeated series of digits, half in the same order and half backwards. To measure vocabulary, we used the Peabody Picture Vocabulary Test (Dunn & Dunn, 1997), shortened to every fourth item (total of 51) to reduce testing time (for validation see Sparks & Deacon, 2015), in which participants chose the pictures that best depicted the meaning of orally presented words. To measure phonological awareness, we used the Elision subtest of the second edition of the Comprehensive Test of Phonological Processing

(Wagner et al., 2013), in which children repeat up to 34 words without specified syllables or phonemes.

Procedure

Participants were tested in their school. In each of Grades 3 to 5, they took part in two individual sessions and one group session, separated by a couple of days on average. In Grades 3 and 5, word reading was measured in the first individual session and reading comprehension was measured in the group session. Orthographic and semantic learning were measured following on the exposure phase in the first (immediate recall) and second (delayed retention) individual sessions at Grade 4. The control variables were measured in the first (i.e., non-verbal reasoning) and second (i.e., working memory, vocabulary, and phonological awareness) individual sessions at Grade 3.

Transparency and Openness

We report how we determined our sample size and we also report on other analyses with these data. Analysis code and the materials for the learning tasks are available at https://osf.io/px29f/?view_only=212e7b05c11d4f61b0fec6ede50130a6 . Due to copyright issues, we have not included the standardised measures. We have consent to share data at the group level, but not at the level of individual participants; our institutional ethics board has concerns about the personal nature of some measures, such as non-verbal ability and reading level. The design of the study and its analyses were not pre-registered.

Analytic Plan

We report on analyses here designed to test whether the ability to learn orthographic and semantic aspects of lexical representations each mediate individual differences in children's word reading and reading comprehension respectively. To tackle this question, we used Mplus

Version 8.1 (Muthén & Muthén, 1998–2017) to test two auto-regressive path analysis models, one focused on word reading development and the other on reading comprehension. For modeling, we used full-information maximum likelihood with robust parameter estimation, which helps to guard against bias stemming from nonnormality and nonindependence of observations (Finney & DiStefano, 2013) and is an appropriate method for handling missing data (Enders, 2012). We evaluated model fit based on the chi-square statistical test, comparative fit index (CFI), Tucker–Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean residual (SRMR). A nonsignificant chi-square signals a good model fit, although this statistical test is often biased to be significant with large sample sizes (Kline, 2016). CFI and TLI values greater than or equal to 0.95 and RMSEA and SRMR estimates less than 0.06 are indicative of good model fit (Browne & Cudeck, 1992; Hu & Bentler, 1999; Kline, 2016). We compared competing (nested) models using the Satorra–Bentler scaled chi-square difference test (Bryant & Satorra, 2012; Satorra & Bentler, 2010). Finally, we used bias-corrected bootstrapped 95% confidence intervals to evaluate the statistical significance of the direct and indirect effects as these are robust to potential deviations from multivariate normality (Hayes & Scharkow, 2013; Preacher & Hayes, 2008).

Results

Descriptive statistics for all measures are presented in Table 1. We used participants' raw scores across all measures for data analysis except for reading comprehension. For reading comprehension, we used the extended scaled score (2006 norms), which is the vertically scaled score that is recommended for longitudinal analyses across different levels of the Gates–MacGinitie. Correlations between measures are presented in Table 2.

Building the Autoregressive Models

In this study, we were interested in testing whether semantic learning and orthographic learning mediate individual differences in the development of children’s word reading and reading comprehensions skills over time. Two a priori autoregressive models were tested, one focusing on gains in word reading from Grade 3 to Grade 5, and the other focusing on gains in reading comprehension from Grade 3 to Grade 5 (see Figure 1). The two models were largely identical and tested using the same approach. Namely, for both models, age, nonverbal reasoning, working memory, vocabulary, and phonological awareness were included as exogenous control variables. One key difference is that word reading as an additional exogenous control in the reading comprehension model only; this is so that we can test effects specific to skill in understanding words (see e.g., Deacon & Kieffer, 2018; Kirby et al., 2012).

Lastly, in both auto-regressive models, latent variables of semantic learning and orthographic learning were included in the analysis at Grade 4; these were included to test our predictions as to whether semantic and orthographic learning mediate the development of children’s reading skills. The latent variables of semantic learning and orthographic learning were informed by the work of Mimeau et al. (2018). Namely, semantic learning consisted of two indicators: the immediate semantic choice post-test and the delayed semantic choice post-test, with factor loadings of .74 and .88, respectively. Orthographic learning consisted of three indicators: the spelling post-test, the immediate orthographic choice post-test, and the delayed orthographic choice post-test, with factor loadings of .95, .66., and .52, respectively. Based on inspection of the modification indices, measurement error associated with the immediate and delayed orthographic choice post-tests of the orthographic learning factor was allowed to covary. We deemed this change reasonable because some of the error covariance between these measures is likely to be attributable to the shared methodology across the two tasks (Asparouhov & Muthén, 2009).

To test our core research questions, we built two theoretically justified and nonredundant autoregressive models (see Figure 1). Given our modest sample size relative to the large number of paths in a conservative autoregressive framework, we began by building a parsimonious control model for each of word reading and reading comprehension models (Agresti & Finlay, 2009; Kline, 2016). This process consisted of initially including all control paths in the models. For the word reading model (top of Figure 1), word reading in Grade 3 and semantic and orthographic learning in Grade 4 were regressed on control variables consisting of age, nonverbal reasoning, working memory, vocabulary, and phonological awareness. The reading comprehension control model adds word reading as an additional control variable (see bottom of Figure 1). All exogenous variables were free to vary as were residual covariances between the mediators of semantic learning and orthographic learning. Note that for each model, the key paths of interests—those which allow tests of mediation via semantic learning and orthographic learning—are omitted at this stage of the analytical process.

Next, we removed individual controls paths associated with a *p* value greater than .30, evaluating whether model fit was negatively impacted after removing each path based on chi-square difference testing. This is considered a highly conservative approach because only the most negligible paths are removed for optimal model parsimony (Agresti & Finlay, 2009) while leaving the effects of both significant and nonsignificant paths (those where $p < .30$) in the model. Moreover, despite the pruning of some negligible paths, the models still account for all exogenous control variables and the influence of covariances between these. For each of the word reading and reading comprehension models, a chi-square difference test was used to compare the fit of the constrained control model (i.e., the model with nonsignificant paths [$p >$ .30] removed) to that of the full control model (i.e., all control paths left in). The results of the chi-square difference tests revealed that the fit of the constrained models were statistically equivalent to that of the full control model for both word reading ($\Delta\chi^2 = 1.41$, $\Delta df = 5$, $p = .92$) and reading comprehension ($\Delta\chi^2 = 4.29$, $\Delta df = 10$, $p = .93$). This suggest that our model building process was well-justified; that is, removal of the nonsignificant controls paths was important for obtaining better model parsimony because estimating such paths comes at a cost to overall model fit and degrees of freedom (Kline, 2016). This approach was important in this study in particular given our modest sample size and very stringent analytical design. The result of this process is shown in Figure 1. The solid lines reflect the control paths that remain in the parsimonious models for each of word reading (top of Figure 1) and reading comprehension (bottom of Figure 1) moving forward. The dash lines reflect those paths with *p* values greater than .30 that were removed from each model.

Word Reading Development

Taking the parsimonious control model for word reading, we then fit our data to the multiple-mediation path analysis model shown in Figure 2. This model tests whether gains in word reading skills over time are mediated by individual differences in children's orthographic and/or semantic learning. The word reading model in Figure 2 had good fit to the data, χ^2 (35) = 35.74, $p = .43$, CFI = .999, TLI = .998, RMSEA = .012, SRMR = .045. Standardized coefficients (β) for the key paths of interest are shown in Figure 2 (see Appendix C for a complete list of path coefficients associated with Figure 2). As expected, earlier word reading skills in Grade 3 were a very strong predictor of later word reading skills in Grade 5. In addition, word reading in Grade 3 had a significant large-sized effect on orthographic learning in Grade 4, which, in turn contributed significantly to word reading skills in Grade 5. Bias-corrected bootstrapped confidence intervals revealed that this indirect effect via orthographic learning was significant, $\beta = .13$, 95% CI [.06, .18]. In contrast, the indirect effect between earlier and later word reading via semantic learning was not significant, $\beta = -.004$, 95% CI [-.04, .01]. Taken together then, the relation between word reading skills in Grade 3 to Grade 5 was partially mediated by children's orthographic, but not semantic, learning in Grade 4 beyond controls for nonverbal reasoning, working memory, vocabulary, and phonological awareness. These results are consistent with our prediction that individual differences in children's orthographic learning mediates gains in their word reading skills across Grades 3 to 5.

Reading Comprehension Development

A second multiple-mediation path analysis model focused on reading comprehension development from Grade 3 to 5 (Figure 3). This model tested whether gains in reading comprehension skills over time are mediated by individual differences in children's orthographic and/or semantic learning. The reading comprehension model demonstrated a good fit to the data, χ^2 (44) = 37.50, $p = .74$, CFI = 1.00, TLI = 1.02, RMSEA = .00, SRMR = .05. Standardized coefficients (β) for the key paths of interest are shown in Figure 3 (see Appendix C for a complete list of path coefficients associated with Figure 3). As expected, earlier reading comprehension skills in Grade 3 was a strong predictor of later reading comprehension skills in Grade 5. In addition, reading comprehension in Grade 3 had a significant, medium-sized effect on semantic learning in Grade 4, which, in turn contributed significantly to reading comprehension in Grade 5. Bias-corrected bootstrapped confidence intervals revealed that the indirect effect via semantic learning was small yet significant, $\beta = .04$, 95% CI [.002, .103]. Interestingly, although orthographic learning in Grade 4 had a medium-sized effect on reading comprehension in Grade 5, the overall indirect effect from reading comprehension in Grade 3 to reading comprehension in Grade 5 via orthographic learning was not significant, $\beta = .03$, 95% CI [-.001, .072]. Taken together, the results revealed that the relation between reading comprehension in Grade 3 to Grade 5 was partially mediated by children's semantic, but not orthographic learning in Grade 4 beyond stringent controls for nonverbal reasoning, vocabulary, and word reading. These results are consistent with our prediction that individual differences in children's semantic learning mediates gains in their reading comprehension across Grades 3 to 5.

Discussion

Prominent theories of reading development have emphasised the centrality of lexical knowledge on the one hand (Perfetti & Hart, 2002) and of children's own ability to learn on the other (Share, 2008). We bring these two ideas together to test whether the ability to learn lexical representations is a mechanism in children's reading development. We test two specific hypotheses: that individual differences in children's ability to learn orthographic representations is a mechanism by which they gain skill in reading words and that individual differences in the ability to learn semantic representations is a mechanism in acquiring reading comprehension skill. To this end, we recruited a large group of children in Grade 3, measuring word reading and reading comprehension at this point and again at Grade 5; this allowed us to capture individual differences in gains in these reading skills. In Grade 4, we asked the children to read a set of short stories containing novel words; after this reading, we tested their memory for the spellings and meanings of these new words, capturing orthographic and semantic learning, respectively. We also assessed well-established control measures for both learning in general and reading in particular: nonverbal ability, working memory, vocabulary, and phonological awareness. Our analyses test mechanisms in reading development by modeling effects of individual differences in learning orthographic and semantic dimensions of new words as a mediator of gains in each of word reading and reading comprehension. In this statistically stringent, theory-driven approach we reveal two clear effects: individual differences in orthographic learning at Grade 4 mediate the gains that children make in word reading between Grades 3 and 5 and individual differences in semantic learning at Grade 4 mediate the gains children make in reading comprehension between Grades 3 and 5.

Findings of a role of orthographic and not semantic learning as a mediator in the gains in word reading between Grades 3 and 5 are a key extension to available data. Coefficients for orthographic learning were far larger and significant in mediating gains in word reading in comparison to those for semantic learning, increasing confidence in these effects. Several studies have confirmed elementary school aged children's ability to learn the spellings of new words through their independent reading (e.g., Cunningham, 2006; Share, 2004), and relations of orthographic learning to word reading at a single point in time (Deacon et al., 2019; Authors et al., 2018). To our knowledge, a single longitudinal study has demonstrated contributions of orthographic learning to word reading development over time (Deacon et al., 2019). Building on this, we show orthographic learning as a mediator of the gains that children make in word reading development over the course of two years, from Grades 3 to 5. Contrasting contributions of orthographic versus semantic learning with similar measures from the same learning context provides a strong test of the specificity of these effects. This finding provides empirical confirmation of Share's (2008) suggestions of individual differences in self-teaching orthographic forms as a mechanism driving children's word reading development.

The emergence of semantic and not orthographic learning as a mediator in the gains that children make in reading comprehension between Grades 3 and 5 extend available evidence.

Available studies have demonstrated a relation of semantic learning to reading comprehension beyond control variables at a single point in time (e.g., Cain, Oakhill, & Lemmon, 2004; Authors et al., 2018; Ricketts et al., 2011). Here we test the prediction that semantic learning is a mechanism in children's reading development far more tightly, modeling whether semantic versus orthographic learning mediates gains in reading comprehension. The total indirect path is the strongest test of these predictions; this was significant for semantic but not orthographic learning. Indeed, both individual paths were significant for semantic learning. Evidence of these relations points to learning the semantic aspects of lexical representations as a mechanism in the development of children's skill in reading comprehension. Isolating these effects from the control of vocabulary shows that these effects emerge beyond crystallised knowledge of word meaning; further, controlling for effects from word reading pinpoints that learning the meaning of words plays a role in children's comprehension of texts specifically.

In terms of theory, these findings establish individual differences in learning lexical representations as a mechanism—one that functions in a targeted manner—in children's reading development. Our findings suggest orthographic and semantic learning as mechanisms in word reading and reading comprehension development, respectively. Certainly, orthographic learning has been suggested for some time as a mechanism in word reading development (e.g., Share, 2008), and yet this prediction has had remarkably little longitudinal investigation to date (but see Deacon, Pasquarella et al., 2019). We confirm this prediction in modeling of gains in word reading over time. Further, and in line with the lexical quality hypothesis (Perfetti & Hart, 2002), semantic aspects of lexical representations matter too—specifically for reading comprehension. Classic predictions of the lexical quality hypothesis have emphasised the centrality of high-quality representations; extending these ideas, our work considers how these high-quality lexical representations are acquired in tandem with the outcome of this learning. We do so by showing that children's own skill in learning the meanings of words, or semantic learning, mediates the gains that they make in reading comprehension; reading comprehension is likely then the basis of skill in semantic learning and its outcome. These findings resonate with encouragement to consider reading as a truly developmental process, including what children learn from reading and what supports them in learning to read (see e.g., Conrad & Deacon, 2023; Nation et al., 2022). Together, these findings and their theoretical framing place children's skill in learning lexical representations as a powerful mechanism driving reading development.

Pushing the bounds of theory even further, we think that there might be cross-over connections that are worth exploring. This possibility is alluded to by a single significant path that was somewhat surprising. In the models of reading comprehension, effects were very clear and consistent for semantic learning; each individual relevant path was significant as was the overall indirect path in mediating gains in reading comprehension. Intriguingly, orthographic learning had a moderately sized significant effect on later reading comprehension, though there was a non-significant overall indirect path. Further, earlier levels of reading comprehension did not contribute significantly to orthographic learning, although beta weights were similar in size (.14) to those of another significant path (.17 for semantic learning to reading comprehension). The significant effect of orthographic learning on later reading comprehension is surprising, both in terms of theoretical predictions and its absence in prior modeling at either Grade 3 (Authors et al., 2018) or 3 to 4 (Authors et al., 2022). That said, it did emerge from Grade 4 to 5 in stringent modeling, suggesting that there might be a role of orthographic learning in determining later skill in reading comprehension in this grade range. Given the non-significant connections of earlier reading comprehension to later orthographic learning, these effects might have their beginnings in earlier levels of word reading, rather than reading comprehension. Unfortunately, we did not have the sample size to combine models of word reading with those of reading comprehension. We think that this is worth exploring, in part because it would help to connect models of word reading with those of reading comprehension.

We note that our findings emerged with English-speaking children in Grades 3 to 5, pointing to key next steps for research. In terms of age range, studies with children across Grades 1 to 3 show correlations between orthographic learning and word reading, and between semantic learning and reading comprehension (Deacon et al., 2019; Authors et al., 2018). And yet, the mechanistic effects of each of orthographic and semantic learning might in fact shift over development. For instance, classic theories predict increasing contributions of oral language factors—specifically crystallised ones—to reading comprehension (Gough & Tumner, 1986; for evidence see e.g., Kendeou et al., 2009) suggesting similar increases in the contributions of semantic learning skill. Such speculations need testing with children as they transition from learning to read to reading to learn (Chall, 1983). Such studies might leverage available measures with younger children (Deacon, Mimeau et al., 2019). Future research might also revisit findings contrasting orthographic learning with regular and irregular words; at the item-level, Wang et al. (2013) found effects of vocabulary on orthographic learning were specific to irregular words, suggesting a stronger semantic basis here. Our data are also from typically developing English-speaking children; there might be variability across languages and reading levels. For instance, semantic learning might operate as a mechanism in word reading development in children with reading difficulties (Deacon, Tong et al., 2019) and/or in languages with a stronger role for semantic factors in written word representations, such as Chinese (see e.g., Tong et al., 2017; see also Li et al., 2020; 2022).

Other research could address some aspects of measures within the study that we report on here. One comes from low reliabilities for individual measures of orthographic and semantic learning. This was addressed in the present study be reporting on analyses with latent variables combining individual measures of orthographic and semantic learning. That said, reliability of individual measures could be improved. Doing so will be challenging. The simplest way to improve reliability lies in increasing the number of items; and yet, in a study of learning this can make the task not feasible for children. This would be even more problematic in the studies of younger children that we suggest. For this reason, it is likely that latent variable modeling will continue to be necessary in future studies. Such studies might also increase sample size; ours was relatively small in comparison to an often-cited rule of thumb of 200 for structural equation modeling (Kline, 2016), though it was adequately powered to test effects within the models here. Another methodological shift could come from tracking shifts in learning as it happens; this could be done through recording either eye-movements and/or handwriting (e.g., Côté, et al., 2023; Ginestet et al., 2021). Individual differences in these adaptations could capture reader-relevant individual differences.

In conclusion, our longitudinal research with English-speaking children across Grades 3 to 5 demonstrates the mechanistic effects of children's skill in two key aspects of their reading development. These findings push the boundaries of key theories of reading development. We show that skill in learning, or self-teaching, is indeed a mechanism that enables their reading development. Within this mechanism, there appear to be relatively targeted effects. Children's skill in learning orthographic forms mediates the gains that they make in word reading and their skill in learning semantic forms mediates the gains they make in reading comprehension. These findings show the power and the specificity of children’s skill in learning lexical representations in determining their progress in learning to read.

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Table 1

Descriptive statistics for all measures

Measures (maximum raw score)	*M*	*SD*	Skewness
Grade 3 measures			
Word reading – Sight Word Efficiency (104)	56.64	14.79	-.83
standardized score[a]	102.82	15.14	-.32
Reading comprehension – Gates-MacGinitie (48)	26.15	11.27	.06
extended scale score	457.64	41.72	.32
normal curve equivalent[b]	41.69	21.79	.26
Nonverbal reasoning – Matrix Reasoning (32)	15.40	6.28	.02
Working memory – Digit Span (32)	13.11	2.42	.00
Vocabulary – PPVT-3 revised (51)	31.87	4.98	-.12
Phonological awareness – Elision (34)	22.95	6.10	-.29
Grade 4 measures			
Semantic learning – Immediate semantic choice (12)	9.68	1.83	-.89
Semantic learning – Delayed semantic choice (12)	9.87	1.70	-.67
Orthographic learning – Spelling (12)	7.89	2.89	-.66
Orthographic learning – Immediate orthographic choice (12)	9.50	1.88	-.58
Orthographic learning – Delayed orthographic choice (12)	8.59	1.89	-.30
Grade 5 measures			
Word reading – Sight Word Efficiency (104)	69.02	11.20	-.58
standardized score[a]	100.78	11.82	.03
Reading comprehension – Gates-MacGinitie (48)	26.90	9.66	-.02
extended scale score	502.07	34.94	.33
normal curve equivalent[b]	46.53	19.06	.21

Note. Raw scores unless otherwise noted. *M* = Mean. *SD* = Standard deviation. [a]Age-based standard score with a mean of 100 (*SD* = 15). [b] Normal curve equivalent has a manual mean of 50 (*SD* =21).

Table 2

Correlations between all measures

Measures	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Gr3 word reading	–													
2. Gr3 reading comprehension	.68*	–												
3. Gr3 Age	.05	.12	–											
4. Gr3 nonverbal reasoning	.19*	.16*	.09	–										
5. Gr3 working memory	.45*	.32*	.08	.31*	–									
6. Gr3 vocabulary	.33*	.42*	.24*	.16	.11	–								
7. Gr3 phonological awareness	.56*	.44*	.06	.30*	.36*	.34*	–							
8. Gr4 SL immediate semantic choice	.19*	.29*	.11	.21*	.14	.28*	.10	–						
9. Gr4 SL delayed semantic choice	.21*	.27*	-.04	.15	.18	.29*	.18	.65*	–					
10. Gr4 OL spelling	.71*	.58*	.16	.21*	.42*	.33*	.58*	.21*	.21*	–				
11. Gr4 OL immediate orthographic choice	.41*	.37*	.02	.07	.30*	.19*	.34*	.17	.06	.63*	–			
12. Gr4 OL delayed orthographic choice	.37*	.30*	-.10	-.03	.22*	.07	.34*	.10	.07	.48*	.58*	–		
13. Gr5 word reading	.89*	.66*	.08	.19*	.39*	.38*	.56*	.13	.20*	.74*	.40*	.33*	–	
14. Gr5 reading comprehension	.59*	.69*	.01	.23*	.32*	.47*	.40*	.34*	.32*	.58*	.41*	.30*	.62*	–

Note. *significant correlation, $p < .05$. Gr3 = Grade 3. Gr4 = Grade 4. Gr5 = Grade 5. SL = Semantic Learning. OL = Orthographic Learning.

Figure 1.

Building a parsimonious control model for word reading (top) and reading comprehension (bottom). Dash lines reflect nonsignificant paths with p > .30, which were removed in subsequent modelling

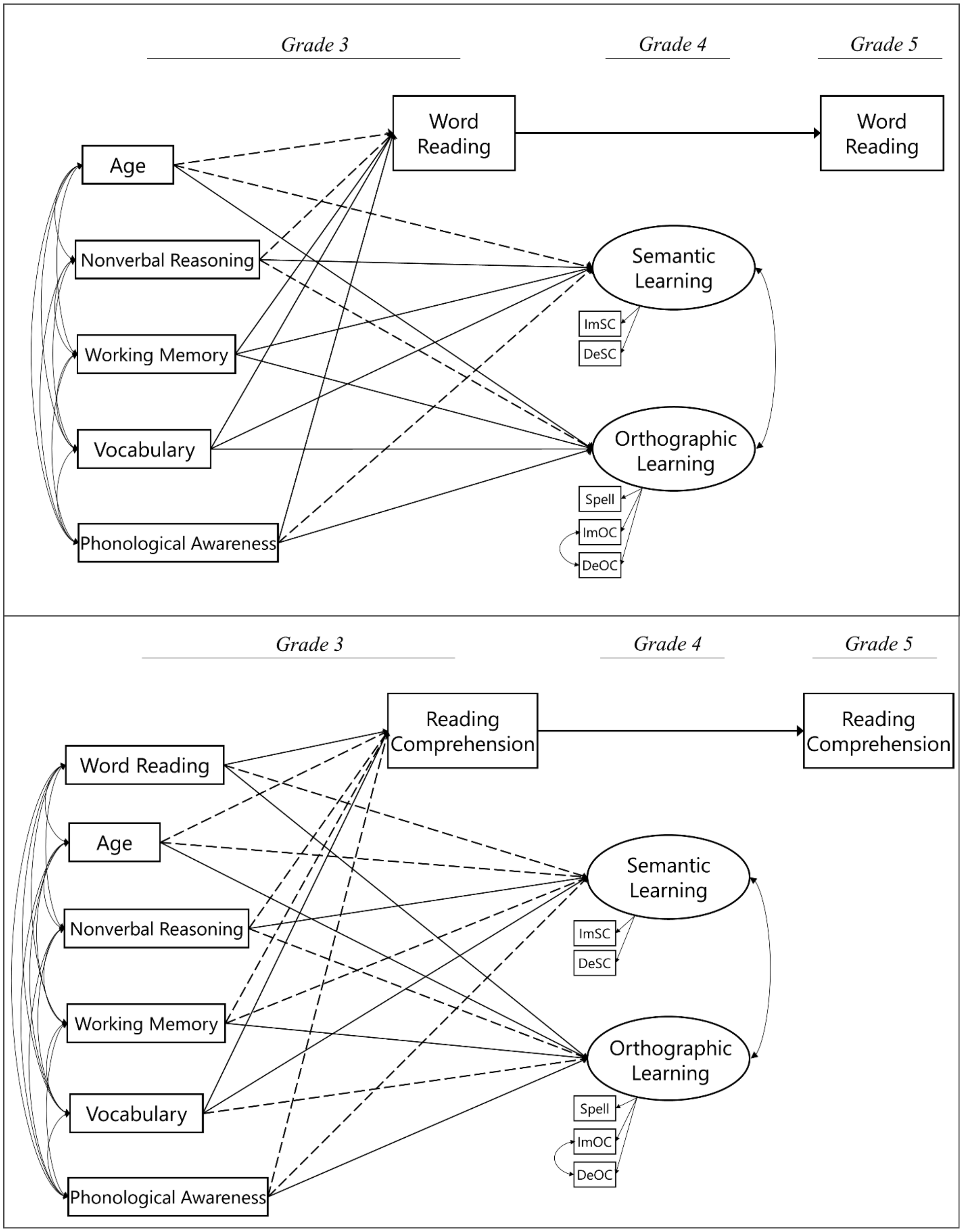


Figure 2.

*Final word reading model. Standardized coefficients for key paths of interest are include (*significant path. Dash lines reflect nonsignificant path). NVR = nonverbal reasoning. WM = working memory. Voc = vocabulary. PA = phonological awareness. Some model details are omitted (e.g., error covariances) for ease of viewing. See Appendix C for a complete list of path coefficients associated with Figure 2.*

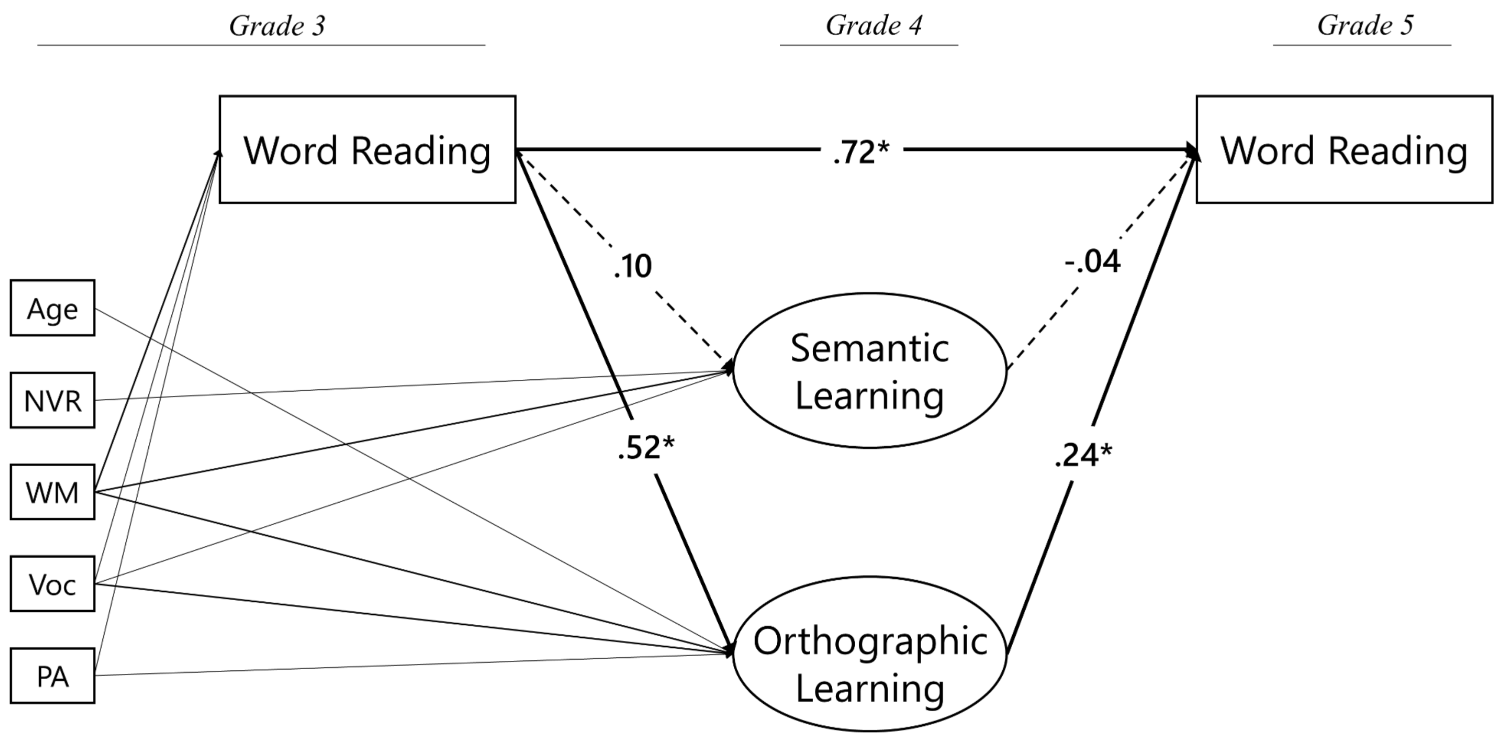
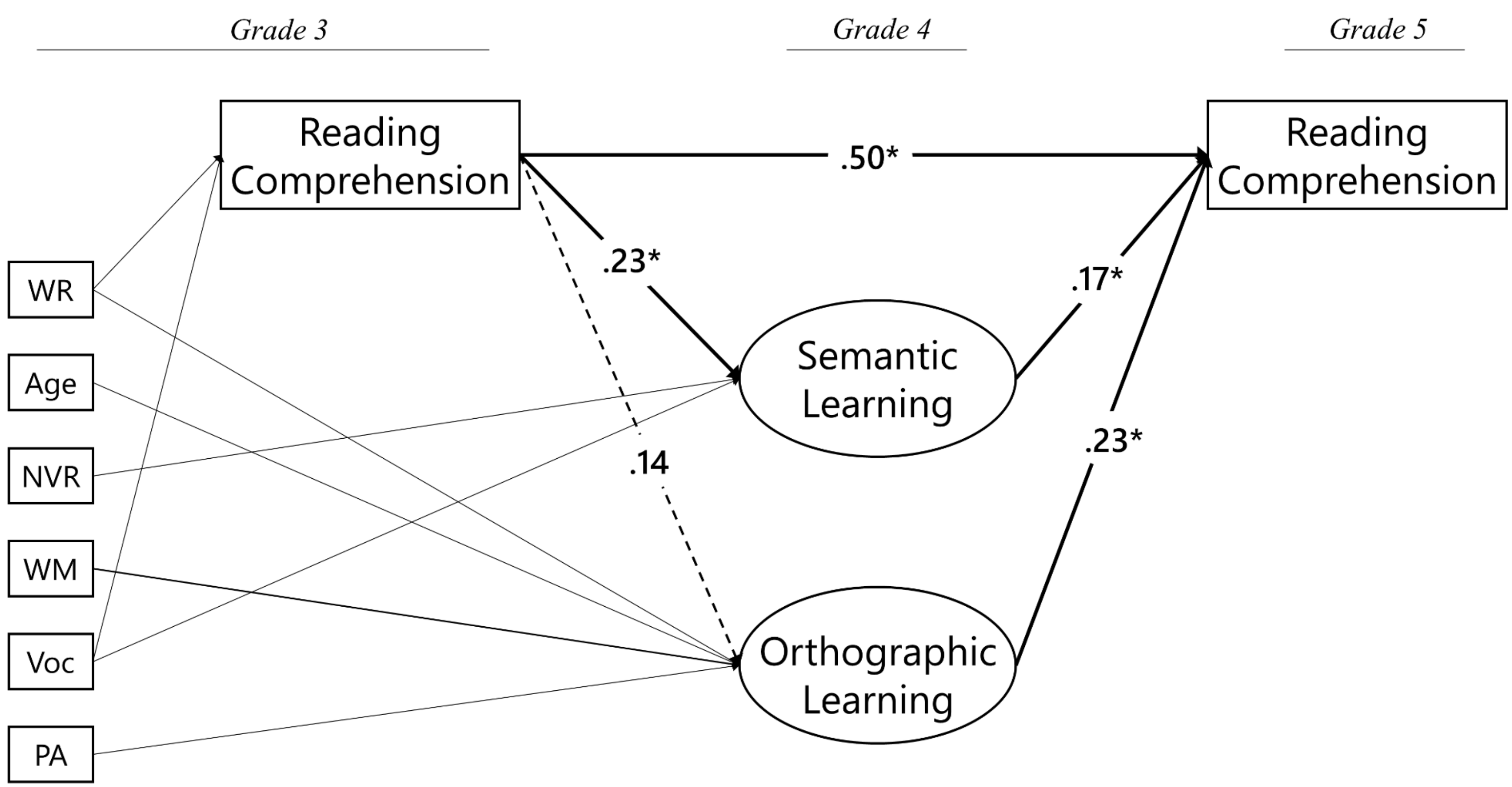


Figure 3.

*Final reading comprehension model. Standardized coefficients for key paths of interest are include (*significant path. Dash lines reflect nonsignificant path). WR = word reading. NVR = nonverbal reasoning. WM = working memory. Voc = vocabulary. PA = phonological awareness. Some model details are omitted (e.g., error covariances) for ease of viewing. See Appendix C for a complete list of path coefficients associated with Figure 3.*



Appendix A

Example of Story Presented in the Exposure Phase of the Learning Task

Ricky was doing his laundry, so his socks were all separated. Ricky started the feep. The feep is used to sort socks. Ricky put his socks into the feep. When his socks were matched, Ricky stopped the feep.

Appendix B

Non-Words Used in the Learning Task

Target sound	Version A		Version B		Frequencies	
/i/	feep	weaf	feap	weef	ee: 249	ea: 245
/ɜ/	burl	lerg	berl	lurg	ur: 234	er: 1,979
/eɪ/	paib	vafe	pabe	vaif	ai: 208	a-e: 790
/ju/	mewd	zule	mude	zewl	ew: 60	u-e: 290
/oʊ/	joap	noke	jope	noak	oa: 126	o-e: 370
/k/	clet	krid	klet	crid	c: 3,452	k: 601

Note. Half of participants were given Version A and the other half were given Version B. Frequencies come from a 17,310-word corpus and are reported in Fry's (2004) study.

Appendix C

Standardized Coefficients (and *SE*) for the Final Word Reading and Reading Comprehension Models

	β	*SE*
Word Reading Model (Figure 2)		
Gr3 word reading → Gr5 word reading	.72*	.05
Gr3 word reading → Gr4 semantic learning	.10	.12
Gr3 word reading → Gr4 orthographic learning	.52*	.07
Gr4 semantic learning → Gr5 word reading	-.04	.05
Gr4 orthographic learning → Gr5 word reading	.24*	.06
Gr3 age → Gr3 word reading	n/a	
Gr3 age → Gr4 semantic learning	n/a	
Gr3 age → Gr4 orthographic learning	.10	.06
Gr3 nonverbal reasoning → Gr3 word reading	n/a	
Gr3 nonverbal reasoning → Gr4 semantic learning	.14	.10
Gr3 nonverbal reasoning → Gr4 orthographic learning	n/a	
Gr3 working memory → Gr3 word reading	.29*	.07
Gr3 working memory → Gr4 semantic learning	.09	.12
Gr3 working memory → Gr4 orthographic learning	.10	.07
Gr3 vocabulary → Gr3 word reading	.17*	.07
Gr3 vocabulary → Gr4 semantic learning	.29*	.10
Gr3 vocabulary → Gr4 orthographic learning	.05	.07
Gr3 phonological awareness → Gr3 word reading	.40*	.07
Gr3 phonological awareness → Gr4 semantic learning	n/a	
Gr3 phonological awareness → Gr4 orthographic learning	.23*	.07
Reading Comprehension Model (Figure 3)		
Gr3 reading comprehension → Gr5 reading comprehension	.50*	.07
Gr3 reading comprehension → Gr4 semantic learning	.23*	.10
Gr3 reading comprehension → Gr4 orthographic learning	.14	.08
Gr4 semantic learning → Gr5 reading comprehension	.17*	.08
Gr4 orthographic learning → Gr5 reading comprehension	.23*	.07
Gr3 word reading → Gr3 reading comprehension	.61*	.06
Gr3 word reading → Gr4 semantic learning	n/a	
Gr3 word reading → Gr4 orthographic learning	.44*	.09
Gr3 age → Gr3 reading comprehension	n/a	
Gr3 age → Gr4 semantic learning	n/a	
Gr3 age → Gr4 orthographic learning	.10	.05
Gr3 nonverbal reasoning → Gr3 reading comprehension	n/a	
Gr3 nonverbal reasoning → Gr4 semantic learning	.16	.11
Gr3 nonverbal reasoning → Gr4 orthographic learning	n/a	
Gr3 working memory → Gr3 reading comprehension	n/a	
Gr3 working memory → Gr4 semantic learning	n/a	
Gr3 working memory → Gr4 orthographic learning	.08	.07
Gr3 vocabulary → Gr3 reading comprehension	.22*	.06
Gr3 vocabulary → Gr4 semantic learning	.23*	.10
Gr3 vocabulary → Gr4 orthographic learning	n/a	
Gr3 phonological awareness → Gr3 reading comprehension	n/a	
Gr3 phonological awareness → Gr4 semantic learning	n/a	
Gr3 phonological awareness → Gr4 orthographic learning	.23*	.07

Note. *significant, $p < .05$. β = standardized coefficient. *SE* = standard error. n/a = path not included in final model.