Title

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Orthographic Learning Through Self-Teaching: Effects of Decoding Accuracy, Decoding Speed, Word Length, Morphology, and Individual Differences

by

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Abstract

Orthographic Learning Through Self-Teaching: Effects of Decoding Accuracy, Decoding Speed, Word Length, Morphology, and Individual Differences

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The self-teaching hypothesis (Share, 1995) posits that readers learn the orthography of new words incidentally through the process of phonological recoding. In the current study, the self-teaching hypothesis was tested by simulating everyday reading through the use of real and pseudowords, analyzing the effects of syllable length, and considering the independent contributions of general cognitive ability, including rapid naming ability and prior orthographic knowledge. A total of 94 second grade children were presented with 24 pseudoword targets over a 7-week period, each embedded 4 times within a short passage to be read aloud and independently. The targets varied by length (containing 1, 2, or 3 syllables) and by morphological legality (with real affixes or fabricated affixes). Findings indicated that the length of a word and its morphological legality significantly influenced decoding speed and accuracy. Shorter words were read faster and more accurately than longer words, although the difference in accuracy between 2- and 3-syllable words was only seen in the morphologically illegal condition. In all cases, morphologically legal words were read faster and more accurately than their morphologically illegal counterparts. A week after encountering a new pseudoword, the children were assessed for orthographic learning using two measures—an orthographic choice task and a naming task. Children demonstrated robust orthographic learning on the orthographic choice posttest for all words, regardless of word length or morphological legality, and for 2- and 3-syllable words on the naming posttest. There were no word length effects on posttest performance, however morphologically legal words resulted in more orthographic learning on the orthographic choice task than their illegal counterparts. In order to examine mediating factors that may contribute to children's orthographic learning, measures of vocabulary, prior orthographic knowledge rapid automatized naming, morphological awareness, and print exposure were administered. Children were also given tests to measure individual levels of vocabulary, prior orthographic knowledge, rapid automatized naming, morphological awareness, and print exposure. These factors, along with decoding speed, decoding accuracy, morphological legality, and word length were then analyzed for the contributions to orthographic learning using hierarchical linear and logistic regression models. Consistent with prior research, decoding accuracy and prior orthographic knowledge were the most powerful independent predictors of orthographic learning. The trajectories of decoding speed and accuracy across 4 exposures to a new word were also examined. It was observed that decoding duration time drops off dramatically after the first encounter and, intriguingly, that children tend to stay with their first pronunciation of a word, accurate or inaccurate.

Introduction

Reading with understanding is a complex cognitive task that requires multiple levels of skill. Before gaining passage to the layers of text, a reader must first translate the written symbols of words into the appropriate sounds of oral language. Skilled word reading summons broader language skills into action, facilitating access to meaning that extends even beyond the printed words. While the ability to read words does not ensure comprehension, it is surely a main portal.

Words can be read in a number of ways—by assembling letters into a blend of sounds (i.e., phonological recoding, also referred to as decoding), pronouncing and blending familiar spelling patterns, retrieving full word pronunciations automatically from memory, analogizing to words already known by sight, and using context clues to predict words (Ehri, 1991, 1994). Although the experienced reader makes use of each of these techniques, they are not equal when it comes to the most efficient path to comprehension.

The ability to recognize words automatically and reliably is a fundamental determinant of reading proficiency (Cunningham & Stanovich, 1997; Juel, 1988) and a necessary requisite for the higher order processes involved in comprehension (see review in Pearson, Dole, Duffy, & Roehler, 1992; Stanovich, 2000). While various theoretical and developmental models of reading may differ in content, architecture, and contention, they all acknowledge the importance of automaticity in word recognition—from dual-route theories (e.g., Baron & Strawson, 1976; Coltheart, 1985, 2005) and connectionist neural-network theories (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg, 2005; Seidenberg & McClelland, 1989; Seidenberg, Plaut, Petersen, McClelland, & McRae, 1994) to the most common developmental stage and phase models (e.g., Ehri, 1980, 1992a, 1992b, 1995, 2005; Frith, 1985; Marsh, Friedman, Welch, & Desberg, 1981). Underlying this consensus is the assumption that our capacity for attention is limited (Laberge & Samuels, 1974; Miller, 1956), and in order to conserve sufficient cognitive resources for the higher level processes needed to construct meaning from print, readers are at an advantage if they are able to recognize words accurately, instantly, and effortlessly (Perfetti, 1985, 1992). For this reason, automatic word recognition is considered to be a hallmark of skilled reading.

How do readers build a vast bank of words that are recognized quickly, accurately, and automatically? The ability presupposes a store of high-quality mental representations spontaneously retrieved upon sight of their printed form (Adams, 1990; Ehri, 1980; Perfetti, 1992; Venezky & Massaro, 1979). Cognitive psychologists liken the process to accessing a dictionary, and often refer to it as a *mental lexicon*. Because various types of information are stored, it is no doubt more accurate to consider the existence of multiple mental lexicons organized like a reference library—a phonological volume that stores the pronunciation of words or word parts, a semantic volume that stores meaning, a grammatical volume that holds syntactic information, and an orthographic volume representing knowledge about the visual forms (Dehaene, 2009). When the reference library is working at optimal efficiency, the volumes work in a highly integrated and parallel manner to identify the orthography and phonology of a word automatically, and to support the identification by confirming a good semantic and syntactical fit (Ehri, 1998; Perfetti, 1985).

With general agreement that orthographic representations are the foundation for automatic word recognition, the question of how these representations are formed persists. What mechanism facilitates accurate phonological matches to the unfamiliar letter strings encountered in reading? Asked another way, what mechanism offers the most viable method for learning to read unfamiliar printed words and creating stable and reliable mental representations needed for automaticity? Potential candidates include (a) direct teaching of new words through rote association, (b) using context clues to predict what a new word might be, and (c) using known sound-symbol correspondences to decode the word.

Support for direct teaching of new words goes back over 100 years, when Cattell (1886) suggested that skilled readers appeared to process words as wholes, rather than letter by letter. Later experiments using improved research design and technology debunked this idea (Reicher, 1969; Wheeler, 1970), finding instead that readers processed all of the letters in a word, not just the global impression of the word based on some of the letters. Yet still, for many years, basal readers used direct teaching of whole words (see Chall, 1987). While students may have been able to memorize whole-word associations of orthography and phonology to varying degrees, the vast number of unfamiliar words readers encounter when reading precludes rote association for all of them. There are simply too many new words encountered in printed text (Carroll, Davies, & Richman, 1971) for direct instruction to be feasible. Nagy and Anderson (1984) estimated that English print for school-aged children contains at least 88,500 word families. Nagy and Herman (1987) estimated that in fifth grade alone, children encounter about 10,000 new words. This onslaught of new words, aptly characterized by Share (1995) as an "orthographic avalanche," rules out direct teaching of all new words as a viable approach. Additionally, it is unlikely that teaching rote associations at the whole-word level would result in attention to the detailed orthographic structure of words (e.g., the identity and order of the letters) necessary for creating accurate mental representations.

Contextual guessing is another process used in some circumstances to read new words. The idea, rooted in 1970s reading theory, assumed that the process of identifying new words was a hypothesis testing activity (Levin & Kaplan, 1970) or a psycholinguistic guessing game (Goodman, 1970). Later research undermined this view, demonstrating that skilled readers are far less apt to use context than unskilled readers (Ashby, Rayner, & Clifton, 2005; Perfetti, Goldman, & Hogaboam, 1979; Stanovich, 1980), and much more likely to, instead, use phonological information to read new words (Perfetti and Zhang, 1995; Van Orden, 1987; Van Orden, Johnston, & Hale, 1988). The ineffectiveness of guessing the identity of individual words using context was exposed in Finn's analysis (1977-1978) of Bormuth's data (1966) that examined the average predictability of over 5000 words in a cloze test given to 675 children in grades four through eight. Results found that only 29.5 percent of the words were correctly predicted. In a later study, Gough (1983) found that while function words were correctly predicted 40 percent of the time, content words carrying the most critical aspects of meaning were correctly predicted only 10 percent of the time. This makes sense, given the fact that writers rarely state the obvious, the inferable, or the redundant (Grice, 1975; Haviland & Clark, 1974). This is not to say that context plays no role at all in word reading. Contextual information likely plays a supplemental, supporting, or confirming role when reading unfamiliar words. However, as a primary method of reading new words, it is unreliable. Even if a reader predicts a synonym that maintains the integrity of text meaning (e.g., *house* instead of *home*), the possibility of creating accurate orthographic representations for the mental lexicon used in automatic word recognition is lost.

Because direct teaching of all new words is unachievable and contextual guessing is unreliable, skilled readers must have another way to independently decipher the large numbers of new words encountered. One proposition, the *self-teaching hypothesis* (Jorm & Share, 1983; Share, 1995; 2008), has garnered considerable support in recent years and is the main focus of this paper. The self-teaching hypothesis posits that readers of all levels add new words to their orthographic lexicon in a two-step process. First, the process of decoding—translating letter strings into sounds—acts as a self-teacher, allowing the reader to decipher an unfamiliar printed word independently and without explicit teaching. Second, correct decoding of the word provides an opportunity for the reader to establish an association between its written and spoken form, yielding the word-specific orthographic knowledge upon which the mental lexicon is built. The fundamental claims made by the hypothesis are twofold:

- Orthographic knowledge, a system of associations between phonology and orthography (Ehri, 1998; Perfetti, 1992; Share, 1995) can be acquired independently, without direct teaching.
- Decoding, the online process of accurately recoding novel letter strings in sounds, is the mechanism (i.e., the self-teacher) by which orthographic knowledge is acquired.

New words are added to the reader's orthographic lexicon through a number of successful decodings that call attention to the details of the word's orthographic structure and result in well-specified orthographic representations (Share, 1999, 2004, 2008). Decoding becomes progressively more accurate and complete with increased reading experience and the reader's understanding of the relationships between phonology and orthography becomes more sophisticated (Perfetti, 1985, 1992, 2007; Share, 1995). Contextual information aids in resolving ambiguities so that only plausible candidates for the new word are considered. According to the hypothesis, readers of all levels, from novice to expert, employ this self-teaching mechanism when they encounter unfamiliar words (Share, 1995).

Empirical Evidence for the Self-Teaching Hypothesis

The claim that orthographic knowledge is acquired independently is supported by a number of studies (Cunningham, 2006; Cunningham, Perry, Stanovich, & Share, 2002; de Jong & Share, 2007; Kyte & Johnson, 2006; Landi, Perfetti, Bolger, Dunlap, & Foorman, 2006; Nation, Angell, & Castles, 2007; Share, 1999, 2004; see also Share, 2008, for a review). Most of these studies asked children to read aloud short stories embedded with a novel word (usually a pseudoword), and then tested the children on how well they learned the orthography of the word they had been exposed to. The novel words were created in homophonic pairs (e.g. *yate* and *yait*); only one spelling was embedded in each story. Because homophones by nature have the same spoken form, posttest differences in children's ability to recognize, name, or spell the form they had been exposed to versus the form they had not previously seen could be solely attributed to orthographic learning. After from two to eight exposures to a target spelling (depending on the study), children recognized their target spellings more often, spelled them more accurately, and in some studies (e.g., de Jong, & Share, 2007; Share, 2004), named their targets faster than their alternative homophonic spelling. Cunningham (2006) refined the knowledge base on self-teaching and orthographic learning by simulating authentic reading experiences through the use of real words and by investigating the role of context, finding evidence of self-teaching across both the context and no-context conditions.

The claim that phonological recoding or decoding plays the critical role in the acquisition of orthographic knowledge is also supported by numerous studies. Cunningham (2006) and colleagues (2002), and Nation et al. (2007) found a moderate relationship between decoding accuracy and orthographic learning. Two other studies (Kyte & Johnson, 2006; Share, 1999) provided strong evidence for the critical role of phonological recoding in orthographic learning. In both, the standard technique of concurrent articulation (e.g., Baddeley, 1986; Baddeley & Hitch, 1974) was used to experimentally reduce a reader's opportunity to phonologically recode by suppressing the ability to verbally rehearse and generate pronunciations. Results showed a reduction in the reader's ability to recognize their target spelling, although the expected decrease in naming speed of target spellings was not found. A study by de Jong, Bitter, van Setten, and Marinus (2009) resulted in similar findings. Target spellings were recognized less often with concurrent articulation; however, naming speed differences were not found.

While most research on the self-teaching hypothesis has used an oral reading paradigm, a few studies have investigated orthographic learning in reading's most common form—silent reading. Bowey and Muller (2005) found that orthographic learning occurred in silent reading; however, their results did not provide empirical evidence that learning was due to phonological recoding—a primary claim of the self-teaching hypothesis. Because it is difficult to see direct evidence of phonological recoding during silent reading, de Jong et al. (2009) devised an elegant study that provided empirical evidence that phonological recoding was, in fact, being used during silent reading. They compared orthographic learning in second-grade readers of Dutch during both silent and oral reading by timing the children as they named target pseudowords (words they had seen), homophonic alternatives, and non-homophonic control pseudowords never seen before. Children in both reading conditions named their target spellings faster than their homophonic spellings, indicating that self-teaching had occurred. The fact that they named the homophonic spellings faster than the non-homophonic control pseudowords was considered evidence that a phonological representation had been generated, something that could have only happened through phonological recoding of their target.

Understanding the variables influencing how readers proceed from novice to expert is vital for researchers, policymakers, and especially teachers. One of the most crucial developments along the way is learning to read fluently. To understand fluency, we must continue to explore the processes that allow readers to decipher new words and create the high quality mental representations that facilitate accurate and automatic word reading.

The Present Study

Overview

The primary goal of the present study was to provide a direct test of the self-teaching hypothesis and to broaden the knowledge base of orthographic learning by investigating the influence of decoding accuracy, decoding speed, word length, and morphology. In addition, we examined the decoding accuracy and speed trajectory that second grade readers follow when encountering a novel letter string for the first, second, third, and fourth time. Finally, to deepen scientific understanding of how within-child variables might contribute to orthographic learning, the effects of prior orthographic knowledge, verbal ability, morphological awareness, rapid automatized naming, and print exposure were also investigated.

A Direct Test of the Self-Teaching Hypothesis

Share (1995) presented the decoding process as the *sine qua non* of reading acquisition. While he acknowledged the secondary role of orthographic processes in fluent word recognition, he considered the translation of a printed letter string into its spoken form to be the primary mechanism by which a reader's orthographic lexicon is built. The process of decoding plays the role of a self-teacher, providing the reader with an opportunity to take note of and remember the identity and order of letters that make up words, and establish an association between its written and spoken form. Share (1999) provided compelling evidence to support his hypothesis in a study with readers of pointed Hebrew—a highly regular script. Since then, researchers have found similar evidence with readers of English and Dutch orthographies (Cunningham, 2006; Cunningham, Perry, Stanovich, & Share, 2002; de Jong & Share, 2007; Kyte & Johnson, 2006; Landi, Perfetti, Bolger, Dunlap, & Foorman, 2007; Nation, Angell, & Castles, 2007).

In this study, evidence of self-teaching was expected to be found through posttest assessments of orthographic learning. Orthographic learning was presumed to have occurred if children were able to identify the correct spelling of target words they had been exposed to with greater frequency than would be expected by chance, and if they were able to name their targets significantly faster than the alternative foils.

Influence of Decoding Accuracy and Speed on Orthographic Learning

As discussed, accurate decoding of unfamiliar letter strings is considered the essential and indispensable means by which orthographic representations are formed (Jorm & Share, 1983; Share, 1995, 2008). In this study, evidence that the process of decoding unfamiliar letter strings served as the self-teacher could be inferred if decoding accuracy of targets was significantly correlated with orthographic learning. In addition, because recent investigations of the self-teaching hypothesis with beginning readers of Hebrew (Share, 2004, Experiments 2 & 3; Share & Shalev, 2004) found weak and statistically unreliable evidence of orthographic learning despite high levels of decoding accuracy, another variable—decoding speed—was considered for its contribution to orthographic learning. The possibility of decoding speed, rather than decoding accuracy, as the "critical bottleneck" in orthographic learning in highly regular orthographies (Share, 2010) is consistent with other research evidence that found fluency to be a more salient factor in reading disability than accuracy (Breznitz, 1997; Lamm & Epstein, 1994; Wimmer, 1996; Zeigler, Perry, Ladner, Ma-Wyatt, & Schulte-Korne, 2003). A small number of recent studies have continued to explore the role of decoding speed in self-teaching in readers of both Hebrew and English. A student of Share's conducted an unpublished study (Lurie, 2004) that found a robust association between decoding speed and orthographic learning in readers of Hebrew ($r = .52$, $p < .05$), yet Share (2010) found only weak and inconsistent evidence to support the link. Bowey and Muller (2005) and MacEachron (2009) found that a combination of decoding speed and accuracy accounted for a substantial amount of variance in orthographic learning (17.8% and 12%, respectively) in readers of English, a much less regular orthography. In this study, the duration of time it took readers of English to decode target words was measured and then analyzed for its influence on subsequent orthographic learning.

Trajectory of Decoding Accuracy and Speed Over Four Exposures

Past studies using the self-teaching paradigm have investigated the necessary number of exposures to a novel letter for a high-quality orthographic representation to be generated (Ehri & Saltmarsh, 1995; Hogaboam & Perfetti, 1978; Reitsma, 1983a; 1983b, 1989; Share, 1994, 1999); findings have ranged from one to four exposures. The present study aimed to extend the knowledge base by mapping the path a second grade reader takes over four exposures to a novel word with respect to decoding accuracy and speed. Is a reader's accuracy and speed trajectory even and gradual over the four encounters, punctuated by dramatic changes at certain points, or does it remain flat?

Effect of Word Length

Share (2010) explored the relationship of word length to orthographic learning in Hebrew readers at three time intervals—the end of first grade, the beginning of second grade, and the end of second grade. Using 1- and 3-syllable words, he found no convincing evidence of differential orthographic learning for long versus short words, despite finding significant decoding accuracy and speed advantages for shorter words. MacEachron (2009) examined the relationship of word length (1- and 2-syllable words) to orthographic learning in end-of-first-grade readers of English with similar findings. Shorter words were decoded more quickly and accurately, but this did not translate into greater orthographic learning as might be expected. These data suggest that while speed and/or accuracy influence orthographic learning, they do not represent the entire story. The present study continued the investigation of the word length/orthographic learning relationship by examining readers of English at the end of second grade reading 1-, 2-, and 3-syllable targets.

Effect of Morphology

Even though written language represents spoken language, it is not an exact translation of each and every phoneme. Morphology, or the compounding of meaningful units into words, is a feature of language that interacts with its phonology and orthography in ways that influence the organization of mental representations (Baayen, 2007; Bybee, 1985; Derwing, 1992). Multisyllabic words commonly contain morphological patterns that may be recognizable to readers as whole units. For instance, because second graders are commonly exposed to prefixes such as *dis-* and *re-*, and suffixes such as *-ing* and *-ed*, it is likely that they have generated orthographic representations for these letter strings that are easily retrievable when encountered in different words. If so, their ability to pronounce these morphemes as units quickly and effortlessly, rather than having to resort to slow and effortful grapheme by grapheme translation, is likely to influence speed and accuracy and, consequently, orthographic learning of words that contain those morphemes. MacEachron (2009) examined the effect of morphemes and found greater orthographic learning when readers of English were presented with targets containing familiar morphemes rather than made-up morphemes, greater decoding accuracy, but no significant difference in decoding speed. Share (2010) found that by the end of second grade, morphological components in targets conferred a strong accuracy and speed advantage for readers of Hebrew, but only weak and inconsistent benefits in terms of orthographic learning. Share hypothesized that the advantages of faster decoding may be offset by an advantage of slower and more conscious decoding, namely greater attention to the orthographic details necessary for creating orthographic representations. The present study examined the role of morphemes in speed and accuracy of decoding and in orthographic learning. By presenting second graders with 2- and 3-syllable targets that contained real affixes, such as *re-* and *-ing*, and targets that contained made-up affixes, such as *ro-* and *-ong*, comparisons were made in their accuracy and speed of decoding as well as the resulting levels of orthographic learning.

Effect of Within-Child Variables

The visual analysis of printed words is likely to be mediated by a number of individual skills. There is abundant evidence for the influence of the phonological system (e.g., Gough & Tumner, 1986; Liberman & Shankweiler, 1979; Share, 1995). The importance of its various components (e.g., phonological awareness, rapid automatized naming, phonological memory) as determinants of reading proficiency has been well substantiated by intervention and correlational studies (e.g., Bradley & Bryant, 1983; Iversen & Tumner, 1993; Torgesen, Wagner, & Raschotte, 1999; Vellutino, Fletcher, Snowling, & Scanlon, 2004). But because it has become increasingly apparent that there are other factors contributing to orthographic processing (Badian, 2001; Cunningham, 2006; Cunningham et al., 2002; Wagner & Barker, 1994), most current models of reading (e.g., dual-route cascaded, connectionist) propose mutually facilitative and interactive relationships among phonology, orthography, semantics, and syntax. For example, Cunningham (2006) and colleagues (2002), and MacEachron (2009) found that prior orthographic knowledge predicted a substantial amount of variance in orthographic learning, above and beyond that predicted by phonological decoding ability. The present study broadened their investigations of the contribution of prior orthographic knowledge using 1-, 2-, and 3-syllable targets, containing both real and made-up affixes. In addition, the relationship between orthographic learning and a number of other individual variables related to reading skill were examined to add to our understanding: vocabulary, known to predict early reading achievement (e.g., Bowey, 1995; Caravolas, Hulme, & Snowling, 2001; Elbro, Borstrom, & Petersen, 1998); rapid automatized naming, widely examined in research on predictors of reading skill (e.g., Badian, McAnulty, Duffy, & Als, 1990; Wagner et al., 1994; Wolf, Bowers & Biddle, 2000); print exposure, associated with multiple components of reading development (see Mol & Bus, 2011 for review); and morphological awareness, for its link to the creation and organization of orthographic representations (Baayen, 2007; Bybee, 1985; Derwing, 1992).

Method

Participants

Ninety-four children (46 girls and 48 boys) from eight second-grade classrooms in a predominantly upper middle-class suburban elementary school in the San Francisco Bay Area participated in the study. The school population was ethnically diverse: approximately 60% of the students identified as Asian, 20% as White, 6% as Filipino, 5% as Hispanic or Latino, 1% as African American, and 8% as mixed ethnicity. Students were recruited by the school principal through an informational invitation sent home to the families of all second graders; only those with written consent were considered for participation. Originally, 101 students were accepted into the study; however, three students were subsequently disqualified—two due to planned prolonged absences during the data collection period, and one due to a Level 1 English Language Proficiency designation. Descriptive data for four special education students were gathered, but not entered into the regression models. The final sample population was representative of the overall school demographics: approximately 63% identified as Asian, 21% as White, 8% as Filipino, and 6% as Hispanic or Latino. Data collection took place during April and May, the final months of the participants' second grade year. Student mean age at the first session was 7.89 years (*Range*: 7.30 years to 8.53 years; *SD* = 0.31).

Of the 94 participants, 20 were designated English Language Learners (ELLs)—all either Level 4 (Early Advanced) or Level 5 (Advanced). To determine final inclusion in the study, data from the English Language Learners was analyzed to see if these subsets of participants were statistically different from the non-ELL population. Because no statistically significant differences were found, all Level 4 and Level 5 ELLs were included in the study.

Procedure

Over a 7-week period, each participant met weekly in a one-to-one session with an examiner for approximately 30 minutes. Examiners were apprised of the overall design of the study, and carefully trained in the administration of all tasks and measures. Sessions were held in quiet rooms with few distractions. Every effort was made to hold each student's session on the same day of the week, at the same time, and with the same examiner. Students participated in a total of 7 sessions.

During each of the first six sessions, students were asked to read aloud, unassisted, four short passages (*M* = 43 words). Within each of the four passages, a single target pseudoword was embedded in the text four times. Students were forewarned about these pseudowords so they would not assume offhand that they were misreading them, and be tempted to shape their pronunciation to fit an actual word. To ensure attention while reading, students were asked to respond orally to two comprehension questions after reading each passage.

Following a 7-day interval, students were administered three posttests to measure orthographic learning of the four target pseudowords from the previous week's passages. After posttest administration, students were presented with the next four passages to read, each with a new target pseudoword embedded four times within the text. Over a 6-week period, each student encountered 24 target pseudowords. During the final session (Week 7), students were not introduced to new passages or targets; they were simply administered posttests to measure orthographic learning from the previous week's passages.

In addition to passage reading and posttests to measure orthographic learning, students were administered a variety of measures to assess individual variables that have been linked with early reading acquisition in an effort to examine predictive value for self-teaching. These individual variables included verbal ability, rapid automatized naming ability, prior orthographic knowledge, morphological awareness, and print exposure. Table 1 summarizes student tasks for each of the seven sessions.

Table 1
Student Tasks for Each Session

Session	Tasks
Week 1	Read passages 1-4
	Individual cognitive measures
Week 2	Posttests for passages 1-4
	Read passages 5-8
	Individual cognitive measures
Week 3	Posttests for passages 5-8
	Read passages 9-12
	Individual cognitive measures
Week 4	Posttests for passages 9-12
	Read passages 13-16
	Individual cognitive measures
Week 5	Posttests for passages 13-16
	Read passages 17-20
	Individual cognitive measures
Week 6	Posttests for passages 17-20
	Read passages 21-24
	Individual cognitive measures
Week 7	Posttests for passages 21-24
	Individual cognitive measures

Measures

To summarize, three types of tasks were administered during the study: (a) a self-teaching task requiring the student to read passages, each embedded with 4 instances of a pseudoword target, (b) posttests administered after a 7-day interval to measure orthographic learning of the previously encountered pseudoword targets, and (c) cognitive tasks designed to measure individual abilities often linked to reading skill and potentially predictive of orthographic learning.

Self-teaching task. The self-teaching task for each session consisted of reading aloud four passages, each with a single pseudoword target embedded within the text. Pseudowords were used to ensure word unfamiliarity. Over six sessions, each student read 24 passages, encountering 24 pseudoword targets. The pseudowords varied in both syllable number and morphological legality (i.e., how word-like they were). To accommodate both within- and between-subject analyses, pseudowords were created in pairs. Of the 24 pseudoword targets encountered by each student, six contained only 1-syllable, nine contained 2-syllables, and nine contained 3-syllables. During each session, a student was exposed to one monosyllabic pseudoword, and three polysyllabic words. Order of presentation of 1-, 2-, and 3-syllable pseudowords was counterbalanced across passages, as was exposure to morphologically legal and illegal pseudowords.

Data collection software program. Opus Pro 04, a tool for developing interactive applications, was used to create a unique computer program specifically designed for executing the self-teaching task and collecting data. Before each session began, the program required input of the examiner's name and the child's ID number to ensure that student data was stored in the proper files. Through the click of a radio button, the examiner activated computerized oral instructions for each task, ensuring that all participants heard exactly the same directions—a full set of instructions during the first session, and an abbreviated set of instructions thereafter, once the children had become familiarized with the protocol. Reminders to activate the microphone, point it toward the child's mouth, and double-check the child's ID number were provided on the screen to increase reliability.

Each passage was presented on a laptop computer screen, frame-by-frame, in lines of various lengths, ranging from one word per frame to seven words per frame. Letters were approximately .5 inches tall. The examiner activated frame changes by pressing the return key immediately after the child finished reading the frame contents. Because capturing decoding times of targets was essential to this study, the targets were necessarily presented alone in a frame. To avoid singling out the targets, four other passage words were also presented alone. The computer program recorded an automated timestamp upon each frame change, thereby labeling the point at which the targets were presented—stimulus presentation. This automated timestamp was achieved silently, an improvement over previous self-teaching studies that labeled this point by an audio beep, which had created an artificial distraction throughout the passage reading.

Decoding time has been operationalized in past studies in different ways. Many studies have measured the latency from onset of target stimulus to onset of pronunciation (Cunningham, 2002; deJong & Share, 2007; deJong et al., 2009; Kyte & Johnson, 2006; Share, 2004, 2010). Others, including this study, have used onset of word stimulus to offset of pronunciation (Lurie, 2004; MacEachron, 2009; Share, 2010). The latter paradigm was chosen for this study because it takes into consideration the varying strategies different children use to decode. For instance, while one child may look at a word and attempt to decode it fully in silence before pronouncing it out loud (creating a long latency between onset of target stimulus and onset of pronunciation), another child may vocalize right away, with no silent analysis of the word prior to pronunciation (resulting in a short latency). Comparing two such children on that latency alone would suggest a decoding speed difference that does not, in fact, exist.

That said, there are inherent challenges in trying to measure decoding speed, no matter what the paradigm. The exact placement of the microphone, the audio settings, the varying levels of a child's voice all introduce variability. Finding the offset of pronunciation is complicated by the fact that some talkers release final stop consonants, and others do not, introducing a 200 ms or more variability in their pronunciation of word endings. Consequently, this study uses a fully automated proxy to measure decoding duration—a proxy that bypasses the painstaking stopwatch and hand measurements used in prior studies. Instead of trying to decipher the exact offset of pronunciation, using a stopwatch to measure the duration, we used the automated timestamp triggered when the target stimulus was shown, and the automated timestamp triggered when the return key was hit to move to the next frame. This proxy is likely to be highly correlated to actual decoding time, since both the student participant and the examiner were motivated to move the experiment along and show the next item promptly. The duration calculated by the computer program is likely to be at least as accurate, and probably more accurate than hand-timing. To investigate the correlation between the automated timestamps used in this study and the manual labeling used in previous studies, nine trials were conducted. The lowest correlation was .98; all others were above .99. The advantage of the automated proxy is that it attenuates the inherent challenges mentioned above, while eliminating the problem posed by human reaction time differences for stopwatch operation, which are estimated at 300 ms (Gust, Graham, & Lombardi, 2004)—larger than many of the decoding time variations found in these studies. While this is the first known study to use automated decoding speed durations, there is precedent for the theory behind using such a proxy in deJong et al.'s recent study (2009), where reading speed was measured from the onset of reading stimulus to the moment children turned the page. The "turn of the page" in that study is akin to the "turn of the frame" in this study.

Blaze Audio Wave Creator, which automatically opened when the children read each passage, recorded the children, and then stored the recordings as both waveform audio files and compressed mp3 backups. For additional data backup, portable mp3 players were used to record each session.

Creation of one-syllable target pairs. The 1-syllable pseudoword targets were created in homophonic pairs (*froon*/*frune*; *clirp*/*clerp*; *peesh*/*peash*; *chofe*/*choaf*; *whaip*/*whape*; *murst*/*mirst*), because pronunciation times would be expected to be identical for words made up of the same sounds in the same order. Half of the students were exposed to one homophonic spelling (e.g., *peesh*) and the other half were exposed to the alternate homophonic spelling (e.g., *peash*). Each of the monosyllabic targets contained exactly five letters—one singleton consonant, a 2-letter vowel pattern, and two consonants together (either a consonant digraph or a consonant blend). Vowel patterns were chosen based on two criteria. First, they were patterns that the participants had been exposed to in their grade-level reading curriculum, and second, they had homophonic alternatives that, based on empirically derived probabilities from grapheme-phoneme correspondences in English (Berndt, Reggia, & Mitchum, 1987), used vowel patterns that were as close in frequency as possible. A range of vowel patterns commonly used in second-grade text was employed—*ai* and *a_e* to represent the long a sound, *ee* and *ea* to represent the long e sound, *oa* and *o_e* to represent the long o sound, *oo* and *u_e* to represent the long u sound, and the r-controlled vowel patterns *er, ir*, and *ur*. Consonant and consonant combinations—digraphs *wh, sh, ch,* and blends *fr*, *st*, and *cl*—were also chosen for their frequency in second-grade text and used equally in both the initial and final positions.

Creation of polysyllabic target pairs. The 2- and 3-syllable pseudoword pairs were created to investigate the effect of both word length and morphology on decoding accuracy, speed, and subsequent orthographic learning. Based on the assumption that familiar letter strings would likely trigger previously learned orthographic representations and could, thus, be read more quickly and accurately, affixes familiar to second graders (e.g., *mis-, dis-, -ing,-ed*) were attached to pseudoword bases to create word-like or legal targets (e.g., *misjope*, *dismurfing, disboaded*), while orthographically altered affixes, or made-up affixes, were added to the bases to create nonword-like or illegal targets (e.g., *musjope, dasmurfung, dasboadod*).

The 2- and 3-syllable pseudoword pairs were created based on multiple criteria. All base morphemes contained exactly four letters—a singleton initial consonant sound, a singleton final consonant sound, and a vowel pattern common to second-grade text (e.g., *or, ee, ea, i_e*). The same base morpheme was used for each member of the pair. Efforts were made to create bases that had only one possible pronunciation. In one instance (the base, *deat*), a few children used the less common pronunciation for *eat* (as in the word *threat*). Because these children were consistent with their pronunciation, their responses were counted as correct and did not affect results.

Affixes were chosen from the American Heritage Word Frequency Book (Carroll, Davies, & Richman, 1971); all were ranked in the top 20 of most frequently occurring prefixes and suffixes. Once selected, the list of affixes was submitted to each teacher to confirm that they had been covered in the second-grade curriculum. Made-up affixes were created using the same number, order, and identity of consonants contained in the real affixes. Although the vowel position remained the same, a different vowel was substituted to create the made-up affix. Care was taken not to create made-up affixes that might inadvertently facilitate decoding in the same way real affixes are expected to. For example, *-ed* was not altered to *–ad* because if added to the base *boad,* it would have created *boadad,* which contains the familiar real word *dad.* Instead, *-ed* was altered to *-od*, creating *boadod,* which does not contain a familiar letter string and, therefore, would not be expected to facilitate decoding.

In total, nine 2-syllable pseudoword pairs were created using the same nine base morphemes for each member of the pair. Two real prefixes (*mis-, un-*) and made-up prefixes (*mus-, an-*) were added to four of the base morphemes (*jope, gurd, kafe, fime*) to create the following pseudoword pairs: *misjope/musjope*, *misgurd/musgurd, unfime/anfime, unkafe, ankafe*. Two real suffixes (*-ful, -ly*) and made-up suffixes (*-fel, -lo*) were added to five of the base morphemes (*veet, sait, boam, lirt, deat*) to create the following pseudoword pairs: *veetful/veetfel, saitly/saitlo, boamful/boamfel, lirtly/ lirtlo, deatful/deatfel.*

To create the nine 3-syllable pseudoword pairs, the same basic process was used; however, both a prefix and a suffix were added to each base. Three real prefixes (*dis-, re-, trans-*), three made-up prefixes (*das-, ro-, truns-*), three real suffixes (*-ing, -ed, -ment*) and three made-up suffixes (*-ung, -od, -mont*) were added to nine bases, resulting in the following pseudoword pairs that contained a morphologically legal target and a morphologically illegal target: *disboaded/dasboadod, renorting/ronortung, transfibement/trunsfibemont, dismurfing/dasmurfung, transpaited/trunspaitod, retarkment/rotarkmont, disfeekment/dasfeekmont, remerted/romertod, transnooping/trunsnoopung.*

Creation of 24 passages. Each short passage (mean number of words = 43) was created using decoding patterns, high frequency words, and spelling rules consistent with a synthesis of California, Texas, and Florida first and second grade curriculum standards for reading. Embedded within each passage were four instances of a single pseudoword target, of 1-, 2, or 3-syllables. The stories were created to be as engaging as possible, so that the children would be attentive and motivated to read them. Half of the students read the passage with one form of the target pair (e.g., *Frune*), and the other half of the students read the same passage with the other form of the target pair (e.g., *Froon*).

For example, children with an even student ID number were asked to read the following passage: *Frune is a lake in the middle of my bedroom. Sometimes I go swimming in Frune before school. One time I went swimming in Frune when I should have been sleeping. I think my mother could hear me splashing in Frune!*

The children with an odd student ID number were asked to read the same passage, but with the alternative form of the pseudoword pair embedded within: *Froon is a lake in the middle of my bedroom. Sometimes I go swimming in Froon before school. One time I went swimming in Froon when I should have been sleeping. I think my mother could hear me splashing in Froon!*

Orthographic learning posttests. Seven days after reading each passage, the children were individually administered three different posttests to measure whether self-teaching of the pseudoword targets had, in fact, occurred. For the sake of consistency with previous similar studies (MacEachron, 2009; Share, 2010), the posttests were given in a fixed order—naming, orthographic choice, and spelling. Prior research suggests that the order of these posttests does not influence either practice effects or interference effects (Share, 2004).

Naming posttest. This posttest was presented on the laptop computer. A list of 16 words/pseudowords was presented to the child, one at a time. The list included the four targets that the child had seen in the four passages read the previous week, the four alternates (i.e., foils) to each target, which the child had not seen, and 16 filler words from taken from the passages. The instructions were automated; children were asked to read each word/pseudoword as quickly and as accurately as possible. The software program automatically time-stamped stimulus onset each time. As soon as the child finished pronouncing the word, the return key was pressed, recording the next time stamp and exposing the next item.

The children were recorded using Blaze Audio Wave Creator, and recordings were stored in both waveform audio files and compressed mp3 backups. Reading accuracy of the targets and foils was determined by one experimenter who listened to all audio files for all children, and labeled the pronunciations as *correct, incorrect,* or *undecipherable.*

Decoding times were measured for the targets and foils only. Orthographic learning was assumed to have occurred if accurate decoding times for the pseudowords the children had been exposed to (targets) were faster than accurate decoding times for the pseudowords they had never seen (foils). Only decoding times for accurate pronunciations were used.

To minimize potential priming effects, two parallel lists were created for each administration of the naming task; one list presented the child's target word first, the other presented the child's foil first. List type was rotated across subjects. Since previous work in the field has suggested the potential for training/learning effects with repeated item presentation (Share, 1999; Share, 2004), each target and foil was presented only one time to further reduce possible priming effects.

Orthographic choice posttest. This posttest was a multiple-choice paper and pencil task. The children were asked to circle the target they had seen in their passage. For 1-syllable pseudowords, they were to choose between the target they had seen in their passage (e.g., *peesh*), and its homophonic alternative, which they had not seen (e.g., *peash*). It was the same process for 2-syllable pseudowords; they were to choose between the target they had seen (e.g., *saitlo*) and the alternate form of the pair, which they had not seen (e.g., *saitly*). For 3-syllable words, they again were asked to circle the target they had seen in their passages, but this time were given four options to choose from instead of two: (a) their target (e.g., *transnooping*), (b) the alternate form of the pair (e.g., *trunsnoopung*), (c) a form with a real prefix and a made-up suffix (e.g., *transnoopung*), and (d) a form with an made-up prefix and a real suffix (e.g., *trunsnooping*). In all cases, the order of choices was rotated and counterbalanced so that each child received the same number of items with their target listed as the first option, last option, or medial option.

Orthographic learning was assumed to have occurred if the child chose the target pseudoword they had read in their passage more often than would be expected by chance. For 1- and 2-syllable words, orthographic learning could be assumed if targets were chosen with significantly greater frequency than 50% of the time; for 3-syllable words, orthographic learning could be assumed if targets were chosen with significantly greater frequency than 25% of the time.

Spelling posttest. Children were asked to write the target pseudowords on paper, as they were dictated orally by the experimenter. Past studies have used this paradigm (Cunningham, 2006; Cunningham et al., 2002; MacEachron, 2009; Share, 1999, 2004); however, it is only effective with homophonic pseudoword pairs. Because the current study examines polysyllabic words for which there are no homophonic alternatives, the spelling test, with its oral dictation prompt, provided the children with phonological information that confounded the learning outcome. In other words, correct responses (i.e., correctly spelled words dictated to them) were influenced by more than the orthographic knowledge the children had gleaned from exposure to their targets; they were also influenced by the phonological information provided through dictation. For example, the words *misjope* and *musjope* are pronounced differently and can be correctly spelled based on phonics knowledge. Although the spelling posttest was administered during the study, it was rejected as invalid because the phonological confound was insurmountable.

Measures of within-child variables. Children vary on many cognitive dimensions—memory, reasoning ability, information processing, language comprehension, and specific knowledge stores to name a few. A number of different tasks were individually administered to the study participants to examine individual cognitive differences, and determine if and how they relate to a child's ability to learn orthography. Two of the measures used in the study were from common standardized test batteries—Comprehensive Test of Phonological Processing (CTOPP) and Peabody Picture Vocabulary Test III (PPVT-III). The published instructions and discontinue rules were followed exactly, but raw scores were used as the unit of analysis instead of normed scores. The remaining measures were non-standardized. To assess reliability of the non-standardized measures, Spearman-Bowman split-halt reliability was calculated for each to determine internal consistency. All measures were administered individually.

Rapid automatized naming (RAN). Rapid naming of objects, colors, digits, or letters requires efficient retrieval of phonological information from long-term memory. RAN tests are purported to measure the fluid access to verbal names in memory, a skill that is theorized to relate directly to word automaticity and reading fluency (Wagner, Torgesen, & Rashotte,1999). The following RAN subtests of the CTOPP were administered:

- RAN Letters required children to name a full page of four rows of letters, nine per row, as quickly and as accurately as possible.
- RAN Digits required children to name a full page of four rows of digits, nine per row, as quickly and as accurately as possible.
- RAN Objects required children to name a full page of four rows of objects, nine per row, as quickly and as accurately as possible.

The process for each was the same; published directions were followed exactly. The children were first introduced to the stimuli used (i.e., the letters, digits, or objects, depending on the subtest) and allowed to review their names. They were then asked to do a quick trial run, naming a practice line of items as quickly and as accurately as possible. Errors were corrected. For the actual test, the children were asked to name all 36 items on the page; their time in seconds and number of errors were recorded. Each child was given a Form A and Form B version of each subtest (same items, different order), and the times were totaled to compute a final score. Children received separate scores for RAN Letters, Digits, and Objects. In addition, the following RAN composite scores were calculated:

- RAN All Composite score was calculated from the total of all three RAN subtest scores (in seconds).
- RAN Alphanumeric Composite score was calculated from the total of just the RAN Digits and RAN Letters subtest scores (in seconds).

Prior orthographic knowledge. Prior orthographic knowledge was measured by the following four tasks:

- The PIAT-III is a standardized test used to assess a child's ability to recognize correctly spelled words. A word was said to the child, then used in a sentence, and then said again (e.g., Glass. The window is made of glass. Glass.). Four options were presented on a page, one correct and three incorrect; the child was asked to point to the correctly spelled option.
- The Spelling Choice task was an abridged version of an orthographic choice task developed by Olson, Kliegl, Davidson, & Foltz (1985). Cunningham (2006) created and used the abridged version as a measure of prior orthographic knowledge. Twenty-three pairs of homophonic letter strings were shown to the children (e.g., *take*/*taik*; *gote*/*goat*; *sleap*/*sleep*) and they were required to choose and circle the correctly spelled version. The child's score on this task was the total number of correct items. Spearman-Brown split-half reliability was measured at .73.
- The Homophone Choice task was similar to the Spelling Choice task in that it required children to choose the correct word from a pair of homophones; however, in this task both homophones were correctly spelled, but only one was the proper choice for the context given. For example, children were asked, "Which is a flower?" and they had to choose between *rose* and *rows.* Spearman-Brown split-half reliability was measured at .67.
- The Legal Letter strings task was given in 3 parts (Letter Strings 1, 2, and 3) because there were a total of 51 items, too many for children to focus on at one sitting. Each part was administered in the same manner, but in different sessions. In each case, children were shown a page of letter string pairs as the examiner read the following instructions aloud: "Look at the letter strings below. I'd like you to choose the one in each pair that looks most like it could be a real word. Circle your answer." Spearman-Brown split-half reliability for Letter Strings 1, 2, and 3 were .61, .48, and .69, respectively.

Morphological awareness. Sensitivity to morphology was measured by a single test. The Morphological Awareness Identification task contained 40 items that required children to listen first to a directive (e.g., "Which word shows there is more than one?"), and then choose from 2 pseudowords with real affixes (e.g., *sloxes* or *slox*). The affixes used were common to the second grade curriculum, and included those used in the target pseudowords embedded in the current study's passages: *-ing, -est, -ed, -s, -es, -er, -able, -est, -ful, -less, re-, un-, dis-, mis-,* and *pre-.* Spearman-Brown split-half reliability was .74.

Verbal ability. For the purposes of this study, receptive vocabulary knowledge was used as a proxy for verbal ability. The PPVT-III was used to measure each child's receptive vocabulary knowledge. It was given in its entirety, and exactly according to published instructions, including basal and ceiling set rules. Children were shown a quadrant of four pictures on a page, then asked to point to the picture that best represents a vocabulary word given (e.g., *cashier, jogging, nutritious, nostril, colliding*). Each child's raw score was standardized and used as the unit of analysis.

Print exposure. One measure of print exposure was used—a title recognition test (TRT) adapted from measures previously used to assess print exposure in similar populations (Cunningham & Stanovich, 1990, 1991; Stanovich & West, 1989). A TRT is a proxy method for measuring print exposure, and is intended to provide a relative rather than absolute measure of print exposure. Because it includes foil titles as well as real titles, it has proven to be effective in controlling for the social desirability confound that plagues more transparent assessments of reading behavior, such as reading diaries or preference questionnaires (Cunningham & Stanovich, 1990; Stanovich & West, 1989). The TRT adapted for this study contained a list of 41 book titles—most actual titles of children's books (e.g., *The Polar Express, Are You My Mother, Nate the Great*), with foils randomly placed throughout (e.g., *Hot Top, He's Your Little, Curious Jim*). The child's score was calculated as the number of real titles chosen minus the number of foils chosen. It was then standardized for data analysis. Spearman-Brown split-half reliability was .68.

Results

The present study investigated the role of self-teaching in the development of word-specific orthographic representations of unfamiliar words, and the influence that decoding accuracy, decoding speed, word length, and morphology have on that learning. Pseudoword targets were used to ensure unfamiliarity, and were created to vary in length (either 1-, 2-, or 3-syllables), and morphological legality. Targets affixed with real prefixes and suffixes familiar to second graders, such as *mis*- and -*ing,* were considered morphologically legal; those affixed with made-up prefixes and suffixes, such as *mus*- and -*ung*, were considered morphologically illegal. Decoding accuracy was measured as the percentage of correctly pronounced pseudowords. Decoding speed was measured as the number of seconds that elapsed from onset of the pseudoword stimulus to offset of the child's pronunciation. A number of fundamental hypotheses were investigated:

- Shorter targets embedded within the passages would be decoded more accurately than longer targets.
- Morphologically legal targets embedded within the passages would be decoded more accurately than morphologically illegal targets.
- Shorter targets embedded within the passages would be decoded more rapidly than longer targets.
- Morphologically legal targets embedded within the passages would be decoded more rapidly than morphologically illegal targets.
- Posttest performance would provide evidence of orthographic learning (i.e., evidence of the acquisition of word-specific orthographic representations).

- Accurate target decoding would be associated with greater orthographic learning, with a significant advantage for shorter and morphologically legal targets.
- Faster passage target decoding times would be associated with greater orthographic learning, with a significant advantage for shorter and morphologically legal targets.

In addition, the trajectory of decoding accuracy and duration, from the first encounter in each passage through the fourth, was investigated to illuminate any patterns that may exist, and to provide insight into how children respond to unfamiliar words over time. Finally, the following within-child variables a number of within-child variables were examined to explore their relationships and potential contributions to orthographic learning; verbal ability, prior orthographic knowledge, morphological awareness, print exposure, and rapid automatized naming ability.

Decoding Accuracy and Speed for Pseudoword Passage Targets

According to the self-teaching hypothesis (Jorm & Share, 1983; Share, 1995, 2008), the ability to accurately decode unfamiliar words in print is the primary means by which readers acquire orthographic representations. Recent investigations of the self-teaching hypothesis have begun to examine yet another potential factor in orthographic learning—the speed of accurate decoding of unfamiliar words (Lurie, 2004; MacEachron, 2009; Share, 2010). To address the first four hypotheses regarding the effect of word length and morphological legality on decoding accuracy and speed, the mean percentage of passage target words read correctly, and the duration of decoding time for accurately decoded targets were analyzed. Results are presented in Table 2.

Table 2
Decoding Accuracy and Duration for Passage Targets

			Target			Differences with *T* Tests for Significance						
						1-syllable	2-syllable			3-syllable		
Variable	Syllables	Legality	*Mean*	*SD*	*N*	Total	Illegal	Legal	Total	Illegal	Legal	Total
Accuracy	1	Total	0.89	0.32	2,294							
	2	Illegal	0.61	0.49	1,738	.28***						
		Legal	0.77	0.42	1,718	.12***	-.16***					
		Total	0.69	0.46	3,456	.20***	-.08***	.08***				
	3	Illegal	0.47	0.50	1,725	.41***	.13***	.29***	.21***			
		Legal	0.76	0.43	1,709	.12***	-.15***	.01	-.07***	-.29***		
		Total	0.62	0.49	3,434	.27***	-.01	.15***	.07***	-.14***	.14***	
	Total		0.71	0.45	9,184	.17***	-.10***	.06***	-.02*	-.24***	.05***	-.09***
Duration	1	Total	1.63	0.80	1,810							
	2	Illegal	2.11	1.08	1,007	-.48***						
		Legal	1.92	0.98	1,238	-.28***	.20***					
		Total	2.00	1.03	2,245	-.37***	.11**	-.09*				
	3	Illegal	3.10	1.60	762	-1.47***	-.99***	-1.18***	-1.10***			
		Legal	2.42	1.33	1,253	-.79***	-.31***	-.51***	-.42***	.68***		
		Total	2.68	1.47	2,015	-1.05***	-.57***	-.76***	-.68***	.42***	-.26***	
	Total		2.12	1.22	6,070	-.48***	-.01	-.20***	-.11***	.98***	.31***	.56***

Note. Data for decoding accuracy includes all responses and is represented as the proportion of words correctly decoded; data for decoding duration includes only times for accurately decoded targets, and is represented in seconds. Only 2- and 3-syllable words were used in the morphological legality condition, since 1-syllable words did not have affixes.
$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Accuracy in general. Overall, decoding accuracy for all targets embedded in the passages when collapsed across word length and morphological legality conditions averaged 71%, which is very similar to the 68% accuracy found by Share (2010) in end-of-the-year Hebrew speaking second graders, while using a similar experimental paradigm that included multisyllabic targets. Cunningham (2002) reported an accuracy rate of 74% with second graders reading 1-syllable targets only. In 2009, MacEachron conducted a similar study with English speaking first graders and reported 65% accuracy.

Accuracy and word length. Word length exerts a significant effect on accuracy, with a strong advantage for shorter words over longer words. One-syllable targets were read accurately 89% of the time, 2-syllable targets were read accurately 69% of the time, and 3-syllable targets were read accurately 62% of the time. The greatest decline in accuracy is seen between 1- and 2-syllable words, a highly significant difference of 20 percentage points ($p < .001$). The decrease in accuracy from 2- to 3-syllable words is a less striking 7 percentage points, but still significant ($p <.001$). In support of Hypothesis 1, and highly consistent with previous findings (MacEachron, 2009; Share, 2010) the data indicate that as the length of unfamiliar letter strings encountered by a reader increases, decoding accuracy decreases.

Accuracy and morphological legality. The morphological condition was applied to 2- and 3-syllable words only; 1-syllable words were not candidates, since they were not affixed. As suggested in Hypothesis 2, morphological legality played an important role in decoding accuracy. Morphologically legal targets (those with real affixes, such as *mis-, re-,* and *-ly*) were read with significantly more accuracy than morphologically illegal targets (those with made-up affixes, such as *mus-, ro-,* and *-lo*). In the 2-syllable condition, legal targets were read accurately 77% of the time compared to illegal targets, which were read accurately 61% of the time. Three-syllable legal targets were read accurately 76% of the time, whereas illegal targets were read accurately only 47% of the time. Although Share (2010) did not introduce any 2-syllable words into his experimental paradigm, results from 3-syllable words (71% accurate for legal 3-syllable targets; 48% accurate for 3-syllable illegal targets) demonstrate the same dramatic and significant decrease in accuracy with morphologically illegal targets that was seen in this experiment.

Interestingly, 2- and 3-syllable legal targets in this study had roughly the same accuracy percentages (77% and 76%, respectively); however, accuracy percentages for illegal targets were significantly lower in the 3-syllable condition (47%) than the 2-syllable condition (61%). Therefore, the small, albeit significant, word length advantage we found for 2-syllable targets over 3-syllable targets (69% vs. 62%) appears to reside solely within the illegal target condition. A likely reason for this is that in legal words, whether 2-syllable (e.g., *deatful*) or 3-syllable (e.g., *retarkment*), the children were faced with only one unfamiliar letter string—the base (e.g., *deat*, *tark*). Assuming the readers had previously encountered the real affixes through independent reading and the second grade curriculum, they had had ample opportunities to establish orthographic representations for those parts of their targets. The illegal targets, on the other hand, were unfamiliar in their entirety (e.g., *deatfel*, *rotarkmont*), with no previously learned orthographic information to aid their decoding. The longer the letter string, the more opportunities for decoding errors, explaining the decrease in accuracy of 14 percentage points when moving from 2- to 3-syllable illegal targets.

With this information, it is important to reconsider the effect of word length on decoding accuracy. While 1-syllable words certainly maintain an accuracy advantage over multisyllabic words, the difference in decoding accuracy between 2- and 3-syllable words appears to depend more on the availability of sub-lexical units for which previously established orthographic representations have been acquired than on word length alone.

Decoding speed in general. Because accurate decoding is presumed to be the self-teaching mechanism leading to orthographic learning, only targets decoded accurately were included in the decoding speed analyses. This methodology is consistent with the body of self-teaching research investigating speed (e.g., MacEachron, 2009; Share, 2010). During the passage reading, the mean decoding duration for all targets across the syllable and morphological legality conditions was 2.12 seconds (*SD* = 1.22), with two thirds of the times falling between 0.90 seconds and 3.34 seconds. Mean decoding times in this study were consistent with those found in Share's study of Israeli second graders (2010), in which overall decoding times of 1- and 3-syllable words averaged 2.10 seconds.

Decoding speed and word length. Evidence supports the third hypothesis; as word length increased, the mean duration time for decoding increased. This is not surprising, given the fact that with each additional syllable, there was additional information to recognize and recode. Accurately read 1-syllable targets had a mean decoding duration time of 1.63 seconds (*SD* = 0.80); 2-syllable targets a mean decoding time of 2.00 seconds (*SD* = 1.03); and 3-syllable targets a mean decoding time of 2.68 seconds (*SD* = 1.47). All differences—.37 seconds faster for 1-syllable targets than 2-syllable targets; .68 seconds faster for 2-syllable targets than 3-syllable targets; and 1.05 seconds faster for 1-syllable targets than 3-syllable targets—were significant at the $p < .001$ level. These results are highly consistent with previous research that has found strong and significant word length effects on decoding speed (Share, 2010, reported mean decoding durations for 3-syllable words 1.11 seconds longer than for 1-syllable words. MacEachron (2009) found that decoding durations for 2-syllable words averaged .86 seconds longer than for 1-syllable words.

Decoding speed and morphological legality. Consistent with Hypothesis 4, decoding was significantly faster for morphologically legal targets than for morphologically illegal targets in both the 2- and 3-syllable conditions, indicating that students read targets containing familiar morphemes more easily than they read targets without them. Again, it is likely that previously established orthographic representations of the familiar affixes allowed them to bypass some of the serial, letter-by-letter decoding that was required to read the illegal targets. The 2-syllable targets with real prefixes or suffixes (e.g., *misgurd*, *veetful*) were read, on average, .20 seconds faster than the 2-syllable targets that were affixed with made-up letter strings (e.g., *musgurd*, *veetfel*), demonstrating an increase in speed of almost 10%. The 3-syllable targets with real prefixes and suffixes (e.g., *disboaded*) were read, on average, .68 seconds faster than the 3-syllable targets that were affixed with made-up letter strings (e.g., *dasboadod*), an increase in speed of almost 22%. Share (2010), using only 3-syllable targets to investigate morphological legality, found a comparable increase in speed (18%) for legal targets over illegal targets. It appears that the greater the number of familiar orthographic units in a target, the greater the advantage for decoding speed.

Trajectory of Accuracy and Decoding Duration Over Four Exposures

Past studies have revealed how quickly orthographic representations are established. Some studies (Ehri & Saltmarsh, 1995; Reitsma, 1983a; 1983b, 1989; Share, 1999) demonstrated that four or more exposures to an unfamiliar letter string produced reliable orthographic learning among normal young readers. Others (Hogaboam & Perfetti, 1978) found that orthographic learning occurred after only three exposures, and Share (2004) found that a single encounter with a novel orthographic string was sufficient to produce reliable recall of orthographic detail. Literature has been sparse, however, on questions about the trajectory of word learning that occurs via self-teaching as the reader engages in multiple opportunities to decode a new word. Does a reader typically move from inaccurate to accurate decoding with increasing exposure to a new letter string? Or, alternatively, does the reader stick with the results from the first attempt at print to speech translation, accurate or not? Does decoding time decrease evenly with every encounter, or is there a critical drop-off in decoding time after a certain number of exposures, with diminishing returns thereafter? Before examining evidence of self-teaching in this study and the potential effects of decoding accuracy and speed on orthographic learning, it may be illuminating to examine the typical trajectory that readers follow as they encounter new words. Table 3 presents data that help elucidate these trajectories in terms of accuracy and speed.

Table 3
Trajectory of Decoding Accuracy and Duration Over Four Target Encounters

	Time 1			Time 2			Time 3			Time 4		
	Category	%	Mean Duration	Category	%	Mean Duration	Category	%	Mean Duration	Category	%	Mean Duration
Reading Passage Targets	Inaccurate (N = 684)	30%	3.86	Inaccurate (N =590)	86%	2.41	Inaccurate (N = 541)	92%	2.31	Inaccurate (N = 517)	96%	2.16
										Accurate (N = 24)	4%	2.32
							Accurate (N = 49)	8%	2.73	Inaccurate (N = 15)	31%	2.18
										Accurate (N = 34)	69%	2.06
				Accurate (N = 94)	14%	3.12	Inaccurate (N = 24)	26%	2.78	Inaccurate (N = 16)	67%	2.45
										Accurate (N = 8)	33%	3.07
							Accurate (N = 70)	74%	2.23	Inaccurate (N = 7)	10%	2.18
										Accurate (N = 63)	90%	1.89
	Accurate (N= 1603)	70%	3.10	Inaccurate (N = 69)	4%	2.68	Inaccurate (N = 45)	65%	2.20	Inaccurate (N = 38)	84%	2.18
										Accurate (N = 7)	16%	2.12
							Accurate (N = 24)	35%	3.18	Inaccurate (N = 8)	33%	2.23
										Accurate (N = 16)	67%	2.84
				Accurate (N= 1534)	96%	1.81	Inaccurate (N = 52)	3%	3.05	Inaccurate (N = 29)	56%	2.26
										Accurate (N = 23)	44%	2.63
							Accurate (N = 1482)	97%	1.69	Inaccurate (N = 13)	1%	2.63
										Accurate (N = 1469)	99%	1.59
Total	N	% Accurate	Mean Duration	Total	% Accurate	Mean Duration	Total	% Accurate	Mean Duration	Total	% Accurate	Mean Duration
	2,287	70%	3.33		71%	2.05		71%	1.94		72%	1.82

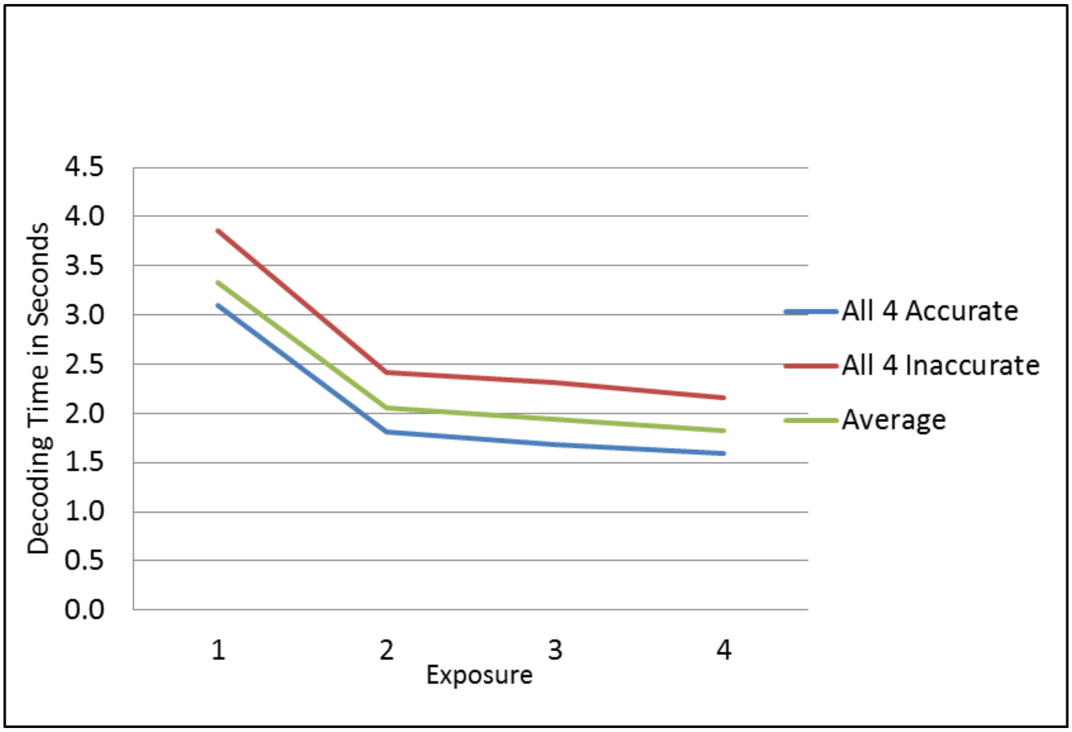
Accuracy trajectory. The data presented in Table 2 indicate that when a target is read accurately when first encountered, there is a 96% likelihood that it will be read accurately the second time it is encountered. If the target is read accurately again, there is a 97% likelihood that it will be read accurately upon the third encounter. Finally, if the target is read accurately during the first three encounters, there is a 99% likelihood that it will be read accurately at the fourth encounter.

On the other hand, if the target is read inaccurately when first encountered, the likelihood of reading it inaccurately in the second encounter is 87%. If read inaccurately again, the likelihood for a third inaccurate reading is 92%. If misread again, there is a 96% likelihood that it will be read inaccurately at the fourth encounter.

Accurate decoding in that first encounter is, therefore, critical in determining whether the reader develops and maintains accurate orthographic representations. Specifically, if the target is read accurately in the first encounter, there is a 90% chance that it will be read accurately all four times. Alternatively, if the target is read inaccurately at the first encounter, there is a 76% chance that it will be read inaccurately all four times. Implications of these trajectories for self-teaching are clear and dramatic. If the primary self-teaching mechanism is accurate decoding, then children who are inaccurate decoders in their first encounters with unfamiliar words do not have subsequent opportunities to acquire orthographic representations to the same extent as those whose initial decoding was accurate. These findings underscore the importance of appropriate pacing of instruction, timely feedback, and adequate code-based instruction that provides children with accurate decoding skills.

Duration trajectory. Mean decoding times went down with each exposure to the target, whether or not the children were accurate (Exposure 1 = 3.33 seconds; Exposure 2 = 2.05 seconds; Exposure 3 = 1.94 seconds; Exposure 4 = 1.82 seconds). An examination of the trajectory when words were accurately decoded all four times indicates a similar pattern, but with slightly shorter mean durations at each exposure (Exposure 1 = 3.10 seconds; Exposure 2 = 1.81 seconds; Exposure 3 = 1.69 seconds; Exposure 4 = 1.59 seconds). Finally, an examination of the trajectory when words were inaccurately decoded all four times indicates, again, a similar pattern, but with longer mean durations at each exposure (Exposure 1 = 3.86 seconds; Exposure 2 = 2.41 seconds; Exposure 3 = 2.31 seconds; Exposure 4 = 2.16 seconds). In sum, the data reveal a large drop in decoding time from Exposure 1 to Exposure 2 (a drop of between 38% and 41%, depending on the accuracy trajectory), with minimal drops after subsequent encounters (between 4% and 7%). Figure 1 depicts graphically the dramatic gain in decoding speed after one encounter with an unfamiliar word, and the diminished gains from subsequent exposures. This is consistent with the learning algorithms posited in connectionist models, where the greatest changes in connection weights occur early on, and the weight changes gradually diminish toward asymptotic values (Harm & Seidenberg, 1999; Plaut et al., 1996).

Figure 1
Target Decoding Times by Accuracy Over Four Exposures



Evidence of Orthographic Learning

Orthographic learning was measured at posttest by examining performance on two tasks: an orthographic choice task and a naming task. The two tasks were not combined to form an orthographic learning composite as has been done in a number of previous studies (Cunningham, 2002, 2006; MacEachron, 2009) for a couple of reasons. First, while both purport to measure orthographic learning, the demands of the two tasks are substantively different, making it interesting to analyze their results separately and within the contexts of those unique demands. For instance, in the orthographic choice task, the stimulus was visual only, and the response required recognition of their target, and then circling it. In the naming task, the stimulus was again visual, but the response was generation of the word orally, which required recall of the orthographic representation formed through self-teaching, and its matched pronunciation. Another reason that an orthographic learning composite was not created using the two posttest tasks is because results of the naming task have been highly inconsistent in previous studies, with non-significant results reported by Kyte and Johnson (2006), for dyslexics by Share and Shalev (2004), under certain experimental conditions by Share (1999), and by MacEachron (2009); and significant results reported by Reitsma (1983a, b), Ehri and Saltmarsh (1995), Cunningham et al. (2002), Share (1995), Bowey and Muller (2005), and under certain experimental conditions by Share (1999).

Orthographic choice posttest. On this task, children were shown either two or four pseudowords in print, and then asked to circle the one they had read in the their passage the previous week (i.e., their target). Orthographic learning was presumed to have occurred if their targets were chosen with significantly greater frequency than would be expected by chance. For the 1-syllable targets in the study, the children were asked to choose between two homophonic options (e.g., *froon* and *frune*); for the 2-syllable words, the children were asked to choose between two alternatives that shared the same base but had either a real affix or its fabricated alternative (e.g., *lirtly* and *lirtlo*); and for the 3-syllable words, the children were asked to choose among four options that shared the same base but had one of four combinations of real and fabricated affixes (e.g., *disboaded*, with a real prefix and suffix; *disboadod*, with a real prefix and a fabricated suffix; *dasboaded*, with a fabricated prefix and a real suffix; and *dasboadod*, with a fabricated prefix and suffix). Because of the difference in chance odds between a two-option task (.50) and a four-option task (.25), percent accuracy over chance was calculated for all conditions to allow comparisons. Values for both percent correct, and percent correct over random are presented in Table 4.

Table 4
Orthographic choice Posttest Results

								Syllables						
						T Tests		1	2			3		
Syllables	Legality	% Correct	*n*	Random	% Correct Over/Under Random	*T* Statistic	*p*	Total	Illegal	Legal	Total	Illegal	Legal	Total
1	Total	75%	580	50%	25%	11.88	0.000							
	Illegal	74%	431	50%	24%	9.78	0.000	1%						
	Legal	87%	439	50%	37%	15.42	0.000	-12%*	-13%*					
2	Total	80%	870	50%	30%	17.83	0.000	-6%*	-7%*	7%*				
	Illegal	39%	433	25%	14%	6.74	0.000	11%*	10%*	23%*	16%*			
	Legal	62%	436	25%	37%	18.03	0.000	-13%*	-14%*	-1%	-7%*	-23%*		
3	Total	51%	869	25%	26%	17.53	0.000	-1%	-2%	11%*	4%*	-12%*	12%*	
Total		68%	2,319	41%	27%	7.66	0.000	-3%*	-4%*	10%*	3%*	-13%*	10%*	-1%

Note: * indicates that the 95% Confidence Interval for listed differences in % correct over random between words of various lengths and morphological legality does not contain *0*, meaning that the difference is significantly different from 0 at the .05 level.

Orthographic learning overall. Across all word length and morphological conditions, targets were chosen in the orthographic choice task, on average, 27% more often than would be expected by chance, $p < .001$, evidence that robust orthographic learning occurred. These results are commensurate with the 24% over chance found by Cunningham (2006) in first graders learning 1-syllable targets, but much higher than the 15% over chance found by MacEachron (2009) in first graders learning multisyllabic words. Perhaps the extra year of reading instruction the second graders had over the first graders was a contributing factor to greater accuracy in multisyllabic words. Also of note is that Share's (2010) orthographic choice results with second grade children reading Hebrew were only 12% over chance, less than half that found in this study. Interestingly, studies with Hebrew readers (Share, 2004; Share & Shalev, 2004) revealed weak and statistically marginal orthographic learning among novice readers. They read pointed Hebrew, a system with almost perfect grapheme-to-phoneme correspondence, where consonants and vowel diacritics have a single unambiguous pronunciation (Navon & Shimron, 1984). Share hypothesized that beginning readers of highly regular orthographies appear to be relatively insensitive to word-specific orthographic details because simple-letter-to-sound translation works so effectively. While the pseudowords in the present study contained regular orthographic patterns familiar to second graders, the children had had enough experience with print to know the unpredictability of their orthography and, according to Share's hypothesis, would have developed this necessary sensitivity to orthographic details.

Orthographic learning and word length. Findings from the orthographic choice task indicate that orthographic learning occurred in all syllable conditions ($p < .001$ in all cases). For 1-syllable words, the target was chosen over the homophonic foil 25 percentage points above what would be expected by chance. For 2-syllable words, the target was chosen over the alternative 30 percentage points above chance. For 3-syllable words, the target was chosen 26 percentage points above chance. Interestingly, the greatest orthographic learning was demonstrated with 2-syllable targets, creating the appearance of an unexpected word length effect (in favor of 2-syllable targets). The 95% Confidence Intervals for these differences do not contain 0, indicating that the differences are significantly different than 0 at the .05 level. Further exploration, however, reveals reasons why this may be a spurious conclusion.

The advantage of 2-syllable targets over 1-syllable targets could lie in the slightly different demands of the orthographic choice task for each. One-syllable targets and their alternative options were homophones, providing absolutely no phonological clue to distinguish them from one another. In contrast, 2-syllable targets contained phonologic and orthographic clues in their affixes that may have boosted performance. Because the children had read their targets a number of times, they were likely to have internalized at least some phonological information to aid in their choice. Additionally, if their target had been legal, previously learned orthographic information (e.g., prefixes or suffixes learned in school) would have been a likely memory aid.

Regarding the advantage of 2-syllable targets over 3-syllable targets, this might be expected because of an increased amount of orthographic information the reader must acquire for longer words; however, examination of the impact of morphological legality below provides a more specific explanation.

Orthographic learning and morphological legality. Children demonstrated robust orthographic learning whether the target was morphologically legal or illegal; however legal targets resulted in significantly greater orthographic learning than illegal targets in both the 2- and 3-syllable conditions. Two-syllable legal targets were correctly chosen 37 percentage points over chance, while 2-syllable illegal targets were correctly chosen 24 percentage points above chance. Three-syllable legal targets were correctly chosen 37 percentage points above chance compared to illegal targets that were correctly chosen 14 percentage points above chance. It is important to note the non-significant difference between 2- and 3-syllable legal targets, and the significant difference between 2- and 3-syllable illegal targets. It was only in the illegal condition that word length exerted an effect.

In sum, the difference in orthographic learning between 2- and 3-syllable words is not driven by word length, but rather morphological legality, suggesting that previously established orthographic representations contained in the targets (in this case, prefixes and suffixes) provide a weighty advantage for orthographic learning—an advantage that appears to become more important as syllable number increases. This finding also provides supportive evidence for the relationship between orthographic knowledge and orthographic learning (Cunningham, 2006;

Cunningham et al., 2002); as children become increasingly attuned to the regularities in their orthography, learning new words becomes a considerably easier task.

Naming posttest. Children were asked to read a list of words aloud, as they were presented one word at a time on a computer screen. The decoding duration time, from the onset of the word stimulus to the end of pronunciation, was recorded automatically by a computer program developed specifically for this study. The list included the four targets the children had encountered in their passages from the previous week (e.g. *musjope*, *dismurfing*, *peash*, *boamfel*), four homophonic or morphological foils they had not encountered (e.g., *misjope*, *dasmurfung*, *peesh*, *boamful*), and eight additional grade level filler words from their passages (e.g., *town*, *lake*, *bedroom*, *mother*, *baby*, *car*, *judge*, *rabbits*). Data from the naming posttest are presented in Table 5. Orthographic learning was presumed to have occurred if children read their targets significantly faster than the alternative foils. Although decoding accuracy of targets and foils is included in the table, it is not considered evidence of orthographic learning because the pseudowords are all phonologically regular and can be decoded sound-by-sound, whether or not orthographic representations have been established. The accuracy data do, however, demonstrate that for 1-syllable pseudowords, there was no advantage to having seen it before, but for both 2- and 3-syllable pseudowords, whether legal or illegal, there was a significant accuracy advantage for words that had been previously encountered ($p < .001$ in both multisyllabic conditions). One possible reason for the lack of difference in decoding times between 1-syllable targets and 1-syllable foils is that they had the same phonological forms. Functional orthographic representations amalgamate graphemic and phonological information. The phonological representation the children developed when reading their target four times, was available when they read their foil as well. The children had no such advantage in the 2- and 3-syllable condition, where the target and foil had different phonological forms.

Table 5
Naming Posttest Results

			Target			Foil			Target vs. Foil T Tests					
	Syllables	Legality	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	Difference in Means	95% CI Lower Bound	95% CI Upper Bound	Test Statistic	*df*	*p*
Accuracy	1	Total	0.940	0.24	562	0.952	0.21	564	-0.013	-0.039	0.014	-0.94	1,124	0.349
	2	Illegal	0.635	0.48	422	0.520	0.50	423	0.115	0.049	0.181	3.38	843	0.001
		Legal	0.799	0.40	423	0.736	0.44	421	0.063	0.006	0.120	2.16	842	0.031
		Total	0.717	0.45	845	0.628	0.48	844	0.089	0.045	0.134	3.91	1,687	0.000
	3	Illegal	0.449	0.50	374	0.353	0.48	377	0.096	0.027	0.166	2.70	749	0.007
		Legal	0.791	0.41	378	0.682	0.47	374	0.109	0.047	0.172	3.40	750	0.001
		Total	0.621	0.49	752	0.517	0.50	751	0.104	0.055	0.154	4.09	1,501	0.000
	Total		0.742	0.44	2,159	0.674	0.47	2,159	0.068	0.041	0.095	4.89	4,316	0.000
Duration - Accurate	1	Total	1.494	0.53	528	1.502	0.48	537	-0.008	-0.069	0.053	-0.25	1,063	0.804
	2	Illegal	1.867	0.62	268	2.224	0.91	220	-0.357	-0.494	-0.221	-5.14	486	0.000
		Legal	1.702	0.64	338	1.879	0.69	310	-0.177	-0.280	-0.075	-3.40	646	0.001
		Total	1.775	0.64	606	2.022	0.80	530	-0.248	-0.332	-0.164	-5.78	1,134	0.000
	3	Illegal	2.686	1.12	168	3.149	1.01	133	-0.463	-0.708	-0.218	-3.72	299	0.000
		Legal	2.200	0.81	256	2.574	1.00	222	-0.374	-0.537	-0.211	-4.51	476	0.000
		Total	2.393	0.98	424	2.789	1.04	355	-0.397	-0.539	-0.255	-5.49	777	0.000
	Total		1.848	0.80	1,558	2.017	0.92	1,422	-0.170	-0.231	-0.108	-5.38	2,978	0.000

Note. Data for decoding accuracy is represented as the proportion of correctly pronounced targets and foils. Data for decoding duration includes only times for accurately decoded targets and foils, and is represented in seconds.

Orthographic learning overall. When the data were collapsed across all conditions of word length and morphological legality, results of the naming task indicate that accurately read targets were read significantly faster (.17 seconds) than accurately read foils, suggesting orthographic learning had occurred, $t(2,978) = -5.38$; $p < .001$. Similar significant differences between target and foil durations have been found in previous studies, such as Cunningham and colleagues (2002), Reitsma (1983a, b), Ehri and Saltmarsh (1995), Share (1995), and Bowey and Muller (2005). In contrast, Share (2010) found no significant difference in naming duration between targets and foils with end-of-the-year second graders—consistent with his theory that early readers in shallow orthographies such as pointed Hebrew show very little orthographic learning on any posttest. Other studies using a similar self-teaching design found no significant difference in naming duration between target and foil (Kyte & Johnson, 2006; MacEachron, 2009). It is likely that the challenge of accurately measuring naming durations is partly responsible for the inconsistent results. The typical behaviors of children (e.g., turning away from the microphone at times) and the difficulty in judging the offset of pronunciation with unsophisticated sound equipment and the normal background noise in a school setting are potential threats to reliably capturing duration times. In addition, different methods of timing used in studies are another potential source of variation.

Orthographic learning and word length. When breaking down the results by word length, there is no evidence in the naming posttest for orthographic learning with 1-syllable targets. As previously discussed, the homophonic nature of the targets and foils in the 1-syllable condition may have provided an advantage to foil reading through an already formed phonological representation. This advantage would likely minimize the differences in naming durations. The difference in means between target and foil duration was small (.01 seconds) and non-significant, $p < .804$. In contrast, the target durations for 2-syllable words (M = 1.76 seconds) were significantly faster than the foil durations (M = 2.02 seconds), a difference of .25 s in favor of targets, $p = < .001$. For 3-syllable words, the target durations (M = 2.39 seconds) were significantly faster than the foil durations (M = 2.79 seconds), a difference of .40 s in favor of targets, $p = < .001$. It might appear that as word length (i.e., syllable number) increases, orthographic learning increases, but overlapping 95% Confidence Intervals (CI for 2-syllable= -0.332, -0.164; CI for 3-syllable= -0.539, -0.255) demonstrate that we cannot be certain that the .40 second advantage for 3-syllable targets over foils is truly different from the .25 second advantage for 2-syllable targets over foils.

Orthographic learning and morphological legality. The duration data from all accurately named multisyllabic targets and foils clearly indicate that targets were named significantly faster than foils, regardless of legality or word length, and these differences were significant at the $p < .001$ level. What becomes challenging, however, is interpreting the results of the naming posttest with regard to morphological legality. The design of the test confounds legality with the target/foil condition; when a target is legal, the foil is always illegal, and vice versa. So when asking the question, how does legality impact differences in naming duration between targets and foils, the answer is, "It depends." If the target is illegal, and the foil is legal, then there is little difference in duration, no matter how long the word (.01 seconds in the 2-syllable condition and .11 seconds in the 3-syllable condition). However, in the opposite condition—a legal target and illegal foil—there is a marked difference in both 2- and 3-syllable words (.82 seconds in the 2-syllable condition and. 94 seconds in the 3-syllable condition). A possible reason is that reading an illegal target confers one advantage (familiarity) and one disadvantage (illegality), just as reading a legal foil confers one advantage (legality) and one disadvantage (unfamiliarity). The combination of advantage and disadvantage inherent in both target and foil acts as an equalizer of sorts. In contrast, reading a legal target confers a double advantage (familiarity and legality), while reading an illegal foil confers a double disadvantage (unfamiliarity and illegality).

The 95% CIs allow us to examine the effect of morphology, controlling for whether or not the word has been seen before. Looking at the difference between 2-syllable illegal words and 2-syllable legal words, the CI for the difference between duration of accurate decoding for 2-syllable illegal words is between -0.494 and -0.221, and the CI for the difference between duration of accurate decoding for 2-syllable legal words is between -0.280 and -0.075. Because these intervals overlap, we cannot be certain (at the .05 significance level) that these differences in mean durations are truly different from one another. Doing the same for 3-syllable words, the CI for the difference between duration of accurate decoding of illegal words is between -0.701 and -0.218, and the CI for the difference between duration of accurate decoding of legal words is between -0.537 and -0.211. Again, the intervals overlap, so we cannot be certain that these differences in mean durations are actually different from one another.

In sum, results of the naming posttest demonstrate no difference in naming speed between 1-syllable targets and foils, and thus provide no evidence for orthographic learning in the monosyllabic condition. As discussed, since the 1-syllable pairs were homophones, the child developed a phonological representation for both the target and foil, which may have minimized differences in naming speed. Two- and 3-syllable targets were always read significantly faster than foils, providing ample evidence for orthographic learning in the multisyllabic conditions. After controlling for whether or not a child had seen a word before, morphological legality demonstrated no influence on orthographic learning in the naming posttest.

Predictors of Orthographic Learning

The key principle of the self-teaching hypothesis is that "each successful identification of a new word provides an opportunity to acquire the word-specific orthographic information that is the foundation of skilled visual word recognition" (Share, 2004; p. 268). A successful identification of a new word assumes accurate decoding. Past studies in English speaking children have reported strong and significant zero-order correlations between accuracy of 1-syllable target reading in passages and subsequent orthographic learning. Cunningham (2006) reported $r = .66$, which was convergent with her previous finding of $r = .52$ (Cunningham et al., 2002). MacEachron (2009) reported a similar $r = .59$ correlation between accurately decoded 1- and 2-syllable targets and a composite of orthographic learning posttest measures. In the present study, significant correlations were found between accuracy of target reading in passages and subsequent orthographic learning, as measured by both posttests. On the orthographic choice posttest, significant correlations were found for 1-syllable targets ($r = .36$, $p < .001$); for 2-syllable targets ($r = .42$, $p < .001$); and for 3-syllable targets ($r = .48$, $p < .001$). On the naming posttest, the correlation between target accuracy and orthographic learning was also significant ($r = .25$, $p < .001$).

Results of recent self-teaching studies with Hebrew novice readers (Share, 1999; Share, 2004; Share & Shalev, 2004) suggest that decoding accuracy alone may not be a sufficient condition for orthographic learning. Consequently, the role of decoding speed has been investigated as a predictor of orthographic learning. In a 2004 unpublished study by Lurie, decoding speed was reliably correlated with orthographic learning ($r = .52$, $p < .05$). Subsequent studies by MacEachron (2009) and Share (2010) produced mixed results. MacEachron found a significant zero-order correlation between decoding speed and orthographic learning, but Share, in contrast, found only weak and inconsistent evidence for an association. The present study found no evidence of zero-order correlations between decoding speed of passage targets and orthographic learning on either posttest measure. (Note: A relationship was found in 3-syllable targets in the hierarchical logistic regressions and is discussed below.)

While zero-order correlations are a good starting point for investigating relationships among variables, the network of factors influencing such a complex process as orthographic learning requires controlling for other reasonable variables in order to further specify the nature of these relationships. A number of child-level variables have been examined as potential predictors of orthographic learning in recent studies, (e.g., prior orthographic knowledge, rapid automatized naming, verbal ability, morphological awareness, print exposure) and, thus, are included in the present study. Multilevel (logistic and linear) regressions were used to investigate the predictors of orthographic learning.

Orthographic choice posttest. Tables 6, 7, and 8 present the results of hierarchical logistic regressions for the orthographic choice posttest for 1-, 2-, and 3-syllable words respectively. These models include random intercepts for students in order to adjust for unobserved heterogeneity between students and the possibility that results are correlated within students.

Table 6
Hierarchical Logistic Regression Analyses Predicting Correct Answers on the Orthographic choice Posttest (1-Syllable Targets)

	1	2	3	4	5	6	7	8	9	10
	or/se	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*
Average Duration of Accurate Targets		0.772		0.767	0.899	0.784	0.696	0.783	0.764	0.761
		0.2022		0.2024	0.2472	0.2104	0.2013	0.2107	0.2069	0.2021
Count of Accurate Passage Targets			1.086	0.926	0.97	0.922	0.896	0.916	0.926	1.026
			0.086	0.3676	0.4107	0.3659	0.3555	0.3647	0.3684	0.4156
Prior Othographic Knowledge					1.579*					
					0.3272					
Morphological Awareness						1.024				
						0.158				
Verbal Ability							1.14			
							0.1569			
RAN Letters								0.941		
								0.1372		
RAN Composite									1.009	
									0.1816	
Print Exposure										0.78
										0.1059
Constant	3.315***	5.317***	2.490**	7.287	4.459	7.034	9.557	7.293	7.3	4.951
	0.4372	2.4776	0.7521	12.2723	7.9688	11.8405	16.2853	12.2885	12.2959	8.4969
n	556	478	556	478	473	475	468	478	478	473
Number of Groups	94	94	94	94	92	93	92	94	94	93
Minimum Number of Obs per Group	4	1	4	1	1	1	1	1	1	1
Average Number of Obs per Group	5.915	5.085	5.915	5.085	5.141	5.108	5.087	5.085	5.085	5.086
Maximum Number of Obs per Group	6	6	6	6	6	6	6	6	6	6
Log Likelihood	-309.92	-264.35	-309.393	-264.331	-260.674	-263.598	-258.414	-264.245	-264.33	-259.967
Rho	0.112	0.148	0.109	0.147	0.124	0.145	0.141	0.147	0.147	0.136
Pseudo R Squared		0.15	0.00	0.15	0.16	0.15	0.17	0.15	0.15	0.16

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

One-syllable targets. The results from the regression analyses for the orthographic choice posttest with 1-syllable targets demonstrate no significant impact of either decoding speed (Average Duration of Accurate Targets), or decoding accuracy (Count of Accurate Passage Targets) on orthographic learning. The only covariate demonstrating any significant impact on orthographic learning as measured by orthographic choice is prior orthographic knowledge; whereby, one standard deviation increase in prior orthographic knowledge is associated with a 58% increase in the odds of making a correct choice when controlling for average duration and count of accurate target reading. This significant and independent contribution of prior orthographic knowledge on orthographic learning is consistent with recent research (Cunningham, 2006; Cunningham et al., 2002; MacEachron, 2009).

Table 7
Hierarchical Logistic Regression Analyses Predicting Correct Answers on the Orthographic choice Posttest (2-Syllable Targets)

	1	2	3	4	5	6	7	8	9	10	11	12
	or/se	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*
Average Duration of Accurate Targets		0.803		0.874	0.903	0.966	1.185	1.036	0.992	0.977	1.005	1.016
		0.1404		0.1589	0.1642	0.1811	0.2386	0.1951	0.187	0.1896	0.1951	0.1977
Target is Legal				1.958**		1.819*	1.878**	1.840*	1.893**	1.820*	1.817*	1.791*
				0.4611		0.4341	0.4513	0.4395	0.4533	0.4344	0.4338	0.4298
Count of Accurate Passage Targets			1.264***		1.544***	1.495***	1.486***	1.477**	1.475**	1.495***	1.505***	1.508***
			0.0609		0.1825	0.1802	0.1776	0.177	0.1767	0.1803	0.1816	0.1832
Prior Othographic Knowledge							1.677**					
							0.282					
Morphological Awareness								1.341*				
								0.1635				
Verbal Ability									1.198			
									0.1395			
RAN Letters										0.971		
										0.1241		
RAN Composite											0.881	
											0.1358	
Print Exposure												1.05
												0.1244
Constant	4.398***	8.192***	2.392***	5.037***	1.355	1.001	0.665	0.9	0.937	0.974	0.892	0.888
	0.4407	3.1091	0.3402	2.1067	0.8413	0.6419	0.4333	0.5747	0.5952	0.6357	0.5852	0.5817
n	834	586	834	586	586	586	582	583	572	586	586	581
Number of Groups	94	93	94	93	93	93	91	92	91	93	93	92
Minimum Number of Obs per Group	6	1	6	1	1	1	1	1	1	1	1	1
Average Number of Obs per Group	8.872	6.301	8.872	6.301	6.301	6.301	6.396	6.337	6.286	6.301	6.301	6.315
Maximum Number of Obs per Group	9	9	9	9	9	9	9	9	9	9	9	9
Log Likelihood	-403.232	-257.291	-391.713	-253.083	-251.09	-247.861	-241.219	-243.113	-244.254	-247.835	-247.527	-245.517
Rho	0.02	0	0	0.009	0	0.006	0	0	0	0.006	0.005	0.01
Pseudo R Squared		0.36	0.03	0.37	0.38	0.39	0.40	0.40	0.39	0.39	0.39	0.39

Note. **p < .05, **p < . 01, ***p < .001*

Two-syllable targets. Turning to 2-syllable targets, decoding speed had no effect on orthographic learning, regardless of the variables in the model, but accuracy in passage readings positively impacted performance on the orthographic choice posttest. For every 2-syllable target accurately read during passage readings, the odds of making a correct choice in the orthographic choice posttest increased by about 26% when considering accuracy alone (Model 3). Whether or not the target word was legal also made a large difference. Instances in which the target was legal resulted in correct choices with almost twice the odds (96% increase) over instances in which the target was illegal. These results remained robust after controlling for across the various model specifications. Beyersmann, Castles, and Coltheart (2011) found support for the facilitative power of affix representations, providing evidence that these representations are accessed at very early pre-lexical stages of word recognition.

After controlling for decoding speed, decoding accuracy, and target legality, a child's prior orthographic knowledge again showed a significant impact on the posttest performance in the 2-syllable condition. Morphological awareness was also observed to predict posttest performance, a finding consistent with research by Nunes, Bryant, and Olsson (2003), where training in morphological awareness had a positive effect on word identification.

Table 8

Hierarchical Logistic Regression Analyses Predicting Correct Answers on the Orthographic choice Posttest (3-Syllable Targets)

	1	2	3	4	5	6	7	8	9	10	11	12
	or/se	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*	*or/se*
Average Duration of Accurate Targets		0.584***		0.635***	0.672***	0.707**	0.760*	0.719**	0.729**	0.727**	0.716**	0.698**
		0.0586		0.0662	0.0704	0.0759	0.0856	0.0781	0.0792	0.0795	0.0792	0.0763
Target is Legal				1.635*		1.461	1.611*	1.526*	1.458	1.504*	1.478	1.433
				0.3308		0.2993	0.3349	0.3151	0.3041	0.3103	0.3054	0.294
Count of Accurate Passage Targets			1.414***		1.458***	1.409**	1.389**	1.398**	1.395**	1.407**	1.410**	1.417**
			0.0624		0.1566	0.1536	0.1503	0.1524	0.1534	0.1533	0.1538	0.1554
Prior Othographic Knowledge							1.456*					
							0.2722					
Morphological Awareness								1.142				
								0.1546				
Verbal Ability									1.285*			
									0.1603			
RAN Letters										0.854		
										0.1118		
RAN Composite											0.931	
											0.1538	
Print Exposure												1.117
												0.135
Constant	1.083	6.568***	0.466***	3.910***	1.215	0.953	0.757	0.894	0.881	0.854	0.906	0.957
	0.1072	2.0291	0.0643	1.4419	0.6738	0.5431	0.4364	0.5115	0.5055	0.4923	0.5271	0.5483
n	833	577	833	577	577	577	572	573	562	577	577	572
Number of Groups	94	92	94	92	92	92	90	91	90	92	92	91
Minimum Number of Obs per Group	6	1	6	1	1	1	1	1	1	1	1	1
Average Number of Obs per Group	8.862	6.272	8.862	6.272	6.272	6.272	6.356	6.297	6.244	6.272	6.272	6.286
Maximum Number of Obs per Group	9	9	9	9	9	9	9	9	9	9	9	9
Log Likelihood	-567.599	-366.026	-537.286	-363.061	-359.842	-358.128	-352.145	-354.851	-346.661	-357.401	-358.034	-354.72
Rho	0.114	0.156	0.05	0.16	0.128	0.132	0.114	0.131	0.118	0.129	0.133	0.125
Pseudo R Squared		0.36	0.05	0.56	0.57	0.58	0.60	0.60	0.62	0.61	0.59	0.59

Note. **p* < .05, ***p* < .01, ***p* < .001*

Three-syllable targets. Finally, in contrast to the 1- and 2-syllable conditions, decoding speed of 3-syllable targets significantly impacted success on the orthographic choice posttest. Considering duration alone, for every extra second increase in average time of target reading, the odds of choosing correctly on the orthographic choice posttest decreased by 42%. Perhaps this finding is related to limits of the phonological store in working memory, and the longer decoding durations for 3-syllable words surpassed a certain threshold. A number of studies argue that memory span is limited to the number of items one can articulate in a 2-second time window (Baddeley, Thomson, & Buchanan, 1975; Naveh-Benjamin & Ayres, 1986). Because the mean decoding duration for 3-syllable words was 2.68 seconds, it is possible that speed began to exert an effect on the quality of the orthographic representations made. Lurie (2004) found evidence to support this hypothesis. Share (2010) found no evidence to support a threshold model, but found small and inconsistent advantages for decoding speed in a linear trend consistent with a continuous decay model. More research investigating the effect of decoding speed will help uncover its impact on orthographic learning as word length increases.

Accuracy had a significant impact as well in the 3-syllable condition; each additional target read correctly during passage reading translated into a 41% increase in odds of success. Model 4 added a control for the legality of the target word to duration. The results demonstrated that after controlling for legality, duration still significantly impacted the odds of success. Model 7 includes both duration and accuracy with legality, showing that the impacts of duration and accuracy were robust, controlling both for one another and legality. The effect of legality, on the other hand, drifted across the margin of significance from model to model, making its impact on orthographic learning in 3-syllable targets unclear.

A child's prior orthographic knowledge did contribute to orthographic learning after controlling for speed and accuracy of target reading and target legality. An increase in one standard deviation of prior orthographic knowledge increased the odds of making the correct choice by 46%. Verbal ability also appears to matter. Each standard deviation increase in verbal ability provided a 29% increase in the odds of a making a correct selection on the orthographic choice posttest.

In sum, decoding accuracy influenced orthographic learning for 2- and 3-syllable targets. Decoding speed was found to matter in this study for 3-syllable targets only. Morphological legality was clearly important for 2-syllable targets, yet only marginally for 3-syllable targets. While verbal ability exerted an impact only in the 3-syllable condition, prior orthographic knowledge influenced orthographic learning for all syllable conditions. This finding is consistent with previous studies that have found that prior orthographic knowledge provides a unique and independent contribution to orthographic learning. Cunningham et al. (2002) reported that prior orthographic knowledge predicted 20% of the variance in orthographic learning beyond accuracy, and Cunningham (2006) reported that it predicted 11% of the additional variance.

Naming posttest. Table 9 presents the result of Hierarchical Linear Modeling regressions predicting performance on the naming posttest as measured by the foil reading duration minus the target reading duration.

These regression models include random intercepts for students in order to adjust for unobserved heterogeneity between students and the possibility that results are correlated within students.

Table 9

Hierarchical Linear Regression Analyses Predicting Difference in Reading Times for Target and Foil Words (Foil Seconds - Target Seconds)

	1	2	3	4	5	6	7	8	9	10	11	12
	b/se	*b/se*	*b/se*	*b/se*	*b/se*	*b/se*	*b/se*	*b/se*	*b/se*	*b/se*	*b/se*	*b/se*
Average Duration of Accuracte Readings	0.047	-0.098**	0.01		0.091**	-0.005	-0.001	-0.002	-0.014	-0.027	-0.026	-0.004
	0.0314	0.0367	0.0293		0.0331	0.0364	0.0379	0.037	0.0387	0.0375	0.0378	0.0366
2 Syllable Word		0.274***				-0.02	-0.019	-0.018	-0.008	-0.008	-0.009	-0.029
		0.0547				0.0607	0.0617	0.0612	0.0624	0.0607	0.0608	0.061
3 Syllable Word		0.559***				0.210*	0.208*	0.210*	0.220**	0.238**	0.237**	0.211*
		0.0781				0.0825	0.0848	0.0832	0.0854	0.0831	0.0833	0.0828
Target is Legal			0.653***			0.618***	0.617***	0.616***	0.613***	0.615***	0.616***	0.632***
			0.0518			0.0612	0.0617	0.0617	0.0626	0.0611	0.0612	0.0616
Count of Accurate Passage Readings				.101***	0.172***	0.149***	0.149***	0.149***	0.153***	0.152***	0.149***	0.145***
				0.0212	0.0439	0.0412	0.0416	0.0415	0.0421	0.0411	0.0411	0.0417
Prior Othographic Knowledge							0.007					
							0.039					
Morphological Awareness								0.004				
								0.0266				
Verbal Ability									0.001			
									0.0235			
RAN Letters										0.059*		
										0.0246		
RAN Composite											0.065*	
											0.031	
Print Exposure												-0.002
												0.023
Constant	0.092	0.173*	-0.007	-0.201*	-0.654**	-0.570**	-0.577**	-0.576**	-0.574**	-0.537**	-0.527**	-0.555**
	0.0674	0.0703	0.0632	0.079	0.2014	0.1903	0.1917	0.1916	0.1955	0.1903	0.1911	0.1923
n	1047	1047	1047	1171	1047	1047	1039	1040	1025	1047	1047	1038
Number of Groups	93	93	93	93	93	93	91	92	91	93	93	92
Minimum Number of Obs per Group	1	1	1	1	1	1	1	1	1	1	1	1
Average Number of Obs per Group	11.258	11.258	11.258	12.6	11.258	11.258	11.418	11.304	11.264	11.258	11.258	11.283
Maximum Number of Obs per Group	20	20	20	21	20	20	20	20	20	20	20	20
Within *R Squared*	0	0.053	0.136	0.016	0.011	0.153	0.153	0.153	0.153	0.154	0.154	0.157
Between *R Squared*	0.036	0.027	0.042	0.06	0.046	0.067	0.058	0.06	0.06	0.127	0.122	0.071
Overall *R Squared*	0.002	0.053	0.134	0.019	0.017	0.154	0.153	0.153	0.152	0.158	0.157	0.157

*Note: * p≤.05, **p≤.01, ***p≤.001*

Model 1 demonstrates that the average duration of accurate passage target readings had no effect on the naming measure of orthographic learning.

Model 2, however, controls for syllable number, and a significant negative effect of duration of reading targets on orthographic learning is observed. Controlling for syllable number is crucial, as how long it takes to read a given target is directly related to the number of syllables it contains. Moving from 1-syllable to 2-syllable words, the speed advantage of target over foil increased by .27 seconds. Moving from 1-syllable to 2-syllable words, the speed advantage improved by .56 seconds.

Model 3 reveals that the effect of decoding speed of accurate passage targets on orthographic learning disappeared, once the legality of the target is controlled for. As described earlier, each word pair in multisyllabic words contained one legal and one illegal alternative (*transnooping*/*trunsnoopung*). Holding decoding speed of targets constant, the differences in reading times (foil minus target) between the condition in which the familiar target is morphologically legal and the unfamiliar foil is morphologically illegal, and the reverse condition, was increase by .65 seconds, on average. This variable alone accounted for 13% of the variation in naming posttest performance.

Model 4 introduces accuracy, revealing that for every additional target read accurately (a maximum of 4), the speed advantage of target over foil increased by .10 seconds.

Model 5 examines the effects of duration and accuracy, controlling for one another. Once duration was held constant, the effect of accurate passage reading jumped from .10 seconds per accurately read word to .17 seconds per accurately read word.

Model 6 enters all of the relevant word and performance variables into one regression model. Not surprisingly, given the results of Model 3, duration of target reading had no significant impact on orthographic learning. In addition, once we control for target legality and decoding accuracy, there was no difference in orthographic learning observed between 1- and 2-syllable words. The gain for 3-syllable words over 1-syllable words was also reduced to about .21 seconds.

Models 7 through 12 retain the variables entered in Model 6, then add in student-level variables, one at a time, in order to examine their effect on orthography learning. The variables examined were prior orthographic knowledge, morphological awareness, verbal ability, rapid automatized naming, and print exposure. After controlling for decoding speed, accuracy, word length and legality), the only variable that had a significant impact on orthographic learning was rapid automatized naming, for both RAN Letters, and RAN Composite (consisting of Letters, Digits, and Objects). For every increase of 1 second on the RAN Letters task, the advantage of target over foil in the naming task increased by .06 seconds. For every increase of 1 second on the RAN Composite task, the advantage of target over foil increased by .07 seconds. The coefficients for duration, syllable number, target legality, and decoding accuracy remained stable throughout these regressions.

In sum, decoding speed of targets in passage reading had no effect on orthographic learning as measured by the naming posttest, after controlling for morphological legality of the target. This cannot be interpreted simply as the effect of legality, but rather must be understood as the effect of having a familiar legal word placed in opposition to an unfamiliar illegal word vs. having a familiar illegal word placed in opposition to an unfamiliar legal word. Decoding accuracy in passage reading and rapid automatized naming, on the other hand, did positively impact orthographic learning, when controlling for decoding speed, legality of target, and word length.

Discussion

The present investigation set out to deepen our understanding of how children approach new words and create reliable mental representations needed for quick and effortless retrieval (i.e., automatic word recognition). Direct teaching of the rote association between the orthography and pronunciation of every new word is an untenable proposition, given the massive number of new words encountered throughout reading development. The use of context to predict the identity of unfamiliar words is also a poor candidate for learning new words, as it offers a mere 1 in 10 chance to accurately predict content words (Gough, 1983).

The self-teaching hypothesis (Jorm & Share, 1983; Share, 1995; 1999) proposes that children are able to learn the orthographic structure of words on their own, through the experience of phonologically recoding them. The first aim of the present study was to examine whether second grade readers of English were able to independently "self-teach" the orthography of unfamiliar letter strings after encountering them only a few times and, if so, would accurate phonological recoding prove to be the primary mechanism for self-teaching. Included in the investigation was an analysis of the decoding speed and accuracy trajectory a reader follows when learning a new word over the course of four encounters. Understanding how fast or slow, or accurate or inaccurate decoding in the first encounter shapes future encounters with the same word has important implications for reading instruction, especially for children with reading disabilities. Our final goal was to explore other factors—factors within the word itself, factors related to the process of decoding, and factors within the individual reader—that might influence the ability to learn the orthography of unfamiliar words, above and beyond the contribution of accurate phonological recoding. The preponderance of research thus far has investigated orthographic learning in 1-syllable words. The present study expanded analyses to 1-, 2-, and 3-syllable words, providing a valuable opportunity to examine how word length and morphology might also play a role in the acquisition of orthographic representations.

Independent Self-Teaching

After just four encounters with unfamiliar target words embedded in short passages, these young readers demonstrated robust orthographic learning on both posttests when data were collapsed across all syllable and morphological conditions. They selected their target words 27% more frequently than would be expected by chance in the Orthographic choice posttest. When asked to read both their targets and foils in the Naming posttest, they read their targets significantly faster, by almost one-fifth of a second. Because the children were given no feedback whatsoever while reading the passages or taking the posttests, it can be assumed that they learned about the orthography of the novel letter strings on their own, and then remembered what they had learned well enough to recognize their targets in a multiple choice format and read them more quickly than novel letter strings that they had not seen. These findings add empirical support to past research that demonstrates children do self-teach unfamiliar words, when reading in Hebrew (Share, 1999; Share, 2010), Dutch (Reitsma, 1983a, 1983b; deJong & Share, 2007), and English (Bowey & Muller, 2005; Cunningham, 2006; Cunningham, et al., 2002; MacEachron, 2009).

Decoding Accuracy in Passage Reading

The self-teaching hypothesis argues that the central means by which readers learn new words is through the translation of print to sound. More specifically, the careful attention a reader must pay to the order and identity of the letters in a new word provides the opportunity to transform the visual patterns of letters into mental representations. If attending to this word-specific information is the mechanism for creating orthographic representations, it follows that accurate decoding is crucial to creating accurate entries in the mental lexicon. Therefore, analyzing decoding accuracy for the target pseudowords embedded in the passages was a necessary first step in examining whether accurate decoding predicted orthographic learning.

When data for all participants and all targets were collapsed across word length and morphological legality, accuracy was measured at 71%. This is consistent with the 68% accuracy Share (2010) found in second grade readers of Hebrew, and the 74% accuracy Cunningham et al. (2002) found in second graders of English. These high percentages of accuracy in decoding indicate that when children encounter unfamiliar words that use letter-sound correspondences and rules at their level of expertise, the opportunity for self-teaching is present. Additionally, an intriguing story emerges from the present study about the effects of two particular qualities of the word—morphological legality and length—on accuracy.

Effect of morphology. Frost, Kugler, Deutsch, and Forster (2005) found that when adults read English words, the morphological characteristics of the word are processed even before the orthographic, phonological, and semantic properties. Given the link between children's morphological awareness and spelling skill (Fowler & Liberman, 1995), it seems reasonable that young readers attuned to morphological information use it while visually processing orthography.

The findings in the present study provide strong evidence to support this assumption. Morphologically legal targets (i.e., targets containing real affixes such as *dis* and *ing*) of any length were decoded more accurately than their morphologically illegal counterparts (i.e., those containing made-up affixes such as *das* and *ong*). In fact, the legal condition provided a 16% accuracy advantage for 2-syllable targets, and almost double that (29%) for 3-syllable targets. These highly significant decoding accuracy advantages ($p < .001$) in legal targets support the contention that when children have had previous opportunities to develop accurate mental representations of morphemes, they automatically access these representations in new words encountered (Bhattacharya & Ehri, 2004; Ehri, 2005; Schreuder & Baayen, 1995). Because accuracy was all but assured for the morphemes that were automatically retrieved from the mental lexicon, only the root had to be decoded, making increased accuracy of the entire target a logical consequence. The fact that morphological legality conferred a greater accuracy advantage in the 3-syllable condition than in the 2-syllable condition is an important finding. It demonstrates that when novel letter strings are merely sequences of letters with no recognizable units that can be retrieved from the mental lexicon, word length matters. The longer the letter string, the more individual letters to process and, consequently, the more opportunities there are for decoding errors. This leads into the next within-word characteristic our study examined for its impact on decoding accuracy and subsequent orthographic learning—word length.

Effect of word length. Baddeley et al. (1975) argued that word length influences decoding accuracy through verbal working memory. All else being equal, longer words have more individual units to process than shorter words and require more time to process—both visually and phonologically. The more time it takes to decode an unfamiliar letter string, the greater the demand on working memory and the more opportunities for decoding errors. All teachers of young readers have witnessed a child slowly and effortfully decoding a long novel letter string, and forgetting the sounds for the first few letters by the time the last letters are reached. It is no surprise that accuracy is compromised. But in this study, we analyzed word length effects when "all else" was not equal; some words were morphologically legal and some were illegal. Results for word length effect differed, depending on the morphological condition.

Overall, shorter words were, decoded more accurately than longer words (1-syllable words = 89% accurate; 2-syllable words = 69% accuracy; 3-syllable words = 62% accurate), with the biggest difference found between 1- and 2-syllable words (20 percentage points). These results were highly consistent with the findings of Share (2010); second graders read 1-syllable Hebrew words with 83% accuracy and 3-syllable Hebrew words with 62% accuracy. MacEachron (2009) found a similar overall word length effect with first graders reading English, although accuracy rates were slightly lower (1-syllable = 76% and 2-syllable = 53%). Lower accuracy rates make sense when considering the fact that first graders have had one less year of reading instruction than second graders.

Although there was a significant difference in accuracy between 2- and 3-syllable words (7 percentage points), it was driven solely by differences in the illegal morphological condition.

When children encountered 2- and 3-syllable targets with legal affixes, there was no word length effect. This finding suggests that the children used their pre-established orthographic representations for the affixes, leaving only one unfamiliar part to decode—the root. Looking at a specific example from the study clarifies the reason why a word length effect was not found. A child encountering the 3-syllable target *disfeekment* had only to decode the root *feek*, just as a child encountering the 2-syllable target *deatful* had only to decode the root *deat.* In the illegal condition, however, a word length effect was found. Without pre-established orthographic representations to facilitate decoding, all of the individual graphemes had to be carefully attended to and decoded. Less accuracy in longer words would be expected, given the greater number of units to process both visually and phonologically, the greater the demand on working memory, and the increase in opportunities for error in longer words.

Trajectory. A compelling finding of the present study is that these young readers were likely to stay with the pronunciation they generated at the first encounter with their target pseudoword through all subsequent encounters. This was true whether they had accurately or inaccurately decoded it on the first try. Connectionist learning algorithms (Harm & Seidenberg, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996) predict the power of the first learning trial. Share (2004) explained the phenomena: "As weights are adjusted over the course of training, the magnitude of changes gradually diminishes toward asymptotic values" (Share, 2004). In this study, if the children were accurate at the first encounter, there was a there was a 96% chance of being accurate at the second encounter, if accurate again, there was a 97% chance of being accurate at the third encounter. Finally, if they were accurate the third time, there was a 99% chance of being accurate at the fourth encounter. The trajectory for inaccurate readings was similar, in that the children generally stayed with their first response; however, there was a small degree of change from inaccurate to accurate along the way. Of those who were inaccurate at the first encounter, 14% changed to an accurate pronunciation on the second exposure, and the majority of those children remained accurate in the reaming encounters. The other 86% read the word inaccurately again at the second exposure, 92% of those repeated the misreading at the 3rd exposure, and 96% of those were inaccurate again at the fourth exposure. In sum, 90% of the students who read the word accurately the first time, read it accurately all four times. 76% of the students who misread the word at the first encounter, misread it all four times. The implications are profound. Children's accuracy at their first encounter with a new word appears to determine what they are likely to self-teach over repeated exposures—be it a correct link between orthography and phonology or an incorrect link. It can be inferred from these results that a child can become automatic not only with an accurate reading of a word, but also with a misreading.

It is important to be cautious when generalizing from pseudowords to real words. As children decode real words, even if they are as novel to them as pseudowords, candidate pronunciations are constrained by semantic fit. Even so, most teachers and clinicians have observed children "overlearning" misreadings, and then using the substitutions in subsequent readings in the same way these second graders did. These findings underscore the importance of a rich reading curriculum that provides instruction of the alphabetic principle, exposure and practice with multiple levels of letter-sound correspondences and the rules that govern them, and comprehension strategies to help solve decoding ambiguities of new words encountered. Continual feedback from teachers is also critical, to limit opportunities for reinforcement of faulty representations.

Decoding Speed in Passage Reading

More recent self-teaching studies have examined the role of decoding speed in orthographic learning. Lurie (2004) found speed of decoding to be a contributor to developing orthographic representations with third grade readers of Hebrew, Bowey and Muller (2005) found it to matter in third grade readers of English, and MacEachron (2009) found it to contribute to orthographic learning in first grade readers of English. In a number of studies with readers of pointed Hebrew, which is a shallow orthography (Share, 2004; Share & Shalev, 2004; Share, 2010), the data suggested that, in the early stages of reading development, decoding speed rather than accuracy was the "critical bottleneck in orthographic learning" (Share, 2010, p. 3). Share hypothesized that novice readers of shallow orthographies do not develop sensitivity to word-specific orthographic detail because their highly regular orthography allows them to accurate decode all words that they encounter. Children reading deeper orthographies like English are, on the other hand, keenly aware early on of the unpredictable nature of their orthography and, consequently, do develop sensitivity to orthographic detail. It is not until the end of second grade that readers of Hebrew are exposed to words that require greater lexical and morphological knowledge (Share, 2010) and accuracy begins to play a significant role in orthographic learning.

The present study asks the question: Might the speed with which individual words are decoded by readers of English influence the creation of mental orthographic representations in the same way that Perfetti (1985) suggested rapid word recognition facilitates reading comprehension in his verbal efficiency theory? In order to answer this question, decoding speed of targets in passage reading were analyzed. The mean decoding duration of passage words was 2.12 seconds. This is highly consistent with Share (2010), where same age readers of Hebrew read multisyllabic legal and illegal targets in 2.10 seconds. First grade readers of English in MacEachron (2009), had a slightly slower mean decoding duration of 2.37 seconds, which is not surprising, given their earlier stage in reading development.

Effect of morphology. Morphologically legal words were read much faster than morphologically illegal words. Children read 2-syllable targets with real affixes 10% faster than those with made-up affixes. The advantage doubled with 3-syllable targets, where decoding durations were 22% faster for targets with real affixes. These percentages are consistent with findings by MacEachron (2009), where children read 2-syllable legal targets 11% faster than illegal targets, and Share (2010), where children read 3-syllable targets 18% faster than illegal targets. Results support the contention that children are able to more quickly read words that contain units for which they have already stored orthographic representations (i.e., a child who has mental representations for the affixes *re* and *ing* will be able to read the word *repacking* faster than a child who has not formed these representations).

Effect of word length. Consistent with a word length effect found in previous findings (MacEachron, 2009; Share, 2010), shorter words were read significantly faster than longer words (1-syllable mean = 1.63 seconds; 2-syllable mean = 2.00 seconds; 3-syllable mean = 2.68 seconds). This is not surprising, as longer unfamiliar letter strings have more letters to process and sounds to pronounce than shorter unfamiliar letter strings have. Even the advantage of morphological legality discussed above did not negate the word length effect. In other words, 2-

syllable words were always read faster on average than 3-syllable words, even if the longer words had recognizable morphemes and the shorter word did not.

Trajectory. Again, the first encounter with the new word was pivotal. Mean decoding duration was at its peak at 3.33 seconds. Upon the second encounter, mean decoding duration dropped dramatically to 2.05 seconds. From then on, mean durations decreased gradually and very little, to 1.94 seconds for the third exposure, and 1.82 seconds for the fourth. In much the same way that the magnitude of changes in decoding accuracy diminished toward asymptotic values after the first exposure, the magnitude of changes in decoding speed gradually diminished, supporting findings from studies of repetition priming with pseudowords (Logan, 1988; Scarborough, Cortese, & Scarborough, 1977) and consistent with the connectionist predictions of single-trial learning.

Another finding of note is the similarity of the decoding speed trajectories of accurate and inaccurate decoders. Those readers who read all four targets in a passage accurately were faster decoders at each of the four encounter points than the readers who read all four targets inaccurately, but the trajectory graphs are virtually identical in form—both show a steep drop from the first encounter to the second, then gradually level off. Whether the reader was accurate or inaccurate, these results imply that orthographic learning happens quickly, underscoring again the weighty significance of first trial learning.

Because pseudowords were used, caution is warranted when generalizing results to real word learning. However, because the pattern of a strong initial decrease in time that gradually decelerates over subsequent exposures to the target is consistent with classic power functions typical of skill acquisition in many domains (Logan, 1988, 2002; Newell & Rosenbloom, 1981), these findings are intriguing and should be further investigated in a real word paradigm.

Orthographic Learning

Overall. Did greater decoding accuracy of passage targets translate into greater orthographic learning? Two posttests were given seven days after exposures to the passage targets—the orthographic choice task, and the naming task. Because the two posttests were considered quite different in their demands and the skills measured, they were analyzed separately. In the orthographic choice posttest, the children were simply asked to choose their target word from multiple options. The stimulus was visual only, and the response required was a visual-motor task; they were to simply circle the correct answer. Success on the naming posttest, on the other hand, required what Bowey and Muller (2005) refer to as “functional orthographic representations that amalgamate graphemic and phonological information” (p. 218). In other words, this posttest required retrieval of both a phonological and orthographic representation of the target. While a number of studies using the self-teaching paradigm have aggregated results from posttests into a single orthographic learning composite (e.g., Cunningham, 2006; Cunningham et al., 2002; MacEachron, 2009), others have analyzed the posttests separately (e.g., Share, 1999; 2004; 2010) as was done in the present study.

Orthographic choice posttest. Data from the orthographic choice posttest, when collapsed across all word length and morphological conditions, demonstrated robust orthographic learning. Overall, children chose their target word correctly 27% more frequently than what would be expected by chance. These findings are consistent with Cunningham’s work

(2006), which found that first grade readers of English chose their targets 24% above chance, and Share (2004), who found that third grade readers of Hebrew chose their targets 22% above chance. The findings are not, however, consistent with MacEachron (2009), who found the mean accuracy to be only 15% above chance for first grade readers of English. The difference between her results and the results of this study cannot be due solely to grade level differences, because first graders in the Cunningham study (2006) had findings consistent with ours. A more likely cause relates to the complexity of the words used—the Cunningham study used all 1-syllable targets and the MacEachron study included 2-syllable targets. Share (2010), found the mean accuracy to be only 12% above chance for second grader readers of Hebrew. His much lower accuracy results may be due to the theory that beginning readers of highly regular orthographies are insensitive to word-specific orthographic details, and therefore do not demonstrate orthographic learning until later stages of reading development. While differences in grade level, time of year, and language specific orthography are potential sources of outcome variability, another probable cause of the discrepant results is variation in test format. Although the studies all used a multiple-choice format for this posttest, some offered two choices, and others offered four. There were even significant variations across studies in how foils were chosen within the. So although percentages over chance were used for comparisons, the different test formats make valid comparisons untenable.

Naming posttest. When the data were collapsed across all word length and morphological conditions, the speed with which children accurately read their targets was significantly faster than the speed with which they accurately read the foils, indicating an overall finding of orthographic learning. A number of past studies reported similar findings of orthographic learning on the naming posttest (Bowey & Muller, 2005; Cunningham et al., 2002; Ehri & Saltmarsh, 1995; Reitsma, 1983a; Share, 1995); however, Share (2010) found no evidence of orthographic learning on the Naming posttest in second grade readers of Hebrew, nor did MacEachron (2009) in first grade readers of English or Kyte and Johnson (2006) in fourth and fifth grader readers of English. Differences in outcomes are most likely attributable to a constellation of factors: (a) different methods of measuring naming speed, from stop watches and sound waves to specialized software with automated time stamps, (b) different ways of operationalizing decoding time of words, from the onset of stimulus to the onset of pronunciation, the onset of stimulus to the offset of pronunciation, and from the onset of pronunciation to the offset of pronunciation, (c) measurement error due to unsophisticated equipment, (d) unpredictability of child behaviors that interfere with quality of recordings, and (e) differences in the tasks themselves (e.g., some attempt to reduce priming effects with filler tasks and some do not). Both Share (2010) and MacEachron (2009) have questioned the reliability of the Naming posttest because of markedly inconsistent findings.

Effect of Morphology. The abundance of new vocabulary that occurs in print as children move up in grades is due in part to the increase in affixed words. While there is much we still do not understand about the process of acquiring morphological knowledge, research has shown that a child's ability to segment and manipulate morphemes within words is related to word reading (Fowler & Liberman, 1995; Singson, Mahoney, & Mann, 2000). According to a model put forth by Schreuder and Baayen (1995), children develop mental representations of affixes by first detecting patterns in words they know (e.g., *er* in *boxer*, *jumper*), and then accessing these representations in new words they encounter. Our study examined the effect that these previously established mental representations for morphemes have on orthographic learning of new words, using 2- and 3-syllable targets that were either affixed with real morphemes or made-up morphemes.

Orthographic choice posttest. Children performed significantly better on the orthographic choice posttest when their targets were morphologically legal, evidence to support the advantage of pre-existing morpheme representations. This was true with both 2- and 3-syllable targets, although the advantage of pre-existing representations of morphemes was greater for 3-syllable targets. As mentioned in the discussion on word-length effects, this makes sense given the fact that without the advantage of pre-established morphemic representations, children have more orthographic information to process within the 3-syllable words than within the 2-syllable words, putting a heavier load on working memory. Perfetti (1992) linked working memory inefficiencies to the disruption of temporary representations during effortful phonological recoding. It follows that only partial or inaccurate representations are formed when working memory is overtaxed (Brady, 1997).

Naming posttest. Unfortunately, it is difficult to unravel the influence of morphology on orthographic learning as measured by the naming posttest, given the confound inherent to the target/foil design of the task. In cases where the target was legal and the foil was illegal, the children were significantly faster at naming their target, demonstrating robust orthographic learning. However, if their target was illegal and the foil was legal, there was no significant difference in naming time. It is possible that a legal target provides two advantages over an illegal foil. First, the child has seen the word before and second, the child is likely to have pre-established morphemic representations, both of which may facilitate the ability to create a more complete representation. Alternatively, the illegal target and legal foil each have one advantage and one disadvantage, creating a situation where the advantage is canceled out by the disadvantage. The illegal target has the advantage of having been seen before, but the disadvantage of no pre-established morphemic representations. The legal foil has the advantage of pre-established morphemic representations but the disadvantage of never having been seen before. When we controlled for whether or not the word had been seen before, results of the naming posttest demonstrate no influence of morphological legality on orthographic learning.

It would be interesting to design a posttest that overcomes this confound. The current design is only capable of examining the effect of legal target/illegal foil pairs or illegal target/legal foil pairs. A design that creates a condition in which both the target and foil are morphologically legal and an alternative condition in which both the target and foil are morphologically illegal would allow us to isolate these additional effects.

Effect of Word length. Did children learn more about the orthography of targets depending on their length? Word length can be thought of as either an orthographic dimension (e.g., number of letters in the word) or a phonographic dimension (e.g., number of phonemes/syllables, and the articulatory times needed to pronounce them). In this study, the 1-, 2, and 3-syllable targets were controlled on both the orthographic and phonographic dimensions for word length. The 1-syllable word pairs were identical in letter number and articulatory lengths, due to their homophonic nature (e.g., *froon*/*frune*). The 2- and 3-syllable pairs were identical in letter number, and very similar in articulatory length given that the root was the same for both members of the pair, and the affixes only differed in a single vowel sound (e.g., *veetful*/*veetfel*; *transfibement*/*trunsfibemont*). When orthographic learning was examined by word length, the results varied, depending on the posttest measure.

Orthographic choice posttest. While the children showed robust orthographic learning for words of all lengths on the orthographic choice posttest, they showed greater learning with 2-syllable words (choosing them with a frequency 30% above chance) than with 1- and 3-syllable words (choosing them with frequencies 25% and 26% above chance, respectively). Although these differences are statistically significant, caution is imperative when interpreting these results. First, the fact that the 1-syllable target pairs were homophones (e.g., *froon/*frune) and the 2-syllable target pairs were not (e.g., *misgurd/musgurd*) is a confound that must be addressed. We can assume that the knowledge children depend upon for accurate word identification is an integrated system that includes both phonological and orthographic associations (Ehri, 1998; Perfetti, 1992; Share, 1995); however, because homophones are identical in pronunciation, the only distinguishing feature that could be used to aid the children on the posttest was orthography. Alternatively, for the multisyllabic targets, both phonological and orthographic information likely played a role in the choices the children made, as both offered distinctions that could aid in choosing the correct option. Using an example to clarify, the only information a child had when asked to distinguish the target *froon* from the foil *frune* is the orthographic representation formed through exposure to the target. But when asked to distinguish the 2-syllable target *misgurd* from the foil *musgurd*, the child had two kinds of information to rely upon—the orthographic representation (*mis* vs. *mus*) and the phonological representation (/*mis*/ vs. /*mus*/).

Regarding the apparent advantage of 2-syllable targets over 3-syllable targets for orthographic learning, the assumption of a word length effect is, again, a spurious conclusion. Closer examination of the data reveals that the difference is driven not by word length, but by morphological legality. In the legal condition, the children chose correct answers in the same proportion beyond chance odds for both 2- and 3-syllable targets (77% and 76%, respectively); whereas, in the illegal condition, they chose correct answers beyond chance odds in very different proportions (61% for 2-syllable targets vs. a much lower 47% for 3-syllable targets). Assuming the children had previously formed orthographic representations for the real affixes in their morphologically legal targets (Bhattacharya & Ehri, 2004; Ehri, 2005; Schreuder & Baayen, 1995), the only new information to be learned was the root. That would explain the findings of similar success in both syllable conditions for legal targets. In multisyllabic targets that contained made-up affixes requiring effortful decoding of each individual grapheme to phoneme, word length did make a difference. There was more new information to take note of, store, and retrieve in the longer 3-syllable targets, than in the 2-syllable targets.

Naming posttest. There was no evidence of orthographic learning for 1-syllable targets as measured by the naming posttest. This finding is consistent with a number of past self-teaching studies that have used naming posttests (Kyte & Johnson, 2006; MacEachron, 2009; for dyslexics in Share & Shalev, 2004), yet inconsistent with others that have found differences (Bowey & Muller, 2005; Cunningham et al., 2002; Ehri & Saltmarsh, 1995; Reitsma, 1983a; Share, 1995.) As mentioned earlier, these inconsistent findings are likely to be a result of the variations in data collection techniques, the different ways that duration times are operationalized, the difficulties inherent in determining the exact end-of-a-word pronunciation from child to child, and the experimental error involved in trying to capture and measure such short times with available technology.

Although there was no evidence for orthographic learning in the present study with 1-syllable targets, there was evidence with 2- and 3-syllable targets. Children named their 2-syllable targets one fourth of a second faster than their 2-syllable foils (an increase in speed of about 13%), and they named their 3-syllable targets almost one half of a second faster than their 3-syllable foils (an increase in speed of over 14%). It might appear that as word length increases, orthographic learning increases; however, the differences in speed between naming 2-syllable targets and foils (.25 seconds faster for targets over foils) and 3-syllable targets and foils (.40 seconds faster for targets over foils) is not statistically significant. In sum, there was no measured word length effect on orthographic learning between 2- and 3-syllable words.

Predictors of Orthographic Learning

The self-teaching hypothesis posits that the process of phonological recoding—translating print to sound—is the primary mechanism by which readers independently learn and store orthographic representations of new words they encounter. In our first set of analyses, we explored how accurately and quickly children decoded targets embedded in passages, and the effects of word length and morphology on their accuracy and speed. Next, we examined the trajectories second graders follow for accuracy and speed over the course of four encounters with a new word. We then investigated whether or not the children learned the orthography of the novel words presented and how morphology and word length influenced orthographic learning. The final aim of the study was to explore through a series of hierarchical logistic and linear regression analyses whether orthographic learning through self-teaching is due solely to accuracy and speed of decoding, or whether other variables, such as morphology, word length, or individual differences within children predicted orthographic learning.

Decisions on which within-child factors to investigate were driven by past research in the field. Cunningham (2006) and Cunningham et al. (2002) provided evidence that children's prior orthographic knowledge influences their ability to self-teach. There is an ongoing debate in the field about the role of rapid automatized naming (RAN) in orthographic learning; Bowers and Wolf (1993) suggested it provided an independent contribution, yet others have argued it explains little or no variance independent of decoding ability (Bowey & Muller, 2005; Cunningham, 2006; Cunningham et al., 2002). Print exposure has been identified as a factor in reading ability (e.g., Anderson, Wilson, & Fielding, 1988; Cipielewski & Stanovich, 1992; Echols, West, Stanovich, & Zehr, 1996), possibly facilitating self-teaching by increasing orthographic knowledge. The contribution of morphological awareness has been demonstrated to influence word recognition (e.g., Beyersmann et al., 2011), and was explored because of its particular pertinence to the present study's examination of morphology's effect on speed, accuracy, and orthographic learning. And finally, vocabulary, widely studied for its link to a number of reading outcomes (e.g., Bowey, 1995; Caravolas, Hulme, & Snowling, 2001; Elbro, Borstrom, & Petersen, 1998) was explored for its potential contribution to orthographic representations.

Decoding accuracy. Because decoding accuracy is central to the self-teaching hypothesis, playing the role of the self-teacher, it was expected to predict orthographic learning in this study in all syllable conditions. While accuracy did predict orthographic learning for 2- and 3-syllable words, it did not predict it for 1-syllable words. Although research in shallow orthographies has observed an absence of orthographic learning in beginning readers, despite high levels of accuracy (Share, 2004; Share & Shalev, 2004), this pattern was not expected in second grader readers of English, a deep orthography that purportedly forces greater sensitivity to word-specific details out of necessity. The theory posits that in shallow orthographies, beginning readers can rely on the regularity of sound-symbol correspondences, so they do (instead of creating orthographic representations). In more irregular orthographies, like English, beginning readers learn quickly that relying on sound-symbol correspondences does not work in all cases. This "need to notice" factor results in a sensitivity toward orthographic details that, in turn, facilitates the creation of orthographic representations. It is unclear why the high level of decoding accuracy (89%) with 1-syllable words did not result in orthographic learning as measured by the Orthographic choice test. The most likely reason is that the 1-syllable words may have been so easy for the second graders that there was not enough variance to predict orthographic learning.

Results of the naming posttest demonstrate that decoding accuracy, when entered alone, confers a significant advantage on orthographic learning. When decoding speed is held constant, accuracy has an even more powerful effect. The effect of accuracy remained stable, even when all other word variables (decoding speed, word length, and legality) were held constant, and within-child variables (prior orthographic knowledge, morphological awareness, verbal ability, RAN letters, and RAN Composite) were controlled.

Decoding speed. Decoding speed has moved to the forefront in more recent self-teaching studies for a number of reasons. It has long been observed that some children with dyslexia can become accurate decoders, but fail to become fluent readers. Lovett, Steinbach, & Frijters (2000) suggested two subtypes of reading disability—accuracy-disabled readers and rate-disabled readers. In other words, for some children on the continuum of reading skill, decoding speed rather than decoding accuracy is the most salient issue. In addition, it has been hypothesized that for young readers or shallow orthographies, decoding speed may be the "critical bottleneck in orthographic learning" (Share, 2010).

In this study, decoding speed contributed to performance on the orthographic choice posttest for 3-syllable words only. The faster a child decoded the 3-syllable target words in the passages, the significantly greater the odds of success on the posttest. The effect was significant; it maintained its positive effect even after controlling for decoding accuracy, morphological legality, and prior orthographic knowledge. It is unclear why decoding speed predicted orthographic learning only in the 3-syllable condition. One possible factor that has been investigated by Lurie (2004), Share (2010) and MacEachron (2009) with conflicting empirical results is finding of a 2-second memory store limit for phonological information (Baddeley, Thomson, & Buchanan, 1975; Naveh-Benjamin & Ayres, 1986). Perhaps the longer decoding times for 3-syllable words (mean = 2.68 seconds) makes decoding speed more likely to impact the quality of orthographic representations.

Results of the naming posttest show that, controlling for word length, the faster a reader decoded the target word in passages, the greater the orthographic learning. Controlling for word length was critical, because the more units there were to decode, the longer it took. When accuracy was held constant, decoding speed influenced orthographic learning, but this time in the opposite direction. Instead of faster speed of decoding conferring greater orthographic learning, slower speed of decoding conferred greater orthographic learning. The effect of decoding speed disappeared, however, once the legality of the target was held constant. The reason for this is related to the experimental design of the naming task.

Word length. Because the orthographic choice posttest was analyzed for each syllable number separately, word length effects on performance are discussed within the context of each of the variables.

Results of the naming posttest indicate that when decoding speed of passage targets was held constant, word length had an impact on orthographic learning. Going from 1-syllable to 2-syllables increased the advantage of target speed over foil by .27 seconds, indicating greater orthographic learning for 2-syllable words than 1-syllable words. Going from 1-syllable to 3-syllables increased the advantage of target speed over foil by .56 seconds, again indicating that more orthographic learning occurred with the longer word. This makes sense, in light of the fact that the children did not show evidence of orthographic learning for 1-syllable words in our earlier analysis of the naming posttest, but they did for 2- and 3-syllable words.

Morphological legality. The impact on orthographic learning of recognizable morphemes in words was evident in the orthographic choice test for both 2- and 3-syllable words. The effect was particularly robust in 2-syllable words, where a legal target resulted in correct choices with almost twice the odds found for an illegal target. Morphological legality maintained its effect even after controlling for the effects of all other variables. Its impact was much less pronounced in 3-syllable words, drifting across the margin of significance from model to model, making its impact less clear. It is possible that the two-option multiple choice format for 2-syllable words vs. the four-option multiple choice format for 3-syllable words confounded the results. All four options for the 3-syllable words were very similar visually (*dismurfing, dasmurfing, dismurfung, dasmurfung*). If the children did not take the time to note the differences—either out of lack of interest, discouragement, or simply wanting to finish—they could have made errors that were unrelated to whether they had learned or not. The 2-syllable format had much less information to choose from (*veetful, veetfel*), requiring less attention and less effort to demonstrate learning.

Results for the effect of morphological legality on performance on the naming posttest are confounded by the design of the task. As described earlier, each word pair in multisyllabic words contained one legal and one illegal alternative (e.g., *transnooping*/*trunsnoopung*). The difference in reading times (foil-target) between legal target/illegal foil pairings and illegal target/legal foil pairings was large (.65 seconds, on average), alone accounting for 13% of the variation in naming posttest performance.

Prior orthographic knowledge. Prior orthographic knowledge predicted orthographic learning for all word lengths. The influence of prior orthographic knowledge remained strong, even after controlling for the influences of decoding speed and decoding accuracy. Findings for the contribution of prior orthographic knowledge are aligned with three recent studies using the self-teaching paradigm (Cunningham, 2006; Cunningham et al., 2002; MacEachron, 2009) that also found it to be an independent and significant contributor to orthographic learning. This is not surprising, given the fact that the theoretical underpinnings of prior orthographic knowledge suggest a critical relationship to the process of creating orthographic representations of new words (Cunningham, Perry, & Stanovich, 2001; Cunningham & Stanovich, 1991).

Prior orthographic knowledge did not contribute to performance on the naming posttest, once decoding speed, accuracy, target legality, and word length were held constant.

Morphological awareness. Prior experimental evidence has demonstrated that readers are capable of mentally decomposing words into morphemes they have been exposed to (e.g., roots, prefixes, suffixes), and subsequently retrieving their pronunciations as units for more automatic and fluent reading (Beyersmann, Castles, & Coltheart, 2011). Because it is clear that morphological structures are represented in the mental lexicon, they were examined to determine whether they contributed independently to the growth of orthographic knowledge. After controlling for decoding speed, decoding accuracy, and target legality, morphological awareness contributed to performance on the orthographic choice posttest for 2-syllable words, but not 3-syllable words. This is most likely related to our earlier findings, regarding the robust impact on morphological legality in 2-syllable words and the unclear impact on 3-syllable words. Again, the difference in number and types of choices presented on this task is a possible culprit. Similar to children's performance regarding prior orthographic knowledge, morphological awareness had no effect on naming posttest performance.

Rapid automatized naming (RAN). A number of studies have linked RAN to orthographic processing skill and word learning (Bowers & Wolf, 1993; Wolf, 1991; Wolf & Bowers, 1999; Wolf, Bowers, & Biddle, 2000; Wolf, O'Rourke, Gidney, Lovett, Cirino, & Morris, 2002); however, many other studies have found no evidence of a contribution of RAN independent of decoding ability (Bowey & Muller, 2005; Cunningham et al., 2002; MacEachron, 2009). It is a critical area of contention in the field, whereby RAN is believed by some investigators to be a key mechanism underlying children's ability to learn and store orthographic representations. In this study, despite our attempt to examine alphanumeric symbols in relation to orthographic processing skill, neither RAN Letters nor RAN Composite had an effect on orthographic learning, as measured by the orthographic choice posttest.

On the naming posttest, when holding all word-level variables (decoding speed, accuracy, length, legality) constant, RAN Letters and RAN Composite each, however, had a significant, albeit small, positive impact on orthographic learning. The reason that RAN impacted demonstrations of orthographic learning on the naming posttest and not the orthographic choice posttest may be related to the nature of the tasks. The ability to verbally name objects, letters or numbers requires automatic retrieval of the sound forms of words, in the same way that looking at a letter string requires retrieval of a sound form. In both tasks, speed is the critical factor. In the orthographic choice posttest, there is no requirement to match a phonological form with a visual form and thus may explain the lack of effect.

Print exposure. Print exposure is a variable that is expected to predict orthographic learning, since most of a child's exposure to the orthography of language is through authentic reading experiences. Stanovich, West, and Cunningham (1991) found robust correlations between print exposure and orthographic processing and print exposure and first grade reading ability, even after controlling for comprehension ability (Cunningham & Stanovich, 1997). Perfetti (2007) argued that the quality of orthographic representations and the orthographic knowledge they are built upon evolve from literacy and language experiences, and decoding words in print. In the present study, neither performance on the orthographic choice posttest nor performance on the naming posttest was impacted by a child's print exposure. Its influence may have been subsumed within the decoding accuracy, speed and prior orthographic knowledge variables, so we should not draw the conclusion from these findings that print exposure is not important to word recognition skills. Another possible reason for these null findings may be related to the Title Recognition Test itself. Because it was created in 1992, it is likely that some of the books that were readily recognizable then are no longer a part of current children's experience.

Verbal ability (vocabulary). Cognitive ability should always be considered as a potential contributor to any learning task. The Peabody Picture Vocabulary Test, a commonly used cognitive measure of verbal ability or intelligence, was administered to each child individually. Performance on the naming posttest was not predicted by verbal ability. Performance on the orthographic choice posttest was only impacted by verbal ability in the 3-syllable condition. One possible reason vocabulary was only linked to the longer words is that rarer vocabulary words are often multisyllabic. Perhaps an underlying constitutional facility for vocabulary development in some way prompts the development of other abilities essential to skilled reading. Walley, Metsala, and Garlock (2003) demonstrated that vocabulary growth prompts a lexical restructuring that is a precursor to phoneme awareness and subsequent reading ability. Garlock, Walley, and Metsala, (2001), found that receptive vocabulary knowledge was related to word reading.

Limitations

Finding a reliable method to capture decoding times of words was the greatest challenge of this study. Because the durations of spoken words are short, and the decoding time differences found among children are small, measurement error is an intractable problem. A hand held stop-watch and visual waveforms have been the most common techniques to capture decoding times, but human reaction times and the difficulty in accurately measuring waveforms introduce variability greater than the decoding duration differences we are studying. The automated methodology in this study was an improvement, but still introduced human variability since the trigger for the automated time stamp was pressing the return key on the computer. Even though the naming posttest is arguably the most direct test of orthographic learning as it relates to word reading, the technical difficulties of measuring decoding speed render it questionable in value.

Another limitation in the present study was the confound created in the design of the orthographic choice task. The fact that the task had a two-choice format for 1- and 2-syllable words, but a four-choice format for 3-syllable words made it difficult to compare results. The decision to have a different number of options for the different syllable conditions was driven by our effort to present all likely foils as options. Although percentage over chance was used in an attempt to standardize the comparison, the experience of taking each test was likely to be qualitatively different. In the 3-syllable condition, the four options looked very much alike. That factor, combined with the demand of attention to four options instead of just two, could have easily discouraged the children from taking the time necessary to show their orthographic learning. Future studies examining multisyllabic words should take this into consideration when designing posttests.

In experimental studies, our goal is often to isolate the effects of factors as we vary them. When studying complex cognitive processes like reading, we lose the ability to understand the integration of processes by doing this. The present study, for example, set out to study the effects of morphology on orthographic learning and word reading. By definition, morphemes are the smallest unit of *meaning* within words. Using pseudowords, as we did, ensured that the targets were unfamiliar to the children, but it also ensured a very inauthentic examination of morphology. Pseudowords carry no meaning. Seeing the *mis-* or *-ed* on a real word not only activates orthographic and phonological lexicons, it activates the syntactic and semantic lexicons as well. Consequently, an authentic study of morphological influences on orthographic learning can only be done with real words.

Summary and Future Directions

Individual words, and the ability to read and write them, are not just important for accessing meaning, they are important for generating meaning. Words do not merely *serve* connected text, they are the very essence of it. They are the clue, but they are also the meaning. Reading accurately is not enough. To get below and beyond the surface of print, we must become fluent. The ability to read words effortlessly and automatically allows us to preserve the flow of language and, in turn, the flow of thought. Simply put, automatic access to words in print is a powerful form of freedom—freedom to comprehend written language.

Fortunately, when children have the tools to read words—their meaning, an understanding of the alphabetic principle, phonological sensitivity, syntactic development, and knowledge of the functional units of their orthography—they can begin to teach themselves newly encountered words. The self-teaching hypothesis (Jorm & Share, 1983; Share, 1995; 1999) argues that the process of accurately translating print into sound is the mechanism by which the orthography of new words is learned, stored, and retrieved when needed. Through continued research in the self-teaching paradigm, we have learned, however, that accurate decoding is not always enough for orthographic learning to occur. Beginning readers in shallow orthographies such as pointed Hebrew demonstrated high levels of decoding accuracy with little or no resultant orthographic learning. The hallmark of remediated dyslexics is accurate, but slow reading, suggesting that they have not been able to from the orthographic representations in the mental lexicon for automatic word recognition, despite accurate decoding. Understanding what other factors influence the ability to form the orthographic representations necessary for fluent reading is important to reading researchers and educators, and even more important to those who struggle with reading.

The present study added to the growing body of research on orthographic processing, using pseudowords of varying lengths, some with recognizable morphemes and some without, to extend our understanding of how children process longer words as they develop as readers, and how they begin to unitize larger functional units in words for greater speed and accuracy. It provided clear evidence for the importance of first learning trials, demonstrating that children tend to stay with their pronunciation of a word upon first encounter, accurate or not. Knowing that children will self-teach a word, even incorrectly, makes it ever more important to front load children with appropriate skills and provide timely feedback before and during all opportunities for practice. Our findings added heft to the mounting evidence that prior orthographic knowledge (pre-existing knowledge of spelling conventions, permissible letter strings, orthographic representations) is a significant and independent predictor of orthographic learning in words of various lengths and morphological make-up.

Investigating the role of rapid automatized naming in this study raised more questions than it answered, adding fodder to the debate among some of the field's most respected researchers about its role in word reading. Neither RAN Letters nor a RAN Composite of letters, digits, and objects predicted performance on the orthographic choice posttest, but it did have a significant, albeit small, impact on the naming posttest, even after controlling for decoding speed, decoding accuracy, word length, and morphological legality. Although the naming posttest has reliability issues that were discussed earlier in the paper, the demands of the task are much more like those required in authentic reading—retrieving the pronunciation of a word to match its orthographic form. Rather than discard the naming task for its disadvantages as some have suggested, it may be a worthwhile endeavor to work on improving it.

Another intriguing finding was the predictive power of receptive vocabulary ability, but only on the orthographic learning of 3-syllable words. We are accustomed to linking vocabulary development with reading and listening comprehension and overall cognitive ability, but its connection to orthographic learning is less transparent. If the targets in the present study had been real words, it would be possible to suggest that the increased orthographic learning was influenced by vocabulary due to the semantic support it provides in new word learning. But pseudowords have no meaning, making that hypothesis untenable for this observation. A more interesting place to explore answers is Walley et al.'s (2003) hypothesis that vocabulary growth promotes a lexical restructuring that leads to phoneme awareness, enhanced word recognition and retrieval skills and, ultimately, higher reading ability.

Untangling the relationship between orthographic skill and word reading has provided insight into how most children self-teach the orthography of new words and create orthographic representations that lead to automatic word recognition and fluent reading. An interesting and valuable direction for future research is to investigate why, for some children, self-teaching does not occur to the same degree. For those readers, words never making their way into the mental lexicon for ready retrieval and fluent reading. Instead, words remain on the page, requiring effortful decoding each time they are encountered. Understanding why this happens may be a matter of science for researchers, but it is a matter of access for struggling readers.

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