EXPLORING THE RELATIONSHIP BETWEEN ORTHOGRAPHIC PROCESSING AND WORD READING

by

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This work is dedicated to Andrew; without his unwavering love and support, this work would not be possible.

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ABSTRACT

Relationships between various types of orthographic processing and word reading were explored in a sample of 90 second and third grade students in a one and a half year longitudinal study. Participants were administered tests of lexical and sublexical orthographic knowledge, orthographic learning, word reading accuracy, word reading fluency, irregular word reading, nonword decoding, phonological awareness, and nonverbal reasoning. Cross-lag hierarchical regression analyses were used in order to predict growth in the dependent variable. In all analyses, the controls of age, nonverbal reasoning, phonological awareness, and an earlier measure of the dependent variable were entered into the regression before the predictor variable. Generally, it was found that orthographic knowledge measures did not predict growth in word reading (with the exception of irregular word reading), whereas word reading measures predicted growth in orthographic knowledge. Orthographic learning did significantly predict growth in all measures of word reading except nonword decoding. Only word reading accuracy predicted growth in orthographic learning measures. Implications for reading development theory and reading education are discussed.

LIST OF ABBREVIATIONS USED

IWR	Irregular word reading
M	Mean
NR	Nonverbal reasoning
NWD	Nonword decoding
OK-L	Lexical orthographic knowledge
OK-SL	Sublexical orthographic knowledge
OL	Orthographic learning
PA	Phonological awareness
SD	Standard deviation
T1	Time 1
T2	Time 2
T3	Time 3
WRA	Word reading accuracy
WRF	Word reading fluency

CHAPTER 1 INTRODUCTION

While researchers have long focused on the skill of phonological awareness – the awareness of and access to the speech sounds in one's language (Wagner & Torgesen, 1987) – and its relationship with reading (e.g., National Reading Panel, 2000), much less research has focused on the skill of orthographic processing. Many definitions have been proposed for the construct of orthographic processing, with no universal agreement on a singular definition (Wagner & Barker, 1994). For the purposes of this study, orthographic processing is defined as the "ability to form, store, and retrieve orthographic representations" (Stanovich & West, 1989, p. 404). These orthographic representations contain information about each letter and letter position within a word as well as letter patterns that occur more generally within the language. For example, an orthographic representation for the word *yacht* would contain information about the letters in the word, but also about the order of the letters; an inaccurate orthographic representation could contain all the correct letters, but not the correct order, potentially resulting in an incorrect spelling such as *yatch*. The ability to form and access these representations is argued to be important for fluent reading through facilitating faster recognition of words than phonological decoding (i.e., sounding words out) can allow (Ehri, 1995). While orthographic processing has been found to be highly correlated with word reading skill (e.g., Stanovich, West, & Cunningham, 1992), the nature of this relationship remains unclear. The purpose of the current study was to explore the direction of the relationship between different aspects of orthographic processing and word reading.

1.1 ORTHOGRAPHIC PROCESSING

As the above definition of orthographic processing suggests, the construct of orthographic processing involves a broad range of skills. As noted, many definitions of orthographic processing, and what that entails, have been proposed (Wagner & Barker, 1994). In this study, we put forward a conceptualization in which we delineate the skills of *orthographic knowledge* and *orthographic learning* under the umbrella term of orthographic processing. We turn to each skill individually in the sections below.

We use the term orthographic knowledge to refer to orthographic information that has already been stored, such as how a word is spelled (Apel, 2011). Orthographic knowledge can be further divided into two types of knowledge: *lexical* knowledge and *sublexical* knowledge. Lexical knowledge pertains to knowledge about the letters and letter positions within a word (Apel, 2011; Perfetti, 1984). A common method of measuring lexical orthographic knowledge is with a forced choice task, in which the participant is provided on paper with two or more options and asked to circle the correct choice. The most commonly used measure of lexical knowledge involves a choice between a real word and a pseudohomophone distractor (e.g., *turtle* vs. *tertle*; as in Olson, Forseberg, Wise, & Rack, 1994). Sublexical knowledge pertains to the knowledge of letter patterns within a language; this includes information about common letter patterns (e.g., -*ight*), as well as information about what letter patterns are uncommon (e.g., the letter combination –*alm* as in the word *balm*) or illegal (e.g., consonant doublets at the beginning of a word). Like lexical knowledge, a choice task can be used to measure sublexical knowledge. For example, Cassar and Treiman (1997) created a choice task in which the participant is provided with nonwords and asked to choose the option most likely to occur in their language – the incorrect options often, but not always, contain illegal spelling patterns. For example, given the choice between *baff* and *bbaf*, the correct choice would be *baff*; consonant doublets do not generally occur at the beginning words in English, making *bbaf* an illegal spelling pattern. An example of an item in which a choice must be made between two legal spelling patterns is *crade* vs. *craid*. In this case, both spellings are possible in English – *crade* shares its spelling pattern with the real word *made*, whereas *craid* shares a spelling pattern with *maid*. However, the spelling pattern -*ade* is more frequent than *–aid,* making *crade* the correct choice.

The term orthographic learning describes the process of forming new word representations, which are then stored in the lexicon for later retrieval (Apel, 2011; Castles & Nation, 2008). This occurs when a new word is encountered and information about its form, including the letters and letter positions, is stored. Share (1995) proposes that by encountering and reading an unfamiliar word using his or her knowledge of letter-sound correspondences, a child acquires orthographic information about the word. For instance, a child might encounter the word *plane*, which they know orally but do not recognize in written form. The child would then attempt to decode the word, using his or her knowledge of letter sounds, and may successfully read the word and discover that it is the written form of a word they know orally. Through this process, the child could gain knowledge about the visual form of the word *plane*. This process of acquiring and storing orthographic information about a word is called orthographic learning (Share, 1999). Thus, orthographic learning is the process of forming new representations, rather than knowledge that already exists.

One way of measuring orthographic learning is with Share's (1999; 2004) paradigm in which children read ambiguously spelled, but permissible, nonwords (e.g., *yait*). In this task, children read nonwords (isolated or within texts) and are later tested on their learning of the nonwords through spelling, reading, or choice tasks (e.g., Ouellette & Fraser, 2009; Share, 2004). In choice tasks, participants are presented with multiple spelling options for each item: the target that they have read, a homophone of the target, and distractors (e.g., *yait, yate, yaid, yade;* Ouellette & Fraser, 2009). The nonwords are spelled ambiguously such that each nonword has two plausible spellings (e.g., *yait* vs. *yate*), meaning that participants cannot rely on how the nonword sounds in order to spell it. Because there are multiple possible spellings, participants must have formed an orthographic representation for the item in order to choose the correct response; if orthographic learning has occurred, the participant should have knowledge about the letters in the nonword as well the position of those letters within the word. For example, if orthographic learning has occurred, the participant would know that *yait* is the correct spelling because they recognize the spelling pattern (whereas *yate* would be an unfamiliar spelling pattern).

1.2 Word Reading

Like orthographic processing, word reading can also encompass a broad range of skills related to reading and for this reason we differentiate between four different types of word reading in the current study: accuracy, fluency, irregular word reading accuracy, and nonword decoding. Word reading accuracy refers to the ability to accurately read real words aloud (Wagner & Barker, 1994). To measure this skill, participants may be asked to read a list of isolated words. The number of words they can correctly read aloud is used as an indicator of their word reading accuracy. Word reading fluency, on the other hand, refers to one's ability to read a list of words quickly and correctly (Clemens, Shapiro, & Thoemmes, 2011). To measure this, participants may be presented with a list of real words and asked to read it as quickly and accurately as possible within a specified time period (Torgesen, Wagner, & Rashotte, 1999). Word reading fluency is the number of words read correctly within the specified time. Irregular word reading refers to the ability to read words whose pronunciations do not follow regular letter-sound rules (Wang, Castles, Nickels, & Nation, 2011). For example, the word *have* is irregular because, based on English pronunciation rules, one would expect the pronunciation to be similar to that of *gave*; attempting to read the word using phonological decoding alone would likely elicit an incorrect pronunciation. Finally, nonword decoding refers to the ability to read nonwords (Torgesen, Wagner, & Rashotte, 1999) – words that do not exist in English but are plausible given English spelling patterns (e.g., *meest*). The ability to decode words is known to correlate with phonological awareness (National Reading Panel, 2000) and relies on the ability to connect letters to their corresponding sounds.

The different types of word reading discussed here reflect different skills and, as such, may relate to the skills of orthographic knowledge and orthographic learning differently. We propose in this study that word reading fluency and irregular word reading may be more dependent upon orthographic processing than either word reading accuracy or nonword decoding, such that both orthographic knowledge and orthographic learning will be concurrent predictors of word reading fluency and irregular word reading and orthographic learning will predict growth in word reading fluency and irregular word reading. Word reading fluency may depend more on orthographic knowledge because participants must be able to read words quickly, which they may find difficult to do if they need to sound out each word (Ehri, 2005). Having orthographic representations stored in memory may allow for faster recognition and reading, and thus increased reading speed (e.g., Georgiou, Parrila, & Papadopoulos, 2008). Indeed, research has found that orthographic knowledge and speed of word identification are correlated. Barker, Torgesen, and Wagner (1992) examined the correlation between orthographic knowledge and three types of word reading in a sample of third grade children. After controlling for age, intelligence, and phonological awareness, orthographic knowledge was significantly correlated with word reading accuracy, nonword decoding, and timed word reading, with timed word reading having the strongest correlation. Once print exposure was entered as a control, orthographic knowledge significantly correlated only with timed word reading. This supports the theory that word reading fluency may be more associated with orthographic knowledge at the concurrent level than either word reading accuracy or nonword decoding.

Irregular word reading may also depend more on orthographic knowledge and orthographic learning. Children who have difficulty reading irregular words have been found to perform more poorly on measures of orthographic knowledge, suggesting that there may be a relationship between irregular word reading and orthographic knowledge (Castles, Holmes, & Wong, 1997; McArthur et al., 2013). Hagliassis, Pratt, and Johnston (2006) go so far as to include irregular word reading as a measure of orthographic processing in a study with children in Grades 3-5; they did find that irregular word reading was highly correlated with measures of orthographic knowledge and factor analysis showed that irregular word reading loaded on a single factor with the other measures of orthographic knowledge. Orthographic learning measures have also been found to correlate with irregular word reading, suggesting that both types of orthographic processing may be important for this type of word reading (Ouellette & Fraser, 2009). While correlational research suggests that word reading fluency and irregular word reading are related to orthographic processing (e.g., Castles, Holmes, & Wong, 1997; Georgiou, Parrila, & Papadopoulos, 2008; Ouellette & Fraser, 2009), no studies have yet explored the direction of this relationship.

1.3 Orthographic Knowledge and Word Reading

This section reviews evidence on the relationship of orthographic knowledge to word reading measured in a myriad of ways. Studies examining the relationship between orthographic knowledge and word reading accuracy consistently find that the two are correlated, even after controlling for other variables such as phonological awareness (Stanovich, West & Cunningham, 1992; Cunningham & Stanovich, 1990; Stanovich & West, 1989; see Wagner & Barker for review, 1994). However, correlational studies, while helpful in determining presence of a relationship, tell us nothing about the direction of this relationship.

In order to test the directionality of the relationship between orthographic knowledge and word reading, it is necessary to use a cross-lag hierarchical regression (Kenny, 1975). This type of analysis controls for skill in the dependent variable at an earlier time point. For example, in testing whether orthographic knowledge predicts growth in word reading accuracy, we know that word reading accuracy at Time 1 is likely to be correlated with word reading accuracy at Time 2 (e.g., Torgesen & Burgess, 1998). Therefore, we need to control for word reading accuracy at Time 1 in order to see the independent strength of orthographic knowledge in predicting growth in word reading. The use of cross-lag hierarchical regressions allows for the examination of the ability of a variable to predict growth in a dependent variable.

Two studies using cross-lag analysis have found support that earlier orthographic knowledge will predict growth in word reading accuracy (Wagner & Barker, 1994; Cunningham, Perry, & Stanovich 2001). Wagner and Barker (1994) tested orthographic knowledge and word reading in a group of children in their first grade and again in their second grade and found that, after controlling for age, prior word reading accuracy, verbal ability, and phonological awareness, orthographic knowledge significantly predicted growth in word reading accuracy. Wagner and Barker included three measures of orthographic knowledge: letter-name knowledge, a homophone choice task in which participants had to choose the correct homophone (e.g., *eye* vs. *I*) to complete a sentence, and a task that measured children's concepts about print. However, other studies have shown that letter-name knowledge is related to reading achievement and is generally treated as separate from orthographic processing (Bowey, 2005); its inclusion as a measure of orthographic knowledge in Wagner and Barker's study leads to some concerns about their conclusions.

Like Wagner and Barker, Cunningham et al. (2001) found that orthographic knowledge (both lexical and sublexical) predicted growth in word reading accuracy after controlling for prior nonword decoding and phonological awareness in a longitudinal study following one group of children from first through third grade. However, nonword decoding is more likely to be a measure of knowledge of letter-sound correspondences (Torgesen, Wagner, & Rashotte, 1999) rather than real word identification. This may be problematic in this instance as the study uses nonword decoding as a control for prior word reading, but nonword decoding is measuring a different aspect of word reading than is the word identification task. Additionally, neither study tested whether word reading accuracy predicted growth in orthographic knowledge. Thus, while both studies found that orthographic knowledge predicted growth in word reading accuracy, there are some concerns as to the choice of measures and they do not allow for a full view of the directionality of the relationships.

Unlike the Wagner and Barker (1994) and Cunningham et al. (2001), Deacon, Benere, and Castles (2012) tested the relationship between orthographic knowledge and word reading accuracy in both directions and only found evidence for earlier word reading predicting growth in orthographic knowledge. In this study, 100 Grade 1 children completed tasks of lexical and sublexical orthographic knowledge, word reading accuracy, and control measures; the tasks were completed once a year for three years. Deacon et al.'s study used cross-lag hierarchical regressions and controlled for vocabulary, nonverbal reasoning, phonological awareness, and earlier word reading accuracy. They found that, once earlier word reading accuracy was included as an autoregressor, orthographic knowledge did not predict later word reading accuracy. Instead, earlier word reading accuracy uniquely predicted growth in lexical and sublexical knowledge. Given that the results of this study are inconsistent with previous research, the direction of the relationship between orthographic knowledge and word reading accuracy remains unclear; however, Deacon et al. might provide some evidence that word reading accuracy predicts growth in orthographic knowledge, and not the reverse. However, orthographic knowledge is only one aspect of orthographic processing;

exploring the direction of the relationship between orthographic learning and word reading may allow for a fuller account of the relationship between orthographic processing and word reading.

1.4 Orthographic Learning and Word Reading

While some research exists on the relationship between orthographic knowledge and word reading (e.g., Cunningham et al., 2001; Deacon et al., 2012), much less research has focused on the relationship between orthographic learning and word reading. It is possible that the construct of orthographic learning might be more predictive of growth in word reading.

Like orthographic knowledge, empirical studies have found a relationship between orthographic learning and word reading, but the direction of that relationship is unclear (Apel, 2009; Bowey & Miller, 2007; Ouellette & Fraser, 2009). Bowey and Miller (2007), for instance, utilized Share's (2004) paradigm and asked third grade children to read passages that contained target nonwords. Bowey and Miller found that children's scores on the orthographic learning choice task (testing how well children recalled the target nonwords) correlated with their word reading accuracy. Similarly, Ouellette and Fraser (2009) measured orthographic learning in fourth grade children after the children read passages describing the nonwords. They found that both irregular word reading and nonword decoding significantly correlated with scores on an orthographic learning choice task measuring recall of the orthographic form of the nonwords read in passages. Only nonword decoding correlated with scores on the orthographic learning spelling task, in which children had to spell the nonwords read in the passages. These results confirm the presence of a relationship between word reading (accuracy, irregular word reading, and nonword decoding) and orthographic learning. To my knowledge, there are no longitudinal studies of the relationship between word reading and orthographic learning, and so the directionality of this relationship remains unclear.

1.5 Theories of Reading Development

This section reviews two prominent theories of reading development and the predictions they make about the relationships between orthographic processing and word reading. The predictions made by these theories about the direction of the relationship between orthographic knowledge and word reading will be discussed first, followed by a discussion of what predictions are made about the direction of the relationship between orthographic learning and word reading.

Ehri's (1995) theory of reading development proposes that there are four phases through which children progress in learning to read. Through this process children transition from primarily reading by phonologically decoding words to primarily reading words by sight. In the pre-alphabetic phase, children know few letters and therefore rely on salient visual information (e.g., the "tail" on the *g* in *dog*) to identify words. Children in the partial alphabetic phase know some letters and are able to identify some words but may make mistakes for words that contain similar letters (e.g., they may mistake the word *spoon* for *skin*). In the alphabetic phase, children are able to connect all letters to sounds and can use this information to phonologically decode words. The final phase is the consolidated alphabetic phase, in which readers store growing numbers of words in memory to allow them to read these words by sight.

Ehri (1995) proposes that through the process of reading and decoding words, children begin to store word representations, which we can consider lexical orthographic knowledge. Once children become more proficient with reading they are able to connect information and to generalize regularities across the language – in other words, they begin storing sublexical orthographic knowledge. Thus, according to Ehri's theory, both lexical and sublexical orthographic knowledge are acquired through the process of decoding and reading words.

Unlike Ehri's (1995) phase-based theory, Share's Self-Teaching (1995) theory is item-based and proposes that children learn words individually and according to exposure. Thus, even very rudimentary readers may be able to recognize some very familiar words by sight. Share's theory hinges on the assertion that children form orthographic representations of words through the process of decoding. Thus, through this process of decoding, children are acquiring lexical orthographic knowledge. Share also proposes that sublexical orthographic information is acquired through a process he calls lexicalization – this process involves learning more complex letter pattern regularities across written language than simply one-to-one letter-sound correspondences. Thus, both Ehri and Share predict in their theories that children gain orthographic knowledge, lexical and sublexical, through the process of reading. The prediction made by these theories is that word reading will predict gains in orthographic knowledge.

Share's (1999) Self-Teaching hypothesis also addresses the relationship between orthographic learning and word reading, and argues that there are likely individual differences in orthographic learning ability that may predict word reading ability. Share posits that while phonological processing is the main factor driving acquisition of orthographic representations, orthographic learning skill plays an important secondary role. Share proposes that the "individual differences in the ability to store and retrieve word-specific orthographic information" (p. 156) affect how quickly and accurately orthographic representations are learned. According to his theory, then, orthographic learning skill independently contributes to gains in word reading. However, unlike Share, Ehri's (1995) theory makes no predictions about orthographic learning and instead maintains that the process of reading is the primary method through which orthographic knowledge about words is acquired. Thus, Ehri and Share present theories with similar predictions about the relationship between word reading and orthographic knowledge, but are quite different in considering the role of orthographic learning, as only Share proposes a role for this skill.

1.6 Current Study

The present study explores the directionality of the relationships between various measures of word reading and three types of orthographic processing: lexical orthographic knowledge, sublexical orthographic knowledge, and orthographic learning. Specifically, the study was designed to test: (1) whether lexical and/or sublexical orthographic knowledge predict growth in word reading, (2) whether word reading predicts growth in lexical and/or sublexical orthographic knowledge, (3) whether orthographic learning predicts growth in word reading, and (4) whether word reading predicts growth in orthographic learning.

We attempted to answer these questions by conducting a longitudinal study that followed a single group of second and third grade children over a year and a half; testing was conducted at three separate time points. Children were tested on their word reading accuracy, word reading fluency, irregular word reading, nonword decoding, phonological awareness, nonverbal reasoning, lexical and sublexical orthographic knowledge, and orthographic learning. Orthographic learning was measured utilizing Share's (1999; 2004) orthographic learning paradigm, in which children read passages that introduce target nonwords and are later asked to spell the nonwords and to complete two orthographic learning choice tasks to measure their orthographic learning. We tested the direction of the relationships of the variables by conducting cross-lag hierarchical regressions.

The control measures of phonological awareness, nonverbal reasoning, and age were chosen as these variables consistently correlate with reading ability (Bowey, 2005). Phonological awareness is well established as an important skill for word reading (e.g., National Reading Panel, 2000). Nonverbal reasoning is controlled for to ensure that results do not reflect the cognitive demands of the task rather than the targeted skill (Bowey, 2005).

We included children in grades two and three for a number of reasons. By including children who progressed from grade two to grade three over the course of the study, we were able to confirm findings from previous studies with the same age group (e.g., Deacon et al., 2012). The addition of children who progressed from grade three to grade four allowed us to extend prior findings to a new age group. According to Ehri (1995), in second grade children begin to consolidate letter patterns into units as they are able to sight-read enough words for this process to begin. Thus, Grade 2 represents an important transitional point for beginning readers. Finally, inclusion of two age groups allowed us to maximize recruitment and increase our sample size.

While previous research has focused largely on word reading accuracy in examining the relationship between orthographic processing and word reading (e.g., Deacon et al., 2012), this study includes four types of word reading. We expect that the word reading skills of word reading accuracy, word reading fluency, irregular word reading, and nonword decoding will relate differently to the various types of orthographic processing in this study. Thus, the inclusion of these various types of word reading measures is intended as an exploratory analysis of the different aspects of word reading skill.

We make several specific predictions about the results of this study. It is predicted that, (1) neither lexical nor sublexical orthographic knowledge will predict growth in word reading but (2) measures of word reading will predict growth in both lexical and sublexical orthographic knowledge. These predictions are based on the previous research of Deacon et al. (2012) as well as prominent theories of reading development (Ehri, 1995; Share, 1999), which posit that lexical and sublexical orthographic knowledge is acquired through the process of reading and thus word reading would predict growth in orthographic knowledge.

In contrast, it is predicted that (3) orthographic learning will significantly predict growth in all four word reading measures and (4) all four word reading measures will predict growth in orthographic learning. The prediction that orthographic learning will predict growth in reading (whereas orthographic knowledge will not) is based on Share's (1995) theory that orthographic learning may represent a secondary factor in word reading in that children who are more adept at creating new orthographic representations will be able to make more gains in word reading ability. It is predicted that this relationship will be bidirectional as Share (1999) proposes decoding is the primary mechanism by which orthographic learning occurs; based on this assertion, it follows that word reading should predict growth in orthographic learning.

Finally, it is predicted that all measures of orthographic knowledge and orthographic learning will have a greater contribution as concurrent predictors of irregular word reading and word reading fluency than of word reading accuracy or nonword decoding. This prediction is based on the suggestion that word reading fluency and irregular word reading may be more dependent upon orthographic knowledge than word reading accuracy (Ehri, 2005), as well as research finding that these types of word reading are correlated with orthographic knowledge (e.g., Castles, Holmes, & Wong, 1997; McArthur et al., 2013).

CHAPTER 2 METHOD

2.1 Participants

A total of 126 children from four different schools participated. Testing was conducted over a year and a half, with three separate testing points (Time 1, Time 2, and Time 3). We conducted analyses only using data from participants who remained in the study across all three testing points (17 participants removed), whose parents reported no developmental disorders (7 participants removed), spoke English as a first language (3 participants removed), and who were not missing data for any entire measures (7 participants removed). Two participants were identified as multivariate outliers and were subsequently removed from analysis. Thus, analyses included 90 participants, of whom 46 were in Grade 2 (18 male, 28 female) and 44 in Grade 3 (21 male, 23 female) at Time 2. The mean age of the Grade 2 students was 7.51 (*SD* = 0.31) years at Time 1, 7.93 (*SD* = 0.29) years at Time 2 and 8.91 (*SD* =0.28*)* years at Time 3. The mean age of the Grade 3 students was 8.60 (*SD* = 0.33) years at Time 1, 8.99 (*SD* = 0.38) years at Time 2 and 10 years (*SD* = 0.36) at Time 3.

2.2 Study Design

This is a three time-point study. As the study included children from two different grades, Time 1 occurred near the beginning of either Grade 2 or Grade 3, Time 2 occurred near the end of either Grade 2 or Grade 3, and Time 3 occurred near the end of either Grade 3 or Grade 4. Data were collected as part of a larger study, thus only phonological awareness was measured at Time 1 and all other measures are from Time 2 and/or Time 3.

2.3 Materials

2.3.1 Phonological Awareness

The Elision subtest of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) was administered. In this task, children hear a word and are asked to say what is left once part of that word is eliminated (e.g., "Say *tiger* without saying /*g*/"). Testing continues until the participant makes three consecutive errors or reaches item 20. Reported alpha reliability coefficients for this age range from .89 - .91.

2.3.2 Word Reading Accuracy

The Word Identification subtest from the Woodcock Reading Mastery Test-Revised (Woodcock, 1998) was used to measure word reading accuracy. In this task, children are asked to read aloud words that get progressively more difficult. Testing is stopped once a child incorrectly reads the last six items on an easel board (each easel page contains nine items). Reported split-half reliability for this age group is .91 - .98.

2.3.3 Word Reading Fluency and Nonword Decoding

The Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999) was administered as a measure of word reading fluency and nonword decoding. This test consists of two subtests. The real-word reading subtest of the TOWRE task is a timed reading task in which participants have 45 seconds to read a list of words – scores are based on how many words the participant can correctly read in this time. The nonword decoding subtest is exactly the same as the real-word subtest except that instead of real words, it is a list of nonwords that the participant must decode within the 45 seconds. Test-retest reliability for this test is .90 - .97 for this age group.

2.3.4 Irregular Word Reading

A subset of items from the Castles and Coltheart Test 2 (CC2; Castles, Coltheart, Larsen, Jones, Saunders, & McArthur, 2009) were used to measure irregular word reading ability. Children are asked to read a set of 40 irregular words, which are presented individually on cue cards, and continue until five consecutive words are read incorrectly. The same list of words was used at each testing point, but it is unlikely that there are test-retest effects (McArthur, Ellis, Atkinson, & Coltheart, 2008). Calculated alpha reliability coefficient was .92 at Time 2 and at Time 3.

2.3.5 Nonverbal Reasoning

Nonverbal reasoning was measured using the Matrix subtest of the Weschler Abbreviated Scale of Intelligence (WASI; Weschler, 1999). In this task, participants are presented with a matrix from which a section is missing; participants must choose the image that completes the matrix from a set of five choices. Testing is discontinued after four consecutive errors, four errors within five consecutive items, or once the participant reaches item 28 (the stopping point for this age group). Reported internal consistency reliability coefficients for this age group range from .93-.94.

2.3.6 Lexical Orthographic Knowledge

This task is designed to measure lexical orthographic knowledge. Children are provided with a sheet containing pairs of words and nonwords (e.g., *explain/explane*). One of these words is the correct spelling of a real word (i.e., *explain*) and the other is nonword that is a homophone of the real word (i.e., *explane*). The tester reads aloud a real word and provides a short sentence containing the word, and the child is asked to circle the item that is the correct spelling. Testing continues until all items have been completed. This task contained 36 items at Time 2, and 61 at Time 3. The items at Time 2 were selected from Olson et al. (1994). Twenty-five items were added between Time 2 and 3 in order to make the task more difficult so that there would be no ceiling effects. The new items were primarily chosen from Olson et al. but some other items were also added that had been used previously in the lab's other research. Calculated alpha reliability coefficients were at .87 at Time 2 and .82 at Time 3. See Appendix C for list of items.

2.3.7 Sublexical Orthographic Knowledge

This task was designed to measure children's knowledge of letter patterns in English. Children are presented with a sheet of items containing nonword pairs or triplets that sound the same but are spelled differently. They are asked to circle the nonword that "looks most like a real word". Some of the pairs require the children to choose between a nonword that would be legal in English (e.g., *screigh*) and one containing a letter pattern that does not occur in English (e.g., *scraie*), while some required the children to distinguish between more or less legal nonwords (e.g., *waught* vs. *waut*). This task included 42 items at Time 2 and 60 items at Time 3. The items used at Time 2 were selected from Cunningham et al. (2001) and also from previous research in the lab. For those items that had been used in previous lab research, items were selected based on having an average less than 80% correct (data from Grade 2 children). Eighteen items were added between Time 2 and Time 3 to make the task more difficult and avoid ceiling effects. The eighteen new items at Time 3 were created using summed frequencies of letter combinations from Ziegler et al. (1997); the correct option was that with the higher summed frequency. The word-endings were also checked in the MRC psycholinguistic database to ensure that the correct option's word-ending was present by count in more real words than the incorrect option. Calculated alpha reliability coefficients for this task were .72 at Time 2 and .69 at Time 3. See Appendix D for a list of items.

2.3.8 Orthographic Learning

In order to assess orthographic learning ability, children were presented with stories that introduced a nonword (e.g., "The new word is Laif. The coldest town in the world is Laif. Laif is in Greenland. The people who live in Laif need very hot houses."). There were 15 stories in total, but the children read three at a time. After they had read three stories, they were asked to spell the new words (e.g., "The coldest town in the world is Laif. Spell Laif."). This was repeated until all stories had been read and all the nonwords had been spelled. Once this was complete, the children completed an immediate orthographic learning choice task in which they were presented with four nonwords, including a homophone and two visual distractors (e.g., *laif, lafe, laip, lape*), and were asked to choose the nonword that they read in the stories. The delayed orthographic learning choice task was completed again two days later. There was a homophone pair for each story (e.g., *laif/lafe*) and so children were shown either *laif* or *lafe* – half of the children saw one set of nonwords (Vowel Set A) and half saw the other set (Vowel Group B). This was to ensure that children were not choosing or spelling one homophone more often simply because it contained an easier or more frequent letter pattern.

At Time 2 testing, nonwords and stories from Byrne et al. (2007) were used for the orthographic learning task. At Time 3 the nonwords and stories were altered to reduce the possibility of learning being carried over from Time 2. See Appendix E for lists of items from Time 2 and Time 3.

Parallel items were created for the stories for Time 3 (See Appendix F). The stories were revised by changing only some words from the original sentences and matching the word frequencies as closely as possible (p = .69). Thus, the semantic content of the story was changed but the sentence structure, overall frequency, and number of words was maintained (e.g., "The coldest town in the world is Laif" became "The fastest car in the world is a Fafe"). In two stories an article (e.g., *the*) had to be added to the sentence for it to make sense, but the number of words was kept the same in all other cases.

Parallel items were similarly created for the nonwords for Time 3 (See Appendix E). The nonwords were revised by changing one or two consonants; the target spellings were always maintained – for example, in *laif/lafe* the *–aif/-afe* remained unchanged and in *krent*/*crent* the *kr-/cr-* remained unchanged. The letters that were changed were either initial consonant(s) (for items in which the target spellings were endings) or the ending consonant(s) (for items in which the target spellings were beginnings). No more than one additional letter was added to the new nonwords. Embedded words were avoided and no nonwords contained embedded words longer than four letters. All nonwords were also checked in a dictionary to ensure they were not obscure real words (*Merriam-Webster's Collegiate Dictionary, 2005)*.

Parallel items were also created for the distractors for the orthographic learning choice task. The distractors from Time 2 were altered such that only the consonant(s) that was changed in the target nonwords was changed between Time 2 and 3. For instance, the distractors for *laif/lafe* at Time 2 were *laip/lape*. The new target nonwords for Time 3 were *faif/fafe* and so the 'l' changed to an 'f' to create *faip/fape*. Like the nonwords, embedded words were avoided and no embedded words in the distractors were more than four letters. Distractors were also checked in a dictionary to ensure they were not obscure real words (*Merriam-Webster's Collegiate Dictionary, 2005)*.

2.4 Procedure

Time 1 testing took place during the fall of the participants' second or third grade. At this time, the control measure of phonological awareness was collected within a larger battery of measures. All testing took place one-on-one with a researcher in a quiet room.

Time 2 testing took place in the spring of the participants' second or third grade. Each participant completed two different testing sessions at this time. During the first testing session, participants completed the lexical and sublexical orthographic knowledge tasks, word reading fluency, nonword decoding, word reading accuracy task, and irregular word reading. During this first session the participants also completed part one of the orthographic learning task – they read the stories, completed the spelling task, and completed the immediate orthographic learning choice task. The second session took place two days later and consisted of completing the delayed orthographic learning choice task as well as the nonverbal reasoning measure. Once again, all testing took place one-on-one with a researcher in a quiet room.

Time 3 testing took place in the spring of the participants' third or fourth grade. As with the previous testing point, each participant completed two different testing sessions. During the first, participants completed the lexical and sublexical orthographic knowledge tasks and the orthographic learning task (reading the stories, completing the spelling task, and immediate orthographic learning choice task). During the second session, participants completed the delayed orthographic learning choice task and also completed the measures of word reading fluency, nonword decoding, word reading accuracy, and irregular word reading. All testing took place one-on-one with a researcher in a quiet room.

CHAPTER 3 RESULTS

3.1 Preliminary Analyses

Table 1 displays the means and standard deviations for age and all variables organized by grade and testing point, including both raw and standard scores for standardized measures. Participants scored within the average range on all standardized tasks. Reliabilities for all experimental measures are reported in Table 1 and all are above .7 with the exception of both the immediate and delayed orthographic learning choice tasks at Time 3 and sublexical orthographic knowledge at Time 3.

Data were inspected for missing values (27 data points), which accounted for less than 1% of the data; missing values were replaced with the participant's mean score for the completed items on that task. Five participants were found to be univariate outliers and these scores were winsorized to one point higher or lower than the next highest or lowest score. Two participants were identified as multivariate outliers and were removed from all analyses. All variables were checked for normality following the guidelines of Tabachnik and Fidell (2007); skewness and kurtosis values are divided by their respective standard error values and any values greater than 3.0 are considered non-normal. All scores with deviations from normality were transformed following the guidelines set out in Tabachnik and Fidell (2007). A negative square root transformation was performed on the variables of Time 2 word reading fluency, Time 2 irregular word reading, Time 2 lexical orthographic knowledge, Time 2 sublexical orthographic knowledge, Time 3 word reading fluency, Time 3 irregular word reading, Time 3 lexical orthographic knowledge, and Time 3 sublexical orthographic knowledge. A positive square root transformation was performed on the phonological awareness variable. All analyses reported below use transformed values (where applicable); all analyses were also conducted using raw scores to confirm results from analyses with transformed variables.

Tables 2-4 show Pearson correlations for all variables and testing points. Tolerance values and variance inflation factors from the regression output confirmed the absence of any multicollinearity (as per Tabachnik & Fidell, 2007).

3.2 Main Analyses

3.2.1 Concurrent Analyses

Hierarchical regressions were run first to determine whether orthographic processing measures and word reading measures were concurrent predictors of each other at each testing point. For all analyses presented here age and nonverbal reasoning were entered as controls in Step 1, phonological awareness was entered as a control in Step 2, and the predictor variable was entered in Step 3. This was conducted for Time 2 measures (e.g., Time 2 lexical orthographic knowledge as predictor variable, Time 2 word reading accuracy as dependent variable) and for Time 3 measures (e.g., Time 3 lexical orthographic knowledge as predictor variable, Time 3 word reading accuracy as dependent variable).

Analyses were first run for Time 2 orthographic processing variables as concurrent predictors of Time 2 word reading measures. Results are presented in the top half of Table 5. After controlling for age, nonverbal reasoning, and phonological awareness, lexical orthographic knowledge significantly predicted word reading accuracy (28%, $p < .01$), word reading fluency (23%, $p < .01$), irregular word reading (5%, $p =$

.03), and nonword decoding (15%, $p < .01$) scores. Sublexical orthographic knowledge significantly predicted word reading accuracy (26%, $p < .01$), word reading fluency (22%, $p < .01$), and nonword decoding (14%, $p < .01$), but not irregular word reading (2%, $p = .23$) scores. Orthographic learning spelling scores significantly predicted word reading accuracy (14%, $p < .01$), word reading fluency (10%, $p < .01$), and nonword decoding (10%, $p < .01$), but not irregular word reading (0%, $p = .74$) scores. Immediate orthographic learning choice scores significantly predicted word reading accuracy (17%, $p < .01$), word reading fluency (13%, $p < .01$), and nonword decoding (5%, $p = .01$), but not irregular word reading (0%, $p = .95$) scores. Delayed orthographic learning choice scores significantly predicted word reading accuracy (11%, $p < .01$) and word reading fluency (7%, $p < .01$) scores, but not nonword decoding (2%, $p = .10$) or irregular word reading (0%, $p = .65$) scores.

Analyses were then run to determine whether Time 2 word reading measures were concurrent predictors of Time 2 orthographic processing measures. Results are presented in the top half of Table 6. Controls were entered as before, with age and nonverbal reasoning entered in Step 1 and phonological awareness entered in Step 2. Word reading accuracy significantly predicted lexical (33%, $p < .01$) and sublexical (30%, $p < .01$) orthographic knowledge, orthographic learning spelling (14%, $p < .01$), and immediate (22%, $p < .01$) and delayed orthographic learning choice scores (13%, $p < .01$). Word reading fluency scores significantly predicted lexical (27%, $p < .01$) and sublexical (25%, $p < .01$) orthographic knowledge, orthographic learning spelling (10%, $p < .01$), and immediate (16%, $p < .01$) and delayed (9%, $p < .01$) orthographic learning choice scores. Irregular word reading significantly predicted lexical orthographic knowledge (5%, $p =$

.03), but not sublexical orthographic knowledge (1%, $p = .23$), orthographic learning spelling (0%, $p = .74$), or immediate (0%, $p = .95$) or delayed (0%, $p = .65$) orthographic learning choice scores. Nonword decoding significantly predicted lexical (19%, $p < .01$) and sublexical (18%, $p < .01$) orthographic knowledge, orthographic learning spelling (11%, $p < .01$), and immediate (6%, $p = .01$), but not delayed (3%, $p = .10$), orthographic learning choice scores.

Analyses were then run to determine whether Time 3 orthographic processing measures were concurrent predictors of Time 3 word reading measures. Results are presented in the bottom half of Table 5. After controlling for age, nonverbal reasoning, and phonological awareness, lexical orthographic knowledge significantly predicted word reading accuracy (24%, $p < .01$), word reading fluency (26%, $p < .01$), irregular word reading (21%, $p < .01$), and nonword decoding (28%, $p < .01$) scores. Sublexical orthographic knowledge significantly predicted word reading accuracy (12%, $p < .01$), word reading fluency (12%, $p < .01$), nonword decoding (8%, $p < .01$), and irregular word reading (10%, $p < .01$) scores. Orthographic learning spelling scores significantly predicted word reading accuracy (15%, $p < .01$), word reading fluency (10%, $p < .01$), nonword decoding (9%, $p < .01$), and irregular word reading (14%, $p < .01$) scores. Immediate orthographic learning choice scores significantly predicted word reading accuracy (14%, $p < .01$), word reading fluency (6%, $p = .01$), and irregular word reading (12%, $p < .01$), but not nonword decoding (3%, $p = .07$) scores. Delayed orthographic learning choice scores significantly predicted word reading accuracy (12%, $p < .01$), word reading fluency (5%, $p = .03$), and irregular word reading (15%, $p < .01$) scores, but not nonword decoding (1%, $p = .24$) scores.

Analyses were then run to determine whether Time 3 word reading measures were concurrent predictors of Time 3 orthographic processing measures. Results are presented in the bottom half of Table 6. Controls were entered as before, with age and nonverbal reasoning entered in Step 1 and phonological awareness entered in Step 2. Word reading accuracy significantly predicted lexical (30%, $p < .01$) and sublexical (16%, $p < .01$) orthographic knowledge, orthographic learning spelling (21%, $p < .01$), and immediate (23%, $p < .01$) and delayed orthographic learning choice scores (19%, $p < .01$). Word reading fluency scores significantly predicted lexical (24%, $p < .01$) and sublexical (12%, $p < .01$) orthographic knowledge, orthographic learning spelling (10%, $p < .01$), and immediate (7%, $p = .01$) and delayed (5%, $p = .03$) orthographic learning choice scores. Irregular word reading significantly predicted lexical orthographic knowledge (29%, $p < .01$), sublexical orthographic knowledge (11%, $p < .01$), orthographic learning spelling (16%, $p < .01$), and immediate (16%, $p < .01$) and delayed (20%, $p < .01$) orthographic learning choice scores. Nonword decoding significantly predicted lexical (21%, $p < .01$) and sublexical (9%, $p < .01$) orthographic knowledge, and orthographic learning spelling (10%, $p < .01$) scores, but not immediate (4%, $p = .07$) or delayed (2%, $p = .24$) orthographic learning choice scores.

3.2.2 Orthographic Knowledge and Word Reading

Cross-lag hierarchical regression analyses were then conducted to determine whether lexical and sublexical orthographic knowledge at Time 2 predicted growth in word reading at Time 3. The results of these regressions are presented in the first six rows of Table 7 and depicted in Figure 1. The control measures of age and nonverbal reasoning were entered in Step 1 and phonological awareness was entered in Step 2; the Time 2 measure of word reading was entered in Step 3, followed by either lexical or sublexical orthographic knowledge in Step 4. For all cross-lag hierarchical regressions, Step 3 of the regression included an earlier measure of the dependent variable. For example, for the regression predicting word reading accuracy at Time 3, Step 3 included Time 2 word reading accuracy as a control. Lexical and sublexical orthographic knowledge did not predict growth in word reading accuracy, word reading fluency, or nonword decoding, accounting for none of the variance in word reading accuracy scores ($p = .97$), a nonsignificant 1% ($p = .16$ and $p = .17$) of the variance in word reading fluency, and none of the variance in nonword decoding ($p = .73$ and $p = .41$). Lexical and sublexical orthographic knowledge significantly predicted growth in irregular word reading, accounting for 25% ($p < .01$) and 20% ($p < .01$) of the variance in irregular word reading scores, respectively.

Cross-lag hierarchical regression analyses were also conducted to examine the reverse relationship of whether Time 2 word reading measures predicted growth in lexical or sublexical orthographic knowledge between Time 2 and Time 3. The control measures of age and nonverbal reasoning were entered in Step 1, followed by phonological awareness in Step 2, either Time 2 lexical or sublexical orthographic knowledge were entered as a control in Step 3, and either word reading accuracy, word reading fluency, irregular word reading, or nonword decoding in Step 4. Results of these regressions are presented in Table 8 and depicted in Figure 1. Word reading accuracy, word reading fluency, and nonword decoding at Time 2 predicted growth in lexical orthographic knowledge at Time 3, accounting for 5% ($p < .01$), 7% ($p < .01$), and 5% ($p < .01$) of the variance, respectively. Irregular word reading accounted for a nonsignificant

1% (p = .19) of the variance. Word reading accuracy, irregular word reading, and nonword decoding scores at Time 2 predicted growth in sublexical orthographic knowledge Time 3, accounting for 3% (p = .04), 4% (p = .02), and 4% (p = .01) of the variance. Word reading fluency did not make a significant contribution to the regression equation, accounting for only 1% (p = .19) of the variance.

3.2.3 Orthographic Learning and Word Reading

Cross-lag hierarchical regression analyses were then conducted to determine whether orthographic learning measures at Time 2 predicted growth in word reading measures at Time 3. Results of these analyses are presented in the last three rows of Table 7 and depicted in Figure 1. Again, age and nonverbal reasoning were entered in Step 1, phonological awareness in Step 2, followed by the appropriate Time 2 word reading measure in Step 3, and orthographic learning spelling, immediate orthographic learning choice, or delayed orthographic learning choice in Step 4. Orthographic learning spelling scores at Time 2 predicted growth in word reading accuracy and irregular word reading at Time 3, accounting for 1% (p = .01) of the variance in word reading accuracy and 17% (p < .01) of the variance in irregular word reading. Orthographic learning spelling scores did not significantly predict growth in word reading fluency or nonword decoding, accounting for a nonsignificant 2% of the variance (p = .06) in word reading fluency and a nonsignificant 1% (p = .11) of the variance in nonword decoding. Immediate and delayed orthographic learning choice scores at Time 2 each uniquely predicted growth in irregular word reading at Time 3 (17%, p < .01, and 8%, p < .01, respectively), but not in word reading accuracy (1%, p = .08, and 0%, p = .80) or nonword decoding (1%, p = .13, and 0%, p = .65). The immediate orthographic learning choice task significantly predicted growth in word reading fluency, accounting for 2% (p = .03) of the variance in word reading fluency, but the delayed orthographic learning choice task accounted for none of the variance (p = .90).

Cross-lag hierarchical regression analyses were also conducted to examine the reverse relationship of whether Time 2 word reading measures predicted growth in orthographic learning measures at Time 3. Results of these analyses are presented in Table 9 and depicted in Figure 1. Only Time 2 word reading accuracy significantly predicted growth in all three measures of orthographic learning at Time 3, accounting for 5% (p = .01) of the variance in orthographic learning spelling, 4% (p = .02) of the variance in the immediate orthographic learning choice task, and 9% (p < .01) of the variance in the delayed orthographic learning choice task, respectively. Word reading fluency accounted for a nonsignificant 2% of the variance in orthographic learning spelling (p = .06). Irregular word reading accounted for none of the variance in spelling scores (p = .89) or the delayed orthographic learning choice task (p = .55), and a nonsignificant 1% (p = .27) of the variance in the immediate orthographic learning choice scores. Nonword decoding accounted for a nonsignificant 2% of the variance in spelling scores (p = .10), a nonsignificant 2% of the variance in immediate orthographic learning choice scores (p = .10) and a nonsignificant 2% of the variance in delayed orthographic learning choice scores (p = .14).

3.2.4 Interaction Analyses

We conducted interaction analyses for each regression to check whether there was an interaction with grade. This was done by creating interaction terms and adding these as a fifth step in the regression, as per Tabachnik and Fidell (2007). All interaction terms were nonsignificant except those for lexical (p = .01) and sublexical (p < .01) orthographic knowledge predicting growth in nonword decoding, lexical orthographic knowledge predicting growth in word reading fluency (p = .03), and word reading fluency predicting sublexical orthographic knowledge (p = .03).

For the interaction analyses that were significant, the regression analyses were conducted separately for each grade. Results of these analyses are presented in Tables 10 and 11. Lexical orthographic knowledge did not significantly predict growth in nonword decoding for grade two students (0%, p = .89) or grade three students (1%, p = .15). Sublexical orthographic knowledge also did not significantly predict growth in nonword decoding for grade two students (0%, p = .45) or grade three students (0%, p = .47). Lexical orthographic knowledge did not significantly predict growth in word reading fluency for grade two students (1%, p = .32) or grade three students (0%, p = .64). Word reading fluency did not significantly predict sublexical orthographic knowledge for grade two students (0%, p = .78) or grade three students (3%, p = .19). Thus, conducting the analyses separately by grade did not change interpretation of the results from the original regressions, as all predictors remained nonsignificant.

3.2.5 Grade 3 Comparisons

Lastly, comparisons were run between the two sets of Grade 3s – those participants who were in Grade 3 at Time 2 and those who were in Grade 3 at Time 3. This was done to determine whether there may have been any practice effects in that the Grade 3s at Time 3 had already completed the tasks once before, whereas the Time 2 Grade 3s had not. *T*-tests were run to compare the two samples on all measures. There was a significant difference between the two samples on the measures of irregular word reading ($p < .05$), lexical orthographic knowledge ($p < .01$), and sublexical orthographic knowledge ($p < .01$). The two groups did not significantly differ on word reading accuracy ($p = .85$), word reading fluency ($p = .46$), nonword decoding ($p = .61$), orthographic learning spelling ($p = .51$), or immediate ($p = .19$) or delayed ($p = .24$) orthographic learning choice scores.

CHAPTER 4 DISCUSSION

The purpose of this study was to explore the direction of the relationships between orthographic processing, including lexical and sublexical orthographic knowledge as well as orthographic learning skill, and word reading, including accuracy, fluency, irregular word reading, and nonword decoding. We examined these questions through a longitudinal study of second and third grade students over the course of a year and a half. In order to determine the direction of the relationships between the variables, cross-lag hierarchical regression analyses (Tabachnik & Fidell, 2007) were used, to control for the contributions of the dependent variable at earlier time points. We also controlled for age, nonverbal reasoning, and phonological awareness to minimize the contributions of extraneous variables known to be related to reading (see Bowey, 2005 for review). Notably, this statistical approach is very conservative, as evident by our analyses in which a great deal of variance was accounted for by our control measures. For instance, age and nonverbal reasoning accounted for up to 10% of the variance, phonological awareness for up to 31%, prior word reading for up to 48%, prior orthographic knowledge for up to 33%, and prior orthographic learning for up to 37%. Thus, in some analyses, as much as 88% of the variance was accounted for before the predictor variable was entered.

Our first research question was whether lexical or sublexical orthographic knowledge would predict growth in word reading, considering different aspects of word reading skill. Our analyses largely supported the prediction that orthographic knowledge would not predict growth in word reading. Specifically, neither lexical nor sublexical orthographic knowledge predicted growth in word reading accuracy, word reading fluency, or nonword decoding after controlling for age, nonverbal reasoning, phonological awareness, and prior word reading. However, lexical and sublexical orthographic knowledge both predicted growth in irregular word reading, after controlling for age, nonverbal reasoning, phonological awareness, and prior irregular word reading.

The findings that lexical and sublexical orthographic knowledge did not predict growth in word reading are consistent with the findings of Deacon et al. (2012), whose longitudinal study of students followed from Grade 1 to Grade 3 found that neither lexical nor sublexical orthographic knowledge predicted growth in word reading accuracy after controlling for age, vocabulary, nonverbal reasoning, and prior word reading accuracy. However, the results of our study and those of Deacon et al. differ from those found by both Wagner and Barker (1994) and Cunningham et al. (2001). The latter two studies found that orthographic knowledge predicted growth in word reading accuracy. This is likely due to a difference in the measures used for orthographic knowledge and to control for prior word reading. As discussed previously, Cunningham et al. used nonword decoding as their prior word reading control, and Wagner and Barker included letter-name knowledge as a measure of orthographic knowledge. The present study used similar measures and methods as Deacon et al. and found similar results, thus it is likely that methodological differences are responsible for the contrasting results found by Wagner and Barker and Cunningham et al.

The current study extends the findings of Deacon et al. (2012) by including measures of word reading fluency, irregular word reading, and nonword decoding in addition to word reading accuracy in examining the relationship between orthographic knowledge and word reading. The results of our study support our prediction that orthographic knowledge would not predict growth in nonword decoding, similar to word reading accuracy, because nonword decoding relies heavily on phonological awareness (National Reading Panel, 2000). The results of our study also support the hypothesis that orthographic knowledge would concurrently predict growth in irregular word reading because irregular words are difficult to read through decoding alone (Wang et al., 2011). Unexpectedly, the cross-lag hierarchical regressions showed that orthographic knowledge also predicted growth in irregular word reading. Our results are also consistent with studies that have found that children who have difficulty reading irregular words also perform poorly on measures of orthographic knowledge (Castles, Holmes, & Wong, 1997; McArthur et al., 2013). However, to the best of the author's knowledge, this is the first study to explore the direction of the relationship and to find that orthographic knowledge predicts growth in irregular reading. It seems that knowledge of the orthographic form of real words, as well as letter patterns across the language, may help students in reading irregular words and in improving their skill in irregular word reading.

We also predicted that orthographic knowledge would concurrently predict word reading fluency because the word reading fluency task requires quick recognition of words (e.g., McArthur et al., 2013), but would not predict growth in word reading fluency. These predictions were supported by the results. Although previous research found a correlation between lexical orthographic knowledge and word reading fluency in first and second grade children (Georgiou, Parrila, & Papadopoulos, 2008), the direction of this relationship had not yet been explored. The findings of the current study suggest that orthographic knowledge does not predict growth in word reading fluency. While it was predicted that irregular word reading and word reading fluency would both be more related to orthographic knowledge concurrently, the cross-lag results of this study raise the possibility that irregular word reading is more dependent upon orthographic representations than is word reading fluency as the words cannot be read using phonological decoding skills alone.

Our second research question examined the opposite relationship: whether word reading would predict growth in orthographic knowledge. Our results largely supported the prediction that word reading measures would predict growth in orthographic knowledge. Specifically, word reading accuracy, word reading fluency, and nonword decoding, but not irregular word reading, predicted growth in lexical orthographic knowledge after controlling for age, phonological awareness, nonverbal reasoning, and prior lexical orthographic knowledge. Word reading accuracy, irregular word reading, and nonword decoding, but not word reading fluency, significantly predicted growth in sublexical orthographic knowledge after controlling for age, phonological awareness, nonverbal reasoning, and earlier sublexical orthographic knowledge.

The finding that word reading accuracy predicted growth in lexical and sublexical orthographic knowledge is consistent with the findings of Deacon et al. (2012) that word reading accuracy predicted growth in lexical and sublexical orthographic knowledge after controlling for age, vocabulary, nonverbal reasoning, phonological awareness, and prior lexical or sublexical orthographic knowledge. While previous studies (Cunningham et al., 2001; Wagner & Barker, 1994) investigated whether orthographic knowledge predicted growth in word reading, Deacon et al. was the first to examine the reverse relationship as well. The findings of the current study are therefore important in confirming the results of Deacon et al. that word reading accuracy predicts growth in orthographic knowledge and not the reverse.

Our study also extends the findings of Deacon et al. (2012) by exploring the relationship between orthographic knowledge and word reading fluency, irregular word reading, and nonword decoding. Nonword decoding consistently predicted growth in both lexical and sublexical orthographic knowledge, which extends previous research that has found a correlation between nonword decoding and lexical orthographic knowledge, albeit not sublexical orthographic knowledge (Loveall, Channell, Phillips, Conners, 2013). This is the first study, to our knowledge, to find that nonword decoding predicts growth in lexical and sublexical orthographic knowledge.

While word reading accuracy and nonword decoding predicted growth in both lexical and sublexical orthographic knowledge, word reading fluency and irregular word reading each unexpectedly predicted growth in only one type of orthographic knowledge. Word reading fluency predicted growth in lexical orthographic knowledge, which is consistent with previous research finding a correlation between word reading fluency and lexical orthographic knowledge in first grade children (Georgiou, Parrila, & Papadopoulos, 2008). In contrast, irregular word reading predicted growth in sublexical orthographic knowledge, which is also consistent with research finding a correlation between these two skills (e.g., Castles, Holmes, & Wong, 1997). These findings suggest that the ability to read words fluently may be important for increasing lexical orthographic knowledge whereas understanding the irregularities of written language may be important for drawing out the regularities, as reflected in the sublexical orthographic knowledge task.

Our third research question explored whether orthographic learning would predict growth in word reading. Overall, results supported the prediction that orthographic learning would predict growth in word reading. We consider the results for our two outcome measures for orthographic learning: spelling and orthographic choice. It was found that orthographic learning spelling and orthographic learning choice scores (immediate and delayed) predicted growth in irregular word reading. In contrast, only orthographic learning spelling predicted growth in word reading accuracy and only the immediate orthographic learning choice test predicted growth in word reading fluency (but the delayed orthographic learning choice task did not). None of the orthographic learning measures predicted growth in nonword decoding.

Our findings of the relationship between orthographic learning and word reading are consistent with some of the findings of Ouellette and Fraser (2009), but not of Bowey and Miller (2007). Ouellette and Fraser found that, in a sample of fourth grade children, irregular word reading correlated with scores on an orthographic learning choice task, but not on the orthographic learning spelling task, after controlling for phonological awareness and nonword decoding. While our finding that orthographic learning choice scores predicted growth in irregular word reading is consistent with Ouellette and Fraser, the present study also found that scores on the orthographic learning spelling task predicted growth in irregular word reading. Bowey and Miller, on the other hand, found a correlation between orthographic learning choice scores and word reading accuracy in third grade children. However, in the present study, only orthographic learning spelling was predictive of growth in word reading accuracy.

The finding that the orthographic learning spelling task and orthographic learning choice tasks predicted growth on different word reading measures suggests that different skills were important for each task. The spelling task could be considered to be a stringent test of orthographic learning, as it requires recall from memory of specific letters in a specific order, with the only assistance being the provided pronunciation. It is possible that the orthographic learning spelling task and the word reading accuracy task share some task demands, contributing to the finding that orthographic learning spelling scores predict growth in word reading accuracy. For instance, the spelling measure may require some amount of sounding-out in order to find the correct letters if an orthographic representation has not been fully formed (although sounding-out alone is not sufficient to achieve the correct spelling). Similarly, children may use sounding-out strategies to read unfamiliar words in the word reading accuracy task. If it is the case that the orthographic learning spelling task required some amount of sounding-out, then the finding that orthographic learning spelling scores did not predict nonword decoding is unsurprising. In this case, it would be more likely that nonword decoding would predict growth in orthographic learning spelling scores (although this was not found).

Given the relationship found between orthographic learning spelling and irregular word reading, it is surprising that orthographic learning spelling did not predict growth in word reading fluency. Both irregular word reading and word reading fluency are believed to be more dependent upon having these orthographic representations (Castles, Holmes, & Wong, 1997; Ehri, 2005; McArthur et al., 2013), so it is surprising that orthographic learning spelling predicted growth in one and not the other. This is especially true considering the finding that the immediate orthographic learning choice scores predicted growth in both irregular word reading and word reading fluency.

Unlike the orthographic learning spelling task, the orthographic learning choice tasks may be more dependent upon identification of the visual form of words rather than sounding words out. In the orthographic learning choice task, children are provided with four options and must identify the correct nonword, without being confused by the homophone or the other distractors. Thus, scores on the orthographic learning choice task may predict growth in word reading fluency and irregular word reading because it reflects the ability to correctly identify the visual form of the word, as we predicted. It is possible that the word reading accuracy measure was less dependent on this ability, as the child could potentially do quite well on this task if they were able to sound out the words (but were not familiar with them). This would also be consistent with the finding that orthographic learning choices scores did not predict growth in nonword decoding. However, only the immediate orthographic learning choice task predicted growth in word reading fluency. This finding suggests that some aspect of the immediate (but not sustained) recognition of new words is important in predicting growth in word reading fluency. In contrast, both immediate and delayed recognition appear to be important in predicting growth in irregular word reading.

The fourth research question was whether word reading would predict growth in orthographic learning. Tests of this relationship showed that only word reading accuracy significantly predicted growth in orthographic learning spelling scores, immediate orthographic learning choice scores, and delayed orthographic learning choice scores after controlling for phonological awareness, nonverbal reasoning, and earlier orthographic learning. These results suggest that the ability to accurately read words in isolation assists in learning the orthographic form of new words. Share (1995) proposes that decoding new words is integral to the process of orthographic learning; thus, word reading accuracy may predict scores on measures of orthographic learning because it reflects, in part, this ability to accurately decode words. However, in this case, we would also expect nonword decoding to predict growth in orthographic learning scores and this is not the case. It is also possible that children who know how to read more words are better able to learn new words, and that this is reflected in the measures used here. However, in this case, the number of words a child can read aloud should also affect the relationship between word reading fluency and irregular word reading with orthographic learning measures in a similar way, and this is not reflected in the results.

Taken together, these findings provide support for theories of reading development that assert that orthographic knowledge is acquired through the process of reading (Ehri, 1995; Share, 1995). For example, both Share (1995) and Ehri (1995) propose that children begin the process of storing word representations while reading words in text and that, as children improve in reading words, they begin to learn regularities of the written word. The finding that nonword decoding predicted growth in both lexical and sublexical knowledge is particularly important as it confirms that phonological decoding plays an important role in acquiring orthographic knowledge, consistent with Ehri's (1995) and Share's (1995) predictions that orthographic knowledge is gained through the process of decoding. However, the contributions of lexical and sublexical knowledge to gains in irregular word reading suggest that orthographic knowledge may be important for growth in reading words that do not follow typical letter-sound correspondences; for these specific types of words, having orthographic representations of the word and/or information about letter patterns may play an important role in word identification. Orthographic learning scores predicted growth on some word reading measures, which is also consistent with the theory of Share (1995); he proposes a secondary role for orthographic learning skill in word reading, in which individual differences in the ability to create new orthographic representations impacts later word reading ability. This finding, however, contradicts Ehri's (1995) theory in that she proposes that the process of reading is the sole means by which later word reading ability is impacted. Thus, while the finding that word reading predicts growth in orthographic knowledge supports the crux of Ehri's (1995) theory, our findings of the role of orthographic learning in predicting growth in word reading raise questions about the completeness of her theory.

The findings of this study have implications for reading education. The results of research questions one and two highlight the importance of word reading in the growth of orthographic knowledge. More importantly, however, the results of the third and fourth research questions highlight the importance of orthographic learning skill in advancing word reading. In general, although word reading accuracy did predict growth in orthographic learning measures, orthographic learning measures contributed more to growth in word reading than the reverse. These results suggest that focusing on improving children's ability to form and store new orthographic representations may allow for gains in word reading. This may be especially important for children with reading difficulties. Research suggests that children with dyslexia struggle with tasks that require letter-position discrimination (e.g., Pammer, Lavis, Hansen, & Cornelissen, 2004). O'Brien, Wolf, Miller, Lovett, and Morris (2011) argue that this difficulty with letter-position discrimination may work to inhibit orthographic learning. Additionally, intervention programs that include instruction about the regularities of the written form of words have resulted in greater improvement in word reading than those that include instruction about phonological awareness alone (Devonshire, Morris, & Fluck, 2013). Notably, this training focuses on orthographic knowledge, as the question of how to teach orthographic learning has not yet been the focus of training research. Focusing on how to teach memory for words that are decoded during reading may be a relevant topic for further research related to improving reading skills. Thus, inclusion of skills related to orthographic learning and processing in reading instruction and intervention may be beneficial in improving word reading skills. This is an area that would benefit from further research and empirical evidence.

Interpretation of these results requires that we consider the limitations of the measures used to evaluate our variables of interest. The measure of lexical orthographic knowledge in particular is problematic as it was not difficult enough at Time 2 and children were near ceiling. This means that the task may not have been adequately capturing variations in skill for those children who were very skilled. Thus, it is possible that the lexical orthographic knowledge task was less sensitive to variations in skill at Time 2 than at Time 3. However, the findings reported here are consistent with previous research (Deacon et al., 2012), suggesting that this lack of sensitivity may not have greatly influenced results. The measure of sublexical orthographic knowledge may have been influenced by the fact that some items had two choices and some had three. The items with three options are likely to be much more difficult as the child must compare each choice to the other two to choose the most likely response of all three. Additionally, the measures of immediate and delayed orthographic learning choice and sublexical orthographic knowledge at Time 3 had reliabilities under .70, indicating that the results of these measures may need to be interpreted with caution. However, the reduced reliability only makes detection of relationships more difficult. Given the low reliability of these measures, it is possible that our study underestimated the relationship of these orthographic processing measures to our measures of word reading. Further research may be necessary to confirm the validity of the results for the measures suffering from reduced sensitivity and/or reliability.

All measures were compared for the two groups of Grade 3 children – that is, the children who were in Grade 3 at Time 2 and those who were in Grade 3 at Time 3. This was done to identify whether there were any differences between the two groups that may have been caused by practice effects, as one group of Grade 3s had completed the measures once before and one group of Grade 3s had not. The t-tests showed that the groups differed significantly on three measures: irregular word reading, lexical and sublexical orthographic knowledge. The significant difference found for lexical and sublexical orthographic knowledge is likely due to the fact that comparisons were made based on raw scores; as items were added to these two measures between Time 2 and Time 3, the scores are very likely to be different. Thus, for most measures, no practice effects were found. However, groups were found to be different on irregular word reading, which is likely to be a practice effect; this measure also displayed other unexpected results.

The measure of irregular word reading produced unusual results at Time 2. There was very little correlation between irregular word reading at Time 2 and irregular word reading at Time 3. This is especially odd in light of the other word reading measures, which had a high correlation from Time 2 to Time 3. It is possible that for irregular word reading in particular, reading may go through phases, during which some children may become worse before getting better. For instance, if a child were to learn how to accurately match letters to sounds, they may apply this knowledge to every word they come across; for irregular words, this is likely to result in reading the word incorrectly as irregular words do not follow typical letter-sound correspondences. Thus, if some children were applying these rules generally to all words, they may become worse at reading irregular words before getting much better. However, it is also possible that these results are due to some other factor. Because of the low correlation, in the cross-lag hierarchical regressions, prior irregular word reading accounts for very little variance. This is likely the reason all measures of orthographic knowledge and orthographic learning were significant predictors of irregular word reading. However, it is possible that these significant results are solely due to the minimal variance accounted for by prior irregular word reading. Thus, further research is required to explore this issue.

This study was also limited by a small sample size for this type of statistical analysis. It is often recommended that a minimum of 10 participants per predictor variable be included (Howell, 2010); in this case, analyses included five predictor variables, so our sample size of 90 meets the minimum requirements. Additionally, our sample included two different age groups and interaction analyses indicated that for some tasks there were grade interactions. These analyses were therefore run separately for each grade. Although the separate grade analyses did not differ overall from the original analyses, they were limited by having very small sample sizes. Individually, the grades included only 46 and 44 participants. Once divided by grade, the samples do not include enough participants for an analysis with five predictors (Howell, 2010). Thus, future research with larger sample sizes may be useful in confirming the accuracy of the results reported here. We present our results as a first exploratory foray into these complex relationships.

The findings presented here generally confirm predictions that word reading measures would predict growth in orthographic knowledge, rather than the reverse, and that orthographic learning measures would predict growth in word reading. We proposed in the introduction that orthographic learning pertains to the formation and storage of new orthographic representations, whereas orthographic knowledge pertains to the retrieval of pre-existing orthographic representations. The findings presented here provide support for the argument that orthographic learning and orthographic knowledge represent distinct and separate skills. These findings also provide empirical evidence for reading development theories that posit that children gain lexical and sublexical knowledge through the process of reading and decoding words (Ehri, 1995; Share, 1995). The finding that orthographic learning predicts growth in word reading supports Share's (1995) theory that individual differences in orthographic learning may play a secondary role in reading, but contradicts Ehri's (1995) theory that phonological awareness and reading experience are the sole means by which children make gains in reading. These findings confirm that orthographic knowledge is primarily gained through word reading, rather than the other way around, but suggest that orthographic learning may predict growth in some word reading skills and vice versa.

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APPENDIX A Tables

Table 1

Means, standard deviations, and reliabilities for word reading accuracy (WRA), word reading fluency (WRF), nonword decoding (NWD), irregular word reading (IWR), lexical orthographic knowledge (OK-L), sublexical orthographic knowledge (OK-SL), orthographic learning spelling (OL Spell), orthographic learning choice immediate and delayed (OL Choice 1, OL Choice 2), nonverbal reasoning (NR), and phonological awareness (PA). Grade equivalencies (GE), standardized scores (SS), and percentages (%) are reported where applicable.

	Time 2				Time 3			
Task	Gr. 2 *M (SD)*	Gr. 3 *M (SD)*	Total *M (SD)*	Reliability	Gr.3 *M (SD)*	Gr. 4 *M (SD)*	Total *M (SD)*	Reliability
WRA	51.63 (12.91)	59.34 (9.62)	55.40 (12.00)		59.76 (11.51)	65.86 (9.41)	62.74 (10.91)	
WRA GE	2.87 (.86)	3.46 (.95)	3.16 (.90)		3.63 (1.18)	4.42 (1.51)	4.02 (1.34)	
WRF	53.15 (15.89)	61.27 (10.5)	57.12 (14.06)		59.37 (13.62)	64.43 (7.45)	61.84 (11.27)	
WRF SS	106.43 (6.62)	107.43 (6.34)	106.92 (12.96)		105.04 (14.44)	101.45 (9.28)	103.28 (11.92)	
NWD	16.65 (10.8)	23.18 (12.96)	19.84 (12.29)		24.63 (13.57)	29.2 (10.71)	26.87 (12.40)	
NWD SS	95.66 (13.02)	97.3 (17.13)	96.46 (15.03)		98.52 (16.48)	98.5 (12.22)	98.51 (14.40)	
IWR	16.43 (5.55)	17.32 (6.56)	16.87 (6.05)	.92	19.96 (5.96)	22.43 (3.98)	21.17 (5.21)	.92
OK-L	29.72 (5.12)	32.45 (4.15)	31.06 (4.84)	.87	47.17 (6.91)	49.68 (5.12)	48.40 (6.19)	.82
OK-L %	82.55 (14.23)	90.15 (11.51)	86.28 (13.44)		77.33 (11.32)	81.45 (8.39)	79.34 (10.15)	
OK-SL	28.98 (5.43)	32.05 (3.7)	30.48 (4.89)	.72	41.96 (5.91)	45.05 (5.62)	43.47 (5.94)	.69
OK-SL %	69 (12.94)	76.3 (8.8)	72.57 (11.64)		69.93 (9.84)	75.08 (9.36)	72.45 (9.9)	
OL Spell	6.91 (3.75)	8.3 (3.72)	7.59 (3.78)	.81	8.8 (3.5)	9.77 (3.84)	9.28 (3.68)	.82
OL Choice	8.46 (3.55)	9.43 (2.71)	8.93 (3.19)	.71	10.22 (2.92)	10.3 (2.97)	10.26 (2.93)	.64
OL Choice	7.98 (2.95)	8.95 (3.21)	8.46 (3.10)	.71	9.72 (2.86)	9.77 (2.77)	9.74 (2.80)	.65
NR	12.87 (6.32)	14.57 (7.07)	13.7 (6.71)					
NR SS	47.39 (10.50)	45.18 (11.43)	46.31 (10.95)					
PA (T1)	9 (3.59)	10.07 (4.13)	9.52 (3.88)					
PA GE (T1)	2.7 (1.66)	3.34 (2.31)						

Table 2

Correlations between word reading accuracy (WRA), word reading fluency (WRF), irregular word reading (IWR), nonword decoding (NWD), lexical orthographic knowledge (OK-L), sublexical orthographic knowledge (OK-SL), orthographic learning spelling (OL Spell), immediate orthographic learning choice (OL Choice 1) and delayed (OL Choice 2) at Time 2.

	WRA	WRF	IWR	NWD	OK-L	OK-SL	OL Spell	OL Choice 1	OL Choice 2
WRA	1	.84**	.28**	.78**	.68**	.68**	.59**	.57**	.48**
WRF		1	.33**	.78**	.64**	.63**	.53**	.51**	.43**
IWR			1	.27**	.29**	.21*	.11	.09	.13
NWD				1	.56**	.56**	.59**	.39**	.31**
OK-L					1	.72**	.44**	.44**	.42**
OK-SL						1	.47**	.49**	.46**
OL Spell							1	.65**	.53**
OL Choice 1								1	.73**
OL Choice 2									1

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

Table 3

Correlations between word reading accuracy (WRA), word reading fluency (WRF), irregular word reading (IWR), nonword decoding (NWD), lexical orthographic knowledge (OK-L), sublexical orthographic knowledge (OK-SL), orthographic learning spelling (OL Spell), immediate orthographic learning choice (OL Choice 1) and delayed (OL Choice 2) at Time 3.

	WRA	WRF	IWR	NWD	OK-L	OK-SL	OL Spell	OL Choice	OL Choice
WRA	1	.79**	.85**	.80**	.74**	.59**	.61**	.50**	.49**
WRF		1	.74**	.85**	.66**	.50**	.47**	.33**	.32**
IWR			1	.76**	.72**	.52**	.55**	.44**	.50**
NWD				1	.64**	.47**	.48**	.27**	.24*
OK-L					1	.62**	.42**	.47**	.45**
OK-SL						1	.38**	.26*	.32**
OL Spell							1	.73**	.71**
OL Choice 1								1	.80**
OL Choice 2									1

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

Table 4

Correlations between word reading accuracy (WRA), word reading fluency (WRF), nonword decoding (NWD), irregular word reading (IWR), lexical orthographic knowledge (OK-L), sublexical orthographic knowledge (OK-SL), orthographic learning spelling (OL Spell), orthographic learning choice 1 (OL Choice 1) and 2 (OL Choice 2), nonverbal reasoning (NR), and phonological awareness (PA) across testing points.

	WRA T2	WRA T3	WRF T2	WRF T3	NWD T2	NWD T3	IWR T2	IWR T3	OK-L T2	OK-L T3	OK-SL T2	OK-SL T3	OL Spell T2	OL Spell T3	OL Choice T2	OL Choice T3	OL Choice 2 T2	OL Choice 2 T3	NR T2	PA T1
WRA T2	1	.916	.840	.794	.842	.766	.279	.851	.683	.722	.682	.599	.592	.566	.571	.496	.480	.497	.177	.466
WRA T3		1	.806	.791	.852	.804	.237	.850	.615	.735	.630	.588	.666	.609	.581	.499	.457	.492	.191	.587
WRF T2			1	.778	.808	.757	.333	.777	.635	.715	.633	.536	.530	.487	.513	.423	.427	.373	.250	.425
WRF T3				1	.790	.852	.226	.736	.563	.657	.560	.501	.538	.469	.524	.327	.339	.318	.142	.408
NWD T2					1	.860	.303	.770	.572	.667	.571	.588	.578	.517	.427	.383	.349	.356	.108	.553
NWD T3						1	.230	.756	.448	.644	.504	.467	.572	.477	.439	.274	.273	.238	.082	.503
IWR T2							1	.232	.289	.172	.209	.356	.108	.114	.091	-.026	.131	.035	.200	.240
IWR T3								1	.656	.718	.614	.517	.612	.549	.566	.444	.436	.504	.229	.461
OK-L T2									1	.716	.715	.601	.435	.470	.441	.471	.416	.467	.116	.280
OK-L T3										1	.733	.619	.505	.420	.486	.465	.324	.450	.128	.450
OK-SL T2											1	.625	.472	.429	.492	.414	.463	.397	.155	.302
OK-SL T3												1	.404	.382	.307	.260	.301	.316	.168	.372
OL Spell T2													1	.653	.645	.490	.526	.442	.052	.538
OL Spell T3														1	.554	.726	.543	.705	.125	.400
OL Choice T2															1	.632	.726	.554	.115	.275
OL Choice T3																1	.527	.803	.035	.214
OL Choice 2 T2																	1	.469	.157	.248
OL Choice 2 T3																		1	.048	.254
NR T2																			1	.012
PA T1																				1

*Note: All correlations above .21 are significant at the .05 level.

Table 5

Concurrent hierarchical regressions to determine whether lexical (OK-L) orthographic knowledge, sublexical (OK-SL) orthographic knowledge, orthographic learning spelling (OL Spell), immediate (OL Choice 1) or delayed (OL Choice 2) are concurrent predictors of word reading accuracy (WRA), word reading fluency (WRF), nonword decoding (NWD), or irregular word reading (IWR).

		Time 2							
		WRA		WRF		NWD		IWR	
Step	Predictor	B	R	B	R	B	R	B	R
1	Age	0.06	.11**	0.06	.13**	0.03	.06	-0.09	.04
	T2 NR	0.1		0.17		0.03		0.19	
2	T1 PA	0.33	.18**	0.27	.15**	0.43	.28**	0.18	.06*
3	T2 OK-L	0.56	.28**	0.52	.23**	0.42	.15**	0.24	.05*
3	T2 OK-SL	0.56	.26**	0.51	.22**	0.42	.14**	0.14	.02
3	T2 OL Spell	0.45	.14**	0.39	.10**	0.38	.10**	-0.04	.00
3	T2 OL Choice 1	0.44	.17**	0.38	.13**	0.23	.05*	0.01	.00
3	T2 OL Choice 2	0.34	.11**	0.29	.07**	0.16	.02	0.05	.00

		Time 3							
		WRA		WRF		NWD		IWR	
Step	Predictor	B	R	B	R	B	R	B	R
1	Age	0.07	.10*	-0.01	.04	-0.04	.03	0.02	.09*
	T2 NR	0.09		0.07		0.02		0.14	
2	T1 PA	0.3	.31**	0.15	.15**	0.27	.24**	0.18	.19**
3	T3 OK-L	0.57	.24**	0.59	.26**	0.53	.21**	0.61	.28**
3	T3 OK-SL	0.39	.12**	0.39	.12**	0.32	.08**	0.36	.10**
3	T3 OL Spell	0.43	.15**	0.35	.10**	0.32	.09**	0.41	.14**
3	T3 OL Choice 1	0.39	.14**	0.25	.06*	0.17	.03	0.36	.12**
3	T3 OL Choice 2	0.36	.12**	0.22	.05*	0.11	.01	0.4	.15**

Table 6

Concurrent hierarchical regressions to determine whether word reading accuracy (WRA), word reading fluency (WRF), nonword decoding (NWD), or irregular word reading (IWR) are concurrent predictors of lexical (OK-L) orthographic knowledge, sublexical (OK-SL) orthographic knowledge, orthographic learning spelling (OL Spell), immediate (OL Choice 1) or delayed (OL Choice 2).

		Time 2									
		OK-L		OK-SL		OL Spell		OL Choice 1		OL Choice 2	
Step	Predictor	B	R	B	R	B	R	B	R	B	R
1	Age	0.08	.08*	0.1	.09*	-0.09	.02	-0.1	.00	-0.08	.01
	T2 NR	-0.02		0.05		0.03		-0.06		-0.04	
2	T1 PA	0.03	.17**	0.05	.11**	0.07	.15**	-0.13	.04*	-0.06	.06*
3	T2 WRA	0.7	.30**	0.52	.16**	0.59	.21**	0.62	.23**	0.56	.19**
3	T2 WRF	0.55	.24**	0.39	.12**	0.36	.10**	0.29	.07*	0.26	.05*
3	T2 IWR	0.64	.29**	0.4	.11**	0.47	.16**	0.47	.16**	0.52	.20**
3	T2 NWD	0.54	.21**	0.35	.09**	0.36	.10**	0.22	.04	0.14	.02

		Time 3									
		OK-L		OK-SL		OL Spell		OL Choice 1		OL Choice 2	
Step	Predictor	B	R	B	R	B	R	B	R	B	R
1	Age	0.11	.10*	0.12	.11*	0.02	.04	0.05	.05	0.07	.06
	T2 NR	-0.03		0.01		-0.03		0.01		0.07	
2	T1 PA	-0.05	.06*	-0.02	.07*	0.33	.26**	0.01	.06*	0.04	.05*
3	T3 WRA	0.68	.33**	0.65	.30**	0.44	.14**	0.55	.22**	0.43	.13**
3	T3 WRF	0.61	.27**	0.58	.25**	0.37	.10**	0.47	.16**	0.35	.09**
3	T3 IWR	0.23	.05*	0.13	.01	-0.03	.00	0.01	.00	0.05	.00
3	T3 NWD	0.54	.19**	0.52	.18**	0.4	.11**	0.3	.06*	0.21	.03

Table 7

Summary of hierarchical regression analyses for lexical orthographic knowledge (OK-L), sublexical orthographic knowledge (OK-SL), orthographic learning spelling (OL Spell), immediate orthographic learning choice (OL Choice 1) and delayed (OL Choice 2) predicting word reading accuracy (WRA), word reading fluency (WRF), irregular word reading (IWR), and nonword decoding (NWD). Controls include age, non-verbal reasoning (NR), phonological awareness (PA), and earlier word reading (WR)[1].

		Time 3 WRA		Time 3 WRF		Time 3 IWR		Time 3 NWD	
Step	Predictor	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2
1	Age	-0.01	.10*	-0.07	0.04	-0.01	.09*	-0.05	0.03
	T2 NR	0.05		-0.03		0.17		0	
2	T1 PA	0.21	.31**	0.09	.15**	0.31	.19**	0.01	.24**
3	T2 WR	0.82	.47**	0.69	.42**	-0.04	0.01	0.8	.48**
4	T2 OK-L	0	0	0.13	0.01	0.56	.25**	-0.02	0
4	T2 OK-SL	0.02	0	0.12	0.01	0.49	.20**	0.06	0
4	T2 OL Spell	0.13	.01*	0.16	0.02	0.49	.17**	0.12	0.01
4	T2 OL Choice 1	0.08	0.01	0.17	.02*	0.44	.17**	0.09	0.01
4	T2 OL Choice 2	0.01	0	0.01	0	0.3	.08**	-0.03	0

* $p < .05$

** $p < .01$

[1] Note: word reading in Step 3 represents the prior measure of the appropriate task

Table 8

Summary of longitudinal hierarchical regression analyses predicting Time 3 lexical (OK-L) and sublexical (OK-SL) orthographic knowledge controlling for age, non-verbal reasoning (NR), phonological awareness (PA), OK-L or OK-SL, and word reading accuracy (WRA), word reading fluency (WRF), irregular word reading (IWR), or nonword decoding (NWD).

	OK-L				OK-SL		
Step	Predictor	β	ΔR^2	Step	Predictor	β	ΔR^2
1	Age	.01	.08*	1	Age	.03	.09*
	Time 2 NR	.01			Time 2 NR	.06	
2	Time 1 PA	.17	.17**	2	Time 1 PA	.13	.11**
3	Time 2 OK-L	.43	.33**	3	Time 2 OK-SL	.40	.24**
4	Time 2 WRA	.35	.05**	4	Time 2 WRA	.25	.03*
4	Time 2 WRF	.37	.07**	4	Time 2 WRF	.15	.01
4	Time 2 IWR	-.10	.01	4	Time 2 IWR	.20	.04*
4	Time 2 NWD	.31	.05**	4	Time 2 NWD	.29	.04**

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

Table 9

Summary of longitudinal hierarchical regression analyses predicting Time 3 orthographic learning spelling (OL Spelling) and choice (OL Choice), controlling for age, non-verbal reasoning (NR), phonological awareness (PA), OL spelling or OL choice, and word reading accuracy (WRA), word reading fluency (WRF), irregular word reading (IWR), or nonword decoding (NWD).

		Time 3 OL Spelling				Time 3 OL Choice 1				Time 3 OL Choice 2	
Step	Predictor	β	ΔR^2	Step	Predictor	β	ΔR^2	Step	Predictor	β	ΔR^2
1	Age	-.11	.02	1	Age	-.14	.00	1	Age	-.09	.01
	Time 2 NR	.07			Time 2 NR	-.04			Time 2 NR	-.05	
2	Time 1 PA	.02	.15**	2	Time 1 PA	-.03	.04*	2	Time 2 PA	.08	.06*
3	Time 2 OL Spelling	.49	.27**	3	Time 2 OL Choice 1	.53	.37**	3	Time 2 OL Choice 2	.39	.18**
4	Time 2 WRA	.29	.05**	4	Time 2 WRA	.26	.04*	4	Time 2 WRA	.38	.09**
4	Time 2 WRF	.19	.02	4	Time 2 WRF	.18	.02	4	Time 2 WRF	.21	.03
4	Time 2 IWR	.01	.00	4	Time 2 IWR	-.10	.01	4	Time 2 IWR	-.06	.00
4	Time 2 NWD	.18	.02	4	Time 2 NWD	.17	.02	4	Time 2 NWD	.18	.02

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

Table 10

Summary of interaction regressions split by grade for lexical (OK-L) and sublexical (OK-SL) orthographic knowledge predicting word reading fluency (WRF) and nonword decoding (NWD), controlling for age, nonverbal reasoning (NR), phonological awareness (PA), and earlier word reading (WR).

		WRF Grade 2		WRF Grade 3		NWD Grade 2		NWD Grade 3	
Step	Predictor	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2
1	Age	-0.01	.06	-0.04	.00	0.04	.03	0.1	.01
	T2 NR	-0.02		-0.1		.00		0.02	
2	T1 PA	0.07	.14**	0.18	.17**	0.04	.11*	0.17	.50**
3	T2 WR	0.79	.59**	0.48	.20**	0.86	.62**	0.81	.27**
4	T2 OK-L	0.1	.01	0.07	.00	0.01	.00	0.12	.01
4	T2 OK-SL					0.07	.00	-0.06	.00

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

Table 11

Summary of interaction regressions split by grade for word reading fluency (WRF) predicting sublexical orthographic knowledge (OK-SL), controlling for age, nonverbal reasoning (NR), phonological awareness (PA), and earlier word reading (WR).

		OK-SL Grade 2		OK-SL Grade 3	
Step	Predictor	β	ΔR^2	β	ΔR^2
1	Age	-0.01	.06	-0.04	.02
	T2 NR	-0.02		-0.1	
2	T1 PA	0.07	.07	0.18	.17**
3	T2 OK-SL	0.79	.36**	0.48	.16**
4	T2 WRF	0.1	.00	0.07	.03

APPENDIX B Figures

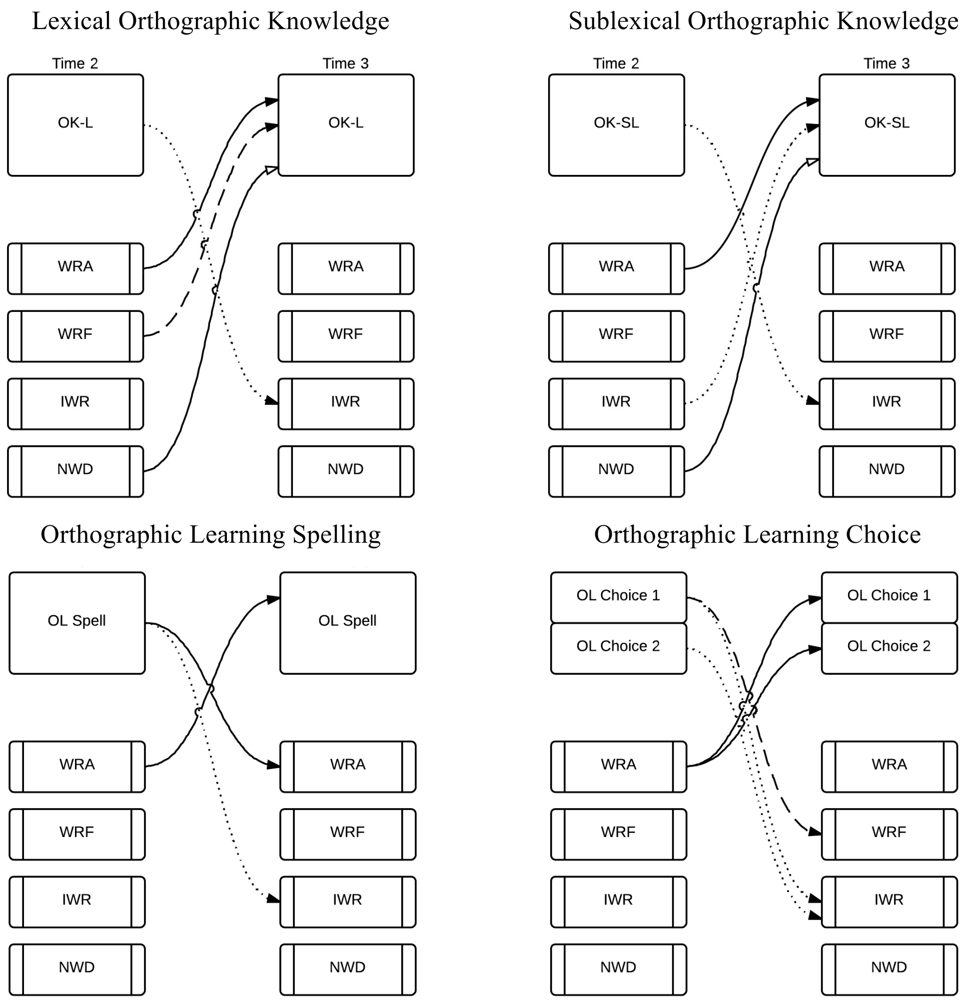

Figure 1. Images showing the relationships between lexical (OK-L) and sublexical (OK-SL) orthographic knowledge, orthographic learning spelling (OL Spell), immediate and delayed orthographic learning choice scores (OL Choice 1 and 2), word reading accuracy (WRA), word reading fluency (WRF), irregular word reading (IWR), and nonword decoding (NWD). Lines indicate a significant predictive relationship, in which the variable from which the line originates significantly predicts growth in skill for the variable to which the arrow points. Different patterns of lines (e.g., dotted) are used to differentiate between the different types of word reading.

APPENDIX C Lexical Orthographic Knowledge Items Time 3

1. **take**/taik	Please take your brother to the store.
2. gote/**goat**	The goat ate the grass.
3. sleap/**sleep**	At night we go to sleep.
4. **hole**/hoal	There was a giant hole in the ground in the field.
5. snoe/**snow**	There was no school today because of the snow.
6. fase/**face**	He made a funny face when playing with the baby.
7. hert/**hurt**	He hurt his knee when he fell off the bike.
8. **sheep**/sheap	We saw sheep at the farm.
9. smoak/**smoke**	There was smoke coming from the building
10. **bowl**/boal	I like to eat my ice cream in a bowl.
11. cloun/**clown**	There was a clown at the birthday party.
12. **word**/wurd	The little girl tried to read the word in the book.
13. cote/**coat**	He wore a warm coat in the winter.
14. **rain**/rane	Take the umbrella in case of rain.
15. stoar/**store**	They bought lollipops at the store.
16. lurn/**learn**	We go to school to learn about the world.
17. **nice**/nise	Mrs. Brown was a nice lady who made the children cookies.
18. scair/**scare**	The boy tried to scare his sister with a frog.
19. **skate**/skait	The little girl learned how to skate on the ice.
20. **true**/trew	The story he told his mother was true.
21. streem/**stream**	The water flowing in the stream was very cold.
22. wize/**wise**	The little boy's teacher was very wise.
23. mysterey/**mystery**	The boy likes to read mystery stories.
24. laik/**lake**	We get to swim in the lake in the summer.
25. **salad**/sallad	I like lots of vegetables in my salad.
26. travle/**travel**	Someday I would like to travel around the world.
27. captin/**captain**	Every ship should have a captain.
28. **few**/fue	She missed a few days of school because she was sick.
29. **explain**/explane	My teacher had to explain how to write a good short story.
30. **wrote**/wroat	I wrote a story about my cat yesterday.
31. sammon/**salmon**	Salmon like to swim in rivers.
32. tertle/**turtle**	The turtle moved very slowly.
33. **wheat**/wheet	The farmer grew wheat in big fields.
34. studdy/**study**	You should study to do well in school.
35. sircus/**circus**	He ate cotton candy at the circus.
36. **believe**/beleave	I couldn't believe the size of the fish I caught!
37. purched/**perched**	The birds were perched on the fence.
38. **trousers**/trowsers	I like wearing trousers more than jeans.
39. pavemant/**pavement**	The cracks in the sidewalk pavement were very large.
40. ashure/**assure**	There will be no school on Saturday, I assure you.
41. **several**/sevral	There were several jellybeans on the table.
42. aplause/**applause**	After the concert the crowd burst into applause.
43. nostrels/**nostrils**	You breathe through your nose using your nostrils.
44. thaught/**thought**	When you give a gift, it is the thought that counts.

45. **tomorrow**/tommorrow	It will be sunny tomorrow.
46. hamster/**hampster**	I had a pet hampster named Ted.
47. forty/**fourty**	The play was forty minutes long.
48. oppurtunity/**opportunity**	Writing a letter is a good opportunity to practice spelling.
49. **possession**/posession	The ball was not in the player's possession.
50. rasberry/**raspberry**	My favourite kind of jam is raspberry.
51. **ridiculous**/rediculous	Clowns wear ridiculous outfits.
52. grone/**groan**	When my mom is annoyed, she can sometimes groan.
53. alternitive/**alternative**	Some kids ride bikes to school as an alternative to walking.
54. **resource**/resourse	When you're looking for information, the library is a good resource.
55. **distance**/distence	In gym, we had to run a long distance.
56. **demon**/deamon	The boy trembled because he thought a demon was in his closet.
57. complimant/**compliment**	The girl's interesting science project earned her many compliments.
58. **dignity**/dignaty	Even though he tripped, the boy managed to recover with dignity.
59. nusance/**nuisance**	When you are trying to study, loud music can be a nuisance.
60. sensative/**sensitive**	A newborn baby's skin is very sensitive.
61. **liberty**/libberty	Soldiers fought in wars for our freedom and liberty.

APPENDIX D Sublexical Orthographic Knowledge Items Time 3

1.	**girve**	gerve	31.	**glain**	glane	
2.	**mose**	moez	32.	**waught**	waut	
3	**tuge**	tewj	33.	**vought**	vaught	
4.	**devave**	devaive	34.	**plame**	plaim	
5.	**bleason**	bleeson	35.	**kume**	keum	
6.	**dage**	daij	36.	**nurge**	nerge	
7.	**sife**	syfe	37.	**keam**	keme	
8.	**tade**	teyd	38.	**ferk**	furk	
9.	**koose**	kooce	39.	**veach**	veech	
10.	**boap**	bowp	40.	**tage**	taje	
11.	**ficker**	fiquor	41.	**craste**	craist	
12.	**lerst**	lurst	42.	**wule**	wuel	
13.	**koom**	kewm	43.	**crade**	craid	
14.	**drailor**	dreilor	44.	**feam**	feem	
15.	**meaf**	mefe	45.	**yoom**	yume	
16.	**lerm**	lurm	46.	**kerge**	kirge	
17.	**proken**	proaken	47.	**smoof**	smufe	
18.	**spacket**	spaket	48.	**smeight**	smaight	
19.	**runk**	runc	49.	**vake**	veighk	vayke
20.	**lape**	laip	50.	**buice**	booce	bewce
21.	**neep**	nepe	51.	**voast**	veaust	voest
22.	**slock**	slauk	52.	**dault**	dallt	dawlt
23.	**bock**	bawc	53.	**nifts**	nyfts	niphts
24.	**bive**	biev	54.	**gurse**	gurce	girse
25.	**kail**	kayl	55.	**keaf**	keeph	kefe
26.	**pleady**	pleddy	56.	**faste**	feyst	fayst
27.	**jestick**	jestik	57.	**founce**	fownce	founse
28.	**fime**	fiem	58.	**taise**	tayze	tayse
29.	**poaf**	pofe	59.	**jores**	joarz	jorze
30.	**beavy**	bevie	60.	**heeks**	heex	hekes

APPENDIX E Orthographic Learning Nonwords Time 2 and 3

Time 2 Nonwords

Target Nonword A	Target Nonword B	Distractor	Distractor
sleer	slear	sleeg	sleag
mees	mese	wees	wese
pute	pewt	pufe	pewf
crent	krent	creng	kreng
berl	burl	berk	burk
vaid	vade	vaip	vape
lail	lale	laig	lage
glore	gloar	plore	ploar
smich	smitch	spich	spitch
stape	staip	stabe	staib
foap	fope	foat	fote
Feap	Feep	Feak	Feek
Lafe	Laif	Lape	Laip
zoop	zupe	zook	zuke
skep	scep	sket	scet

Time 3 Nonwords

Target Nonword A	Target Nonword B	Distractor	Distractor
pleer	plear	pleeg	pleag
blees	blese	klees	klese
Dute	Dewt	Dufe	Dewf
cresh	kresh	cresk	kresk
verl	vurl	verk	vurk
yaid	yade	yaip	yape
Zail	Zale	Zaig	Zage
klore	kloar	slore	sloar
krich	kritch	klich	klitch
smape	smaip	smabe	smaib
zoap	zope	zoat	zote
Veap	Veep	Veak	Veek
Fafe	Faif	Fape	Faip
voop	vupe	vook	vuke
skem	scem	skeb	sceb

APPENDIX F Orthographic Learning Stories Time 2 and 3

Time 2

1. The new word is Laif. The coldest town in the world is Laif. Laif is in Greenland. The people who live in Laif need very hot houses.

2. The new word is vade. There is a hairy monster called a vade. The vade is very big. If you see a vade, you should run away.

3. The new word is lale. Farmers grow a fruit called lale. Lale trees are red. Children like to eat lale when they are hungry.

4. The new word is slear. There is a very big animal called a slear. The slear has big feet. If you have to carry a slear, you will need help.

5. The new word is berl. Farmers grow a plant called berl. Berl likes to grow in wet places. Summer is the time to cut berl.

6. The new word is Feap. There are lots of rocks on the planet Feap. Feap is very far away. To get to Feap, you need a rocket.

7. The new word is pewt. There is a small hut called a pewt. A pewt has tiny windows. Some children found a pewt with three puppies inside.

8. The new word is staip. There is a bird called a staip. The staip eats nuts and seeds. You can see a staip in the zoo.

9. The new word is noar. Farmers make a warm drink called noar. Noar is made from milk. Noar is good in winter.

10. The new word is mese. Some planets have sticky red stuff called mese. Mese drips out of the rocks. People do not like to stand on mese.

11. The new word is krent. There is a very shy animal called a krent. The krent only comes out in the daytime. If you see a krent, it will run away.

12. The new word is scep. There is a kind of boat called a scep. The scep is made from a log. If you ride in a scep, you will be safe.

13. The new word is smitch. There is a bug called a smitch. The smitch has lots of teeth. If a smitch bites you it will hurt.

14. The new word is fope. There is a new ball called a fope. The fope is made of rubber. Some kids will get a fope for Christmas.

15. The new word is zupe. There is a giant fish called the zupe. A zupe can jump very high. Some children like to swim with the zupe.

Time 3

1. The new word is plear. There is a very kind dog called a plear. The plear is quite social. If you have to walk a plear, you will feel happy.

2. The new word is blese. Some flowers have bright red pollen called blese. Blese falls out of the flower. People do not like to smell the blese.

3. The new word is Dewt. There is a large zoo called the Dewt. The Dewt has rare animals. Some children say that the Dewt has three dragons inside.

4. The new word is kresh. There is a very lazy animal called a kresh. The kresh only wakes up to get food. If you see a kresh, it is probably hungry.

5. The new word is vurl. Snakes eat a food called vurl. Vurl likes to grow in clear water. Spring is the time to find vurl.

6. The new word is yade. There is a tiny horse called a yade. The yade is very light. If you had a yade, you might lose it.

7. The new word is Zale. Policemen protect a village called Zale. Zale police are strong. Children like to stay in Zale where they are safe.

8. The new word is kloar. Dancers use soft shoes called kloar. Kloar are made from cloth. Kloar are good for moving.

9. The new word is kritch. There is an ape called a kritch. The kritch has a funny walk. If a kritch likes you, it will laugh.

10. The new word is smaip. There is a flower called a smaip. The smaip blooms purple and pink. You can see the smaip in the springtime.

11. The new word is zope. There is a little bed called a zope. The zope is made for dolls. Some kids will make a zope as a gift.

12. The new word is Veap. There are lots of snakes in the river Veap. Veap has very deep water. To get across Veap, you need a boat.

13. The new word is Fafe. The fastest car in the world is a Fafe. The Fafe is from Norway. The people who buy a Fafe need very good tires.

14. The new word is yupe. There is a smart bird called a yupe. A yupe can fly very far. Some children like to chase the yupe.

15. The new word is scem. There is a kind of chair called a scem. The scem is made for an alien. If you sit on a scem, you will be sore.