Oral Vocabulary Knowledge and Orthographic Learning

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Thesis Summary

Children's reading evolves from the slow and effortful process of using letter-to-sound correspondences during word identification to rapid and skilled whole word recognition - a process referred to as orthographic learning. The question of how this is achieved remains open. This thesis explores the role of vocabulary knowledge in the process of orthographic learning and tests a possible mechanism for its influence. It is presented in two parts.

Part One is a broad literature review that outlines what is currently known about the relationship between vocabulary knowledge and orthographic learning. Possible mechanisms via which vocabulary might exert an effect on orthographic learning are discussed, and are linked back to theoretical accounts that differ with respect to the proposed timing of the influence. Some posit an effect that begins at the time a word is seen in print, such as the self-teaching hypothesis of Share (1995) and the lexical quality hypothesis of Perfetti (1992). Another – the orthographic recoding hypothesis – predicts that the effect may begin prior to any visual exposure (McKague, Davis, Pratt & Johnston, 2008). Topics relevant to how the proposed mechanisms might be understood and tested are then discussed.

Part Two presents an empirical study which draws on the literature review to propose and test three hypotheses: first, that the partial knowledge engendered by oral familiarity with a word should confer an online processing advantage when children's eye movements are monitored during reading; second, that words with predictable spellings based on their phonology should enjoy a processing advantage relative to words with unpredictable spellings; and finally, that the presence of a word in a child's oral vocabulary, together with their knowledge of phoneme-grapheme mappings, allows them to form an orthographic "skeleton" of that word before seeing it in print. The principal findings from this study supported all three hypotheses, and are consistent with the position that orthographic learning can commence prior to visual exposure. Implications for theories of orthographic learning are discussed.

Statement

I, Signy Wegener, certify that the work in this thesis entitled “Oral vocabulary knowledge and orthographic learning” has not previously been submitted for a degree, nor has it been submitted as part of requirements for a degree to any other university or institution other than Macquarie University.

I also certify that this thesis is an original piece of research and it has been written by me. Any help and assistance that I have received in my research work and the preparation of the thesis itself has been appropriately acknowledged.

In addition, I certify that all information sources and literature used are indicated in the thesis.

The research presented in this thesis was approved by the Macquarie University Ethics Review Committee, reference number: **5201500098** on 28th August 2015.

Signed:

Signy Wegener (Student ID: 30473144)

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Chapter 1

Thesis Overview

Introduction

How children become literate is a question that has inspired enormous research interest. As a consequence, some aspects of how children learn to read are well understood. For example, it is now well established that early progress in word reading development is facilitated by the understanding that letters map onto sounds in a reasonably predictable way (Byrne, 1998). When this understanding is buttressed by knowledge of specific letter-sound relationships, along with an appreciation that spoken words can be decomposed into manipulable constituent parts, this allows children to translate a printed word into its corresponding spoken form via a process known as alphabetic decoding (Melby-Lervåg, & Hulme, 2012).

While it is widely acknowledged that alphabetic decoding plays a pivotal role in early reading development, the process of sequential decoding is slow and effortful, which contrasts with the end state of development – skilled and fluent reading (Ehri, 1992, 2005; Share, 1995). How reading evolves from the deliberate processes that characterise beginning readers to the automatic processes that characterise the end state has been referred to as orthographic learning (Castles & Nation, 2006). It is particularly within the context of this transition that researchers have proposed that elements other than alphabetic decoding must make a causal contribution to reading development (Share, 1995; Castles & Nation, 2008). A number of candidate factors have been identified (see Share, 1995; Bosse, Chaves, Largy, & Valdois, 2013; Wang, Castles, Nickels, & Nation, 2011; Nation & Cocksey, 2009; Arciuli & Simpson, 2012), but this thesis concentrates on one: vocabulary knowledge.

The general aim of this thesis was to clarify the nature of the association between vocabulary knowledge (of both pronunciation and meaning) and word reading, and to contribute to the theoretical debate about how this relationship operates. To this end, the remainder of this thesis is divided into two sections. The first is a review article and the second is an empirical paper. This work is written in a “thesis by publication” format, with each section representing a stand-alone journal article. These are now described in more detail.

Part One:

Oral vocabulary knowledge and reading acquisition: A literature review

This section takes the form of a broad literature review with two main aims. The first is to evaluate what is known about the association between vocabulary knowledge and word recognition. Evidence is synthesised from empirical studies that have employed a number of different methodologies, including: an individual differences approach, longitudinal designs, item-based analyses and training studies. The second aim is to identify existing accounts that attempt to explain how vocabulary might exert an influence on word reading. The stage theory of Ehri (1992, 2005, 2014), the self-teaching hypothesis of Share (1995, 1999, 2004, 2008) and the lexical quality hypothesis of Perfetti (1992, 2007; Perfetti & Hart, 2001) all contend that vocabulary exerts an effect on word recognition that commences when the word is first seen in print, because information flows only from orthography to phonology. In contrast, the orthographic recoding hypothesis predicts that vocabulary may influence word recognition prior to any visual exposure (McKague, Davis, Pratt & Johnston, 2008), because allowance is made in this account for a bidirectional flow of information between phonology and orthography. The review is drawn to a conclusion with suggestions for future research, including a proposal for how the competing mechanisms might be tested.

Part Two:

“Orthographic learning commences before written words are seen: Evidence from eye movements.”

Drawing on the literature review, this section presents an empirical study with two aims: (1) to provide converging evidence for the previously reported association between children's vocabulary knowledge, at an item-level, and their ability to read those words; and (2) to explore the basis of this association by testing the theory that the presence of a word in a child's oral vocabulary, in combination with their knowledge of how sounds map onto letters, allows them to form a partial orthographic representation prior to seeing it in print for the first time. Children in Year 4 were trained in the phonology and semantics of nonwords. A key manipulation was the spelling predictability of the nonwords when they were shown in print for the first time within sentences. Children's eye movements were monitored as an index of online processing. Three hypotheses were tested: first, that the partial knowledge engendered by oral familiarity with a word should confer an online processing advantage when children's eye movements are monitored during reading; second, that words with predictable spellings based on their phonology should enjoy a processing advantage relative to words with unpredictable spellings; and finally, that the presence of a word in a child's oral vocabulary, together with their knowledge of phoneme-grapheme mappings, allows them to form a partially specified orthographic representation of that word before seeing it in print. The findings are interpreted in the context of differing accounts of the mechanism that underlies the advantage of oral vocabulary knowledge in the process of word recognition.

Summary

The overarching aim of this thesis is to clarify the evidence base linking oral vocabulary knowledge with word recognition, and to contribute to it by using a novel methodology (monitoring eye movements) to test a proposed mechanism of this influence. Because this dissertation adopts a "thesis by publication" format, there is some unavoidable overlap in the information contained in different chapters. Efforts have been made to minimise this wherever possible. A general discussion that summarises the central findings, and theoretical and practical implications of this thesis constitutes the final chapter.

Chapter 2

Oral Vocabulary and Reading Acquisition: A Literature Review

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Abstract

Orthographic learning refers to the transition from slow and effortful alphabetic decoding to rapid whole word recognition. Much remains to be learned about how this is achieved. Oral vocabulary knowledge, comprising information about the sound and meaning of words, has been implicated as having a role in this process but the mechanism via which this influence operates is not well understood. The aim of this literature review was to: (1) provide a broad overview of the evidence supporting the existence of an association between oral vocabulary and word reading; and (2) to outline the possible mechanisms via which oral vocabulary could exert an effect on reading, drawing particular attention to differences in the time course of this influence. Some theorists (Ehri, 1992; Share, 1995; and Perfetti, 1992) suggest the influence occurs upon first seeing a word in print, while others (McKague, Davis, Pratt & Johnston, 2008) suggest that the influence may occur prior to any visual exposure because oral exposure alone is sufficient to generate an incompletely specified orthographic form. This possibility has not yet been tested with children; if true, it would have significant implications for how reading acquisition should best be supported. Possible approaches to testing this hypothesis with children are suggested.

Introduction

Learning to read is known to be intimately related to children's language skills. At the most basic level within an alphabetic writing system, children must learn and understand the alphabetic principle, which refers to the fact that a series of more-or-less systematic relationships exists between graphemes in printed words and phonemes in spoken words (Byrne, 1998). In English these relationships are lower in systematicity than many other languages because the consistency of grapheme to phoneme correspondences is low; multiple sounds map onto a single letter (e.g. the phoneme /s/ maps onto the graphemes 's' and 'c') and multiple letters map onto a single sound (e.g. the letters 'f' and 'ph' both map onto the /f/ sound). Nevertheless, most children manage to acquire the alphabetic principle, and once they do, they are in possession of the tools required to begin to sequentially decode, one grapheme at a time, the pronunciation of a newly encountered printed word. Indeed, sequential decoding has been referred to as a signature of alphabetic reading (Nation, 2012).

Appreciation of the alphabetic principle is thought to rely on two precursors to its emergence: letter-sound knowledge and phonological awareness. Letter-sound knowledge refers to the understanding that a given printed letter corresponds with a given spoken sound; for example, the letter *d* corresponds to the spoken sound /*d*/. Phonological awareness refers to the ability to analyse and manipulate spoken speech sounds; for example, changing the /*f*/ sound in the spoken word *fight* to a /*t*/ sound creates the spoken word *tight*. The combination of letter-sound knowledge and phonological awareness is generally agreed to be central to the early development of reading (Melby-Lervag, Lyster, & Hulme, 2012). This consensus is manifest within educational policy statements in Australia (Rowe, 2005), the United Kingdom (Department for Education and Skills, 2006) and the United States of America (National Institute of Child Health and Human Development, 2000).

Notwithstanding the central role of decoding and phonological skill in the process of literacy acquisition, it has been suggested that other aspects of children's language ability must also contribute to reading development (Castles & Nation, 2006). One candidate factor is children's oral vocabulary knowledge. Nation and Cocksey (2009) distinguish between two aspects of word knowledge: lexical phonology and semantics. Lexical phonology is defined as familiarity with the phonological form, or pronunciation of a word and can be assessed using auditory lexical decision tasks in which the child hears a spoken word prior to deciding whether it is a word or a nonword. Semantics is defined as the understanding of word meaning, and is often assessed either receptively (the child listens to a word and indicates its meaning from an array of choices) or expressively (via spoken definitions).

In this review, the role of vocabulary knowledge in reading acquisition will be examined. First, the rationale for the interest in this association will be outlined. Next, a distinction is drawn between how vocabulary knowledge is related to different aspects of reading outcomes: word recognition accuracy and reading comprehension. The association between vocabulary knowledge and reading comprehension will be briefly considered before turning to the topic that is the focus of this review: detailing what is currently known about the role of oral vocabulary knowledge within word recognition. Evidence for the existence of the association will be reviewed, and the discussion will be organised according to the methodologies researchers have employed to investigate it. Theories of orthographic learning that provide accounts of *how* oral vocabulary knowledge influences word recognition will then be outlined, drawing particular attention to differences between theories in terms of the hypothesised timing of the effect. The review is concluded with a discussion relating to how the predictions of the mechanisms might be tested empirically.

Why might there be an association between vocabulary knowledge and reading?

Interest in the possible role of vocabulary knowledge in reading acquisition arose from the observation that when young children begin the process of learning to read, many of the words they encounter in print will already be familiar to them orally (Chall, 1987). On this basis, researchers have asked whether this pre-existing knowledge conveys any advantage in the process of learning to read. If oral vocabulary was indeed shown to be causally related to the process of reading acquisition, then this would suggest that reading outcomes may be supported via the application of interventions designed to boost oral vocabulary. It is not enough, however, to identify a plausible causal association between oral vocabulary knowledge and reading if the aim is to design an effective treatment. Rather, any successful treatment must capture the underlying mechanism via which the influence operates. In the case of oral vocabulary knowledge and reading, precisely what this mechanism might be is not well understood.

The components of reading success

According to the simple view of reading (Gough & Tunmer, 1986), two main components of reading success may be distinguished: reading accuracy and listening comprehension. Reading accuracy refers to the ability to correctly map printed letters to spoken sounds, while listening comprehension underpins the reader's ability to extract the meaning of printed text. Oral vocabulary knowledge has been implicated as having a role in both decoding accuracy and comprehension.

Vocabulary and reading comprehension

Successful decoding of print, while necessary, is not sufficient for comprehension (Gough & Tunmer, 1986). This fact is exemplified by observations that some children demonstrate age appropriate decoding skills, but nevertheless struggle to understand what they have read – so called *poor comprehenders* (Nation & Snowling, 1997). A number of factors over and above word recognition have been identified as supporting reading comprehension, most notably oral language skills (for reviews, see Nation, 2005; Floyd, Bergeron, & Alfonso, 2006; Cain and Oakhill, 2007; Carretti, Borella, Cornoldi, & De Beni, 2009). This finding seems intuitive: to understand the meaning conveyed in connected text, one must minimally comprehend the individual words with which the sentence is constructed. While reading comprehension is much more complex than this alone, it has reliably been shown that children who have difficulty with understanding what they read often present with associated poor word knowledge (Nation, Clarke, Marshall, & Durand, 2004; Ricketts, Nation, & Bishop, 2007).

Longitudinal studies have established vocabulary knowledge as a plausible causal factor underlying children's subsequent reading comprehension skills. This finding holds when children's reading comprehension outcomes at school-age are predicted by their vocabulary skills assessed in the school-age years (Nation & Snowling, 2004), at school entry (Muter, Hulme, Snowling, & Stevenson, 2004) and in infancy (Lee, 2011; Duff, Reen, Plunkett, & Nation, 2015). The latter finding, which suggests that vocabulary knowledge prior to the developmental onset of reading predicts subsequent achievement represents particularly strong evidence for a causal role for vocabulary in reading comprehension.

Intervention studies provide the ultimate test of the veracity of a causal hypothesis and there are a number of findings showing that training in oral vocabulary is associated with improvements in reading comprehension skills. For example, in a randomised controlled trial, eight to nine-year-old poor comprehenders showed significant improvements in reading comprehension following an oral language intervention (Clarke, Snowling, Truelove, & Hulme, 2010). In another randomised controlled trial, pre-schoolers with weak oral language skills who received an oral language intervention demonstrated gains in their oral language skills immediately and improvements in reading comprehension that were observable at six month follow-up testing (Fricke, Bowyer-Crane, Haley, Hulme, & Snowling, 2013). These findings support the proposition that oral vocabulary plays a causal role in reading comprehension outcomes.

Vocabulary and reading accuracy

Associations between vocabulary and reading accuracy. Initial efforts directed towards investigating the potential association between oral vocabulary and reading accuracy took an individual differences approach. The rationale for this is that if oral vocabulary plays a role in reading skill, then individual differences in oral vocabulary should predict individual differences in reading, even after individual differences in decoding and phonological skill have been accounted for. Within a sample of school-age children, Nation and Snowling (2004) found precisely this pattern. Specifically, children's scores on standardised tests of language accounted for unique variance in their word reading scores when word reading was assessed cross-sectionally at eight years of age and when those children were reassessed at 13 years of age, even when decoding and phonological skill were taken into account first.

Ricketts, Nation and Bishop (2007) subsequently extended this work by exploring the relationship between children's oral vocabulary and their ability to read regular and exception words in a sample of eight to nine-year-olds. They found that oral vocabulary was associated with exception word reading but not regular word reading. Ouellette (2006) found the same pattern when vocabulary was used to predict reading performance: vocabulary predicted significant variance in irregular word reading but not in nonword reading. Notably, both Ricketts et al. (2007) and Ouellette (2006) assessed expressive vocabulary knowledge, which is generally taken to reflect depth of semantic knowledge. However, when measures reflecting breadth of semantic knowledge have been used, vocabulary has been implicated in both regular and irregular word reading, though the latter relationship tends to be stronger. For example, in a sample of 13-year olds, Bowey and Rutherford (2007) employed the

Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 1981, 1997) and found a correlation of .57 between receptive vocabulary and irregular word reading; and a correlation of .39 between receptive vocabulary and nonword reading. Also employing the PPVT, Goff, Pratt, and Ong (2005) found the same pattern of results in a sample of nine to eleven-year-old children: receptive vocabulary correlated .53 with irregular word reading and .28 with regular word reading.

Vocabulary as a potential causal factor in reading acquisition. The studies described to date provide evidence for the existence of an association between oral vocabulary and reading outcomes. The possibility that this relationship might be causal has since been investigated longitudinally. For example, Lee (2011) followed a sample of more than 1,000 infants in the United States. Their vocabulary was assessed via parent report on a questionnaire, the MacArthur-Bates Communicative Development Inventory (CDI; Fenson et al., 1994) at two years of age, and correlations with subsequent language and literacy skills between the ages of three and eleven years were reported. The correlation between vocabulary and reading accuracy was fairly stable across the age range, with an average value of .23. This corresponded to infant vocabulary accounting for five percent of the variance in school-age reading outcomes. Although representing a small effect size, the large sample meant that this value was highly statistically significant. Using a similar approach, Duff, Reen, Plunkett and Nation (2015) followed 300 infants in the United Kingdom, assessing their vocabulary by parent report in their second year of life. An average of five years later children were seen again and their vocabulary, phonological and reading skills were assessed. Using structural equation modelling, they found that infant vocabulary was a highly significant predictor of subsequent reading accuracy, accounting for 11% of the variance. This value, while larger than that found by Lee (2011), remains small. The relatively modest size of the effect has been attributed to a lack of stability in infant language skills.

Nevertheless, this does not detract from the significance of this predictive relationship, which lends weight to the position that vocabulary knowledge may be one causal factor supporting reading development, in so far as oral vocabulary knowledge prior to the developmental onset of reading predicts subsequent achievement, thereby establishing that the putative cause (in this case vocabulary) precedes the effect (reading outcomes).

While findings from studies exploring associations and those employing longitudinal designs are consistent with there being a relationship between vocabulary knowledge and reading outcomes, they do not clarify the nature of that relationship. It is conceivable that the observed association merely reflects the operation of a general learning mechanism wherein children who are good (or poor) at vocabulary learning also later turn out to be good (or poor) at reading. One way of addressing this issue has been to explore associations at the item level.

Item-level associations between vocabulary and reading accuracy. Item-level analyses involve relating an individual's knowledge of particular words in the oral domain with their ability to read those same words. This design has the potential to provide stronger support for the influence of word knowledge on reading, as item-level associations are not as susceptible to the argument that vocabulary and reading are related via the operation of a general learning mechanism. Nation and Cocksey (2009) took this approach and were interested in several questions. First, they asked if the relationship between vocabulary knowledge and reading would hold at an item-level. Second, they asked whether the relationship would be stronger for words with irregular spelling-to-sound correspondences. And finally, they asked whether familiarity with the phonological form of a word was sufficient to support the association between vocabulary knowledge and reading, or whether a deeper knowledge of word meaning was necessary.

To address these questions, seven-year-old children were presented with regular and irregular real words and asked to perform three tasks: to rate the stimuli as either aurally familiar or unfamiliar, to provide oral definitions for the words they knew, and to read the words aloud. It was found that those words known orally were easier for the children to read than words that were unknown orally, and that this relationship was stronger for irregular words (odds ratio of 3.97 with lexical phonology and 2.34 with semantic knowledge) than regular words (odds ratio of 2.35 with lexical phonology and 1.71 with semantic knowledge). They also found that when irregular word reading accuracy was predicted from knowledge of lexical phonology and from knowledge of semantics, lexical phonology accounted for unique variance in reading accuracy after semantics was accounted for, whereas definition knowledge did not account for unique variance in reading accuracy once lexical phonology was accounted for. These results were interpreted as being consistent with the idea that lexical phonology was sufficient to predict reading accuracy, but that knowledge of the meanings of these words conferred no additional advantage. In sum, this item-level study provided some initial evidence for a more active and direct role of vocabulary within the process of reading than suggested by studies employing standardised measures and longitudinal designs.

Item-level associations between vocabulary and reading within training studies. Training studies provide the most powerful evidence for the existence of causal effects (Hulme & Snowling, 2015). This is based on the rationale that if a given skill is causally related to an outcome, then training in that skill should produce improvements in the outcome. Training paradigms have been employed to explore, on an item basis, the relationship between oral vocabulary knowledge and reading outcomes. In this paradigm, novel words are taught aurally prior to orthographic exposure and the effect of the pre-existing knowledge on subsequent reading is assessed, usually via comparison with words for which there is no pre-existing knowledge. This approach is an analogue for the experience, common when children are in the beginning stages of reading, of encountering a familiar spoken word in print for the first time. Within this approach, the elements of representation that are trained are often manipulated with a view to distinguishing the relative contributions of those elements to the effect. The typical manipulation involves contrasting training in lexical phonology with the effects of training in both lexical phonology and semantics.

A training method was piloted by Pratt, Johnston, and Morton (1999) in which children in Grades 2 and 3 were taught to associate the phonology and meaning of nonwords. These were presented within a story, with a picture referent taking the form of imaginary creatures. On the basis of oral pre-exposure, children were expected to generate representations of the novel words within their oral vocabularies. Training was provided on at least two occasions with intervals between sessions of two to three days. Following training, children were asked to read aloud the names of the orally trained words, along with matched untrained items. Children were found to read the orally trained nonwords more accurately than the untrained nonwords.

McKague, Pratt and Johnston (2001) adapted the method employed by Pratt, Johnston, and Morton (1999) to train Grade 1 children with the phonology and meaning of nonwords. In another condition, children were trained in the phonology of nonwords using only a repetition task. A control condition consisted of untrained nonwords. Training occurred over two sessions and children were tested during a third session, with each subsequent session occurring two to three days following the previous one. At test, children read aloud the trained and untrained nonwords. Children were found to be more accurate at reading aloud orally trained (approximately 57% correct) versus untrained (approximately 28% correct) nonwords on their first visual presentation but there was no further benefit associated with knowledge of word meaning over knowledge of the phonological form alone.

In their second experiment, Duff and Hulme (2012) trained five to six-year-old children in various aspects of representation of novel, regular nonwords. The first condition involved oral pre-exposure to the phonology of the novel nonwords; the second condition involved oral pre-exposure to the phonology and meaning of novel nonwords; and the final condition was comprised of items that had not received any training. The pre-exposed nonwords were trained orally over two sessions on different days, with phonology training occurring first for all nonwords, followed by semantic training for nonwords in that condition. At test, children were asked to read the nonwords over six trials and feedback was provided regarding accuracy. Orally pre-exposed items showed an advantage over untrained items at the first visual presentation and this advantage remained over subsequent presentations. However, training in phonology and semantics provided no additional benefit over training in phonology alone.

While the findings of McKague et al. (2001) and Duff and Hulme (2012) both suggest that the advantage of orally trained words on reading accuracy is achieved via the provision of phonological information alone, these findings contrast with those of Ouellette and Fraser (2009). The latter study employed a sample of slightly older children in Grade 4. The children were taught to read the orthography of 10 nonwords, five with phonological pre-exposures alone and other five with phonological and semantic pre-exposure over six learning trials. In the orthographic condition, children thus had access to phonology and orthography while in the semantic condition, children had access to phonology, orthography and semantics. Children were tested on two occasions, one and four days after training. On an orthographic choice task, children were better able to recognise words that had been presented with both phonological and semantic information, though the advantage in the semantic condition was small (82% vs. 76%). However, on a spelling task there was no significant effect of semantic pre-exposure on spelling.

Adult studies have also investigated the contributions of phonology and semantics to nonword reading in the context of training studies. For example, in their second experiment McKay, Davis, Savage and Castles (2008) trained adults to read two sets of novel words, some of which were presented along with meanings while the others were not. Some of the words in each condition had a regular pronunciation for the body while others included an irregular but phonetically plausible vowel pronunciation. Training began with oral familiarisation in which participants were given the phonological form of the novel words, while those in the semantic condition also received training in definitions. Following this, participants were familiarised with the orthographic form of the words in the context of a reading aloud task. They were given the correct pronunciation initially, but thereafter needed to produce it themselves. Corrective feedback was provided over up to eight trials. Follow-up testing took the form of a reading aloud task. On this task, phonological and semantic pre-exposure was associated with more accurate and faster responses compared to phonological pre-exposure alone, but only when words had inconsistent spelling-to-sound correspondences. Participants were also more accurate at recognising them in an old-new decision task. These findings were interpreted as consistent with the notion that semantics makes a small contribution to reading aloud, over and above any effects of lexical phonology.

In their second experiment, Taylor, Plunkett and Nation (2011) considered the role of semantics as adults learned an artificial orthography. Participants were pre-exposed to the phonology of all experimental items, and to a definition for half of the items. Performance was compared to a no pre-exposure condition drawn from their first experiment. During the training phase, participants were taught to read word level representations in an artificial orthography within which frequency and vowel consistency were manipulated. Initially, participants viewed each item, listened to its pronunciation and repeated it. Then, during training, each item was viewed and participants read them with corrective feedback until they reached a predetermined accuracy criterion. At the beginning of training, both lexical phonology and semantic pre-exposure facilitated reading accuracy, regardless of frequency or consistency and there was no additional advantage for semantically trained items over the benefit conferred by training in lexical phonology. These findings were interpreted as being consistent with evidence from children suggesting that the early stages of orthographic learning may be more dependent on phonological than semantic familiarity (e.g. McKague et al., 2001; Nation & Cocksey, 2009). However, by the end of training in Taylor et al.'s (2011) second experiment, pre-exposure to semantics improved reading accuracy for items with low frequency inconsistent vowels compared to both the lexical phonology and the untrained condition. Additionally, at this point lexical phonology did not provide a reading accuracy advantage over and above the untrained condition. These findings were interpreted as suggesting that, when skill level is higher (as in adults), semantic knowledge has a role in supporting the reading of low frequency and inconsistent words in particular.

Together these findings suggest that: (1) prior knowledge of oral vocabulary conveys an accuracy advantage on the first visual presentation of a word; (2) in young children, the current evidence suggests that knowledge of a word's phonology alone conveys the advantage, although semantics may be more important with age and when skill level is higher; and (3) the effect of vocabulary on orthographic learning can vary with the print-to-pronunciation regularity of the written words.

How does oral vocabulary influence reading acquisition?

While there is clearly evidence supporting the existence of a relationship between oral vocabulary knowledge (whether phonology or phonology and meaning) and reading accuracy, the mechanism of influence is debated. Proficient word recognition is thought to be rapid, automatic and almost effortless (Share, 2008; Ehri, 1992). For this reason, skilled reading is thought to be reliant on the reader building a mental store of specialised word-specific memories, or *orthographic representations*: that is, knowledge that a particular letter string is the written form of a word in speech that can be retrieved as a whole unit, rapidly and accurately via direct lexical access (Share, 2008). Dominant theories contend that oral vocabulary knowledge confers some advantage within the process of acquiring orthographic representations, known as *orthographic learning* (Castles & Nation, 2006). Each of these theories will now be considered in turn.

Stage (phase) theory. Ehri (1992, 2005, 2014) described the stage theory of orthographic learning. According to this view, children's storage of orthographic representations in memory develops in a series of phases across developmental time which are named to reflect the most common types of connections (linking the written forms of words to their pronunciations and meaning) that are formed to support orthographic learning and these are conceptualised as qualitatively distinct. The first stage is termed *pre-alphabetic* or *logographic*, in which children tend to rely on salient visual features to read a few printed words because they have very limited letter-sound knowledge. Children in this stage are thought to read the word "moon" by attending to the "oo", which could plausibly be viewed as resembling two full moons. In the *partial alphabetic* stage children are thought to start to develop letter-sound knowledge, which they can use to remember how to read a few words. In the *full alphabetic* phase, children can learn to read words by using their full letter-sound knowledge and phonemic skills to form complete connections between letters in the printed form and phonemes in the spoken form. The final stage is the *consolidated alphabetic stage*, which is proposed to occur when there is an accumulation of sight words held in memory, allowing children to identify recurring letter patterns within these words that become consolidated into multi-letter units representing specific phonological blends. These larger units take the form of grapho-syllabic and morphemic spelling-sound units such as, for example, *–ump, -est, -tion, -ed* and *–ing*. Letter units of this type are thought to benefit orthographic learning because they reduce memory load: for example, if a child had learned an orthographic unit *ing* on the basis of previous experience with words containing these letters, then this might assist the child to learn additional orthographic forms containing this unit, a process that is assumed to be easier than one requiring separate encoding of individual letters. It is this final consolidated alphabetic stage that corresponds to orthographic learning as it is conceptualised elsewhere (e.g. Castles & Nation, 2006).

Ehri (2014) theorised that for an orthographic representation to be formed, *orthographic mapping* must occur, which is believed to be largely driven by decoding. Orthographic mapping is conceived of as a process in which connections are formed between aspects of lexical representation that begins when a reader sees a new printed word and then either produces the spoken word or hears its pronunciation. When this occurs the spelling of the word is thought to become mapped onto its pronunciation and meaning. These mapping connections are proposed to "glue" spellings to their pronunciations in memory, while processing the meanings of words is thought to connect semantic information to word units. Within the *consolidated alphabetic* phase of word reading, oral vocabulary knowledge is viewed as assisting orthographic learning by connecting semantic information to word units, and through a process in which the child decodes a printed word, then looks through their mental store of known spoken words to find an option that matches their decoding effort and is consistent with the context.

While developmental change has been acknowledged to take place over the course of reading development, Ehri's (1992, 2005, 2014) stage theory has been criticised on the basis that the weight of empirical evidence supports the view that reading development is better characterised by continuities in underlying skills rather than by distinct, qualitative changes over developmental time (for a review of this literature see Nation, 2012). Nevertheless, the role that stage theory ascribes to oral vocabulary knowledge within reading does share significant similarities with theories of orthographic learning that enjoy substantial empirical support, such as the self-teaching hypothesis (Share, 1995) and the lexical quality hypothesis (Perfetti, 1992).

Self-teaching hypothesis. Share (1995, 1999, 2004, 2008) delineated the self-teaching hypothesis, which has proved to be a very influential account of how orthographic learning might occur. According to this theory, once children have achieved some basic skills enabling them to translate, or recode, printed letters into sounds (so-called phonological recoding) then even beginning readers have the tools to begin to teach themselves to read. Self-teaching of orthographic forms occurs when a child manages to apply phonological recoding to correctly deduce the pronunciation of an unfamiliar printed word. Whenever this transpires, the child has effectively provided themselves with a discrete learning trial in which they have the opportunity to encode that word's orthographic form. Ultimately, over one or more learning trials, an orthographic representation of that word is generated that facilitates future rapid and accurate retrieval of its phonology and meaning. In contrast to Ehri's stage theory (1992, 2005, 2014), the self-teaching hypothesis is considered to be an item-based theory of orthographic learning. On this view, words that are known to an individual should be recognised quickly via direct lexical access, whereas novel or less familiar items should be more reliant on phonological recoding. Therefore all individuals, whether children or adults, will deploy self-teaching of orthographic forms to create orthographic representations for newly encountered words while the parallel procedure of rapid and direct lexical access will be used for familiar words.

The self-teaching hypothesis (Share, 1995, 1999, 2004, 2008) conceptualises vocabulary knowledge as assisting with the process of linking the phonological and orthographic forms of a word, and additionally, as furnishing top-down support via the provision of an additional source of information that is useful for resolving partially successful decoding attempts. For example, a child might produce a partially successful phonological recoding of a newly encountered printed word, resulting in an output that does not exactly match a lexical entry held in oral vocabulary. If, however, the child holds a similar phonological representation then this may cause the child to review their decoding attempt in view of this. The child may then accept their existing phonological representation as a more likely match for the given orthography.

Lexical quality hypothesis. Perfetti (1992, 1997; Perfetti & Hart, 2001) advanced the lexical quality hypothesis. Another item-based theory of orthographic learning, it contends that literacy is the successful outcome of the integration of components of word knowledge: phonology, orthography and semantics. According to this view, lexical representations can vary in quality, where quality is understood to reflect the degree to which components of word knowledge are represented and bonded within the reader. Perfetti (1992) suggested that high quality orthographic representations must be *autonomous:* that is, the input (orthography) must be sufficient to result in word recognition without the need to rely on context or decoding. Autonomy is proposed to depend on the *precision* of its representation: a precisely specified representation will include finely-grained encoding of the unique letter string that renders it readily distinguishable from visually similar words. For example, the orthographic representation of *from* is fully specified when it can be distinguished from the spelling *form* or *frog*. Autonomy also depends on the *redundancy* of the connections between the lexical form (orthographic representation and phonology) and its meaning (one accessed orally and one from orthographic-to-phonological mappings). When multiple sources of information about a word are available, these parallel retrieval processes assist rapid identification. In other words, both the quality and quantity of lexical representations is viewed as essential for reading success.

The lexical quality hypothesis (Perfetti, 1992) views the presence of oral vocabulary knowledge as assisting children to form and strengthen links between phonological and orthographic representations. Further, it would predict that when lexical quality is low, reliance on vocabulary knowledge will increase. The finding that oral vocabulary is more strongly associated with learning irregular words has been described as being consistent with the lexical quality hypothesis, insofar as irregular words have lower lexical quality by virtue of the reduced correspondence between orthography and phonology, with the result that vocabulary knowledge becomes particularly important for these words.

Orthographic recoding hypothesis. Each of the theories described above (Ehri, 1992; Share, 1995; Perfetti, 1992) operate in an explicitly feedforward direction, from print to pronunciation. By virtue of this assumption, vocabulary knowledge must be seen as exerting an effect on reading accuracy that commences once a word is seen in print for the first time. An alternative possibility is that children may actually start to form incompletely specified orthographic representations on the basis of oral vocabulary knowledge *before* any visual exposure occurs. On this view, a child who has adequate sound-letter knowledge may form an expectation of how an orally familiar word might be represented orthographically prior to seeing it in print for the first time. Stuart and Coltheart (1988) initially raised this possibility, suggesting that if a child had good letter-sound knowledge along with the ability to phonemically segment spoken words, and an appreciation that spoken words can be converted to letters, then that child could begin to construct an orthographic lexicon prior to the commencement of formal reading instruction. Two formulations of this hypothesised process were provided. The first, and weaker, formulation proposed that children generate an expectation of the orthographic form of a known spoken word. For example, they suggested that if a child was familiar with the spoken word *pig*; understood that it could be separated into the phonemes /p/, /I/ and /g/; and knew that those phonemes were represented by the graphemes p, i and g; then they would expect the spoken word *pig* to be written as p, i, g. The second, and stronger, formulation proposed that a child with those aspects of knowledge could form an incomplete or partially specified orthographic representation of that known spoken word prior to visual exposure.

Johnston, McKague, and Pratt (2004) tested this proposition empirically within the context of an adult training study. They taught the sound and meaning of a set of highly obscure real words. The orally trained words appeared in print for the first time in a lexical decision task, along with a set of familiar words and nonword foils. Using a masked priming paradigm, which has been shown to be sensitive to automatic processing of orthographic information in visual word recognition, they found a pattern of priming effects for the orally trained words that was consistent with the hypothesis that orthographic representations had been established before visual exposure, and that they could be accessed automatically in the lexical decision task.

Because the dominant theories of orthographic learning (Ehri, 1992; Share, 1995; Perfetti, 1992) all take the view that vocabulary can only influence reading upon exposure to the printed form of a word, they cannot accommodate findings suggesting a mechanism of influence that begins to operate prior to visual exposure. McKague, Davis, Pratt and Johnston (2008) addressed this issue by proposing the existence of another mechanism capable of explaining the finding that oral vocabulary knowledge could support the formation of an incompletely specified orthographic representation prior to print exposure. According to this account, termed the *orthographic recoding hypothesis*, orthographic learning operates on an item-level in both a feedforward direction (print-to-pronunciation), and crucially, in a feedback direction (from pronunciation-to-print). The proposed item-specific feedback learning mechanism employs feedback from phonology to orthography in the process of orthographic learning. Both feedforward accounts (Share, 1995; Perfetti, 1992) and the account that proposes information flows reciprocally in feedforward and feedback directions (McKague et al., 2008), agree that lexical entries should gradually approach autonomy. Where the accounts diverge is that, according to the orthographic recoding hypothesis, until autonomy is achieved, visual word recognition is based on an incompletely specified orthographic representation, which is hypothesised to be supported by feedback from phonology. Once the orthographic representation is sufficiently well specified, there is no need for feedback. Hence, feedback from phonology to orthography is hypothesised to be limited to the learning process and should be strongest on the first opportunity for orthographic learning; its initial visual exposure.

The orthographic recoding hypothesis rests on the existence of bidirectional connections between orthographic and phonological codes. Recent models of visual word recognition all permit feedback from phonology to orthography in word recognition. For example, explicit feedforward and feedback connections between orthography and phonology are present within the Dual Route Cascaded model of reading (Coltheart, Rastle, Perry & Langdon, 2001) and in connectionist models of reading (e.g. Harm & Seidenberg, 2004; Plaut, McClelland, Seidenberg, & Patterson, 2006).

The existence of feedback activation in word reading is inferred from experiments showing that phonological activation affects the activation of orthographic units. Stone, Vanhow and Van Orden (1997) were the first to report on the so-called *feedback consistency effect*, and argued that it strongly supports the position that feedback from phonology to orthography plays a role in visual word recognition. Consistency within reading refers to the degree of predictability between spelling patterns and pronunciations (feedforward consistency) and between sound patterns and spellings (feedback consistency). See Figure 1 for a schematic of this relationship.

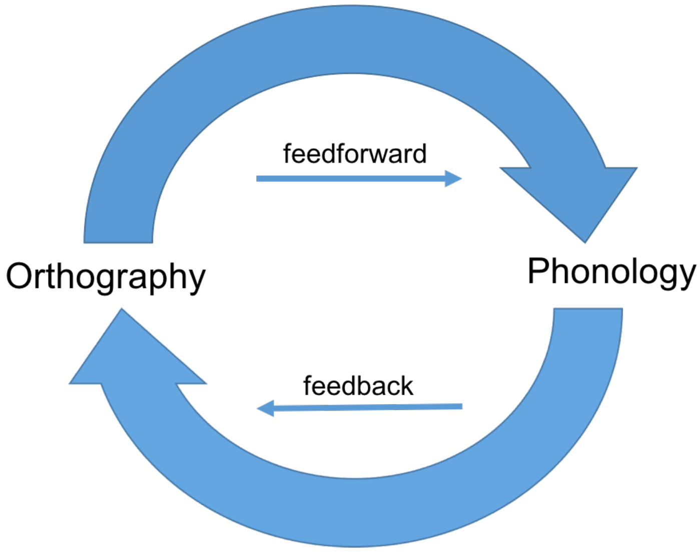

Figure 1. A schematic representation of bidirectional connections between spelling and phonology during reading (adapted from Ziegler, Petrova, & Ferrand, 2008).

Consistency has also been referred to as *predictability* (Stone, Vanhow & Van Orden, 1997) or *ambiguity* (Van Orden & Kloos, 2005). It is a feature of the relationship *between* spoken words and written forms, rather than being resident within either phonology or spelling individually, and it is present at multiple levels of representation ranging from the word level, to the rime-body level, to the phoneme level (Van Orden & Kloos, 2005). When a word body is always pronounced the same way, such as *_ab* as in *grab,* it is referred to as feedforward consistent or regular for reading; and when a pronunciation body is always written in the same way, such as *_ab* in *grab,* it is referred to as feedback consistent, or regular for spelling. The word *grab* may therefore be understood as both feedforward and feedback consistent. When a word body can be pronounced in more than one way, such as *_amp,* as in *stamp* and *swamp*, it is considered to be inconsistent in a feedforward direction (spelling to pronunciation); and when a pronunciation is associated with more than one plausible spelling pattern, like /*Im*/ as in *team, deem* and *theme*, it is considered to be inconsistent in a feedback direction (pronunciation to spelling). Evidence for the backwards flow of information from phonology to orthography is inferred from situations in which spoken words give rise to multiple plausible spellings, resulting in competition occurring between the candidate spellings, which takes time to resolve. This feedback consistency effect is observable in longer response latencies in visual lexical decision and naming tasks (Stone et al., 1997). Whereas feedback consistency is usually conceptualised within models of skilled reading, in their orthographic recoding hypothesis, McKague et al. (2008) argue that its primary role is within the process of early learning.

As an initial test of their orthographic recoding hypothesis, McKague et al. (2008) conducted a training study with adults. Two key manipulations were carried out: first, training was either oral or visual; and second, feedback consistency was manipulated at the level of the rime-body allowing a comparison of words whose spellings were predictable from their spoken form with words whose spellings were not predictable as multiple plausible options were available. In the oral training condition, participants learned the sound and meaning of novel words that were embedded in short stories over three sessions on separate days. In the visual training condition, participants silently read the short stories. Masked priming within a lexical decision task were employed to measure orthographic learning. They found that there was a significant two-way interaction in the by-subjects analyses between training and feedback consistency, showing that recognition of orally, but not visually, trained words was disrupted by feedback inconsistency. This finding was interpreted as being consistent with the idea that the visually trained items had become precisely specified over the course of training whereas the orally trained items had not. Additionally, the finding of robust masked identity and form priming effects for orally trained words at their first visual exposure was interpreted as being consistent with the idea that training in the phonology and semantics of novel words reflected automatic access to partially specified orthographic representations of those words.

The hypothesis that the mechanism underlying the influence of oral vocabulary on word reading accuracy is the generation of an incompletely specified orthographic representation has not yet been tested with children. To do so is important because if the mechanism of the influence of oral vocabulary on reading occurs prior to orthographic exposure, then this would have significant implications for how reading should be taught: it would suggest that explicit teaching of oral vocabulary (sound and sound-to-meaning relationships) should occur prior to phonics instruction.

How might the timing of the mechanism of influence of oral vocabulary on reading be tested?

If a partially specified orthographic representation is indeed generated by virtue of its representation in oral vocabulary, strong evidence for this possibility would be derived from an experimental methodology known to be sensitive to implicit or incremental learning. To date, researchers have employed masked priming as a means of indexing the implicit knowledge conferred by training in oral vocabulary (e.g. Johnston, McKague, & Pratt, 2004; McKague et al., 2008). Another methodology that holds promise is the monitoring of eye movements, which has the added advantage of providing a temporally sensitive metric of how new words are processed in a naturalistic setting. While eye monitoring has a long history of use with adults, it is only relatively recently that the technology has been employed to investigate the development of reading in childhood (e.g. see Blythe & Joseph, 2011; Joseph, Nation & Liversedge, 2013; Blythe, 2014).

Recent work with adults also suggests that eye movements are useful for investigating orthographic learning specifically. For example, it has been shown that as adults become more familiar with orthographic forms over repeated presentations, they require less time to process them ‘online’ (e.g. Joseph, Wonnacott, Forbes, & Nation, 2014; Taylor & Perfetti, 2016). Indeed, Taylor and Perfetti (2016) recently reasoned that eye movement monitoring should be sensitive to partial knowledge, making it an ideal methodology for indexing the effect of pre-exposure to elements of lexical knowledge on reading. They found that partial lexical knowledge of form (orthography and phonology) impacted on early processing measures such as first fixation duration and gaze duration; whereas knowledge of word meaning impacted the later measure of re-reading probability.

The issue of whether vocabulary knowledge exerts an influence on reading prior to, or from the point of, initial orthographic exposure might be achieved by performing two manipulations. In line with previous research, reading of orally trained items could be contrasted with reading of orally unfamiliar items. The second manipulation might draw on the literature pertaining to the feedback consistency effect (Stone, Vanhow, & Van Orden, 1997) to create conditions in which the hypothesised partial orthographic representation either matches or does not match the actual orthographic form when it is first seen in print. If a partial orthographic representation does indeed drive the oral vocabulary advantage, then this advantage should be disrupted by the provision of an orthographic form that does not match the partial orthographic representation, effectively creating a surprise that should take time to resolve. Moreover, this disruption should be most evident when words have been orally pre-exposed but not when words are orally unfamiliar.

Conclusion

This review has outlined evidence for the existence of an association between oral vocabulary knowledge (comprising familiarity with the sound and meaning of spoken words) and word reading, with a particular focus on word reading accuracy. It has been shown that oral vocabulary knowledge is associated with word reading when investigated using a range of different approaches: individual differences, longitudinal designs, and item-level analyses within training studies. Theoretical accounts of how oral vocabulary knowledge might exert an effect on orthographic learning have been discussed, and differences with respect to the proposed timing of the influence are highlighted. Existing feedforward accounts such as

Ehri's (1992) stage theory, Share's (1995) self-teaching hypothesis and Perfetti's (1992) lexical quality hypothesis propose that vocabulary exerts an effect on reading that begins upon orthographic exposure. This is contrasted with a less well-known account, McKague and colleagues' (2008) orthographic recoding hypothesis, that also allows for feedback from phonology to orthography in the process of orthographic learning and predicts that vocabulary exerts an effect prior to visual exposure.

The latter hypothesis has not yet been tested with children, but it is important. If vocabulary does indeed drive a reading advantage that originates prior to orthographic exposure, then this would have significant implications for how reading should be taught. It is suggested that eye movement monitoring is a methodology that has been shown to be sensitive to partial and incremental knowledge, indicating that it would be ideally suited to future work in this area. Finally, two experimental manipulations have been outlined which would test the hypothesis that the advantage of orally known words over unknown words results, at least in part, from the generation of an orthographic representation prior to first seeing the words in printed form.

Chapter 3

Orthographic Learning Commences Before Written Words Are Seen: Evidence from Eye Movements

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Abstract

There is existing evidence that children's oral vocabulary knowledge is associated with their word reading ability but its basis is not well understood. In this experiment, we tested two hypotheses: (1) that oral familiarity with a word should confer an online processing advantage when reading it; and (2) that the presence of a word in a child's oral vocabulary, together with their knowledge of phoneme-grapheme mappings, allows them to form an orthographic "skeleton" of that word prior to first seeing it in print. Two groups of 18 Grade 4 children received oral vocabulary training on one set of 16 novel words (e.g. "nesh", "coib") over four sessions, but received no training on another set. The spellings of half the items were highly predictable from their phonology (e.g., *nesh*) while the other half were unpredictable (e.g., *koyb*). Both trained and untrained items were subsequently shown in printed form for the first time, embedded in sentences, and eye movements were monitored. The children demonstrated shorter fixations on orally familiar than orally unfamiliar items, and on words with predictable than unpredictable spellings. Importantly, there was also an interaction: a larger effect of spelling predictability was observed for orally familiar words than orally unfamiliar words. These results suggest that orthographic learning may commence on the basis of oral knowledge alone, before any visual exposure. Implications of this finding for theories of orthographic learning are discussed.

Introduction

It is well established that children's ability to learn to read is closely connected to their underlying language skills. In the earliest stages of learning to read within an alphabetic orthography, children must come to understand the alphabetic principle: that graphemes in printed words map onto phonemes in spoken words in a reasonably systematic way (Byrne, 1998). Once appreciated, children can use this knowledge to begin to sequentially decode the pronunciation of unknown printed words. Letter-sound knowledge and phonological awareness, an aspect of phonological language skill referring to a child's ability to analyse and manipulate sounds within spoken words, are generally agreed to be vital to the early development of reading (e.g. Melby-Lervag, Lyster, & Hulme, 2012). Without challenging the primary importance of decoding and phonological skill, it has been proposed that other aspects of children's language ability may be causally related to reading outcomes (Nation & Snowling, 2004; Nation, 2008). One candidate factor is children's oral vocabulary knowledge, comprising both familiarity with the pronunciation of a word (phonological form) and its meaning (semantics).

When young children begin the process of learning to read, they bring with them an existing oral vocabulary, meaning that they often encounter unfamiliar orthographic forms of known spoken words (Chall, 1987). If vocabulary does indeed drive a reading advantage, then this raises the possibility that reading outcomes may be enhanced via interventions aimed at boosting oral vocabulary. Understanding the mechanism by which vocabulary influences reading is therefore vital for the task of designing appropriate interventions, but the issue of exactly what this mechanism might be is not well understood.

When considering the role of oral vocabulary in reading, it is helpful to distinguish between the two main components of reading success. According to the simple view of reading those components are: reading accuracy (decoding), which refers to the ability to correctly map printed letters to their pronunciation; and listening comprehension, which is thought to underpin children's ability to draw meaning from text (Gough & Tunmer, 1986). Oral vocabulary knowledge has been implicated as having a role in both decoding accuracy and text comprehension. The evidence for each will be considered in turn, focussing first on comprehension where the most straightforward association exists.

Vocabulary and reading comprehension.

The relationship between oral vocabulary and reading comprehension seems intuitive. To infer meaning from text, one must minimally comprehend the individual words with which the sentence is constructed. Reading comprehension involves much more than this, of course (see Nation, 2005 for a review), but children who have difficulty with understanding what they read do frequently present with associated poor word knowledge (Nation, Clarke, Marshall, & Durand, 2004; Ricketts, Nation, & Bishop, 2007). Longitudinal studies have established vocabulary knowledge as a plausible causal factor underlying children's subsequent reading comprehension skills. This finding holds when children's reading comprehension outcomes at school-age are predicted by their vocabulary skills assessed in the school-age years (Nation & Snowling, 2004), at school entry (Muter, Hulme, Snowling, & Stevenson, 2004) and in infancy (Lee, 2011; Duff, Reen, Plunkett, & Nation, 2015). Intervention studies have also shown that training in oral vocabulary is associated with improvements in reading comprehension skills (Clarke, Snowling, Truelove, & Hulme, 2010; Fricke, Bowyer-Crane, Haley, Hulme, & Snowling, 2013), supporting the proposition that oral vocabulary skills play a causal role in reading comprehension outcomes.

Vocabulary and reading accuracy

Although a relationship between oral vocabulary knowledge and word reading accuracy is less obvious, there is converging evidence for its existence. For example, in longitudinal studies, infant vocabulary has been found to be a modest but highly statistically significant predictor of later reading accuracy (Lee, 2011; Duff, Reen, Plunkett, & Nation, 2015). Nation and Snowling (2004) employed standardised language and reading tests and found that vocabulary accounted for variance in children's word reading assessed cross-sectionally at 8 years of age and longitudinally when the same children were reassessed at 13 years of age, even when decoding and phonological skill were taken into account first. In a cross-sectional study, Ricketts, Nation and Bishop (2007) extended the findings of Nation and Snowling (2004) by showing that oral vocabulary was associated with exception word reading but not regular word reading. This is consistent with some other findings suggesting that oral vocabulary knowledge is more closely associated with irregular word reading (e.g. Bowey & Rutherford, 2007; Nation & Snowling, 1998; Ouellette, 2006).

Stronger support for the influence of word knowledge on reading comes from item-level analyses in which an individual's pre-existing knowledge of a word is related to their ability to read that word. Nation and Cocksey (2009) employed an item-based approach in which they presented 7-year old children with regular and irregular real words. They found that those words known orally were easier for the children to read than words that were unknown orally, but that knowledge of the meanings of these words conferred no additional advantage. In line with findings from studies employing standardised tests, this relationship was strongest for words that had inconsistent spelling-to-sound relationships.

Another item-based approach adopts a training paradigm to teach novel words and has the advantage of being an analogue for the experience of encountering a familiar spoken word in print for the first time. In these studies, children are trained in the phonology alone or the phonology and meaning of novel nonwords prior to any visual exposure to them. McKague, Pratt and Johnston (2001) applied a technique originally developed by Pratt, Johnston and Morton (1999) to train Grade 1 children either with the phonology of a set of regular novel nonwords, or with their phonology and meanings. Children were more accurate at reading aloud orally trained nonwords versus untrained nonwords on their first visual presentation, with an accuracy advantage of 29% for trained items. There was no further benefit associated with knowledge of word meaning over knowledge of the phonological form alone. Duff and Hulme (2012) took a similar approach when they trained 5- to 6- year old children in the phonology alone, or the phonology and meaning of novel regular words, and compared their reading of trained words with words that had not received any pre-exposure. Consistent with the findings of McKague et al (2001), children read orally trained words more accurately than orally untrained words, with training in phonology alone producing equivalent scores to training in both phonology and semantics. Together, these findings suggest that prior knowledge of oral vocabulary conveys an accuracy advantage on the first visual presentation of a word.

What is the mechanism for the influence of vocabulary on reading accuracy?

While there is evidence for the association between vocabulary and reading accuracy, the mechanism underlying this relationship is less clear. Prominent theories propose that the presence of a word in oral vocabulary in some way assists the formation of orthographic representations and their links with phonology – so called orthographic learning (Castles & Nation, 2006). These theories, most notably the self-teaching hypothesis (Share, 1995, 2004, 2008) and the lexical quality hypothesis (Perfetti, 1992, 2007; Perfetti & Hart, 2001) operate in a feedforward direction, from print to pronunciation, and therefore assume that vocabulary exerts an effect on reading that begins once a word is seen in print.

According to the self-teaching hypothesis (Share, 1995, 1999, 2004, 2008), orthographic learning occurs when a child is able to serially decode unfamiliar written words. Each correctly decoded pronunciation of a word is thought of as a learning trial in which the child has the opportunity to encode the word-specific orthographic form: that is, its constituent letters and their order. Self-teaching is framed as an item-based learning mechanism which operates across the lifespan, with performance being governed by an individual's familiarity with the input. On this view, vocabulary knowledge can assist the reader to link the sound and orthographic form of a word, and additionally, it is proposed to furnish top-down support via the provision of an additional source of information that is useful for resolving partially successful decoding attempts. If a child's decoding attempt yields a word that does not match one in their vocabulary, yet they do have a representation for a word that is phonologically similar, then the child may draw on this information to conclude that their decoding attempt should be modified to match the close phonological representation they hold in oral vocabulary.

The lexical quality hypothesis (Perfetti, 1992, 2007; Perfetti & Hart, 2001) also views orthographic learning as occurring on an item basis, and is conceptualised as the result of successful integration of information pertaining to orthography, phonology and semantics. Lexical entries are thought to vary in quality, where quality is viewed as reflecting the degree to which each aspect of lexical knowledge is represented. A word has high lexical quality when multiple sources of information about it are available, and these parallel retrieval processes assist word recognition. The lexical quality hypothesis would predict that vocabulary knowledge should assist children to form and strengthen links between phonological and orthographic representations, and that when lexical quality is low, reliance on vocabulary knowledge will increase.

An alternative and less well-explored theory of the relationship between oral vocabulary and word reading is that children may actually start to form orthographic representations of words, albeit incompletely specified, on the basis of their vocabulary knowledge *prior* to having any visual exposure to them. That is, children who are orally familiar with a word and who have adequate knowledge of phoneme-grapheme relationships, may form an expectation of how that word might be spelled before having seen it in print. To our knowledge, this idea was first proposed by Stuart and Coltheart (1988) and was subsequently tested empirically by Johnston, McKague and Pratt (2004) in a training study with adults. Johnston et al. taught the sound and meaning of a set of obscure real words and presented those words in print for the first time in a lexical decision task, along with a set of familiar words and nonword foils. They found a pattern of masked priming effects for the orally pre-exposed words that was consistent with the hypothesis that orthographic representations had been generated prior to visual exposure, and that they could be accessed automatically in the lexical decision task.

Building on these findings, McKague, Davis, Pratt and Johnston (2008) proposed an extension of existing feedforward item-based accounts of orthographic learning (Share, 1995, 1999, 2004, 2008; Perfetti, 1992, 2007; Perfetti & Hart, 2001), to suggest the existence of another item-specific learning mechanism which operates in a feedback direction, employing feedback from phonology to orthography in the process of orthographic learning. They termed this *orthographic recoding*. Common to both accounts is the notion that each word undergoes a process, the endpoint of which is an autonomous orthographic representation sufficient on its own to drive recognition. In McKague and colleagues' (2008) account, until autonomy is achieved, visual word recognition is based on an incompletely specified orthographic representation that is hypothesised to be supported by feedback from phonology. Once the orthographic representation is sufficiently well specified, there is no need for feedback. Therefore, phonology is hypothesised to influence orthography during the learning process and should be strongest on the first opportunity for orthographic learning; its initial visual exposure.

McKague, Davis, Pratt and Johnston (2008) tested their orthographic recoding hypothesis by using either oral or visual training to teach adults the sound and meaning of novel nonwords, and by manipulating feedback consistency, or the extent to which the spelling of the word could be predicted from its sound pattern (Stone, Vanhow, & Van Orden, 1997), at the level of the rime-body. Masked priming within a lexical decision task was employed as a probe of orthographic learning and it was concluded that recognition of orally, but not visually trained words was disrupted by feedback inconsistency. They proposed that this was because the visually trained items had become precisely specified over the course of training whereas the orally pre-exposed items had generated imprecise orthographic expectations of those words. The hypothesis that the generation of an incompletely specified orthographic representation is the mechanism that underlies the reading accuracy advantage for orally known words has not yet been tested with children.

Eye movements, vocabulary knowledge and orthographic learning in children

Eye movement monitoring has recently begun to be employed to investigate reading processes in children (Blythe & Joseph, 2011; Joseph, Nation & Liversedge, 2013; Blythe, 2014). Recent work also suggests that using eye movements to investigate orthographic learning is a promising technique. For example, studies with adults have shown that shorter processing times are required as novel printed words become more familiar via repeated orthographic presentations (Joseph, Wonnacott, Forbes, & Nation, 2014; Taylor & Perfetti, 2016), suggesting that this methodology is sensitive to partial or incremental knowledge. Further, Taylor and Perfetti (2016) have suggested that it is an ideal methodology for indexing the effect of training in elements of lexical representations during the 'online' reading process. They found that partial lexical knowledge of form (orthography or phonology) impacted on early processing measures, particularly first fixation duration and gaze duration; whereas partial knowledge of word meaning impacted on the probability of re-reading. To our knowledge, no study to date has used eye movement monitoring to explore the effect of vocabulary knowledge on reading at the first orthographic exposure.

Aims and hypotheses.

The aims of the present study were twofold: (1) to provide converging evidence for the previously reported association between children's vocabulary knowledge, at an item-level, and their efficiency in reading those words; and (2) to explore the basis of this association by testing the hypothesis that the presence of a word in a child's oral vocabulary, in combination with their knowledge of how sounds map onto letters, allows them to form a partial orthographic representation prior to seeing it in print for the first time. We term this partial orthographic representation an *orthographic skeleton*.

To ensure that children would not have representations of our experimental items in either their oral vocabulary or their orthographic lexicon, we adopted a training paradigm similar to that developed by Wang, Castles, Nickels & Nation (2011). Within this approach, we taught the phonology and meaning of a set of nonwords to two groups of children over several training sessions, with a second set serving as the untrained items. Subsequently, we manipulated the predictability of the spellings of the orally trained and untrained nonwords, such that half the items when seen in print for the first time had highly predictable spellings based on their phonology (e.g. *nesh*) while the other half had unpredictable spellings (e.g. *veme*, which would be more likely to be spelled as *veem* or *veam*). Both trained and untrained nonwords were presented in sentences and eye movements were monitored during this initial orthographic exposure.

Based on previous research, it was hypothesised that having prior oral vocabulary knowledge of the nonwords would to confer an overall processing advantage on seeing them in print for the first time, as evidenced by shorter looking times and fewer return fixations. It was further hypothesised that the items with spellings that were predictable on the basis of their phonology would enjoy an overall processing advantage relative to those with unpredictable spellings. As the items with unpredictable spellings were more unusual looking and therefore possibly more difficult to decode than the predictable items, this overall spelling predictability effect could be due to feedforward or feedback influences, or both.

Importantly, based on the orthographic skeleton theory, an interaction between oral vocabulary training and spelling predictability was hypothesised, with children being expected to show a larger effect of spelling predictability for orally trained than for orally untrained items. The logic of this was as follows: if children indeed generate an orthographic skeleton on the basis of their oral familiarity with a word, when an orally trained item is shown in print for the first time with a highly predictable spelling, the match between the child's orthographic skeleton and the presented orthography should facilitate their online processing. In contrast, when an unpredictable spelling of an orally trained item is presented, it would give rise to a mismatch with the child's orthographic skeleton, creating a "surprise" effect that takes time to resolve. In the case of orally untrained items, the children would not generate an orthographic skeleton and so the effect of spelling predictability would be smaller than for orally trained items, reflecting only the difference in processing time between a common and unusual spelling.

Follow-up testing was also conducted after the eye movement investigation to explore the effects of our manipulations on the children's ongoing reading and orthographic learning performance. Specifically, the children read aloud and performed lexical decisions on the trained and untrained items immediately after initial exposure, and were required to spell the items one week later.

Method

Design

Two groups of 18 children received oral vocabulary training on a set of 16 novel nonwords, but received no training on another set. Set allocation was counterbalanced across groups. Within-subjects factors were training (trained vs. untrained) and predictability of spelling (predictable vs. unpredictable).

Participants

Children were recruited from two parallel mainstream classes at an independent primary school in the metropolitan region of Sydney, Australia. Consent forms were given to all children in those two classes and children who returned the forms participated in the study. No child who returned a consent form was excluded. Eighteen children participated from each of two Year 4 classes (fifth year of schooling), making a total of 36 participants. Children ranged in age from 9 years and 2 months to 10 years and 11 months (*M* = 10 years and 1 month). The age of participants did not differ between the two classes (Class 1: *M* = 121 months, *SD* = 4.94; Class 2: *M* = 121 months, *SD* = 4.77). Children in this age range were recruited because they were expected to have well-developed knowledge of the mappings between sounds and letters (such that they would be capable of forming orthographic skeletons) and to be at the stage where they were rapidly acquiring orthographic representations through instruction and independent reading.

Standardised tests

Standardised measures of reading, spoken vocabulary knowledge and spelling were administered in order to characterise the nature of the sample. Word reading and phonological decoding were assessed using the Castles & Coltheart 2 (CC2; Castles, Coltheart, Larsen, Jones, Saunders & McArthur, 2010), which consists of sets of regular, irregular and nonwords for reading aloud. Spoken vocabulary knowledge was assessed using the naming subtest from the Assessment of Comprehension and Expression 6-11 (ACE 6-11; Adams, Cooke, Crutchley, Hesketh & Reeves, 2001). The tests of reading and spoken vocabulary knowledge were administered individually. Spelling ability was assessed with the Diagnostic Spelling Test irregular words (DiSTi; Kohnen, Colenbrander, Krajenbrink & Nickels, 2015) and sound-to-letter knowledge was assessed using the Diagnostic Spelling Test – nonwords (DiSTn; Kohnen, Colenbrander, Krajenbrink & Nickels, 2015). The spelling tests were administered at a whole class level. Summary data are presented in Table 1 and show that mean performance was broadly within the average range across all measures.

Table 1

Participants' age and performance on standardized tests.

	M	SD	Min	Max
Age (years; months)	10;1	4.78	9;2	10;11
Spoken vocabulary knowledge (ACE)[a]	8.08	2.20	4.00	12.00
Reading aloud (CC2)				
Regular [b]	0.08	1.17	-2.03	2.99
Irregular [b]	-0.02	0.85	-1.82	1.14
Nonwords [b]	-0.42	0.82	-2.27	2.03
Spelling				
DiSTn [b]	-0.54	0.82	-2.00	2.00
DiSTi [b]	0.00	0.64	-1.20	1.58

Note: ACE, Assessment of Comprehension and Expression 6-11; CC2, *Castles & Coltheart 2;* DiST*, Diagnostic Spelling Test – nonwords;* DiSTi*, Diagnostic Spelling Test irregular words.* [a] *Age scaled score* (M = 10, SD = 3); [b] *Grade-based z scores (M* = 0*, SD* = 1*)*

Experimental materials and procedure

Two sets of three phoneme, monosyllabic nonwords matched for consonant/vowel structure were constructed. Each set consisted of 16 items. All items were regular for reading and employed the most common grapheme to phoneme correspondence (type frequency *M* = 94.23%, *SD* = 10.78%). Half of the items in each set had spellings that were predictable from their phonology, while half had spellings that were unpredictable from their phonology. Items were selected following piloting with a group of 10 adults and children. The phonology of a group of three phoneme nonwords was given to pilot participants and they were asked to write down their spellings. Items that were consistently spelled the same way across pilot participants were selected as predictable items. Unpredictable spellings were assigned by selecting uncommon phoneme-to-grapheme correspondences (e.g. 'ph' for /f/) and/or long vowel sounds, and the spellings did not match any produced by pilot participants. The predictability manipulation meant that the spellings of the predictable and unpredictable items could not be matched for number of letters or bigram frequency, but these features were matched across training sets and all items were matched on number of phonemes. The full item sets appear in Table 2.

Table 2

Experimental target words.

	Set 1		Set 2	
	Phonology	Orthography	Phonology	Orthography
Predictable Items	/dʒev/	jev	/tem/	tem
	/jæg/	yag	/nId/	nid
	/vIb/	vib	/dʒIt/	jit
	/tʌp/	tup	/jæb/	yab
	/neʃ/	nesh	/vIʃ/	vish
	/tʃɒb/	chob	/ʃep/	shep
	/ʃʌg/	shug	/θɒg/	thog
	/θʌb/	thub	/tʃIg/	chig
Unpredictable Items	/viːm/	veme	/juːn/	yune
	/baɪp/	bype	/kaɪv/	kyve
	/jɜːp/	yirp	/bɜːp/	birv
	/kɔɪb/	koyb	/dʒaɪf/	jayf
	/dʒiːb/	jeabb	/miːf/	meaph
	/fɜːf/	phirf	/gʌz/	ghuzz
	/gæk/	ghakk	/feg/	phegg
	/mɜːb/	mirbe	/veɪp/	vaype

A simple sentence frame was constructed for each pair of target nonwords. An example is provided in sentences 1a and 1b (target words were not italicized during the experiment) and all experimental sentences appear in Appendix A. The sentences were designed to provide contextual information relevant to the inventions learned by the children, so that as participants read the sentences, the context would lead them to expect to see the word they had learned about during training (if they had been trained on that item). The initial portion of the sentence provided a semantic feature, then the target word was provided, and the sentence was concluded with the function of the invention.

1a. Sara picked up her wet hat and put it on the *vib* to dry it.

1b. Sara picked up her wet hat and put it on the *jit* to dry it.

Training phase.

Each class was trained on one set of nonwords, while the other set constituted their untrained items. The sets were counterbalanced between the two classes. During this phase, children were presented with the target items in spoken form alongside corresponding pictures. The written form of the target nonwords was not presented during the training phase. To create an age appropriate learning task akin to a typical classroom activity, the nonwords were presented as “Professor Parsnip’s Inventions” after the method developed by Wang, Castles, Nickels & Nation (2011). Each nonword was given a function and two perceptual features. For example, “This invention is called *vib*. It is used to dry hats. It is made of plastic and spins”. Inventions were depicted in the form of coloured cartoons demonstrating the features highlighted during training. The original 8 pictorial inventions used by Wang et al (2011) were employed in this study along with an additional 8 items selected from a larger group of items developed by Mimeau, Ricketts and Deacon (In preparation) to make a total set of 16 inventions. A sample cartoon can be found in Appendix B.

Children were encouraged to remember the invention names and their functions. Training occurred over four 20-minute sessions on four days, with a weekend between the third and fourth sessions. The items in each session were presented to the classes sequentially in a predetermined pseudorandom order via PowerPoint presentation. During the first and second training sessions, eight items (four from each condition) were introduced. Four inventions were introduced initially, followed by a picture naming task in which one child was chosen to provide a response before the whole class repeated the correct name. After four items had been introduced, another four items were presented in the same way. Once all eight inventions had been presented, the picture naming task was repeated twice with the eight inventions presented in a predetermined random order. On the third and fourth days, all sixteen items were rehearsed, with items presented in two blocks of eight inventions. The experimenter provided the semantic and perceptual features of the invention and asked the class if they remembered what it was called. One child was selected to provide a response before the correct invention name was repeated by the whole class. Children were then asked to make up a sentence with the invention name in it starting with "If I had a(n) [invention name], I would use it for _____". They were instructed to say this sentence quietly so that only the child sitting next to them could hear it, then the whole class repeated the invention name. Once all sixteen inventions had been presented, the picture naming task was repeated twice with all inventions using the same procedure as in the first and second training sessions. A total of 32 phonological exposures were given for each item.

If a child missed a training session through absence or for any other reason, then a make-up training session was provided. All children completed each of the four training sessions prior to completing the test phase.

Test phase

Because of time constraints associated with the use of a single eye-tracker, testing occurred between 1 and 3 days following the final training session, with the mean delay being equivalent across groups.

Picture Naming. As a measure of children's explicit learning of the phonology and meaning of invention names, a picture naming task was administered individually to each child immediately prior to the collection of the eye movement data. In this task the children were shown pictures of the inventions one at a time and asked if they remembered what the invention was called and what it was used for. They were given 5 seconds to respond and feedback was given regarding accuracy. If a child produced a correct response the experimenter said, “Yes, you are correct, this is a(n) [invention name]. It is used for [invention function]”. If the child provided no response or an incorrect response, they were given the name and function of the invention and asked to repeat it aloud.

Eye Movements. The participants’ eye movements were recorded using a remote Eyelink 1000 eye tracker (SR Research; Mississauga, Canada) sampling at 500 Hz as they read sentences on a computer monitor at a viewing distance of approximately 70cm. Each character covered 0.36˚ of horizontal visual angle. Sentences were presented in black, Courier New font on a white background. Participants read binocularly but only the movements of the right eye were monitored. An initial calibration of the eye tracker was performed during which the participant was asked to look at thirteen fixation points on the screen, while their fixation position was recorded for each point. Once the eye tracker had been calibrated, three practice trials were presented, immediately followed by the experimental sentences. Each sentence was preceded by the appearance of a small fixation cross. When the participant was looking at the fixation cross, the experimenter pressed a button to trigger the appearance of the experimental sentence. After reading the sentence, participants were required to fixate a cross to the right and below the sentence at which point the experimenter terminated the trial. Following each sentence, the participant was asked whether the invention was one they had learned about in class. A “yes” or “no” response was required. This was included to promote attention to task, but was not analysed. Children silently read 16 sentences containing the inventions they learned about and 16 sentences containing interventions learned by the other class. There were also an additional 4 pairs of filler sentences that included novel words and referred to inventions that were not learned about by either group of participants.

Eye movement dependent variables were: first fixation duration (the duration of the initial fixation on the target word); gaze duration (the sum of all fixations made on the target word before the eyes move past the target to a subsequent word within the sentence); total reading time (the sum of all fixations on the target word, including any regressions back to it); and regressions in (the probability of making a regression back to the target word from a later portion in the sentence).

Post exposure measures of reading and orthographic learning.

Following orthographic exposure during the eye movement monitoring task, three post exposure measures were administered as further probes of children's knowledge of the experimental target words.

Visual lexical decision. To assess the children's ability to recognise the visual forms of the novel words, a visual lexical decision task was conducted. All trained and untrained items were presented one at a time, in a random order on a laptop using DMDX software (Forster & Forster, 2003). Children were asked to read the word and to press a "yes" response button if it was one of the inventions they had learned or a "no" response button if it was not. Each trial began with an 800 ms presentation of a fixation cross in the centre of the screen. The fixation cross was replaced by the stimulus, which remained on the screen for 3000 ms even when a response was recorded during this period. Accuracy of response and response latency were recorded.

Reading Aloud. To assess the accuracy and speed with which children could link the orthographic form of words with their phonology, a reading aloud task was conducted. Children were asked to read all invention names aloud as accurately and rapidly as possible. Words were presented in a random order on a laptop using DMDX software (Forster & Forster, 2003) and responses were recorded using a voicekey and by the experimenter using a score sheet. Words were displayed for 3000 ms and remained present for this period even if a response was recorded. CheckVocal (Protopapas, 2007) was employed to check accuracy and response time data and this was cross-checked with hand scoring.

Spelling. To assess whether children had been able to learn the fully specified orthographic forms of inventions, a spelling task was conducted. Children were asked to write the words in exactly the same way as they had seen them during the eye-tracking task at a delay of one week. Responses were categorized as correct or incorrect.

Results

Picture Naming

Children were able to name a mean of 10.67 words of the pictures of the orally trained nonwords (*SD* = 4.13) out of 16 overall. The mean number of successfully named items with predictable spellings was 5.36 (*SD* = 1.93), while the mean number of named items with unpredictable spellings was 5.31 (*SD* = 2.41). In line with expectations, the difference between these was not significant, $t(35) = .236$, $p = .82$, indicating that children had learned the phonology of the predictable and unpredictable items equally well. In addition, the difference in the number of items learned by children in each class (Class 1: $M = 10.78$, $SD = 3.49$; Class 2: $M = 10.56$, $SD = 4.79$) was not significant, $t(34) = .159$, $p = .88$.

Eye movements

Eye movement data were analysed in the R computing environment (R Development Core Team, 2015), using the package lme4 (Bates, Maechler, & Bolker, 2013) and employing linear mixed-effects models (Baayen, 2008; Jaeger, 2008; Quene & van den Bergh, 2008). Reading time data were log transformed prior to analysis.

Separate models were run for each dependent variable: first fixation duration; gaze duration; total reading time; and regressions in. All data were checked to ensure that no participant skipped either the target interest area, or the text preceding or following the target. If any interest area (target, pre-target or post-target) was skipped, the trial was removed for the purpose of analysis. This resulted in the loss of 5.1% of trials. Otherwise, all trials were included in the analyses. Arithmetic means and standard error values of the four target word dependent variables are depicted in Figure 1.

The area of interest was the name of an invention (target word). Fixed effects were training (trained vs. untrained), spelling predictability (predictable vs. unpredictable) and their interaction. Group was included as a fixed covariate. Random factors were participants and items. A data driven approach to model selection was employed in view of findings suggesting that this offers the best balance of protection against Type 1 error and power (Matuschek, Kliegl, Vasishth, Baayen & Bates, 2015). The procedure followed that recommended by Zuur, Ieno, Walker, Savelieve and Smith (2009) and was similar to that implemented by Perez, Joseph, Bajo and Nation (2015). Briefly, the full fixed structure was kept initially along with random intercepts for participants and items to take into account the possibility that both could have different baseline levels of performance. Next, the optimal random slopes structure was found using data driven model comparison with a forward-selection heuristic (see Appendix D for details). Then the best fixed factor structure was found using stepwise model comparison from most to least complex. For each analysis the t or z statistic is reported. When a model produced one or more significant fixed effects, p values for the main effects and planned interaction contrasts were obtained using the *lsmeans* package (Lenth, 2016), applying the Holm-Bonferroni correction for multiple comparisons. The optimal random slopes structure for each model is reported in Appendix D. Model predictions for time data are back-transformed from log fixation durations for display in ms using *predict.SE.SR* (Robidoux, unpublished).

For first fixation duration, the selected model (Appendix D, Model 1) showed a fixed effect of training ($t = -2.78$, $p = .016$) such that trained items were fixated for shorter periods than untrained items; a fixed effect of predictability ($t = -3.33$, $p = .009$) such that predictable items were fixated for shorter periods than unpredictable items; and a significant interaction between training and predictability (t = -2.348, p =.002), such that the effect of spelling predictability was larger for trained items than for untrained items. Model predictions for each significant fixed effect are presented in Table 3(a).

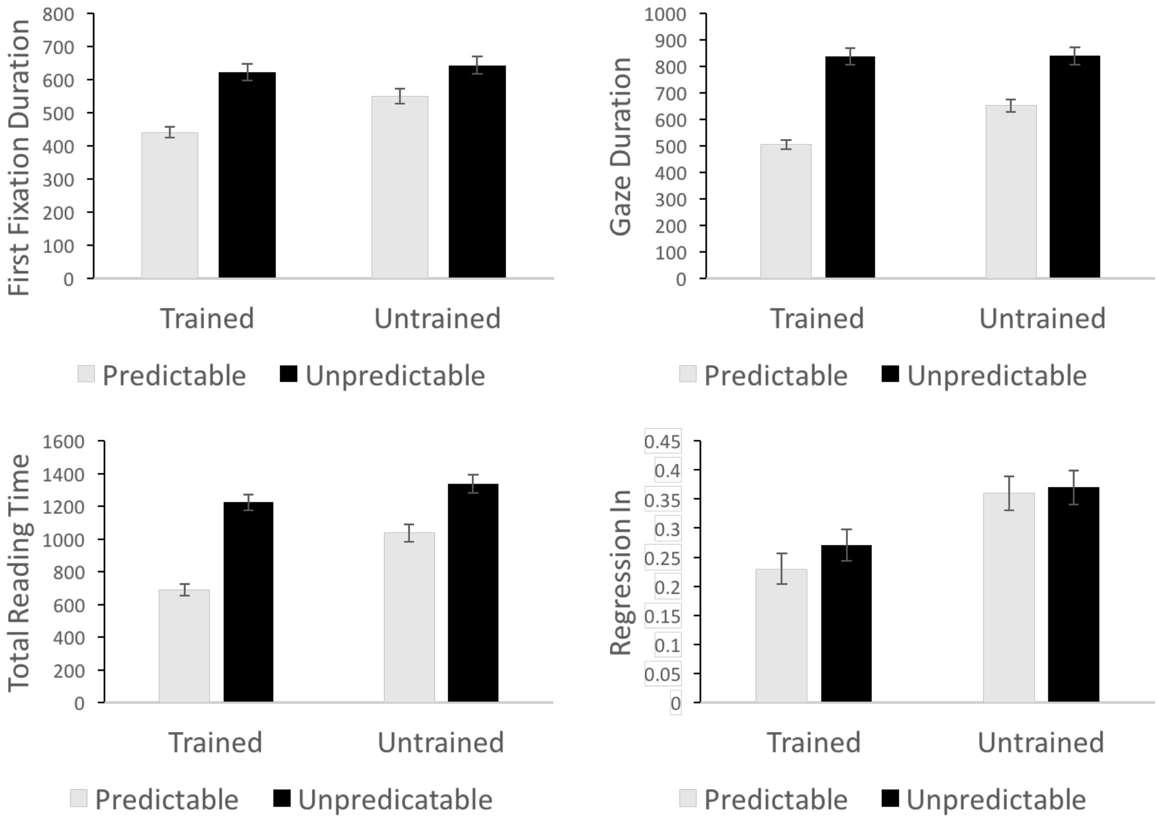

Figure 1. *Arithmetic (untransformed) means and standard errors of eye movements in the target word interest area. First fixation duration, gaze duration and total reading time are all expressed in milliseconds. Probability of regressions reflect the likelihood of occurrence.*

For gaze duration, the model (Appendix D, Model 2) showed the same overall pattern: there was a fixed effect of training (t = -3.314, p = .002) such that trained items were looked at for shorter periods than untrained items; a fixed effect of predictability (t = -5.624, p < .001) such that children spent less time looking at predictable items than unpredictable items; and a significant interaction between training and predictability (t = -3.967, p = .002), such that the effect of spelling predictability was larger for trained items than for untrained items. Model predictions are presented in Table 3(b).

Table 3

Means and standard errors for each level of the significant fixed effects within each linear mixed model for the eye movement data.

Measure	Fixed effects	M	SE
(a) First Fixation	**Training**		
	trained	435	22
	untrained	481	25
	Predictability		
	predictable	412	24
	unpredictable	509	29
	Training*Predictability		
	trained*predictable	375	24
	trained*unpredictable	505	32
	untrained*predictable	452	28
	untrained*unpredictable	513	32
(b) Gaze Duration	**Training**		
	trained	556	30
	untrained	618	33
	Predictability		
	predictable	493	30
	unpredictable	698	42
	Training*Predictability		
	trained*predictable	439	28
	trained*unpredictable	705	45
	untrained*predictable	554	35
	untrained*unpredictable	691	44
(c) Total Reading Time	**Training**		
	trained	748	49
	untrained	961	61
	Predictability		
	predictable	687	46
	unpredictable	1046	68
	Training*Predictability		
	trained*predictable	553	44
	trained*unpredictable	1013	77
	untrained*predictable	855	62
	untrained*unpredictable	1080	80
(d) Regressions In	**Training**		
	trained	0.22	0.03
	untrained	0.34	0.04

Analysis of total reading time again produced the same pattern of results (see Appendix D, Model 3). There was a fixed effect of training ($t = -4.203$, $p < .001$) such that trained items were read for shorter periods than untrained items; a fixed effect of predictability (t = -6.572, p < .001) such that predictable items were read for shorter periods than unpredictable items; and a significant interaction between training and predictability (t =-3.979, p < .001), such that the effect of spelling predictability was larger for trained items than for untrained items. See Table 3(c) for model predictions.

For regressions in, the model (Appendix D, Model 4) showed an effect of training (z = 4.237, p < .001) such that children were more likely to return to the target word if they had not been trained in its phonology and semantics. There was no main effect of predictability, and no interaction between training and predictability. Model predictions appear in Table 3(d).

Post-exposure tests of reading and orthographic learning

Visual lexical decision accuracy: Children's accuracy in recognising target words as trained or untrained was recorded in a visual lexical decision task. Means and standard deviations of lexical decision accuracy appear in Table 4. The effect of training on discrimination accuracy was examined using d' separately for words with predictable and unpredictable spellings. For each participant, the proportion of hits and false alarms for items with predictable spellings (hits: M = .88, SD = .13; false alarms: M = .18, SD = .19) and unpredictable spellings (hits: M= .79, SD= .13; false alarms: M = .22, SD = .19) was calculated. These values were transformed to z scores, and z for false alarms was subtracted from z for hits to give a d' statistic for each participant in the predictable and unpredictable spelling conditions. One sample t-tests confirmed that d′ was above chance for both words with predictable, $t(35)$ = 17.57, p < .001 and unpredictable spellings, $t(35)$ = 11.92, p < .001, indicating that participants were sensitive to the effect of training in both conditions. A paired-samples by subject t-test indicated that d′ was higher in the condition with predictable spellings (M = 2.35, SD = .80) than in the condition with unpredictable spellings (M = 1.80, *SD* = .91), *t*(35) = 4,265, *p* < .001, demonstrating that discrimination accuracy was enhanced by predictable spellings.

Visual lexical decision latency: Means and standard deviations of lexical decision latency appear in Table 4. Only correct responses were analysed. A linear mixed effects model on log transformed data was run using the same approach as applied to the eye movement data. The model (Appendix D, Model 5) showed a significant fixed effect of training (*t* = -6.572, *p* < 0.001) such that children correctly classified trained items more rapidly than untrained items; and a significant fixed effect of predictability (*t* = -3.978, *p* < 0.001) such that children correctly classified items with predictable spellings more rapidly than items with unpredictable spellings. The interaction was not significant; see Table 5.

Table 4

Arithmetic (untransformed) means and standard errors of accuracy and latency data for the lexical decision tasks. Accuracy reflects proportion correct, time is expressed in milliseconds.

		Trained		Untrained	
		M	SE	M	SE
Lexical decision accuracy	Predictable	0.92	0.02	0.85	0.02
	Unpredictable	0.80	0.02	0.81	0.02
Lexical decision (RT)	Predictable	1057	18	1269	24
	Unpredictable	1199	23	1381	28

Table 5

Means and standard errors for each level of the significant fixed effects within the linear mixed effects model of lexical decision reaction time.

Measure		M	SE
Lexical Decision	Training		
	trained	1092	26
	untrained	1293	38
	Predictability		
	predictable	1120	28
	unpredictable	1260	37

Reading Aloud

Accuracy: Means and standard deviations of reading aloud accuracy are represented in Figure 2. A logistic linear mixed effects model was performed in which the dependent variable was reading aloud accuracy. The same method as was employed for eye movement data was used for this analysis. The model (Appendix D, Model 6) showed a main effect of training ($z = 7.75$, $p < 0.001$) such that children read trained words more accurately than untrained words; a main effect of predictability ($z = 5.27$, $p < 0.001$) such that children read words with predictable spellings more accurately than words with unpredictable spellings; and a significant interaction between training and predictability ($z = -2.05$, $p = 0.040$), such that the effect of spelling predictability was larger for untrained items than for trained items.

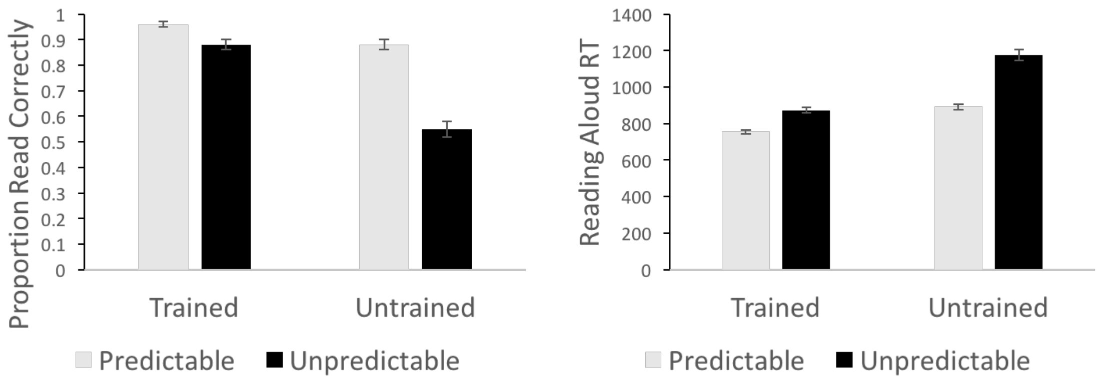

Figure 2. *Means and standard errors of reading aloud data. Reading accuracy is reflected in the proportions read correctly. Reading aloud data is reflected in time to the initiation of a verbal response (untransformed) and is expressed in milliseconds.*

Latency: Means and standard deviations of response time data are represented graphically in Figure 2. A linear mixed effects model was performed in which the dependent variable was time to the initiation of a verbal response. Data were log transformed prior to analysis. Only correct responses were analysed. The model (Appendix D, Model 7) showed a main effect of training ($t = -15.03$, $p < 0.001$) such that children read trained words more rapidly than untrained words; a main effect of predictability ($t = -6.44$, $p < 0.001$) such that children read words with predictable spellings more rapidly than words with unpredictable spellings; and a significant interaction between training and predictability ($t = 5.37$, $p < 0.001$), such that the effect of spelling predictability was larger for untrained items than for trained items. Table 6 shows the model predictions.

Table 6

Means and standard errors for each level of the significant fixed effects within the linear mixed effects models of reading aloud latency (in milliseconds).

Measure		M	SE
Reading Latency	**Training**		
	trained	796	21
	untrained	1013	34
	Predictability		
	predictable	805	24
	unpredictable	1002	36
	Training*Predictability		
	trained*predictable	740	21
	trained*unpredictable	856	29
	untrained*predictable	876	30
	untrained*unpredictable	1172	49

Spelling Accuracy: Means and standard deviations of spelling accuracy, administered one week after orthographic exposure, are represented in Figure 3. Spelling scores in the unpredictable condition were very low, in line with expectations given children's very limited exposure. A logistic linear mixed effects model was performed in which the dependent variable was spelling accuracy. The same method as employed for eye movement data was used for this analysis. The model (Appendix D, Model 8) showed a main effect of training ($z = 3.78$, $p < 0.001$) such that children spelled trained words more accurately than untrained words; and a main effect of predictability ($z = 14.\ 58$, $p < 0.001$) such that children spelled words with predictable spellings more accurately than words with unpredictable spellings. The interaction between training and predictability was not significant.

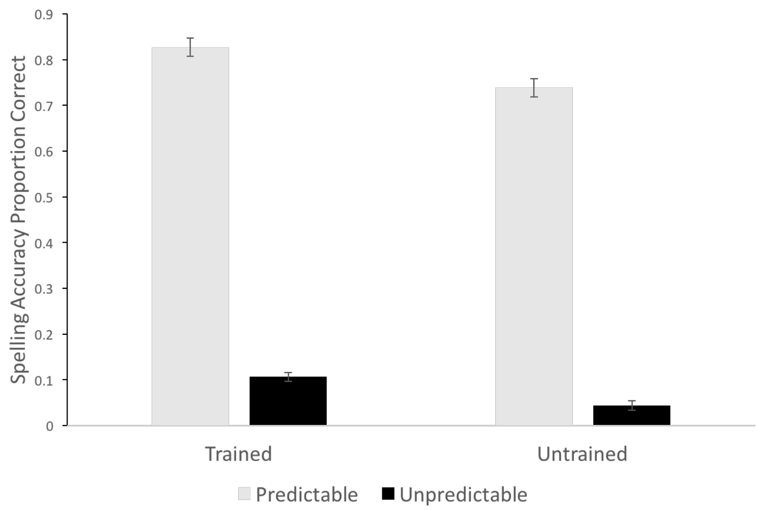

Figure 3. *Means and standard errors of spelling data.*

Discussion

The present study aimed to investigate the association between children's vocabulary knowledge and their reading, and to explore the basis of this association. To do so, we tested the hypothesis that the presence of a word in a child's oral vocabulary, in combination with their knowledge of how sounds map onto letters, allows them to form an orthographic expectation of that word prior to seeing it in print for the first time. This prediction was termed the orthographic skeleton hypothesis. We addressed this in a novel way by providing extensive training in the phonology and semantics of different sets of nonwords to two groups of Grade 4 children, and then monitoring their eye movements as they read those novel words for the first time within sentences. A key manipulation was the sound-to-spelling predictability of the orthographic forms of the novel words: half were highly predictable while half were highly unpredictable. We hypothesised that training in a word's sound and meaning should confer an online processing advantage over unknown words, and that typical spellings would be processed faster than uncommon spellings. Critically for the orthographic skeleton hypothesis, we further hypothesised that the size of the spelling predictability effect for trained and untrained novel words would differ, wherein the size of the effect of spelling predictability would be greater for orally familiar words than for unfamiliar words.

Previous work with children that has shown an accuracy advantage, at an item level, for reading words that are familiar in oral vocabulary over words that are unfamiliar (e.g. McKague, Pratt, & Johnston, 2001; Nation & Cocksey, 2009; Duff & Hulme, 2012). Based on these findings, we reasoned that the partial knowledge engendered by training in a word's sound and meaning should confer an online processing advantage that would be observable in shorter looking times for trained compared to untrained nonwords. In line with this hypothesis, the data were clear in showing that oral familiarity with a word was associated with a processing advantage across all eye movement measures. As expected, the advantage for trained words was also apparent in a measure reflecting the probability of regressions, demonstrating that children were less likely to need to reread orally familiar than unfamiliar words. These findings are compatible with the view that oral vocabulary knowledge benefits reading at an item level (McKague, Pratt, & Johnston, 2001; Nation & Cocksey, 2009; Duff & Hulme, 2012), and confirms the utility of the eye movement methodology for indexing the effect of partial knowledge (Joseph, Wonnacott, Forbes, & Nation, 2014; Taylor & Perfetti, 2016).

The finding of an overall processing advantage for orally trained over untrained words is consistent with several possible interpretations, some of which give more weight to phonology, while others emphasise the role of semantics. For example, interpreted within the context of the self-teaching hypothesis (Share, 1995), the processing advantage for orally known words at the first visual encounter is consistent with the notion that the presence of the trained words in children's oral vocabulary assisted them to decode those words, and in the event that a decoding attempt was partial, to resolve the mismatch between the decoding attempt and the child's existing phonological representation. Interpreted within the context of the lexical quality hypothesis (Perfetti, 1992), these findings are consistent with prior knowledge of vocabulary serving to assist with the formation of the link between the new orthographic representation and the existing phonological representation, making it easier for children to access the phonology and thereby freeing processing capacity to access semantics. A third interpretation gives most weight to the role of semantics and arises because in the current study, oral vocabulary training generated phonological and semantic representations of novel words which were predictable within the context of the experimental sentences used during eye movement recordings. Although not yet demonstrated with developing readers, adults do show online facilitation from words that are contextually predictable (Erlich & Rayner, 1981; Balota, Pollatsek & Rayner, 1985; Rayner & Well, 1996; Rayner, Ashby, Pollatsek &Reichle, 2004; Ashby, Rayner & Clifton, 2005).

The current study was not designed to differentiate between these interpretations of the overall effect of oral vocabulary training, but future work could seek to do so. These possibilities could be explored by employing neutral sentences during eye movement monitoring, and by determining which elements of vocabulary knowledge (phonology alone or phonology and semantics together) must be trained in order to produce the online processing advantage for those words. There is reason to believe that knowledge of phonology alone may drive the training effect in young children (e.g. McKague et al., 2001; Duff & Hulme, 2012), but there is some evidence that semantics conveys an additional benefit in older children (Ouellette & Fraser, 2009) and adults (McKay et al., 2008; Taylor, Plunkett, & Nation 2011). The question remains: is the combination of phonology and meaning required, or is phonology alone sufficient to produce an effect for children in this age range?

Returning to the dominant theories of orthographic learning – the self-teaching hypothesis (Share, 1995) and the lexical quality hypothesis (1992) – both accounts operate in a feedforward direction from print to pronunciation and therefore take the position that the timing of the influence of vocabulary knowledge on reading is at the point of orthographic exposure. An alternative mechanism is proposed by the orthographic recoding hypothesis (McKague et al., 2008), which suggests that vocabulary exerts an influence *prior* to orthographic exposure. According to this account, children are thought to employ their letter-sound knowledge to begin to form an incompletely specified orthographic representation, which we term an orthographic skeleton, on the basis of their oral vocabulary knowledge. The demonstration of a simple effect of training on reading at the first orthographic exposure does not bear on the issue of the timing of the influence of vocabulary knowledge on reading.

To explore the alternative mechanism of the generation of an orthographic skeleton prior to orthographic exposure, we reasoned that, when an orally known word is subsequently presented with an orthographic form that is highly predictable from its spoken form, then the match between the orthographic skeleton and its actual form should facilitate online processing. Further, when an orally known word is presented with an unexpected orthographic form, then this mismatch should be surprising and result in a processing cost. Because orally unfamiliar words would not give rise to an orthographic expectation, the effect of spelling predictability was expected to be smaller, reflecting only the difference between a typical and an uncommon spelling. The eye movement data were clear and striking in their support of the orthographic skeleton hypothesis: there was a significant effect of spelling predictability and a significant interaction between training and spelling predictability which were present across all eye movement measures; orally known words were consistently associated with a larger effect of spelling predictability than orally unknown words.

This finding would not be predicted by either the self-teaching hypothesis (Share, 1995) or the lexical quality hypothesis (Perfetti, 1992). Rather, these accounts would suggest that because vocabulary only influences reading upon exposure to the printed form, the size of the spelling predictability effect should be the same regardless of a child's oral familiarity with a word. This is because, under these accounts, there is no flow of information in a feedback direction, from phonology to orthography, that might allow children to generate orthographic expectations about how words are spelled before seeing them in print for the first time. The present data suggest that pre-existing vocabulary knowledge can actually exert an effect on word recognition prior to any visual exposure. This is compatible with Stuart and Coltheart's (1988) suggestion that adequate knowledge of letter sounds in combination with the ability to segment spoken words into sounds, could allow a child to begin to form an orthographic lexicon prior to print exposure. It also supports McKague and colleagues' (2008) orthographic recoding account, which argues for an extension of feedforward accounts to propose that another item-specific learning mechanism exists which operates in a feedback direction, utilising information from phonology to generate an incompletely specified orthographic representation. The present data provide evidence for the existence of such a mechanism by showing that manipulating the correspondence between the orthographic skeleton and its actual form when first seen in print can be beneficial or detrimental to online processing at the first visual exposure.

We constructed the words with highly unpredictable spellings with the intention that they would appear unusual, so that children would be unlikely to generate orthographic skeletons of these words that matched the orthographic forms. This meant that words with predictable and unpredictable spellings, although all regular for reading, were not able to be matched on variables such as number of letters and bigram frequency (though they were matched on number of phonemes and across training sets). We expected to observe an effect of spelling predictability across both trained and untrained items, which we anticipated would partly reflect these differences between stimuli, and indeed this was consistently found across all eye movement measures. The key evidence, from our perspective, that children generate an orthographic skeleton on the basis of their vocabulary knowledge prior to visual exposure is the larger effect of spelling predictability for orally known words compared to unknown words. However, it cannot be completely ruled out that children had more difficulty decoding and arriving at the phonology of words with unpredictable orthographic forms than words with predictable orthographic forms, and that this interacted in some way with the effect of training. One possibility is that children might have spent time attempting to match their decoding attempt with the phonology they had learned during training, whereas when decoding a word for which they had no phonological representation this additional process of matching would not have been required.

Future work might address this by manipulating only the spelling predictability of the vowel as exemplified by Perry (2003). While providing closer matching of stimulus properties, this type of manipulation would likely result in less frequent mismatches between a child's orthographic skeleton and the actual orthographic form than the manipulation employed in the current study. An ideal design would enable close matching of stimulus properties while preserving a high likelihood of mismatches between an orthographic skeleton and an unpredictable orthographic form. An artificial orthography paradigm (e.g. Taylor et al., 2011) may provide a solution to this issue, because it offers tight control over stimulus properties, including frequency.

While clearly showing that orthographic skeletons are a plausible mechanism for the influence of oral vocabulary knowledge on orthography, the present data do not address the question of whether the orthographic skeleton is generated automatically or deliberately. It could be the case that, during encoding, the children in our study automatically and implicitly generated an orthographic skeleton that was later activated during print exposure. Alternatively, the children may have strategically sought to imagine what the orally trained word might look like in its printed form at the point of initial encoding as an explicit strategy for improving their learning of phonology. Information pertaining to whether children used any strategies at the point of encoding was not collected. While our instructions did not promote the use of this type of strategic encoding at the time of training in phonology, it is possible that it was employed by some children. Future work might address this issue by either manipulating task instructions to promote strategic encoding or by limiting the likelihood that it occurs by altering the task itself so that the learning context becomes more implicit.

Follow-up testing was performed to explore the orthographic knowledge children had acquired during initial exposure in the eye movement task. On visual lexical decision and reading aloud tasks, effects of spelling predictability were observed in accuracy measures and response times. Importantly, the children consistently demonstrated sensitivity to the effects of training for words with both predictable and unpredictable spellings across all follow-up measures. Most interesting, however, was the finding that although children were disproportionately surprised by the unpredictable spellings of the orally familiar words during their initial presentation in the eye movement task, training benefited their reading aloud accuracy and speed for all words regardless of whether their orthographic form was predictable or unpredictable on the basis of their phonology. This finding replicates previous work showing children's reading aloud accuracy is improved by training in oral vocabulary (McKague et al., 2001; Duff & Hulme, 2012). Further, it suggests that the surprise generated by a mismatch between the orthographic skeleton and its actual form as observed during eye movement monitoring is able to be resolved on subsequent measures of orthographic processing.

The current study focuses on how training in oral vocabulary impacts reading at the first orthographic exposure and consistently shows a benefit for known words over unknown words. Whether oral vocabulary knowledge and the orthographic skeleton confer any ongoing advantage in the process of orthographic learning over repeated presentations is of theoretical interest. Our findings on the visual lexical decision and reading aloud tasks suggest that oral familiarity does convey a learning advantage that persists beyond the benefits observed during initial orthographic processing, and this is consistent with the findings of Duff and Hulme (2012) who showed that the advantage of oral training was evident over six reading trials. Future work could use monitoring of eye movements over successive orthographic exposures at test to track the effect of multiple exposures on processing time according to training condition.

Of further interest is the question of whether oral pre-exposure benefits retention and consolidation of orthographic forms. The present data on spelling after a one-week delay suggested an effect of training, but performance on the unpredictable items was very low, even for orally familiar items. Children had very limited exposure, which likely accounts for their low spelling accuracy. Future experiments might provide more exposures and monitor spelling performance over time. Another approach might draw on the literature in which retention and consolidation of newly learned spoken (Gaskell & Dumay, 2003; Davis & Gaskell, 2009) and written words (Bowers, Davis & Hanley, 2005) are indexed by lexical competition and semantic judgement tasks. These latter methods might be employed with children following the initial orthographic exposure during eye movement monitoring, in order to compare the consolidation trajectories of pre-exposed and unfamiliar items.

Conclusions

This study shows that partial knowledge conferred by training in oral vocabulary conveys an online processing advantage at the first orthographic exposure and provides initial evidence that children generate an orthographic skeleton on the basis of their oral vocabulary knowledge. The latter finding contributes to the theoretical debate about the proposed timing of the influence of vocabulary knowledge on reading by supporting the view that orthographic learning can begin prior to visual exposure, in line with the orthographic recoding hypothesis of McKague and colleagues (2008). Because children already know the spoken form of many words prior to encountering their orthography (Chall, 1987), this enhanced understanding of the mechanism via which oral vocabulary knowledge influences reading could prove to be important in developing interventions to support children's reading acquisition.

Chapter 4

General Discussion

General Discussion

Introduction

Within reading research there is now a trend towards identifying factors beyond letter-sound knowledge, phonological awareness and decoding that contribute to reading outcomes. This is particularly so within the context of investigations that relate to the issue of how orthographic learning occurs: that is, how children evolve from beginning to skilled readers (Castles & Nation, 2006). Vocabulary knowledge is one factor that has been implicated within the process of orthographic learning. Against this background, the general aim of this thesis was to clarify the nature of the association between vocabulary knowledge – where this is understood to comprise both pronunciation and meaning – and word reading, and to contribute to the theoretical debate about how this relationship operates. To achieve this aim, two stand-alone articles were presented. The first took the form of a broad literature review outlining the nature of the association between vocabulary knowledge and word reading, drawing attention to accounts that would seek to explain its influence. The second took the form of an empirical study designed to test the predictions of one proposed mechanism. In the following sections, the outcomes of this work are summarised, along with their theoretical implications. Limitations of this work are considered and suggestions are offered for how the field might move forward.

Summary of Studies

Study 1: Vocabulary knowledge and orthographic learning: what are they and how are they related?

This review addressed two aims: (1) to evaluate the existing evidence for the association between vocabulary knowledge and orthographic learning; and (2) to consider how this association has been explained in the context of the process of orthographic learning. In relation to the first issue, empirical studies employing a range of methodologies to address this issue were identified and evaluated. Studies employing an individual differences approach have found that oral vocabulary predicts variation in reading ability, even when differences in decoding and phonological abilities are accounted for (Nation & Snowling, 2004) and this relationship has been shown to be stronger for words with inconsistent letter-to-sound mappings – so-called irregular words (Ricketts, Nation & Bishop, 2007; Ouellette, 2006; Bowey & Rutherford, 2007; Goff, Pratt & Ong, 2005). Further, longitudinal studies have identified vocabulary knowledge as a plausible causal factor in reading acquisition (Lee, 2011; Duff, Reen, Plunkett & Nation, 2015). While these findings were all interpreted as being consistent with the notion that vocabulary knowledge is associated with reading outcomes, they cannot exclude the possibility that the association arises as a result of the operation of a general learning mechanism.

Therefore, studies employing item-based analyses relating an individual's knowledge of particular words in the oral domain with their ability to read those same words have been identified as providing stronger support for the influence of word knowledge on reading, because this design is not as susceptible to the argument that vocabulary and reading are the result of a general learning mechanism. A study employing this design with real words provided support for the role of oral vocabulary in reading at an item-level that was stronger for irregular words (Nation & Cocksey, 2009).

In line with the recommendations of Hulme and Snowling (2015), it was argued that the strongest evidence for oral vocabulary exerting a causal effect on reading would be provided by training studies. In such paradigms, either the phonology or the phonology and meaning of novel words are taught aurally before presentation of the orthographic form, and the effect of the prior knowledge of vocabulary on reading is assessed. Comparisons are typically made between conditions in which there is training in phonology alone with those in which there is training in phonology and meaning, and those in which there is no training at all. Three main findings were identified: pre-exposure to oral vocabulary produces an accuracy advantage when the word is seen in print for the first time (McKague et al, 2001; Duff & Hulme, 2012); knowledge of phonology alone appears to convey the advantage when age or skill level are low, with no further benefit from semantics, but semantics may be more important with increasing age and skill (McKague et al., 2001; Duff & Hulme, 2012; McKay et al., 2008; Taylor et al., 2011); and finally, the effect of vocabulary knowledge on orthographic learning varies with the print-to-pronunciation consistency of the orthography (Nation & Cocksey, 2009; McKay et al., 2008; Taylor et al., 2011; Wang, Nickels, Nation & Castles, 2013).

The second aim was to identify existing accounts that attempt to explain how vocabulary might exert an influence on orthographic learning. Dominant theories in orthographic learning and reading development (Ehri, 1992, 2005, 2014; Share, 1995, 1999, 2004, 2008; Perfetti, 1992, 2007; Perfetti & Hart, 2001) contend that vocabulary exerts an effect on word recognition that commences when the word is first seen in print. In contrast, the less well known orthographic recoding hypothesis predicts that vocabulary may influence word recognition prior to any visual exposure (McKague, Davis, Pratt & Johnston, 2008), because allowance is made in this account for a bidirectional flow of information between phonology and orthography.

Suggestions for how the theories might be tested empirically were outlined. Monitoring of eye movements was identified as a method likely to be sensitive to partial knowledge (Joseph, Wonnacott, Forbes, & Nation, 2014; Taylor & Perfetti, 2016), making it an ideal methodology for indexing the effect of pre-exposure to elements of lexical knowledge on word recognition within a naturalistic reading environment. Two experimental manipulations were identified to illuminate the issue of whether vocabulary knowledge exerts an influence on reading prior to, or from the point of, initial orthographic exposure: a training manipulation and a manipulation of spelling predictability. It was proposed that if a partial orthographic representation contributes to the oral vocabulary advantage, then it should also cause disruption when children are provided with an orthographic form that does not match this partial orthographic representation, effectively creating a surprise that should take time to resolve. Moreover, this disruption should be most evident when words have been orally pre-exposed.

Study 2: "Orthographic learning commences before written words are seen: Evidence from eye movements."

Drawing on the literature review, an empirical study was conducted. There were two aims: (1) to provide converging evidence for the previously reported association between children's vocabulary knowledge, at an item-level, and their ability to read those words; and (2) to explore the basis of this association by testing the theory that the presence of a word in a child's oral vocabulary, in combination with their knowledge of how sounds map onto letters, allows them to form a partial orthographic representation prior to seeing it in print for the first time. We termed this partial orthographic representation the *orthographic skeleton.*

Children in Year 4 were trained in the phonology and semantics of a set of nonwords, but received no training on another set. Half the items had highly predictable spellings from their phonology (e.g., *nesh*) while the other half were unpredictable (e.g., *koyb*). Both trained and untrained items were subsequently shown in printed form for the first time, embedded in sentences, and eye movements were monitored.

Three hypotheses were tested. First, that the partial knowledge engendered by oral familiarity with a word should confer an online processing advantage during eye movement recordings at the initial orthographic exposure. In line with this hypothesis, oral familiarity with a word was found to be associated with a processing advantage across all eye movement measures, and was also associated with a lower probability of rereading. This finding supported previous work showing that oral vocabulary knowledge benefits reading at an item level (McKague, Pratt, & Johnston, 2001; Nation & Cocksey, 2009; Duff & Hulme, 2012), and that the eye movement methodology is sensitive to the effects of partial knowledge (Joseph, Wonnacott, Forbes, & Nation, 2014; Taylor & Perfetti, 2016). Further, we suggested three specific interpretations of the training effect, the first two of which give more weight to the role of phonology, while the last gives more weight to semantics. The self-teaching hypothesis (Share, 1995) would suggest that the processing advantage from trained words arises because vocabulary knowledge assisted decoding, and that it helped children to resolve the mismatch between a partial decoding attempt and the child's existing phonological representation. The lexical quality hypothesis (Perfetti, 1992) would suggest that the advantage arose by assisting with the development of the link between the new orthographic representation and the existing phonological representation, which in turn made it easier for children to access the phonology and semantics. The third interpretation gives most weight to the role of semantics because oral vocabulary training generated phonological and semantic representations of novel words which were predictable within the context of the experimental sentences used during eye movement recordings (Rayner, Ashby, Pollatsek &Reichle, 2004; and Ashby, Rayner & Clifton, 2005).

Our second and third hypotheses were considered together and tested the orthographic skeleton hypothesis. It was reasoned that: (a) when an orally known word is subsequently presented with an orthographic form that is highly predictable from its spoken form, then the match between the orthographic skeleton and its actual form should facilitate online processing; (b) when an orally known word is presented with an unexpected orthographic form, then this mismatch should be surprising and result in a processing cost; and (c) orally unfamiliar words would not give rise to an orthographic expectation, so the effect of spelling predictability should be smaller, reflecting only the difference between a typical and an uncommon spelling. On this basis, three hypotheses were made for the empirical study: words with predictable spellings based on their phonology should enjoy a processing advantage relative to words with unpredictable spellings; and, that the presence of a word in a child's oral vocabulary, together with their knowledge of phoneme-grapheme mappings, allows them to form a partially specified orthographic representation of that word before seeing it in print. In support of the orthographic skeleton hypothesis, the expected pattern of results was obtained across all eye movement measures.

The data were interpreted as compatible with both Stuart and Coltheart (1988) and McKague et al. (2008). Stuart and Coltheart (1988) suggested that adequate knowledge of letter sounds in combination with the ability to segment spoken words into sounds, could allow a child to begin to form an orthographic lexicon prior to print exposure. McKague and colleagues' (2008) orthographic recoding account, argued for an extension of feedforward accounts to propose that another item-specific learning mechanism exists which operates in a feedback direction, utilising information from phonology to generate an incompletely specified orthographic representation.

Implications and Directions for Future Research

The current study suggests a number of avenues for future research that would further clarify the role of oral vocabulary knowledge in the process of orthographic learning.

As a starting point, attempts to distinguish the influence of pre-existing knowledge of phonology and semantics on reading should employ neutral sentences during eye movement monitoring. This should identify whether the oral training advantage is enhanced when the context supports the meaning. Manipulation of the elements of representation that are pre-exposed (sound versus sound and meaning) should also clarify the role played by each in the online processing advantage of training.

Beyond this, it would be illuminating to track this effect across development from early reading to skilled reading. Current evidence suggests that knowledge of phonology alone may drive the training effect in young children (e.g. McKague et al., 2001; Duff & Hulme, 2012), but that semantics may convey an additional benefit in older children (Ouellette & Fraser, 2009) and adults (McKay et al., 2008; Taylor, Plunkett, & Nation 2011). Tracking the effects of phonology and semantics over developmental time would more directly address the issue of whether semantics plays a growing role as age and/or reading skill increase. It would also have important implications for instruction methods; if semantics does indeed become more important across development, then that would imply that early instruction methods should emphasise how new words sound, whereas later methods should evolve to a combined emphasis on sound and meaning.

Future work might attempt to create closer matching of stimulus properties for words with predictable and unpredictable spellings. By equating conditions on ease of decoding, the possibility that words with unpredictable spellings drew on some sort of post-hoc process of matching the decoding attempt with the trained phonology should be minimised. Ideally, stimulus properties should be closely matched while concurrently maintaining a high likelihood that the orthographic skeleton matches predictable orthographic forms, and a high likelihood that the orthographic skeleton is incongruent with unpredictable orthographic forms.

Existing manipulations drawing on the literature pertaining to feedback consistency (Perry, 2003; Ziegler, Petrova, & Ferrand, 2008) would enable adequate control over stimulus properties but may not offer the desired level of control over matching between orthographic skeletons and their actual form. An artificial orthography paradigm, such as that used by Taylor and colleagues (2011) may be a useful alternative approach because it offers tight control over features such as frequency and consistency. This approach would be best suited to initial work with adults, who could be taught consistent grapheme-phoneme correspondences along with variations in sound-to-spelling consistency. Stimulus properties such as frequency of these sound-spelling correspondences could be experimentally manipulated. Once learned, pre-exposure to phonology and semantics could be manipulated before participants read new items for the first time.

It remains possible that when novel words are presented in the context of an explicit learning task such as the one employed in this study, children may generate an orthographic skeleton as a deliberate strategy to improve their learning of the new vocabulary knowledge. Two main approaches to this issue are suggested. The first involves manipulating task instructions to actively encourage children to adopt an explicit strategy of imagining what the spoken words might look like in print. This could be compared to a condition in which no allusion is made to the use of any type of strategy at the point of encoding (as in the current study). The second involves altering the learning task to render it more implicit, thereby minimising the likelihood that explicit learning strategies will be employed, with specific tasks drawn from the literature relating to spoken word learning.

It has been proposed that oral vocabulary knowledge results in the generation of an orthographic skeleton, but the nature of its form is unclear. One possibility raised by McKague et al (2008) is that the partial representation is anchored by the consonants because they are usually more predictable than vowel sounds (see Perry, Ziegler & Coltheart, 2002). Under this view, the vowel sounds remain to be specified during subsequent visual exposure. Initial support for this position was inferred from McKague et al's (2008) masked priming results which showed that, for orally trained words, there was no difference in processing for the identity prime and a prime in which the consonant structure was preserved. This was contrasted with results from the visually trained words, which did show a difference between the identity and consonant preserving primes. Future work might attempt to further explore the nature of the orthographic skeleton by manipulating feedback consistency of vowels and consonants.

Whether oral pre-exposure conveys a longer term advantage for the retention and consolidation of orthographic forms remains to be explored. Our results suggest that training confers an advantage that is evident over multiple presentations on the same day, and on a spelling task one week later. Further, they suggest that the disruption to online processing at the first visual exposure is resolved on subsequent exposures, such that those items that experienced a processing cost initially because of incongruence between the orthographic skeleton and the orthographic form, were later read and spelled better than untrained words with unpredictable spellings. This is consistent with training conveying a longer-term advantage, but future work might employ some additional methods drawing on the literature related to lexical consolidation.

Lexical representations are considered to be consolidated within long-term memory when they are integrated within the lexicon (Davis & Gaskell, 2009). The key feature of this integration is the lexical competition effect, which is evident when responses to known words are slowed down by learning new, similar words. For spoken words, this effect is evident when a newly taught spoken word such as *cathedruke* slows down responses to a known spoken word such as *cathedral* (Gaskell & Dumay, 2003). This effect has also been demonstrated with written words using a semantic judgement task in which subjects are asked to decide if a written word is man-made or natural. On this task, a newly taught written word, such as *banara* slows down responses to a known written word such as *banana* (Bowers, Davis & Hanley, 2005). Drawing on this literature, and another study with adults (Bakker, Takashima, van Hell, Janzen & McQueen, 2014), the effect of phonological pre-exposure on retention and consolidation of orthographic forms in children might be investigated as follows. Children could be trained in the phonology of novel words that are neighbours of existing words over a period of several days, while having no pre-exposure to a second set. The following day children could be exposed to the orthography of trained and untrained items and their eye movements monitored, as in the current study. One day later, children's consolidation of the orthographic forms could be tested by showing children the orthographic neighbours of the words they have learned orally, and the items for which they have received no oral pre-exposure, and asking them to perform the semantic judgement task. If oral vocabulary knowledge also conveys a consolidation advantage, then we would expect to see evidence of a stronger consolidation effect for orally pre-exposed items compared to those that had received no pre-exposure when both item sets have had the same number of orthographic exposures.

Broader Theoretical Implications

These findings add another facet of evidence to the growing literature on the interactivity of phonological, orthographic and semantic aspects of lexical representation (Stone, Vanhow & Van Orden, 1997; Perfetti, 2007; Bakker et al., 2014). Findings of the current work are consistent with the notion that exposure to phonology and semantics interacts with orthography via a process that invokes a skeleton orthographic representation prior to any visual exposure. The interaction between phonology/semantics and orthography in this study is exemplified by the finding that the orthographic skeleton can be beneficial or detrimental to online processing as a function of the correspondence between the orthographic expectation and its actual written form. This represents the first study to have shown evidence for this mechanism in children, establishing it as one developmentally plausible mechanism via which vocabulary knowledge might benefit reading *acquisition*, at least when children have some prerequisite sound-to-letter knowledge and phonological awareness.

In general, these findings support the position that bidirectional connections between orthography and phonology should be present in models of word reading, whether dual route (Coltheart, Rastle, Perry & Langdon, 2001) or connectionist (e.g. Harm & Seidenberg, 2004; Plaut, McClelland, Seidenberg, & Patterson, 2006). Further, they suggest that theories of orthographic learning (e.g. Share, 1995; Perfetti, 1992) should also be revised to incorporate a mechanism that allows information to flow backwards from phonology to orthography.

Finally, the current study suggests that training in oral vocabulary knowledge may be a useful way of supporting reading acquisition in children. Practically, this suggests that explicit teaching of oral vocabulary should precede and accompany phonics instruction.

Summary

In sum, this thesis set out to clarify the nature of the association between oral vocabulary knowledge and reading development, and to test a possible mechanism of its influence. To this end, a broad literature review of this field was conducted. This gave rise to testable hypotheses that were addressed in the context of an empirical study. The outcome of this work supported the contention that pre-existing vocabulary knowledge conveys a reading advantage, and that the mechanism of this influence operates, at least in part, via the generation of an orthographic skeleton *prior* to any exposure to orthography. This is consistent with the orthographic recoding hypothesis of McKague and colleagues (2008) and suggests that the dominant models of orthographic learning (Share, 1995; Perfetti, 1992) should be revised to incorporate a mechanism that employs feedback from phonology to orthography within the learning process. This study also provided initial evidence that this mechanism operates during childhood and establishes it as one plausible mechanism that might support children to learn to read.

Chapter 5

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Appendix

Chapter 3

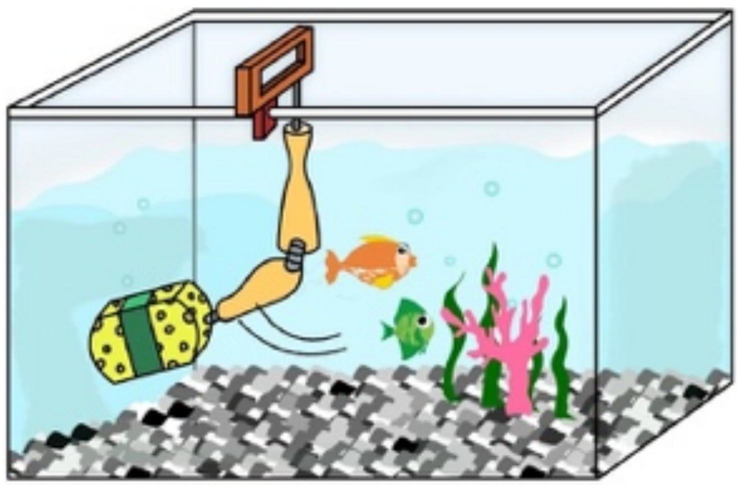
Appendix A.

Experimental sentences.

	Set 1	Set 2
1.	Rick put his dirty socks into the jev to clean them.	Rick put his dirty socks into the tem to clean them.
2.	Diana put the best orange on the veme to juice it.	Diana put the best orange on the yune to juice it.
3.	Pam put the dirty flowers under the yag to polish them.	Pam put the dirty flowers under the nid to polish them.
4.	Max put his food in the bype to remove the peas.	Max put his food in the kyve to remove the peas.
5.	Sara put her soaking wet hat on the vib to dry it.	Sara put her soaking wet hat on the jit to dry it.
6.	Lucy loaded the rubbish into the yirp to sort it for recycling.	Lucy loaded the rubbish into the birv to sort it for recycling.
7.	Lucas put his sore tummy beside the tup and he felt better.	Lucas put his sore tummy beside the yab and he felt better.
8.	Jennifer put her soggy chips under the koyb to make them crispy.	Jennifer put her soggy chips under the jayf to make them crispy.
9.	Nick put the deck of playing cards into the nesh to shuffle them.	Nick put the deck of playing cards into the vish to shuffle them.
10.	Rex put the tennis ball back into the jeabb to keep playing fetch.	Rex put the tennis ball back into the meaph to keep playing fetch.
11.	James put the girl's picture into the chob to find out her name.	James put the girl's picture into the shep to find out her name.
12.	Jane put her cold and sore feet into the phirf to warm them.	Jane put her cold and sore feet into the ghuzz to warm them.
13.	Matt put his feet into the shug so he could climb up the wall.	Matt put his feet into the thog so he could climb up the wall.
14.	Sam waited for the birds to land on the ghakk to hear them sing.	Sam waited for the birds to land on the phegg to hear them sing.
15.	Ben picked up the fish tank and the thub to clean the dirty glass.	Ben picked up the fish tank and the chig to clean the dirty glass.
16.	Pip waited while the brushes on the mirbe removed the sand from his body.	Pip waited while the brushes on the vaype removed the sand from his body.

Appendix B

Example of a cartoon used during training.



Appendix C

Justified-by-the-design model comparisons for obtaining the optimal random slopes structure.

```
M1 <- lmer([D.V.] ~ [full fixed structure] + (1|subj) + (1|itemN), REML=TRUE)
M2 <- lmer([D.V.] ~ [full fixed structure] + (training|subj) + (1|itemN), REML=TRUE)
M3 <- lmer([D.V.] ~ [full fixed structure] + (predict|subj) + (1|itemN), REML=TRUE)
M4 <- lmer([D.V.] ~ [full fixed structure] + (training+predict|subj) + (1|itemN), REML=TRUE)
M5 <- lmer([D.V.] ~ [full fixed structure] + (training*predict|subj) + (1|itemN), REML=TRUE)
M6 <- lmer([D.V.] ~ [full fixed structure] + (1|subj) + (training|itemN), REML=TRUE)
M7 <- lmer([D.V.] ~ [full fixed structure] + (training|subj) + (training|itemN), REML=TRUE)
M8 <- lmer([D.V.] ~ [full fixed structure] + (predict|subj) + (training|itemN), REML=TRUE)
M9 <- lmer([D.V.] ~ [full fixed structure] + (training+predict|subj) + (training|itemN), REML=TRUE)
M10 <- lmer([D.V.] ~ [full fixed structure] + (training*predict|subj) + (training|itemN), REML=TRUE)
```

Appendix D

Model 1. Linear mixed model on *first fixation duration* with significant fixed effects of training, predictability and their interaction. Beta estimates are based on log-transformed values.

AIC	BIC	LogLik	Deviance	
2082.4	2122.4	-1033.2	2066.4	
Random effects				
Variable	Variance	St. Deviation		
Participant	0.053	0.230		
Item	0.021	0.146		
Fixed effects	β	SE	t	p
Training	-0.101	0.036	-2.80	0.016*
Predictability	-0.211	0.063	-3.340	0.009**
Training*Predictability	-0.170	0.072	-2.348	0.002**

Model 2. Linear mixed model on *gaze duration* with significant fixed effects of training, predictability and their interaction. Beta estimates are based on log-transformed values.

AIC	BIC	LogLik	Deviance	
1822.2	1862.1	-903.08	1806.2	
Random effects				
Variable	Variance	St. Deviation		
Participant	0.057	0.238		
Item	0.0211	0.145		
Fixed effects	β	SE	t	p
Training	-0.106	0.032	-3.31	0.002**
Predictability	-0.348	0.062	-5.62	<.001***
Training*Predictability	-0.253	0.064	-3.967	0.002**

Model 3. Linear mixed model on *total reading time* with significant fixed effects of training, predictability and their interaction. Beta estimates are based on log-transformed values.

AIC	BIC	LogLik	Deviance	
1866.2	1941.1	-918.1	1836.2	
Random effects				
Variable	Variance	St. Deviation		
Participant	0.0893	0.299		
Training	0.047	0.217		
Predictability	0.029	0.171		
Item	0.018	0.135		
Training	0.039	0.197		
Fixed effects	β	SE	t	p
Training	-0.250	0.059	4.23	<0.001***
Predictability	-0.419	0.064	6.57	<0.001***
Training*Predictability	-0.371	0.093	-3.98	<0.001***

Model 4. Linear mixed model on *regressions in* with significant fixed effect of training.

AIC	BIC	LogLik	Deviance	
1284.8	1329.8	-633.4	1266.8	
Random effects				
Variable	Variance	St. Deviation		
Participant	0.386	0.621		
Predictability	0.514	0.717		
Item	0.168	0.410		
Fixed effects	β	SE	z	p
Training	-0.604	0.143	-4.24	<0.001***

Model 5. Linear mixed model on *lexical decision latency* with significant fixed effects of training and predictability. Note that beta estimates are based on log-transformed values.

AIC	BIC	LogLik	Deviance	
94.3	152.6	-35.1	70.3	
Random effects				
Variable	Variance	St. Deviation		
Participant	0.013	0.115		
Training	0.012	0.109		
Item	0.001	0.035		
Training	0.002	0.049		
Fixed effects	β	SE	t	p
Training	-0.168	0.026	-6.572	<0.001***
Predictability	-0.103	0.026	-3.978	<0.001***

Model 6. Linear mixed model on *reading aloud accuracy* with significant fixed effects of training, predictability and their interaction.

AIC	BIC	LogLik	Deviance	
871.6	906.9	-428.8	857.3	
Random effects				
Variable	Variance	St. Deviation		
Participant	0.910	0.954		
Item	0.421	0.649		
Fixed effects	β	SE	z	p
Training	1.712	0.221	7.75	<0.001***
Predictability	1.697	0.322	5.27	<0.001***
Training*Predictability	-0.889	0.433	-2.05	0.0403*

Model 7. Linear mixed model on *reading invention names latency* with significant effects of training, predictability and their interaction. Beta estimates are based on log-transformed values.

AIC	BIC	LogLik	Deviance	
-228.3	-166.6	127.1	-254.3	
Random effects				
Variable	Variance	St. Deviation		
Participant	0. 009	0.096		
Training	0.002	0.048		
Predictability	0.005	0.072		
Item	0.006	0.080		
Fixed effects	β	SE	t	p
Training	-0.242	0.016	-15.030	<0.001***
Predictability	-0.219	0.034	-6.435	<0.001***
Training*Predictability	0.146	0.027	5.372	<0.001***

Model 8. Linear mixed model on *spelling accuracy* with significant fixed effects of training and predictability.

AIC	BIC	LogLik	Deviance	
814.8	849.7	-400.4		
Random effects				
Variable	Variance	St. Deviation		
Participant	0.7268	0.8525		
Item	0.2137	0.4623		
Fixed effects	β	SE	z	p
Training	0.822	0.217	3.779	0.001**
Predictability	4.543	0.312	14.579	<0.001***

Ethics Approval

Appendix E

From: "Fhs Ethics" <fhs.ethics@mq.edu.au>
Subject: RE: HS Ethics Amendment 1 - Approved (Ref No. 5201500098)(New personnel)
Date: 28 August 2015 at 9:56:18 AM AEST
To: "Professor Anne Castles" <anne.castles@mq.edu.au>
Cc: "Dr Hua-Chen Wang" <huachen.wang@mq.edu.au>, "Ms Signy Victoria Wegener" <signy.wegener@students.mq.edu.au>

Dear Professor Castles,

RE: 'Making words stick: Lexical consolidation effects in learning to read ' (Ref: 5201500098)

Thank you for your recent correspondence regarding the amendment request.

The amendments have been reviewed and we are pleased to advise you that the amendments have been approved.

This approval applies to the following amendments:

1. New personnel - Ms Signy Wegener added to the project;
2. Supporting documentation - Revised School Information Form attached and noted.

Please accept this email as formal notification that the amendments have been approved. Please do not hesitate to contact us in case of any further queries.

All the best with your research.

Kind regards,

FHS Ethics
****

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