The role of oral vocabulary in the development of children's orthographic representations

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Summary

When children learn to read, how do they come to be able to recognise whole written words quickly and accurately? Knowledge of letter-to-sound correspondences and the sound structure of language are known to be important early in reading acquisition but other cognitive factors must also contribute to the development of skilled reading. One such factor is oral vocabulary (knowledge of the pronunciation and meaning of words), yet its association with reading acquisition remains poorly understood. This thesis aims to elucidate the nature of the relationship between oral vocabulary and reading, with a particular focus on how they might interact as children acquire representations of new written words. According to the orthographic skeleton hypothesis (Chapter 2), children can draw on their knowledge of phoneme-to-grapheme correspondences to generate expectations of the spellings of known spoken words prior to viewing them in writing for the first time. In a series of training studies, Grade 4 children are taught novel oral vocabulary prior to reading these trained items and matched untrained items in sentence contexts while their eye movements are monitored. In each experiment the orthographic skeleton hypothesis is interrogated with a view to providing an elaborated account of their generation and influence on written word learning. Results shed light on the roles of lexical phonology and semantics within the development of orthographic expectancies (Chapter 3); the form of the skeleton (Chapter 4); and the influence of the skeleton on subsequent visual exposures to target words (Chapter 5). Findings are linked back to established theories of reading acquisition, the role of oral vocabulary within this process and the causal mechanisms that support this influence (Chapter 6).

Declaration

A version of the work presented in Chapter 2 was previously submitted in partial fulfillment of the requirements for the degree of Master of Research. It is included within this dissertation because the experiment it reports forms the theoretical foundation for each of the subsequent experiments conducted during the period of my PhD candidature. Its inclusion is intended to aid the reader's understanding, and to demonstrate that this dissertation presents a unified and cohesive body of work. However, it should not be examined.

I certify that all other work reported in this dissertation entitled "The Role of Oral Vocabulary in the Development of Children's Orthographic Representations" has not previously been submitted for a degree, nor has it been submitted as part of the requirements for a degree to any university or institution other than Macquarie University. This dissertation is an original piece of research and it has been written by me. Any assistance that I have received has been appropriately acknowledged. All information sources and literature used are appropriately attributed in the dissertation.

The research presented in this dissertation was approved by the Macquarie University Human Ethics Review Committee, reference number: 5201500098.

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Chapter 1

General Introduction

Introduction

Spoken language developmentally precedes the emergence of reading, from which point the two skills remain intimately intertwined throughout development. It is well known that aspects of children's oral language skills make strong contributions to their early progress in learning to read. Chief among these is children's appreciation of the sound structure of their native spoken language, or phonological awareness (Rack, Hulme, Snowling, & Wightman, 1994; Wagner & Torgesen, 1987). When children also have some knowledge about the mappings between letters and sounds, they gradually come to understand that letters code for spoken speech sounds (Byrne, 1998; Ehri, 1992). Together these skills underpin children's emerging ability to assemble the pronunciations of printed words via a process of translating from letters to sounds, or phonological decoding (Melby-Lervåg, Lyster, & Hulme, 2012). Notwithstanding the central roles of phonological awareness and decoding skill within early literacy acquisition, it has been suggested that other aspects of children's language ability must also contribute to reading development (Castles & Nation, 2006; Nation & Castles, 2017; Nation & Snowling, 2004). Children's oral vocabulary, or spoken word knowledge, is one such factor.

Oral vocabulary refers to knowledge about spoken words and is one component of broader oral language skill. Spoken word knowledge can further be fractionated into two separable, yet tightly connected aspects of representation: one reflecting knowledge about the pronunciation of spoken words and another reflecting knowledge about their meaning (Levelt, Roelofs, & Meyer, 1999). Oral vocabulary was initially identified as playing a key causal role in the development of children's reading comprehension skills (Gough & Tunmer, 1986; Stanovich, 1986) but more recent evidence suggests that spoken word knowledge also makes a causal contribution to written word learning. The latter association, which is borne out in studies using a range of methodologies, is the focus of this dissertation.

Although there are substantial individual differences in the size of children's oral vocabularies throughout development, estimates suggest that by the time children are in Grade 1 at school, on average they are familiar with the spoken form of approximately 3100 root words (Anglin, Miller, & Wakefield, 1993). Consequently, during the initial phases of reading development, children will encounter in writing for the first time many words that are already familiar to them in spoken form (Chall, 1987). Given the developmental precedence of oral language, and in view of the likely causal relationship between oral vocabulary and reading acquisition, interventions targeting the mechanism through which oral vocabulary supports reading acquisition may have the potential to improve children's reading outcomes. However, the cognitive mechanism or mechanisms that underlie this association remain understudied and therefore not well understood.

The overarching aim of the current dissertation is to elucidate the nature of the relationship between oral vocabulary knowledge and reading, with a particular focus on how they might interact as children acquire representations of new written words. Accordingly, the first aim of this dissertation was to propose and test a novel cognitive mechanism through which oral vocabulary knowledge might benefit word reading (Chapter 2, not presented for examination). Crucially this proposed mechanism – the orthographic skeleton hypothesis – suggests that children can draw on their knowledge of sound-to-letter correspondences to generate expectations of the spellings of known spoken words *before* the word has been seen in print for the first time. The second aim was to build on this initial work with a view to providing an elaborated account of the generation of orthographic skeletons and how they influence ongoing written word learning. The experiments that follow address the roles of lexical phonology and semantics within the development of orthographic expectancies (Chapter 3); the early form of orthographic expectancies (Chapter 4); and the influence of orthographic expectancies on subsequent visual exposures to target words (Chapter 5).

The remainder of this introductory chapter will provide an overview of the extant literatures that are most relevant to these aims. First, the case will be made that oral vocabulary plays a causal role in written word learning. Next theories of orthographic learning will be outlined, all of which offer accounts of the cognitive mechanism that permits oral vocabulary knowledge to influence word recognition. In the context of this discussion, the hypothesised timing of this influence will be highlighted. It will then be argued that spoken and written language are characterised by bidirectional interactivity, and on this basis it will be proposed that an alternative and complementary cognitive mechanism might exist that could permit oral vocabulary to support written word learning via phonology-to-orthography connections. Next the merits of existing measures of orthographic learning will be considered, and it will be argued that eye movements are uniquely placed to provide insight into the influence of partial lexical knowledge on reading as it unfolds over time and builds with experience. Finally the specific research questions that are addressed within each experimental chapter will be outlined.

Evidence for an association between oral vocabulary knowledge and word reading

Support for a role of oral vocabulary knowledge within word reading is derived from studies employing a range of methodologies, including cross-sectional studies, item-level analyses, longitudinal and training studies. As already alluded to, oral vocabulary comprises two separate but closely related aspects of knowledge. The basic distinction between knowledge of pronunciations (lexical phonology) and knowledge of meaning (semantics) has been highlighted as an important consideration for understanding the role of oral vocabulary in reading acquisition because these aspects of oral vocabulary knowledge may not be equally represented in the reader and may exhibit different relationships with reading outcomes (Nation & Cocksey, 2009; Ouellette, 2006; Ouellette & Beers, 2010). Indeed, familiar spoken word forms may be associated with variable knowledge of word meanings. For instance, children may possess rich, elaborated semantic representations for some words that are familiar in spoken form while having no, or only partial knowledge of the meanings of others. The distinction between knowledge of the form and meaning of spoken words also features prominently in assessment tasks. For instance, knowledge of form (sometimes referred to as oral vocabulary breadth) is typically measured with spoken word-picture matching, picture naming or spoken word recognition tasks[1], while knowledge of meaning (sometimes referred to as oral vocabulary depth) is measured with spoken definition tasks.

A further important distinction in this literature concerns the print-to-pronunciation regularity[2] of written words. It is well known that the English orthography contains substantial variability in the pronunciation of graphemes. This variability is observed in consonant pronunciations but is especially marked for vowel pronunciations (Carr & Pollatsek, 1985). For example, the consonant grapheme *ch* can be pronounced as in *chop* or *chef*, while the vowel grapheme *ea* can be pronounced as in *bleak, head* or *break*. When words contain the most common pronunciation for each grapheme they are regarded as regular for reading (eg., *chop* and *bleak*), whereas words containing one or more grapheme pronunciations that differ from the most common pronunciations are considered irregular for reading (eg., *chef*, *head* and *break*). As such, print-to-pronunciation regularity is a binary distinction between regular and irregular words.

It is well known that print-to-pronunciation regularity influences word reading, most notably manifesting in longer reading latencies for low frequency irregular words (Seidenberg, Waters, Barnes, & Tanenhaus, 1984). In the context of understanding the role

[1] As pointed out by Nation and Cocksey (2009), only spoken word recognition tasks strictly assess knowledge of lexical phonology independent of any links with semantics.

[2] Print-to-pronunciation regularity is distinct from a word's *consistency*. When applied to reading, consistency describes the predictability of grapheme-to-phoneme correspondences. It is sometimes employed as a binary measure, but is more often used continuously, with a theoretical range of zero to one. When employed as a continuous measure, consistency refers to the proportion of all words with the same graphemes that share the pronunciation.

of oral vocabulary within word reading, print-to-pronunciation regularity is of further relevance because models of word reading (e.g., Plaut, Seidenberg, McClelland, & Patterson, 1996) predict that spoken word knowledge may be differentially associated with regular and irregular word reading (Dawson & Ricketts, 2017; Ricketts, Nation, & Bishop, 2007; Taylor, Duff, Woollams, Monaghan, & Ricketts, 2015).

The discussion that follows reviews evidence for the existence of an association between children's oral vocabulary knowledge and word reading. Because research methodologies offer different levels of evidence for the existence of causal effects (Hulme & Snowling, 2013), the subsequent section is organised on this basis. Where possible and relevant, distinctions are drawn between knowledge of pronunciation/meaning and reading of regular/irregular words.

Cross-sectional studies of individual differences

Most cross-sectional studies have computed by-participant correlations between independent measures of oral vocabulary knowledge and word reading, thereby providing evidence for the existence of a general relationship between these skills (Ricketts, Davies, Masterson, Stuart, & Duff, 2016). Using such methods, it has long been acknowledged that children who know more spoken words also tend to be better at word reading. Meta-analytic estimates, for instance, suggest the correlation between the two skills is in the moderate range (Scarborough, 2001).

More recent work has differentiated between aspects of oral vocabulary knowledge (breadth and depth) and word reading proficiency (regular and irregular). Measures of oral vocabulary breadth are usually associated with both regular and irregular word reading, though the latter relationship tends to be stronger (Bowey & Rutherford, 2007; Goff, Pratt, & Ong, 2005). The same pattern has also been observed when vocabulary breadth is entered into regression analyses while controlling for other reading-related skills (Ouellette, 2006; sixth grade sample reported by Ouellette & Beers, 2010). Measures of oral vocabulary depth have also been associated with children's reading attainment. Nation and Snowling (2004), for example, found that eight year-old children's semantic knowledge accounted for unique variance in their word recognition scores, even when decoding and phonological skill were taken into account first. When regular and irregular word reading are distinguished, there is some evidence that the latter is more strongly associated with semantic knowledge. Ricketts, Nation and Bishop (2007), for example, in a sample of eight to nine year-old children found that semantic knowledge was associated with irregular, but not regular word reading. The same pattern was reported by Ouellette and Beers (2010) in their sample of children in first grade. These studies consistently support the existence of an association between oral vocabulary (both breadth and depth) and reading, but imply the relationship may be stronger for the reading of irregular words.

Item-level analyses

Item-level analyses have been applied in a small number of cross-sectional studies. This approach tests a more precise hypothesis about the nature of the relationship between oral vocabulary knowledge and word reading; namely that spoken word knowledge is related to word reading directly, such that knowledge of a given spoken word benefits reading of that specific word. Thus, item-level relationships are probed by relating an individual's knowledge of words in the oral domain with their ability to read those same words.

Nation and Cocksey (2009) were the first to adopt this item-level approach, and distinguished between lexical phonology and semantics, and between regular and irregular word reading in their sample of seven year-old children. When entered into regression analyses only irregular word reading accuracy was predicted by oral vocabulary knowledge. Further, children's knowledge of lexical phonology was a stronger predictor of irregular word reading accuracy than knowledge of word meaning. Ricketts and colleagues (2016) employed the same assessment methods but found that *both* regular and irregular word reading were associated with oral vocabulary knowledge. Additionally, and contrary to findings reported by Nation and Cocksey (2009), the ability to provide word definitions was a stronger predictor of reading accuracy than knowledge of lexical phonology.

A third study recently investigated item-level relationships between oral vocabulary knowledge and word reading (Kearns & Al Ghanem, 2019). Third and fourth grade children read a set of polysyllabic words which varied continuously with respect to the print-to-pronunciation consistency (as defined in Footnote 2) of the rhyme. Word-specific orthographic knowledge, semantic knowledge and phonological knowledge were all assessed. Phonological knowledge was assessed using a task requiring children to blend spoken syllables into a correct pronunciation of the target words, and merits a specific mention for this reason as it arguably taps a more general phonological skill than spoken word recognition. Bearing this in mind, children's reading accuracy was predicted by their performance on each of the three tasks tapping word-specific knowledge, suggesting that in this case semantics played a role in children's word reading.

Although studies of item-level relationships converge on the view that oral vocabulary contributes to children's reading, the relative roles of lexical phonology and semantics are less clear. Of the three studies of this type, one (Nation & Cocksey, 2009) gives weight to the role of lexical phonology, while two suggest that semantic knowledge (Kearns & Al Ghanem, 2019; Ricketts et al., 2016) also contributes to word reading.

Longitudinal studies

Longitudinal studies employ individual differences in an early measured skill to predict later performance on another task, thereby identifying factors that could plausibly make a causal contribution to skill development. While infant oral vocabulary skills have been shown to predict later language skills, there is thought to be a high degree of variability in vocabulary attainment during the early stages of development (Reilly et al., 2010). Supporting this view is the finding that many children identified as late talkers during infancy subsequently present at school age with age-appropriate language scores, while others who present with typical language scores during infancy go on to meet criteria for language delay at school age (Rescorla, 2011). This lack of early stability in vocabulary scores presumably constrains the outcomes of studies that employ infant vocabulary scores to predict subsequent reading achievement. Nevertheless, studies on this topic support the existence of a small but highly significant predictive relationship between infant oral vocabulary, as measured by parent report, and subsequent school-age word reading achievement. For example, Lee (2011) obtained parent oral vocabulary ratings at 24 months of age for a sample of more than 1,000 children and tracked their language and literacy skills between the ages of three and eleven years. Early oral vocabulary was a significant predictor of school-age literacy, accounting for approximately five percent of the variance in attainment. Similarly, Duff, Reen, Plunkett and Nation (2015) obtained parent ratings of the oral vocabulary knowledge of 300 infants between the ages of 16 and 24 months. The children's vocabulary, phonological and reading skills were assessed an average of five years later. Infant oral vocabulary ratings were a highly significant predictor of subsequent reading accuracy, accounting for approximately 11% of the variance in outcomes.

Results of longitudinal studies addressing the issue of whether oral vocabulary measured during the school years predicts later reading achievement are less consistent. For example, Nation and Snowling (2004) found that children's oral vocabulary knowledge as assessed at eight and half years of age accounted for unique variance in their word recognition scores at 13 years of age, even when decoding and phonological skill were taken into account first. Muter and colleagues (2004) investigated whether oral vocabulary as measured at school entry predicted reading achievement two years later, but found no significant predictive relationship. Instead, the bulk of the variance was accounted for by individual differences in letter knowledge and phoneme sensitivity.

While not unanimous, the weight of evidence from longitudinal studies suggests that oral vocabulary knowledge could plausibly play a causal role in reading acquisition.

Training studies

Training studies provide the most powerful evidence for the existence of causal effects (Hulme & Snowling, 2013a, 2013b; Nation & Castles, 2017). A causal relationship between oral vocabulary knowledge and word reading would be supported by studies showing that training in spoken word knowledge boosts reading accuracy for those words relative to untrained items. Further, the influence of semantic knowledge over and above knowledge of lexical phonology can be also be estimated if such paradigms distinguish between these elements of knowledge during training.

Two studies have adopted a training paradigm to investigate the influence of oral vocabulary knowledge on reading performance in children and both support the view that spoken word knowledge benefits word reading. McKague, Pratt and Johnston (2001) taught first grade children either the pronunciations and meanings, or only the pronunciations of a set of novel words over several sessions. At test, children read aloud the trained novel words and a set of untrained items. Reading aloud accuracy was better for orally trained than untrained items, with an accuracy advantage of almost 30%. Duff and Hulme (2012) similarly taught five and a half to six and a half year-old children either the pronunciations and meanings, or only the pronunciations, of a set of novel words while retaining another untrained set. They too found an accuracy advantage for the orally trained over the untrained items. Neither study, however, found evidence that semantic knowledge conveyed any additional benefit over knowledge of the phonological form alone.

While child training studies suggest that the advantage of orally trained words on reading accuracy is achieved via the provision of phonological information alone, these findings contrast with adult studies when word regularity is taken into account. For example, McKay, Davis, Savage and Castles (2008) trained adults to read novel words, some of which were presented along with meanings while the others were not. When participants were taught both pronunciations and meanings, their reading of irregular but not regular words was faster and more accurate than when only pronunciations were taught, suggesting that semantics conveys an additional small accuracy advantage for these words. In an artificial orthography learning paradigm, Taylor, Plunkett and Nation (2011, experiment 2) pre-exposed adults to either the phonology alone, or the phonology and meanings of a set of items that varied in both frequency and vowel consistency, and compared reading of these items with reading of untrained items. Early in training, both lexical phonology and semantic pre-exposure facilitated reading accuracy, regardless of frequency or consistency, and there was no additional advantage observed for semantically trained items. However, by the end of training, pre-exposure to semantics improved reading accuracy for items with low frequency inconsistent vowels whereas lexical phonology did not confer a reading accuracy advantage compared to untrained items. These findings are consistent with evidence from beginning readers suggesting that the early stages of orthographic learning may be more dependent on phonological than semantic familiarity (McKague et al., 2001; Nation & Cocksey, 2009) whereas semantic knowledge plays a more prominent role in the reading of low frequency and inconsistent words when skill level is higher.

How might oral vocabulary influence reading acquisition?

While evidence supports the existence of a causal relationship between oral vocabulary knowledge and reading accuracy, the mechanism of influence is debated (Duff, Reen, Plunkett, & Nation, 2015). Oral vocabulary is generally thought to assist with the process of acquiring representations of written words that support rapid and accurate word recognition, or *orthographic learning* (Castles & Nation, 2006; Nation & Castles, 2017). In the following section major theories of reading development and orthographic learning are outlined, each of which offer mechanistic accounts of the role of oral vocabulary knowledge within the process of reading acquisition.

Ehri's stage theory of reading development

Ehri (1992, 2005, 2014) proposed that as children learn to read they progress through a series of phases across developmental time. The phases are named to reflect the main types of connections children form to assist them to remember how to read words. The earliest stage of reading development occurs largely prior to formal reading instruction. It is referred to as *pre-alphabetic* because, due to a lack of knowledge about the writing system, children tend to rely on prominent visual features to read a very small number of written words. When children acquire some limited knowledge of letter names or sounds, they enter the *partial alphabetic phase* in which this knowledge is employed to make connections between some letters and sounds in printed words. Not all letters will be accompanied by a pronunciation in this phase because children's knowledge of letter-to-sound correspondences and their appreciation of the sound structure of language are limited. When knowledge about grapheme-to-phoneme correspondences is sufficient to permit children to make complete connections between the letters in printed words and the sounds with which they are associated, they enter the *full alphabetic phase*. In this phase, children are thought to employ several reading *strategies*. Prominent among these is a decoding strategy in which graphemes are converted to phonemes and then blended to form a word. Use of this strategy is thought to permit children to map a spelling pattern onto a pronunciation. This serves, through repeated encounters with the written word form, to permit children to begin to build a store of *sight words*, or words that can be read rapidly without recourse to the slow process of phonological decoding. The final stage is the *consolidated alphabetic stage*, which occurs when there is an accumulation of sight words held in memory. Sight word acquisition accelerates in this phase because children can draw on their existing knowledge to identify recurring letter patterns which then 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, -in, -and, -er, -ed* and *–ing*. Units of this type are thought to benefit reading acquisition because they reduce the number of connections between letters and sounds that must be retained in memory.

Orthographic learning as conceptualised elsewhere (Castles & Nation, 2006; Nation & Castles, 2017) occurs both in the full alphabetic stage and particularly in the consolidated alphabetic stage. Ehri (2014) theorised that for an orthographic representation to be formed, *orthographic mapping* must occur, a process thought to be largely driven by phonological decoding. Orthographic mapping refers to the process of forming connections between aspects of lexical representation, and is initiated when a reader encounters a new printed word and then either attempts to produce 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 between lexical representations of form are proposed to "glue" spellings to their pronunciations in memory. Oral vocabulary knowledge is viewed as assisting within this process in two ways. First, processing the meanings of words is thought to connect semantic information to word units. And second, immediately following phonological decoding, the child attempts to match the outcome of their decoding attempt to a known spoken word that is also consistent with the context in which it appears.

Self-teaching hypothesis

Rather than describing the process of learning to read as unfolding in a series of phases across developmental time, Share (1995) proposed that children acquire orthographic representations at an item level[3]. Explanations of orthographic learning that focus on the item-level are advantageous as they readily account for the observation that

[3] On this account, each written word is considered to be an "item" which must be individually acquired.

novel written words will be acquired throughout the lifespan. According to the self-teaching hypothesis (Share, 1995, 1999, 2004, 2008), the chief means by which orthographic learning occurs is via a process of phonological decoding. When a child is able to apply their knowledge of grapheme-to-phoneme correspondences, they have the potential to deduce the pronunciation of newly encountered written words. Whenever phonological decoding produces a correct pronunciation, this is thought to provide the child with an opportunity to learn its spelling. Ultimately an orthographic representation of that word is generated that facilitates future rapid and accurate retrieval of its phonology and meaning. While orthographic learning can occur very rapidly (Share, 2004), perhaps even following a single encounter with a novel written form, the self-teaching hypothesis favours the view that word recognition and orthographic learning should depend, at least in part, on the frequency with which it has been seen.

The self-teaching hypothesis conceives of oral vocabulary knowledge as providing assistance within the process of linking orthographic and phonological word forms (Share, 1995, 2008). A child may achieve only a partial or erroneous phonological decoding of a novel printed word, either because they possess inadequate knowledge of grapheme-to-phoneme correspondences or because the word contains irregularities in these mappings. Oral vocabulary is thought to confer a particular advantage in these instances because the failure to arrive at a known pronunciation should prompt the child to revise their initial phonological decoding attempt in an effort to align it with a phonologically similar known word. The availability of contextual information is thought to facilitate this posthoc matching process (Share, 2008).

The lexical quality hypothesis

The lexical quality hypothesis (Perfetti, 1992, 2007; Perfetti & Hart, 2002) is another item-specific theory of orthographic learning that provides a useful framework for conceptualising word representations. According to this view, lexical representations are thought to have three parts – the orthographic form, the phonological form and semantics – each of which can vary in quality. In an early iteration of the theory, Perfetti (1992) described two key principles that characterise the development of lexical quality: *precision* and *redundancy*. A lexical form is said to be precise when it accurately encodes an exact spelling such that a given sequence of letters can be recognised rapidly via direct lexical access and distinguished from other visually similar words. For example, the orthographic representation of *from* is fully specified when it can be distinguished from the spelling *form* or *frog*. A lexical representation is said to have the property of redundancy when there are multiple connections between the orthographic form, the phonological form and semantics. Together these connections serve to bind the three aspects of representation, thereby assisting visual word recognition. The properties of precision and redundancy are assumed to emerge upon visual exposure to an orthographic form (Perfetti, 1992), and to improve in quality with repeated encounters with the written form (Reichle & Perfetti, 2003).

The lexical quality hypothesis views the presence of oral vocabulary knowledge as assisting children to form and strengthen links between phonological and orthographic representations. It further predicts that when lexical quality is low, reliance on vocabulary knowledge should increase. Lexical quality might be low for a number of reasons. For example, irregularities in the mappings between letters and their pronunciations can weaken connections between orthography and phonology, thereby reducing lexical quality. Alternatively, lexical quality might be low because an aspect of lexical representation is absent or degraded in some way.

A mechanism that operates from the point of visual exposure

The basic idea that oral vocabulary might benefit word reading accuracy from the point of visual exposure predates modern theories of orthographic learning. Over 50 years ago Gibson (1965) proposed the concept of *set for diversity*. Its original conceptualisation and a more modern iteration called *set for variability* (Venezky, 1999) both suggest that phonological decoding attempts will frequently result in a reader arriving at an unknown pronunciation. When this occurs, the reader is prompted to consciously attempt to adjust their pronunciation until they find one that matches a known word and makes sense within the context. Early theorists largely discussed this matching process in the context of irregular word reading, because phonological decoding should typically[4] not result in a recognisable pronunciation, so the requirement to adjust an assembled pronunciation is obvious. The assumption that set for variability is most relevant for irregular words has been echoed more recently (e.g., Dyson, Best, Solity, & Hulme, 2017; Tunmer & Chapman, 2012; Zipke, 2016), while others have argued such a process operates even during regular word reading because assembled pronunciations for these words still require some, albeit smaller, adjustment for matching to occur[5] (Elbro, de Jong, Houter, & Nielsen, 2012; Kearns, Rogers, Koriakin, & Al Ghanem, 2016; Savage, Georgiou, Parrila, & Maiorino, 2018).

Several studies have evaluated set for variability as a possible mechanism through which word reading might be supported. For example, in a cross-sectional study of seven to eleven year-olds, Kearns and colleagues (2016) found that the ability to link inaccurate pronunciations to real words was a significant concurrent predictor of children's word reading even after controlling for other reading related skills. Similarly, two longitudinal studies have reported that the ability to reconcile mispronunciations with their correct spoken form predicts later reading of both irregular and regular words (Elbro et al., 2012; Tunmer & Chapman, 2012). Two brief training studies have explicitly taught children to

[4] However, there will be some instances in which phonological decoding of an irregular word produces a known pronunciation that is in fact an incorrect reading of the written word. For instance, the written word *sweat* is phonologically decoded as /swi:t/, which matches the pronunciation of the written word *sweet*. In this instance, without the benefit of contextual support, no significant adjustment to the pronunciation is likely.
[5] This proposed phenomenon avers that a blended pronunciation such as /k/+/æ/+/t/ is not phonologically identical to uttering the whole word /kæt/ as a single unit. Therefore the blended pronunciation requires some (minimal) form of matching to the known spoken word.

adjust mispronunciations of irregular words, and both concluded that while training improved children's ability to modify their pronunciations relative to the control group, the benefit did not appear to generalise to untreated items (Dyson et al., 2017; Zipke, 2016). A longer-term training study with at-risk readers provided explicit instruction in mispronunciation correction alongside intensive teaching of grapheme-to-phoneme correspondences and found clear evidence of a general intervention benefit on untreated materials (Savage et al., 2018). Since the latter study included multiple intervention components, it is not possible to draw conclusions regarding the locus of the benefit. Nevertheless, when taken together, results of these studies suggest that the ability to resolve discrepant pronunciations could plausibly play a role in reading acquisition.

An alternative mechanism?

Each of the mechanistic accounts discussed thus far have proffered the view that spoken word knowledge should assist children to make mappings between written words and their pronunciations. As such, each predicts that spoken word knowledge begins to influence written word learning upon visual exposure to the printed form. An alternative possibility is that spoken word knowledge may actually exert an effect on word reading that commences prior to visual exposure, via the ability to translate from pronunciation to print. This possibility was initially raised by Stuart and Coltheart (1988) but was not tested. Their suggestion was that a child who could segment spoken speech sounds and had reasonable knowledge of the mappings between letters and their sounds could potentially begin to develop a store of orthographic representations prior to commencing formal literacy instruction.

While not yet tested with children, some initial data from skilled readers is consistent with the notion that oral vocabulary knowledge might influence reading prior to visual exposure. For example, Johnston, McKague, and Pratt (2004, Experiment 1) taught skilled readers the pronunciations of a set of highly obscure real words. When later encountered in the context of a masked priming task, lexical decisions to the orally trained words exhibited a pattern of facilitation that was commensurate with that observed for familiar written words, a finding potentially consistent with the idea that orthographic representations had been established prior to visual exposure. Building on this work, McKague and colleagues (2008) proposed that oral vocabulary knowledge permits the formation of partially specified orthographic representations, possibly built around a word's consonants, prior to visual exposure. To test this hypothesis, skilled readers were taught the pronunciations and meanings of a set of novel words. In one condition training was provided orally, while in another condition participants read the novel words in short passages. A second manipulation concerned the predictability of the spellings of the trained items: some spellings were highly predictable from their pronunciations while others were not. When encountered in a masked priming lexical decision, there were four prime types: identity prime, consonant preserving, vowel preserving and all letters different. Results suggested that participants' visual word recognition of orally, but not visually, trained words was disrupted when spellings were not predictable from their pronunciations. This finding was interpreted as being consistent with the idea that visual exposure to the items during training had permitted participants to acquire precise orthographic representations for these words, whereas the absence of visual exposure in the oral training condition unsurprisingly permitted participants to acquire less well-specified orthographic representations. Robust masked identity and form priming effects were observed for orally trained words at their first visual exposure, which were 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. Further, there was no disruption to visual word recognition when the word's consonants were preserved but there was obvious disruption when the consonants were altered, a finding that is potentially consistent with the idea that early orthographic representations may be built around a word's consonants.

Orthographic influences on spoken word processing

The viability of hypotheses proposing that orthographic representations may begin to be generated prior to visual exposure depends upon the existence of bidirectional interactivity between written and spoken language. Major models of visual word recognition include bidirectional connections between orthography and phonology, thereby acknowledging phonological influences in visual word recognition (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Plaut et al., 1996). This implies, by extension, that there may be symmetry within the language system whereby orthography may influence spoken word processing. In line with this proposition, there now exists a body of evidence, largely based on skilled readers but also drawn from work with developing readers, that orthographic information is activated during the processing of spoken words (see Taft, 2011 for a review).

Experiments that explore the influence of orthographic knowledge on spoken word processing exploit differences between words in terms of the consistency of their spellings. In this instance, consistency refers to the degree to which a spelling can be predicted from the phonological form of a word (Stone, Vanhoy, & Orden, 1997). The term consistency can also be used to refer to the degree to which a pronunciation can be predicted from the orthographic form of a word. Consistency is therefore a feature of the relationship *between* spoken words and written forms that is present bidirectionally – from pronunciations to written forms (as in spelling) and from written forms to pronunciations (as in reading).

Consistency can be defined at multiple levels of representation; the word level, the rime-body level and the phoneme level (Van Orden & Kloos, 2005) but is most frequently discussed at the level of the rime-body. When a word body is always pronounced the same way, such as *_ing* as in *bring,* it is referred to as consistent for reading; and when a pronunciation body is always written in the same way, such as *_ing* in *bring,* it is referred to as consistent for spelling. The word *bring* is therefore consistent for both reading and spelling. 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 for reading (written form to pronunciation); and when a pronunciation is associated with more than one plausible spelling pattern, as in the words *team, deem* and *theme*, it is considered to be inconsistent for spelling (pronunciation to written form).

As previously mentioned, differences in consistency have been used to explore the notion that an individual's knowledge of orthography penetrates their spoken word processing. The hallmark of this effect is slower responding to words with inconsistent spellings, such as *theme*, than words with consistent spellings, such as *bring*, during auditory lexical decision tasks. This effect has repeatedly been found among skilled readers (Pattamadilok, Morais, De Vylder, Ventura, & Kolinsky, 2009; Pattamadilok, Morais, Ventura, & Kolinsky, 2007; Perre, Pattamadilok, Montant, & Ziegler, 2009; Petrova, Gaskell, & Ferrand, 2011; Ziegler & Ferrand, 1998; Ziegler, Ferrand, & Montant, 2004; Ziegler, Petrova, & Ferrand, 2008) and initial evidence suggests it is also observable in developing readers (Ventura, Kolinsky, Pattamadilok, & Morais, 2008; Ventura, Morais, & Kolinsky, 2007). Alternative experimental paradigms offer converging evidence for automatic activation of orthography during spoken word processing. For example, using an auditory lexical decision task Chéreau and colleagues (2007) found that while phonological overlap (*hurt-dirt*) facilitates processing, orthographic overlap (*shirt-dirt*) provides an additional facilitatory boost to word recognition. A similar effect has been found using pseudohomophone priming – responses to words in an auditory lexical decision task were facilitated when preceded by a pseudoword that could be spelled in the same way as the target (Taft, Castles, Davis, Lazendic, & Nguyen-Hoan, 2008). That is, hearing the spoken pseudoword prime /trʌθ/ facilitated subsequent processing of the target word /tru:θ/. These data, together with those of McKague and colleagues (2008), imply the existence of a mechanism that permits oral vocabulary knowledge to influence word reading prior to visual exposure is plausible.

Measuring orthographic learning

Pioneering studies of orthographic learning (e.g., Manis, 1985; Reitsma, 1983a, 1983b) used reading aloud accuracy and latency to evaluate whether learning had taken place. More recent work in the self-teaching tradition instead indexes learning via either orthographic choice or spelling. The orthographic choice task is a test of recognition memory and as such, performance tends to be quite high. The task requires the child to differentiate from amongst a group of distractors the specific spelling of an item encountered during learning (e.g., *sloak* or *sloke*). A benefit of this task is that it cannot be successfully completed on the basis of phonological decoding alone; a correct response suggests that something about the word-specific orthographic form was acquired. However, the orthographic choice task limits the range of possible stimuli because items must have available a plausible homophone (Nation & Castles, 2017). If an item has a spelling that is unpredictable from its pronunciation, there will typically be at least one useful homophonic alternative. While there are virtually always multiple plausible spellings for a given pronunciation (Kessler, Treiman, & Mullenix, 2008), devising homophonic alternatives is challenging for items with spellings that are highly predictable from their pronunciation. For example, the spoken word 'nesh' readily brings to mind the spelling *nesh* but alternative spellings for that pronunciation are unlikely to maintain print-to-pronunciation regularity (e.g., *neash*), which is a crucial requirement if learning is evaluated with orthographic choice. Spelling assesses recall and requires children to retrieve from memory the precise orthographic form they experienced during learning. As such, it is both the most rigorous and difficult test of orthographic learning, with accuracy rates frequently being quite low. When both orthographic choice and spelling have been employed within the same study, observed estimates of the level of learning are often highly discrepant (Kyte & Johnson, 2006; Wang, Castles, Nickels, & Nation, 2011).

Theories of orthographic learning generally agree that representations of written words are acquired gradually via building visual experience (Ehri, 2014; Perfetti, 1992; Share, 2008). This presumed incremental learning, however, is not well captured by either orthographic choice or spelling because learning is indexed in a binary fashion (correct/incorrect)[6]. Several authors have proposed that an alternative method – the monitoring of eye movements during reading – may be a more sensitive metric of the incremental learning theorised to occur when novel words are encountered (Joseph & Nation, 2018; Joseph, Wonnacott, Forbes, & Nation, 2014; Nation & Castles, 2017). Recent work suggests that eye movements do tap incremental and implicit learning processes during orthographic learning. One line of inquiry addresses incidental novel word learning across visual exposures, showing that fixation durations decrease with building visual experience even prior to the emergence of robust explicit word-specific knowledge (Elgort, Brysbaert, Stevens, & Van Assche, 2018; Joseph & Nation, 2018; Joseph et al., 2014). A parallel approach combines a training study design in which aspects of lexical representation are pre-exposed, and then employs eye movements during reading to index the effect of this partial knowledge on online reading behaviour (Taylor & Perfetti, 2016).

Outline of experimental papers

Drawing on the evidence outlined above, the aim of this dissertation is to provide an elaborated account of a novel cognitive mechanism through which oral vocabulary knowledge might support word reading even prior to visual exposure. This dissertation is presented in a "thesis by publication" format, with each chapter written in the form of an

[6] Spelling can also be scored in a continuous fashion (see, for example, the scoring method adopted in the computer program "Ponto" available at: http://spell.psychology.wustl.edu/ponto/), though this approach is yet to be adopted in studies of orthographic learning.

independent manuscript. Chapter 2 is not presented for examination (for an explanation of this please see the “Declaration” on page *vii* of this dissertation). It proposes and provides an initial test of the orthographic skeleton hypothesis, and has been published in *Developmental Science* (Wegener et al., 2018). Chapters 3 to 5 report the outcome of experiments designed to provide an elaborated account of the generation of orthographic skeletons and their influence on ongoing written word learning. These experiments were pre-registered (see the Supplemental Materials chapter), and the papers have been prepared for submission to specific journals. Because each experimental chapter tests a prediction arising from the orthographic skeleton hypothesis, they necessarily contain overlapping information.

All of the experiments reported in this dissertation adopt a version of the training paradigm first employed by Taylor and Perfetti’s (2016). Each study commences with a training phase in which aspects of oral vocabulary knowledge are taught. At test, the primary measure of processing is children’s eye movements during moment-to-moment reading at the first (Chapters 2 to 5) and subsequent visual exposures (Chapter 5). Secondary follow-up tests of learning take the form of reading aloud accuracy and latency (Chapters 3 and 4), spelling accuracy (Chapters 3 and 4) and visual lexical decision (Chapter 5). Below the specific research questions addressed within each manuscript are outlined.

Chapter 2: Children reading spoken words: Interactions between vocabulary and orthographic expectancy

Based on the idea that oral vocabulary knowledge might influence written word learning prior to visual exposure, this paper proposed the orthographic skeleton hypothesis. This hypothesis suggests that when a child holds a word in their oral vocabulary, and when that child also has knowledge of the mappings between phonemes and graphemes, they may form an expectation of the likely spelling of that word even if it has not yet been encountered in print. To test this hypothesis, oral familiarity was manipulated during an oral vocabulary training phase, while spelling predictability was manipulated at the point of visual exposure to trained and untrained items. Together these two manipulations were intended to create conditions in which the orthography children saw was either congruent or incongruent with their likely expectations. By monitoring children's eye movements as they read the novel words for the first time, it was possible to index the effect of the prior oral vocabulary knowledge on fixation durations at the initial visual exposure to target words and to infer the operation of a causal mechanism that begins prior to visual exposure.

Chapter 3: The contributions of lexical phonology and semantics to the generation of orthographic expectancies

Building on the initial findings from Chapter 2, this paper examines the roles of lexical phonology and semantics within the generation of children's spelling expectations. The specific question addressed is whether familiarity with the phonological form of a word is sufficient to stimulate orthographic expectancies, or whether semantic information conveys a further advantage within this process. In the initial investigation of the orthographic skeleton (reported in Chapter 2), children benefited from semantic support derived from the lexical representation itself and from context during reading. In this paper, the manipulations of oral familiarity and spelling predictability are retained while a third manipulation is added. This latter manipulation relates to the type of vocabulary training children received: one group were taught pronunciations and meanings, while another group were only taught pronunciations. The vocabulary manipulation also influenced the nature of the sentences children read: the availability of semantic information during training meant that sentences at test conveyed some meaningful contextual information, whereas the absence of semantics during training rendered sentences at test neutral. The results of this paper shed light on the roles of lexical phonology and semantics within the formation of the orthographic skeleton, and their longer term influence on orthographic learning.

Chapter 4: Partial or complete? The early form of orthographic expectancies

Based on the assumption that children's initial spelling expectancies are unlikely to exhibit the properties of well-developed orthographic representations as delineated in the lexical quality hypothesis (Perfetti, 1992, 2007; Perfetti & Hart, 2002) this paper sought to investigate what form these early orthographic representations might take. The lexical quality hypothesis (Perfetti, 1992) proposes two alternative possibilities that could describe the form of early orthographic representations: they could be partial representations built around a word's consonants, or they could be complete representations that could potentially be incorrect. These possibilities were tested in this paper by employing a manipulation of oral familiarity and a modified spelling predictability manipulation. The latter manipulation distinguished between spellings that were highly predictable from pronunciations, and spellings that included either an unpredictable consonant or unpredictable vowel spelling. This paper provides key insights into the likely form of the spelling expectations children generate on the basis of their spoken word knowledge, and their influence on longer term orthographic learning.

Chapter 5: Tracking the evolution of orthographic expectancies over building visual experience

The initial findings from Chapter 2 suggest that children can form initial spelling expectations of words they have heard before but have never seen in writing. Having previously found evidence for this at the first orthographic exposure to orally known words, this paper addressed the question of what happens to the orthographic skeleton over repeated visual exposures. Employing the same manipulations of oral familiarity and spelling predictability as adopted in Chapter 2, in this paper the evolution of the orthographic skeleton was tracked over three blocked visual exposures. The primary aim of this experiment was to determine whether orthographic skeletons remain evident with accumulating visual experience, or whether they can instead be shown to undergo an updating process which would bring them closer to the form experienced in print. A secondary aim was to evaluate the influence of the orthographic skeleton on longer term orthographic learning. The results of this paper provide an initial insight into the evolution of the orthographic skeleton with increasing visual experience, and its longer term impact on reading.

Summary

This introductory chapter has reviewed existing empirical evidence converging on the view that oral vocabulary plays a causal role in children's word reading development. It has been argued that two complementary cognitive mechanisms might permit oral vocabulary knowledge to support children's word reading. The first, and more widely recognised possibility, is that oral vocabulary influences word reading from the point of visual exposure via the provision of top-down support that is particularly useful for resolving partially successful decoding attempts (Share, 2008). This dissertation is concerned with the second, and less commonly held view, that oral vocabulary knowledge might influence reading even prior to visual exposure. Prior work that points to the plausibility of such a mechanism was described. On this basis, the orthographic skeleton hypothesis is proposed and tested (Chapter 2). The remainder of the dissertation builds on this initial work to shed light on the roles of lexical phonology and semantics within the development of orthographic expectancies (Chapter 3); the form of the orthographic skeleton (Chapter 4); the influence of the orthographic skeleton on subsequent visual exposures to target words (Chapter 5); and the longer-term effect of the orthographic skeleton on orthographic learning (Chapters 3 to 5). The dissertation is concluded with a general discussion (Chapter 6), which brings together the key experimental findings, their implications and directions for future research.

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Chapter 2

Children reading spoken words: Interactions between vocabulary and orthographic expectancy

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Abstract

There is an established association between children's oral vocabulary and their word reading but its basis is not well-understood. Here, we present evidence from eye movements for a novel mechanism underlying this association. Two groups of 18 Grade 4 children received oral vocabulary training on one set of 16 novel words (e.g. "nesh", "coib"), but no training on another set. The words were assigned spellings that were either predictable from phonology (e.g., *nesh*) or unpredictable (e.g., *koyb*). These were subsequently shown in print, embedded in sentences. Reading times were shorter for orally familiar than unfamiliar items, and for words with predictable than unpredictable spellings but, importantly, there was an interaction between the two: children demonstrated a larger benefit of oral familiarity for predictable than for unpredictable items. These findings indicate that children form initial orthographic expectations about spoken words before first seeing them in print.

Introduction

Children's oral vocabulary skills are known to be strongly associated with their word reading. This association has been demonstrated in cross-sectional studies (Nation & Snowling, 2004; Nation & Cocksey, 2009) and also within longitudinal and training designs (Lee, 2011; Duff, Reen, Plunkett, & Nation, 2015; McKague, Pratt & Johnson, 2001; Duff & Hulme, 2012), suggesting a causal role for oral vocabulary in reading development. Given that children typically have many words established in oral vocabulary prior to seeing them in print, understanding the mechanism by which this influence occurs is critical, as it offers the potential to create language learning conditions that maximise reading outcomes for children. Here, we present novel evidence from eye movements in support of one such mechanism: that children build initial representations of the written forms of words present in their oral vocabulary prior to first encountering them in print.

Most accounts of the way in which oral vocabulary enhances children's word reading propose that it assists in the process of forming representations of new written words – or *orthographic learning* (Castles & Nation, 2006) – and that this assistance occurs at the point of first seeing the printed word. According to the self-teaching hypothesis (Share, 1995), the presence of a word in oral vocabulary furnishes top-down support during the process of phonological decoding, assisting a child to resolve partially successful attempts. Specifically, if a child's initial decoding attempt does not match the phonology of any word present in their oral vocabulary, they may modify their decoding so as to align it with a phonologically similar word that they do know. In a similar vein, the lexical quality hypothesis (Perfetti, 1992) proposes that the presence of a word in oral vocabulary assists children to form and strengthen links between phonological and orthographic representations, and that when only partial orthographic or phonological information is available reliance on vocabulary knowledge increases. Thus, both of these theories propose a causal mechanism in which oral vocabulary influences orthographic learning upon visual exposure.

A less widely canvassed possibility is that the presence of a word in oral vocabulary assists the orthographic learning process even *before* a child has seen the word in its printed form. That is, a child who is orally familiar with a word, and who has an adequate knowledge of sound-letter mappings, may form an expectation as to how that word might be spelled, a suggestion first made but not tested by Stuart and Coltheart (1988). Indeed, children may, without intention, establish an initial orthographic representation of the word, which we refer to here as an *orthographic skeleton* (see Figure A1). This would aid reading when the word was first seen in print, particularly for words with highly predictable spellings.

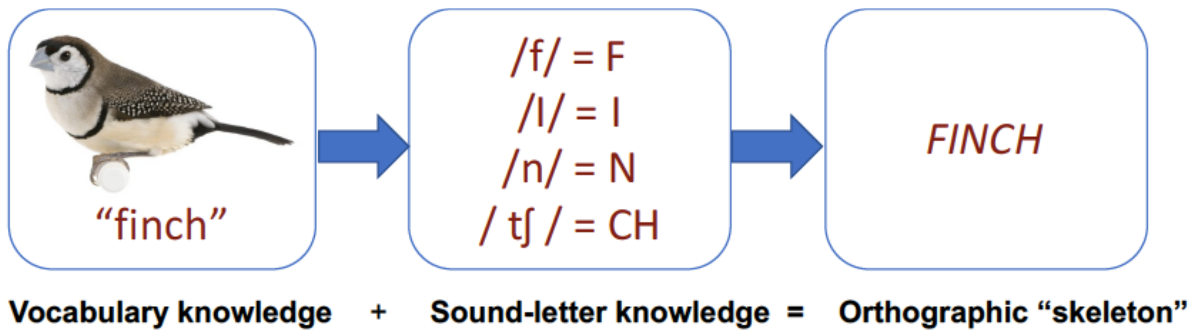

Figure A1. The orthographic skeleton hypothesis

Evidence from skilled readers is consistent with this alternative causal hypothesis. McKague et al. (2008; see also Johnston et al., 2004) conducted a learning study in which they taught adults the pronunciations and meanings of sets of novel words. Critically, they manipulated the spelling consistency of the words; that is, the extent to which their spellings could be predicted from their phonology (Stone, Vanhow, & Van Orden, 1997). In a condition in which the initial training was in oral form only, the participants' subsequent visual word recognition was disrupted by spelling inconsistency, suggesting that they had generated some kind of orthographic expectancy about the words based on their phonology. This is consistent with reports from a range of studies of skilled readers of pervasive effects of orthography on spoken word processing (e.g., Chéreau, Gaskell & Dumay, 2007; Rastle, McCormick, Bayliss & Davis, 2011; Taft, Castles, Davis, & Lazendic, 2008).

If spoken word learning leads to the formation of initial orthographic representations in children, this would inform the mechanisms by which oral vocabulary influences reading acquisition. We know that children make tight mappings between orthography and phonology from very early in reading development (Rack, Hulme, Snowling & Wightman, 1994; Savage & Stuart, 2006; Savage, Stuart & Hill, 2001; Ventura, Morais & Kolinsky, 2007; Perfetti, 1992). Given this, it seems likely that, as they build their proficiency in rapidly and automatically converting sounds into their written form, children would increasingly form expectations about the spellings of words present in their oral vocabulary. Here, we report on the first direct test of the orthographic skeleton hypothesis in developing readers. We reasoned that if children generate orthographic skeletons for orally familiar words, then two experimental manipulations might reveal this. Firstly, a training study design enables the manipulation of oral familiarity. Accordingly, Year 4 children received oral vocabulary training on a set of novel words (e.g. “nesh”, “coib”), but received no training on a second set. Both the trained and untrained items were subsequently presented to the children in printed form, and it was at this point that the second manipulation was applied: spelling predictability. By assigning half of the items spellings that were highly predictable from their phonology (e.g., *nesh*) while the other half were assigned unpredictable spellings (e.g., *koyb*), we sought to create conditions in which the orthography of the orally trained novel items was either in line with children’s likely expectation (predictable) or incongruent with it (unpredictable). To index the children’s online processing when first seeing the novel words in print, their eye movements were monitored as they read the words, embedded in sentences. Eye movement monitoring is a sensitive measure of dynamic reading processes in children (Blythe, 2014; Blythe & Joseph, 2011; Joseph, Nation & Liversedge, 2013), and is an ideal methodology for indexing the effects of training on aspects of word representation (Taylor & Perfetti, 2016).

Based on the orthographic skeleton hypothesis, we predicted an interaction between oral vocabulary training and spelling predictability in eye movement indices of looking time, with the children showing a larger effect of spelling predictability for those items that had been orally trained. The logic for this was as follows: if children generate orthographic skeletons for orally familiar words, when a trained item is shown in print with a predictable spelling, the match between the child's orthographic skeleton and the presented orthography should facilitate processing. In contrast, when a trained item with an unpredictable spelling is presented, a mismatch would occur between the orthographic skeleton and the presented orthography, creating a "surprise" that takes time to resolve. Since no orthographic skeletons are created for untrained items, the effect of spelling predictability should be smaller or non-existent, reflecting only any baseline difference in processing time between the more common spelling patterns of the predictable words and the more unusual patterns of the unpredictable words.

Orthographic expectations, should they exist, might be expected to exert a very early effect on lexical processing. As such, the interaction between oral vocabulary training and spelling predictability was anticipated for eye movement measures thought to reflect the operation of initial lexical identification processes; namely first fixation duration and gaze duration (Rayner & Liversedge, 2011). Persistence of the interaction on the later processing measure of total reading time, which reflects the sum of all fixations on a target word including any time spent rereading, was also anticipated. Expectations regarding the probability of rereading were different: consistent with findings showing that novel words are associated with a greater likelihood of rereading (Chaffin, Morris & Seely, 2001), we anticipated that untrained items would be more likely to be refixated than trained items. Because all the items were phonologically decodable, irrespective of the predictability of their spellings, we did not anticipate an effect of spelling predictability or an interaction with training.

Because the orthographic skeleton hypothesis proposes that children draw on their knowledge of sound-letter mappings to form expectations of the spellings of orally known words, we reasoned that children with a higher level of reading and language proficiency would be more capable of forming robust orthographic expectations of orally trained items than children with a lower proficiency level. This in turn would lead them to be more surprised when shown an unexpected orthographic form for an orally familiar word than children with weaker orthographic expectations. Therefore, we hypothesised that there would be a positive correlation between children's level of reading and language proficiency, particularly their ability to convert novel phonology into orthography (as indexed by nonword spelling) and the size of spelling predictability effect, with more able children showing a larger effect of spelling predictability than their less able peers.

Method

Participants

Participants were 36 Year 4 children from two parallel classes at a primary school in the metropolitan region of Sydney, Australia (N = 18 in each group; 17 female; mean age:10y;1m; range: 9y;2m -10y;11m). No child who returned a consent form was excluded. Children of this age were selected 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. The sample size was informed by previous investigations of orthographic learning (e.g., Wang et al., 2011; Share, 2004). Moreover, we employed inferential statistics (linear mixed-effects models) that are recognized to reduce error variance, and thereby increase power, as a consequence of treating both participants and items as random effects (Baayen et al., 2008).

Table A1

Children's performance on standardized tests of vocabulary, reading and spelling.

	M	SD	Min	Max
Oral Vocabulary (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 (DiST)				
Nonwords [c]	-0.54	0.82	-2.00	2.00
Irregular [c]	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.* [a] *Age scaled score (M = 10, SD = 3);* [b] *Age-based z scores (M = 0, SD = 1);* [c] *Grade-based z scores (M = 0, SD = 1)*

Standardized tests

Standardized measures of reading, spelling, and oral vocabulary were administered to characterise the sample, and so that associations with the eye movement indices could be examined. Regular, irregular and nonword reading were assessed with the Castles and Coltheart 2 (CC2; Castles, Coltheart, Larsen, Jones, Saunders & McArthur, 2010), word and nonword spelling with the Diagnostic Spelling Test (DiST; Kohnen, Colenbrander, Krajenbrink & Nickels, 2015) and oral vocabulary with the Naming subtest from the Assessment of Comprehension and Expression 6-11 (ACE 6-11; Adams, Cooke, Crutchley, Hesketh & Reeves, 2001). Summary data are presented in Table A1 and show that mean performance was within the average range across all measures.

Experimental materials

Two sets of 16 three-phoneme monosyllabic nonwords, matched for consonant/vowel structure, were constructed. Half of the items in each set were assigned spellings that contained frequent phoneme to grapheme mappings and thus were highly predictable from their phonology (e.g. "f" for /f/). The other half were assigned spellings that were unpredictable due to containing less frequent mappings (e.g. 'ph' for /f/). The spelling predictability manipulation was confirmed through pilot testing on five adults and five children: When presented orally for dictation, the predictable items were spelled in the same way by all pilot participants (e.g., *nesh*, *coib*) while the unpredictable items were not spelled in that way by any participant (e.g., *veme, koyb*). Despite the variation in spelling predictability, all items were regular for reading in that they could be read aloud correctly using the most common grapheme to phoneme correspondences. The strong spelling predictability manipulation meant that the predictable and unpredictable items could not be matched for number of letters (varying from 3 – 5 letters) or bigram frequency, although items were matched on these properties across the two training sets. The full item sets appear in Appendix A1.

Procedure

Oral Vocabulary Training. Each group was trained on one set of 16 novel words, with the other set constituting their untrained items and the sets being counterbalanced across groups. The children were told that they would be learning about "Professor Parsnip's Inventions" (procedure following Wang, Castles, Nickels & Nation, 2011; additional inventions from Mimeau, Ricketts & Deacon, in preparation) and engaged in a range of activities to learn about the names of the inventions as well as their function and two perceptual features. For example they learned that a "nesh" is "used to shuffle cards" and "is made of metal and has two hands". Each invention was paired with a picture demonstrating its features, such as shown in Figure A2. The written form of the words was never shown.

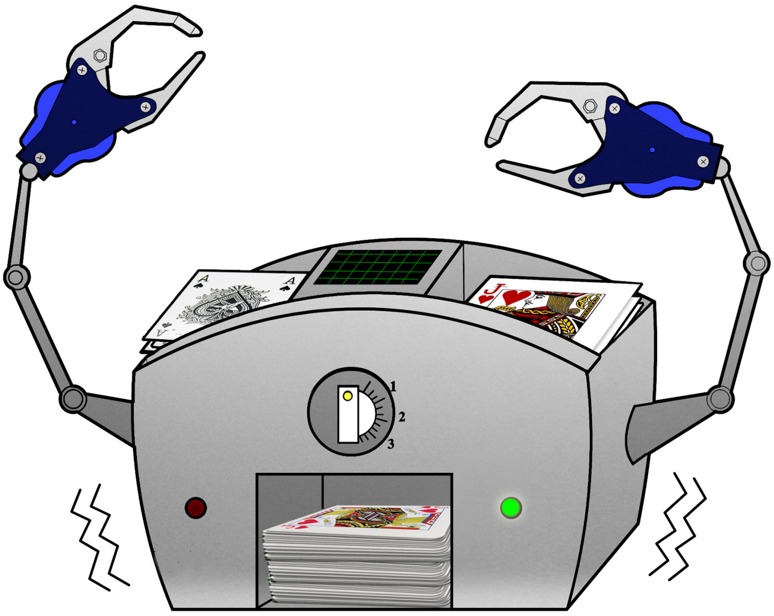

Figure A2. Sample picture: A 'nesh' is used to shuffle cards

Training took place in four 20-minute sessions over four days, with eight items (four from each spelling predictability condition) being introduced in the first session and the remaining eight in the second session. If a child was absent, a catch-up session was provided. A detailed description of the training protocol is provided in the Supplementary Materials.

After completion of training, and immediately prior to their initial orthographic exposure (see below), the children's oral vocabulary learning was assessed with a picture-naming task. They were individually shown the pictures of the inventions one at a time and asked if they remembered what the invention was called and what it was used for. Accuracy was recorded but, to ensure that the number of phonological exposures to the novel words was controlled, feedback was given regardless of accuracy.

Initial Orthographic Exposure. The children were exposed to the words in written form for the first time between one and four days after their final oral vocabulary training session, with the mean delay being equivalent across groups, $t(34) = -1.017$, $p = .316$ (group 1: $M = 1.89$, $SD = .900$; group 2: $M = 2.22$, $SD = 1.060$). They silently read interleaved sentences referring to the 16 inventions they had learned about and the 16 inventions learned by the other group. There were also an additional four pairs of filler sentences that included novel words not learned by either group. The carrier sentences were designed to be contextually rich, such that as the children read them, they would expect to see the word they had learned about during oral vocabulary training, if they had been trained on that item. For example, *Nick picked up the cards and put them into the nesh to shuffle them*. All experimental sentences can be found in Appendix A2.

The children's eye movements were recorded using a remote Eyelink 1000 eye tracker (SR Research; Mississauga, Canada) sampling at 500 Hz as they read the sentences on a computer monitor at a viewing distance of approximately 65cm. 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, followed by three practice trials, and then the experimental sentences. The experimenter triggered the beginning and end of each trial after the children looked at a fixation cross to indicate their readiness. To promote attention to task, they were required to answer a (yes/no) question after each trial.

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).

Results

Oral Vocabulary Learning: Picture Naming

Children were able to name a mean of 10.67 out of 16 words of the pictures of the orally trained nonwords (*SD* = 4.13), with no differences between those subsequently assigned predictable or unpredictable spellings, $t(35) = .236$, $p = .815$ (predictable: *M* = 5.36, *SD* = 1.93; unpredictable: *M* = 5.31, *SD* = 2.41). In addition, the difference in the number of items learned by children in each group (group 1: *M* = 10.78, *SD* = 3.49; group 2: *M* = 10.56, *SD* = 4.79) was not significant, $t(34) = .159$, $p = .875$.

Orthographic Exposure: Eye movements

The 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). Following Baayen (2008), to normalize the distributions of residuals, 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. Models were Gaussian with the exception of the model for the probability of rereading, which was logistic. 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 analysis (5.1% of trials removed). Arithmetic means and standard error values of the four target word dependent variables are depicted in Figure A3.

The area of interest was the name of an invention (target word). Fixed effects included training (trained vs. untrained), spelling predictability (predictable vs. unpredictable) and their interaction. Group (group 1 vs. group 2) 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; see also Perez, Joseph, Bajo & Nation, 2015; Zuur, Ieno, Walker, Saveliev & Smith, 2009). 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 Table SA1 in the Supplementary Materials). For each analysis the *t* or *z* statistic is reported. When a model produced one or more significant fixed effects, *p* values were obtained using *lsmeans* (Lenth, 2016). When a significant interaction was identified the testInteractions function from the phia package (De Rosario-Martinez, 2015) was used to compute contrasts. Mean and standard error values for significant model predictions are reported in Table S2 in the Supporting Information, with time data back-transformed from log fixation durations for display in ms using *predictSE.SR* (Robidoux, S., 2017).

All three dependent measures reflecting looking time produced the same pattern of results: a fixed effect of vocabulary training such that trained items were fixated for shorter periods than untrained items (first fixation duration: $\beta = -0.101$, $SE = 0.036$, $t = -2.797$, $p = 0.011$; gaze duration: $\beta = -0.106$, $SE = .032$, $t = -3.314$, $p = .001$; total reading time: $\beta = -0.250$, $SE = 0.059$, $t = -4.203$, $p < .001$); a fixed effect of spelling predictability such that items with predictable spellings were fixated for shorter periods than unpredictable spellings (first fixation duration: $\beta = -0.211$, $SE = 0.063$, $t = -3.340$, $p = 0.007$; gaze duration: $\beta = -0.348$, $SE = 0.062$, $t = -5.624$, $p < .001$; total reading time: $\beta = -0.419$, $SE = 0.064$, $t = -6.572$, $p < .001$); and critically, an interaction between the two factors such that the effect of spelling predictability was larger for orally familiar than unfamiliar items (first fixation duration: $\beta = -0.085$, $SE = 0.036$, $t = -2.348$, $p = .0191$; gaze duration: $\beta = -0.126$, $SE = 0.032$, $t = -3.967$, $p < .001$; total reading time: $\beta = -0.186$, $SE = 0.047$, $t = -3.979$, $p < .001$).

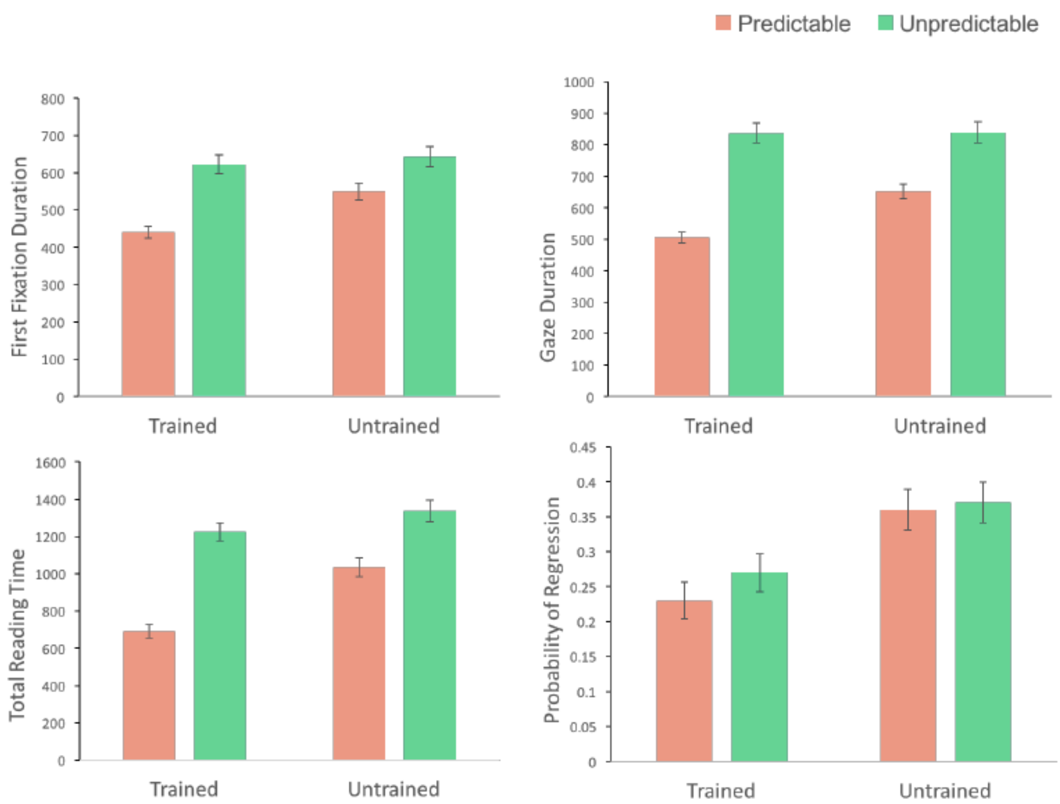

Figure A3. Arithmetic (untransformed) means and standard errors of eye movements in the target word interest area. First fixation duration, gaze duration and total reading time are all expressed in milliseconds. Probability of regressions reflect the likelihood of occurrence.

Interaction contrasts showed that items with predictable spellings benefited from training (first fixation duration: χ^2 = 13.001, p <.001; gaze duration: χ^2 = 26.046, p <.001; total reading time: χ^2 = 33.257, p <.001) whereas items with unpredictable spellings did not (first fixation duration: χ^2 = 0.103, p =.749; gaze duration: χ^2 = 0.217, p =.642; total reading time: χ^2 = 0.732, p =.392). The effect of spelling predictability was present for items that had received oral training (first fixation duration: χ^2 = 16.525, p <.001; gaze duration: χ^2 = 46.467, p <.001; total reading time: χ^2 = 53.346, p <.001). For items that had not received oral training, the effect of spelling predictability was marginal for first fixation (χ^2 = 2.997, p =.083) and significant on both other measures (gaze duration: χ^2 =

10.127, p = .001; total reading time: χ^2 = 9.691, p = .002).

For regressions in, the model showed an effect of training (β = -0.604 , *SE* = 0.143, *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.

Table 2

Correlations between the spelling predictability effect and vocabulary, reading and spelling ability

	First Fixation	Gaze Duration	Total Reading Time
Vocabulary (ACE)	0.25	0.24	0.36*
Nonword Reading (CC2)	0.53**	0.43**	0.42*
Irregular Word Reading (CC2)	0.41*	0.40*	0.29^{+}
Nonword Spelling (DISTn)	0.33^{+}	0.28^{+}	0.21
Irregular Word Spelling (DISTi)	0.36*	0.37*	0.24

*$^{+}$p<.10, *p<.05, **p<.01 (uncorrected)*

Relationship between the spelling predictability effect and standardized reading and language measures

We conducted exploratory by-participant Pearson product-moment correlational analyses to investigate the relationship between children's raw scores on standardized assessments of vocabulary, reading, and spelling and the size of their spelling predictability effect [(trained unpredictable/trained predictable)-(untrained unpredictable/untrained predictable)]; see Table 2). Correlations with vocabulary were not significant for the early processing measures of first fixation duration and gaze duration, but the correlation with the later processing measure of total reading time was significant. Correlations with reading were significant or approaching significance across all eye movement measures. Correlations with spelling were significant or approaching significance for early processing measures, but not for the later measure of total reading time. The overall pattern suggests that reading, spelling and language skills are positively correlated with the effect of spelling predictability. However, these exploratory results should be read with some caution. When correcting for multiple comparisons (using the Holm-Bonferroni method with a family-wise error rate of .05), only the largest correlation (between nonword reading and first fixation duration) remains significant.

Discussion

This experiment provides the first direct evidence that children generate initial orthographic representations of words present in their oral vocabulary prior to seeing them in print. When Year 4 children were taught novel words in oral form, they responded differently to those words on first encountering them in print depending on whether their spellings were predictable or not from their sound: they spent less time looking at the words whose spellings were predictable, consistent with the idea that these spellings matched their expectations. Importantly, this effect was much less pronounced when the children had not previously received oral training on them, ruling out an account based simply on differences in the orthographic complexity of the predictable versus unpredictable words. This interaction between training and spelling predictability, providing key evidence for our *orthographic skeleton* hypothesis, was consistently observed across the early processing measures of first fixation duration and gaze duration, and the later measure of total reading time. Further support for the hypothesis comes from correlational analyses revealing that children with relatively stronger language and literacy skills, including phonological decoding, tended to experience a greater spelling predictability effect than those with weaker skills.

These findings have important implications for theories of reading acquisition, providing evidence for a plausible but little-explored mechanism by which oral vocabulary may influence written word learning. Theories of orthographic learning such as the self-teaching (Share, 1995) and lexical quality (Perfetti, 1992) hypotheses, presume that oral vocabulary knowledge exerts an effect that commences at the point of exposure to the printed form of a word. Our findings build on these accounts to suggest that oral vocabulary knowledge may further confer an advantage prior to initial visual exposure, via a mechanism that explicitly allows for a flow of information from phonology to orthography.

More broadly, and in line with previous work that has shown an accuracy advantage for reading orally known words over unfamiliar words (McKague, et al., 2001; Nation & Cocksey, 2009; Duff & Hulme, 2012), we found that training in a word's sound and meaning was associated with a general processing advantage across all eye movement measures, and with a reduced likelihood of rereading. These findings are compatible with the view that oral vocabulary knowledge benefits reading at an item level (McKague et al., 2001; Nation & Cocksey, 2009; Duff & Hulme, 2012); they also confirm the utility of eye movement monitoring for addressing questions about reading development (Taylor & Perfetti, 2016; Blythe & Joseph, 2011).

Much remains to be learned about how the orthographic skeleton influences ongoing orthographic learning: future studies should address the issue of its precise form and its impact on the retention and consolidation of orthographic representations in long-term memory. A further key question is whether the orthographic expectancy is stimulated by knowledge of the sound of the spoken words alone, by a combination of knowledge of the sound and meaning of words, or by semantic support provided by contextual factors. We did not seek to differentiate these alternatives in the present study, but it is important to do so to maximise the potential benefits of vocabulary knowledge for ongoing reading development.

We viewed it as critical for the initial test of the orthographic skeleton hypothesis that our manipulation of spelling predictability be as strong as possible, such that there was a high likelihood that the orthographic expectancy children generated matched the predictable items and was incongruent with the unpredictable ones. A limitation of adopting this strong manipulation was that items with predictable and unpredictable spellings, although regular for reading, could not be matched on number of letters or bigram frequency. We therefore expected to observe an effect of spelling predictability across all items, including those that had not been trained orally, and this was consistently found. Importantly though, this cannot account for the interaction we observed between oral training and spelling predictability. Future studies might nevertheless seek to replicate these findings in more closely matched stimuli.

An alternative account of our results might continue to attribute the observed interaction to the operation of processes that occur from the point of visual exposure, based on the idea that oral familiarity in combination with a more typical spelling might facilitate phonological decoding. However, we suggest that the pattern of results is more in line with the view that the interaction arises as a result of processes that operate prior to visual exposure. Under the alternative hypothesis, both predictable and unpredictable spellings would be expected to benefit from training, with possibly a larger advantage for predictable items. While the orthographic skeleton hypothesis also predicts a benefit of training when items have predictable spellings, in contrast to the alternative account, the effect of training is expected to be *reduced* when an unpredictable spelling is presented; because its incongruence with the child's orthographic expectation is surprising to them. Consistent with the orthographic skeleton hypothesis, interaction contrasts showed that items with predictable spellings benefited from oral familiarity, whereas unpredictable items did not. However, further research is needed to the disentangle the complex interactions that appear to be occurring between the children's processing of phonology and orthography.

In summary, we provide the first direct evidence for a new and developmentally plausible mechanism via which vocabulary knowledge benefits reading acquisition, at least once children have some prerequisite literacy level. As well as contributing to theories of the nature of the association between oral vocabulary and reading, it has important implications for practice in the teaching of reading. Our findings clearly support the inclusion of oral vocabulary instruction as part of a comprehensive teaching program, and, with further elaboration, may provide direction as to the nature, level, and timing of this instruction.

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Appendices

Appendix A1

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	/bɜːv/	birv
	/kɔɪb/	koyb	/dʒaɪf/	jayf
	/dʒiːb/	jeabb	/miːf/	meaph
	/fɜːf/	phirf	/gʌz/	ghuzz
	/gæk/	ghakk	/feg/	phegg
	/mɜːb/	mirbe	/veɪp/	vaype

Appendix A2

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.

Chapter 3

The Contributions of Lexical Phonology and Semantics to the Generation of Orthographic Expectancies

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This experiment was pre-registered with AsPredicted.org. Please see the Supplementary Materials section of this dissertation for further details.

Abstract

There is a known causal relationship between children's oral vocabulary knowledge and their word reading. Initial evidence (Wegener et al., 2018) suggests a cognitive mechanism that supports this link: oral vocabulary knowledge along with knowledge of sound-to-letter mappings permits the formation of spelling expectations, or *orthographic skeletons*, even before written words are seen. Here, we asked what form of oral vocabulary knowledge is needed for children to generate orthographic skeletons: is knowledge of a word's pronunciation sufficient, or does semantics confer a further benefit? Grade 4 children (N=83) were taught either the pronunciations and meanings or only the pronunciations of one set of 16 novel words while another set were untrained. Spellings of half the items were predictable from their phonology (e.g. *nesh*) while the other half were unpredictable (e.g. *koyb*). Trained and untrained items were subsequently shown in print for the first time, embedded in sentences, and eye movements were monitored. Sentences were contextually meaningful for children who had learned pronunciations and meanings but were neutral for those who had learned only pronunciations. Replicating our previous work, we found evidence that spelling expectations are generated on the basis of knowledge about the pronunciations and meanings of words, and these were evident from early in processing (first fixation duration, gaze duration, total reading time) during the first visual exposure. Pronunciations alone were sufficient to give rise to strong spelling expectations later in processing, suggesting that semantics benefits the formation of orthographic expectancies. However, on follow-up tests of reading aloud and spelling, there was no persisting benefit from semantics. Future work should seek to clarify the roles of lexical semantics and contextual support.

Introduction

Children who know more spoken words tend to be better at reading than children who know fewer spoken words (Scarborough, 2001). Outcomes from longitudinal and training studies further suggest that this association is likely to be causal (Duff & Hulme, 2012; Duff, Reen, Plunkett, & Nation, 2015, 2015; Lee, 2011; McKague et al., 2001), raising the possibility that children's reading outcomes may be improved by interventions that effectively target the underlying mechanism or mechanisms supporting this association. Recently we provided an initial demonstration of one such mechanism: by drawing on their knowledge of phoneme-to-grapheme correspondences, children can generate *orthographic skeletons*, or expectations of the spellings of known spoken words prior to seeing them in print for the first time (Wegener et al., 2018). Here, we build on this work by distinguishing two elements of oral vocabulary knowledge – lexical phonology (pronunciation) and semantics (meaning) – and investigating the role these distinct sources of information play in the formation of orthographic skeletons.

Oral vocabulary knowledge is thought to benefit children's learning of novel written words, or their *orthographic learning* (Castles & Nation, 2006; Nation & Castles, 2018). Precisely how this support is conveyed remains to be established. A major point of departure between explanatory accounts is the proposed timing of the influence of spoken word knowledge on written word learning. Most theories converge on the view that oral vocabulary knowledge assists written word learning from the point of visual exposure. The self-teaching hypothesis (Share, 1995, 2008), for example, proposes that when a child achieves only a partial or erroneous decoding of a novel written word this prompts a search of their store of spoken word knowledge. If a phonologically similar word is present in the child's oral vocabulary, the child may revise their initial decoding attempt in order to match it to the known pronunciation. This explanation closely parallels other work suggesting that the ability to align discrepant pronunciations may contribute to children's reading acquisition (Dyson et al., 2017; Elbro et al., 2012; Kearns et al., 2016; Savage et al., 2018; Tunmer & Chapman, 2012).

These accounts all focus on how spoken word knowledge might assist children to translate from orthography (print) to phonology (pronunciation). But children's ability to translate from pronunciation to print could also play a role, leaving open the possibility that a complementary causal mechanism might exert an influence on reading even prior to visual exposure. Existing evidence from skilled readers is consistent with such an alternative causal mechanism; using a range of experimental masked priming paradigms, it has been shown that orthographic information can be automatically activated when adults listen to spoken words (Chéreau, Gaskell, & Dumay, 2007; Pattamadilok, Morais, De Vylder, Ventura, & Kolinsky, 2009; Pattamadilok, Morais, Ventura, & Kolinsky, 2007; Taft, 2011; Taft, Castles, Davis, Lazendic, & Nguyen-Hoan, 2008; Ziegler & Ferrand, 1998). Investigations with developing readers have revealed similar effects in children as young as seven years of age (Ventura, Kolinsky, Pattamadilok, & Morais, 2008; Ventura, Morais, & Kolinsky, 2007), suggesting that this alternative causal mechanism may also be developmentally plausible.

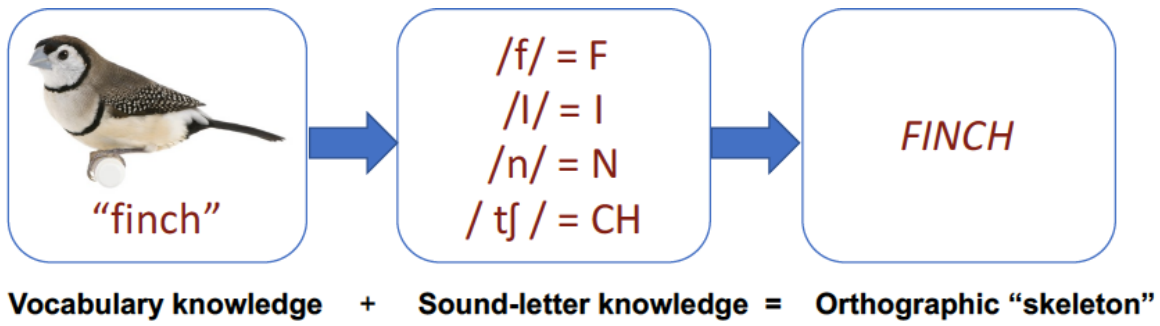

Figure B1. The orthographic skeleton hypothesis

In earlier work we proposed the orthographic skeleton hypothesis (see Figure B1), which described how such a mechanism might function during reading development (Wegener et al., 2018; presented here as Chapter 2). We reasoned that when spoken word knowledge is accompanied by a reasonable appreciation of the mappings between phonemes and graphemes, children might combine these sources of information in order to generate initial expectations about the likely spellings of words they have heard before but never seen. Using a novel word training study design, we tested this possibility for the first time with developing readers. Children received training on the pronunciations and meanings of a set of novel words before reading contextual sentences containing the items they had learned as well as another set of items they had not been trained on. Children's eye movements revealed that, compared with untrained items, those that had received oral training and were shown in print with predictable spellings (e.g. the spoken word '*nesh*' written as *nesh*) were associated with shorter fixation durations. This was interpreted as being consistent with the idea that when children's orthographic expectancy and the actual orthographic form are congruent, online processing is facilitated. However, when orally trained items were presented with unpredictable spellings (e.g. the spoken word '*coib*' written as *koyb*) there was no benefit of training, suggesting that incongruence between children's orthographic expectancy and the orthographic form results in a processing cost. Since children's online processing of orally taught novel words varied according to the predictability of their spellings to a greater extent than orally untrained words, we interpreted this as being consistent with the operation of a causal mechanism that begins prior to visual exposure.

In our initial investigation of the orthographic skeleton hypothesis, children were provided with semantic support during oral vocabulary training and from sentence context at the point of reading. While oral vocabulary knowledge is typically thought of as including both familiarity with a word's phonological form and an understanding of a word's meaning (Nation & Cocksey, 2009), this need not be the case. Rather, a spoken word representation may be limited to a word's phonological form. Similarly, the context in which a written word is embedded may be supportive of its meaning, or it may be neutral. A key outstanding issue therefore relates to the roles of lexical phonology and semantics in the generation of orthographic skeletons: is familiarity with a word's phonological form sufficient to stimulate orthographic expectancies, or does semantic support (from the lexical representation itself and from the context in which it appears) convey an additional benefit within this process?

Most theories of visual word recognition identify a role for semantics within the reading process. For example, the lexical quality hypothesis (Perfetti, 1992, 2007; Perfetti & Hart, 2002) views efficient reading as being reliant on the presence of high quality lexical representations characterized by tight integration of information about a word's form (orthography and phonology) and meaning (semantics). In general, semantic information is thought to assist with the process of forming and strengthening orthography-phonology links. However, when lexical quality is low, perhaps because orthography-phonology connections are weak, or in the event that either aspect of representation is degraded or absent, reliance on semantic information is anticipated to increase.

Evidence from developing readers supports the view that oral vocabulary knowledge, when comprised of both lexical phonology (word pronunciations) and semantics (word meanings), is closely associated with children's word reading. This association is supported by data from cross-sectional (Bowey & Rutherford, 2007; Goff, Pratt, & Ong, 2005; Mitchell & Brady, 2013; Nation & Snowling, 2004; Ouellette & Beers, 2010; Ricketts, Nation, & Bishop, 2007) and longitudinal studies (Duff et al., 2015; Lee, 2011; Nation & Snowling, 2004). Studies employing item-level analyses (Nation & Cocksey, 2009; Ricketts, Davies, Masterson, Stuart, & Duff, 2016) and training designs (Duff & Hulme, 2012; McKague et al., 2001; Ouellette & Fraser, 2009) provide further support for this link, and additionally shed light on the roles that knowledge of lexical phonology and semantics may play within children's reading. We will now discuss these in turn.

Item-level analyses address the question of whether knowledge of an individual spoken word – either its pronunciation or its pronunciation and meaning – is associated with reading accuracy for that specific word. Ricketts and colleagues (2016) adopted the same approach to the assessment of these aspects of children's lexical knowledge as Nation and Cocksey (2009) had adopted in earlier work: lexical phonology was evaluated using an auditory lexical decision task, while lexical semantics was assessed using a spoken definitions task. In both studies, children also read lists of regular and irregular words. Nation and Cocksey (2009) found that only irregular word reading accuracy was predicted by oral vocabulary knowledge, and that correctly accepting an item as a word was a stronger predictor of reading accuracy than the ability to define it. Ricketts and colleagues (2016), however, found that both regular and irregular word reading were associated with oral vocabulary knowledge and that the ability to define an item was a stronger predictor of reading accuracy than the ability to correctly accept it as a word. Although both studies support the position that oral vocabulary knowledge plays a role in word reading, their conclusions about the roles of lexical phonology and semantics within word reading differ: in one case the benefit was attributed to knowledge of pronunciations whereas in the other it was attributed to the addition of knowledge about word meaning. A third and more recent item-level analysis (Model 1 in Kearns & Al Ghanem, 2019) lends weight to the suggestion that semantic knowledge plays a role in reading. In a sample of children in grades three and four, they found that word-specific orthographic, phonological, and semantic knowledge all made independent contributions to the prediction of children's ability to read a set of polysyllabic words which varied continuously with respect to their print-to-pronunciation consistency.

Training studies provide powerful evidence for the existence of causal effects (Hulme & Snowling, 2013). In these paradigms, participants receive instruction in aspects of lexical knowledge; the influence of this prior knowledge on subsequent test performance is then evaluated relative to performance on untrained items. McKague, Pratt and Johnston (2001) and Duff and Hulme (2012, Experiment 2) taught young school-age children either the pronunciation alone, or the pronunciation and meanings of a set of novel words. When the children subsequently encountered the words in print for the first time, both studies observed an accuracy advantage for the orally trained words, with no additional advantage conveyed when pronunciations had been taught with associated meanings. Importantly, training studies with children have employed items with regular print-to-pronunciation mappings. Training studies with skilled readers, which have employed items with both regular and irregular print-to-pronunciation mappings, tend to support the position that prior knowledge of semantics can benefit adults' reading more than prior knowledge of pronunciations alone, at least when the learned items have irregular pronunciations (McKay, Davis, Savage, & Castles, 2008; Taylor, Plunkett, & Nation, 2011).

Context has also been identified as potentially playing a role in orthographic learning (Ehri, 2005; Perfetti, 1992; Share, 1995, 2008), with influences theorized to affect both phonological decoding and the retention of written word forms (Nation & Castles, 2017). A distinct line of inquiry considers the role of context within sentence comprehension processes during reading. Studies on this topic have used various methods to show that processing of a given word can be influenced by the context that precedes it. For example, behavioural studies have found that when a target word is congruent with the meaning of a preceding sentence fragment, naming speed and lexical decision times tend to be faster than when the target word is incongruent with the meaning of the sentence (Fischler & Bloom, 1979; Perfetti, Goldman, & Hogaboam, 1979; Stanovich & West, 1979, 1983). Eye-movement studies have also shown that contextual predictability matters during moment-to-moment sentence reading (e.g., Ehrlich & Rayner, 1981; Rayner & Well, 1996). Effects have been found on a range of eye-movement indices, but most notably (and consistent with behavioural work), words that are highly predictable from their context are associated with shorter fixation durations than words that are less contextually predictable. This finding holds across the eye movement record, extending from early to late looking time measures. These effects have been interpreted as reflecting the operation of lexical expectation processes, whereby readers draw on context to develop predictions about upcoming words as they read; and these processes are captured in dominant models of eye-movement control during reading (e.g., Rayner, Ashby, Pollatsek, & Reichle, 2004).

Having considered the roles of lexical phonology, lexical semantics and context within reading, we now turn to the issue of how these features might contribute to the formation of children's spelling expectations. We assume that a word's lexical phonology is an essential prerequisite to the formation of orthographic expectancies. Knowledge of the phonological form of a word provides a basis for the generation of spelling expectancies because the spoken word can be decomposed into its constituent phonemes, which are then able to be mapped to corresponding graphemes. This being the case, what role might lexical semantics play? As already alluded to, the lexical quality hypothesis suggests that lexical representations which include integrated information about phonology, semantics and orthography should be higher in quality than representations for which there are fewer available sources of information. Since orthographic skeletons are expectations about an orthographic form that has not yet been seen, the maximum number of available information sources is two – lexical phonology and lexical semantics (Perfetti, 1992, 2007; Perfetti & Hart, 2002). Therefore, a prediction arising from the lexical quality hypothesis might aver that the availability of lexical semantic information in addition to knowledge of lexical phonology renders this a higher quality representation, by virtue of which children's ability to generate orthographic expectancies may be boosted. However, while lexical phonology likely exerts a direct influence on the generation of orthographic skeletons, lexical semantics presumably does not because meaning does not provide cues to spelling, at least for monomorphemic words (Rastle, 2019). Therefore, if lexical semantic knowledge benefits the formation of orthographic skeletons, this influence is presumably indirect and occurs via its connections with lexical phonology. Context could also conceivably play a role in the formation of orthographic skeletons. If readers do indeed draw on context to make predictions about upcoming words in a sentence, then the orthographic skeleton of a known spoken word might be brought to mind as children read a constraining sentence fragment. On this view, context may perhaps be thought of as pre-activating the child's orthographic skeleton, with the result that it is more pronounced at an early point in processing than when such contextual support is absent.

The current experiment

The current experiment investigated the roles of lexical phonology and semantics (from the lexical representation itself and from context) in the formation of the orthographic skeleton. In our original demonstration of the effect, children were taught pronunciations with associated meanings and subsequently received contextual support at the point of reading. Here, we sought to contrast a condition in which Year 4 children were taught only the pronunciations of a set of novel words (e.g., 'nesh', 'coib'), with another condition in which children were taught both their pronunciations and meanings. A second set served as untrained items. Later, children silently read both the trained and untrained items in sentences while their eye movements were monitored. When children had learned both pronunciations and meanings, sentences, were contextual at test; whereas when children had learned only pronunciations sentences were, by definition, neutral at test. In line with our previous work, the spelling predictability of the novel words was manipulated such that half of the items in each set had spellings that were highly predictable from phonology and therefore consistent with children's likely orthographic expectation (e.g., *nesh*), while the remaining items had spellings that were unpredictable from phonology and therefore inconsistent with children's likely expectations (e.g., *koyb*).

Based on our initial findings (Wegener et al., 2018), it was anticipated that orally trained items would be associated with shorter fixation durations than untrained items and that predictable spellings would be associated with shorter fixations than unpredictable spellings. Our key prediction relating to the orthographic skeleton hypothesis was that a larger effect of spelling predictability should be observed for trained compared to untrained items across each of the looking time measures of interest (first fixation duration, gaze duration, total reading time). Extending our previous work, we anticipated that this orthographic skeleton effect would be present when children had learned only pronunciations and when children had learned both pronunciations and meanings. Further, if the availability of semantic information increases lexical quality even prior to visual exposure, then orthographic expectancies generated under these circumstances should be stronger than those generated on the basis of phonological knowledge alone. Similarly, if the availability of contextual support pre-activates semantic information during reading, then this would also support the prediction that spelling expectancies should be stronger for children who are taught both pronunciations and meanings.

Follow-up testing investigated the effects of our manipulations on children's subsequent reading aloud and delayed orthographic learning performance. Immediately following the initial orthographic exposure children read aloud all items, both trained and untrained, over four trials without corrective feedback. At a mean delay of approximately one week, children were required to spell all items to dictation. We elected to provide four reading aloud trials in view of prior findings demonstrating that orthographic representations can be acquired from four visual exposures (spelling accuracy ≈ 50%, Wang, Castles, Nickels, & Nation, 2011), although we did so in the knowledge that spelling would likely be particularly challenging in the current experiment as half of the items have unusual spellings. We made five predictions relating to the follow-up tests. 1) For the reading aloud task, it was anticipated that repeated exposures might support the reduction of reading latencies, but the absence of feedback regarding accuracy would preclude a corresponding improvement in children's reading aloud accuracy over trials. 2) Training in both lexical phonology and semantics may provide an ongoing benefit to reading aloud accuracy, latency and spelling accuracy. 3) Regardless of the type of vocabulary knowledge available to children, it was anticipated that trained items would be read aloud more accurately and quickly, and spelled more accurately than untrained items. 4) Items with predictable spellings would be read more accurately and quickly, and spelled more accurately than items with unpredictable spellings. 5) Because multiple visual exposures to the target words were provided, this might provide children with an opportunity to resolve any incongruence between their orthographic expectancy and the orthographic form they experienced in print, with the possible effect that training and spelling predictability would not continue to interact on these follow-up measures of learning.

Method

Participants

A total of 87 children in Year 4 were recruited from a large primary school in the metropolitan region of Sydney, Australia. All children who returned a consent form were considered eligible. Of the total number of recruited children, four were unable to be adequately calibrated so data is reported for the remaining 83 participants (46 females). Children were drawn from four (Class 1: n = 23; Class 2: n = 21, Class 3: n = 19; Class 4: n = 20) parallel mainstream classes. The mean age of children was 9 years and 6 months (range: 8y;9m -10y;4m). Classes were allocated to one of two oral vocabulary training conditions: phonological and semantic pre-exposure (two classes, N = 40), or phonological pre-exposure only (two classes, N = 43). There was no significant difference in the ages of children allocated to each of these conditions (phonology plus semantics: $M = 114$ months; phonology only: $M = 114.3$ months; $t(81) = 0.293$, $p = 0.770$). The sample size was informed by previous investigations of orthographic learning (Share, 2004; Wang et al., 2011) and by our own prior work in which the basic orthographic skeleton effect was first demonstrated (Wegener et al., 2018).

Table B1

Children's performance on standardized tests of spoken vocabulary, reading and spelling

	M	SD	Min	Max
Spoken vocabulary knowledge (ACE)[a]	8.66	2.65	3.00	17.00
Reading aloud (CC2)				
Regular [b]	0.60	1.14	-2.33	2.37
Irregular [b]	0.08	0.63	-1.35	2.26
Nonwords [b]	0.20	1.21	-2.29	2.70
Spelling				
DiSTn [b]	-0.09	1.09	-1.90	2.30
DiSTi [b]	0.50	0.82	-1.41	2.29

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)*

Standardized tests

Standardized measures of spoken vocabulary knowledge, reading and spelling were administered to characterise the sample. 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). Reading of regular, irregular and nonwords was assessed using the Castles & Coltheart 2 (CC2; Castles, Coltheart, Larsen, Jones, Saunders & McArthur, 2010). These tests were administered individually. Spelling ability was assessed with the Diagnostic Spelling Test irregular words (DiSTi; Kohnen, Colenbrander, Krajenbrink & Nickels, 2015) and the Diagnostic Spelling Test – nonwords (DiSTn; Kohnen, Colenbrander, Krajenbrink & Nickels, 2015) with administration occurring at a group level. Summary data are presented in Table B1 and show that mean performance was broadly within the average range across all measures.

Table B2.

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	/bɜːv/	birv
	/kɔɪb/	koyb	/dʒaɪf/	jayf
	/dʒiːb/	jeabb	/miːf/	meaph
	/fɜːf/	phirf	/gʌz/	ghuzz
	/gæk/	ghakk	/feg/	phegg
	/mɜːb/	mirbe	/veɪp/	vaype

Experimental materials

Items were taken from Wegener and colleagues (2018), and consisted of two sets of 16 three-phoneme, monosyllabic nonwords matched for consonant/vowel structure. All items were regular for reading: they employed the most common grapheme-to-phoneme correspondence (type frequency *M* = 94.23%, *SD* = 10.78%). Half of the items in each set were assigned spellings that were highly predictable from phonology because they contained frequent phoneme-to-grapheme mappings (e.g., ‘f’ for /f/). The other items were assigned spellings that were unpredictable from phonology because they contained less frequent phoneme-to-grapheme mappings (e.g., ‘ph’ for /f/). For details of the pilot testing that confirmed this manipulation, the reader is referred to the original paper. Of note, 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 B2.

Procedure

Oral vocabulary training. Children were taught one set of 16 novel spoken words at a class level, while the other set was untrained. Oral vocabulary training condition and item sets were counterbalanced across classes. The two oral vocabulary training conditions were equated for the number of novel word exposures, both receptive and expressive, and approximate duration of the training sessions. Children were introduced to the novel spoken words in sessions over a period of four days. Each session was of approximately 20-minutes duration. In the first session, eight items were introduced (four from each spelling predictability condition) while the remaining eight were introduced in the second session. All 16 items were rehearsed in the third and fourth training sessions. If a child was absent for any training session, a catch-up session was provided at the earliest opportunity. All children, regardless of the type of vocabulary training they received, were provided with the general instruction that they would be learning about ‘Professor Parsnip’s Inventions’ (Wang et al., 2011; Wang, Nickels, Nation, & Castles, 2013).

In the phonological plus semantic pre-exposure condition the training procedure was identical to Wegener and colleagues (2018). Spoken invention names were paired with a picture referent (see Figure B2) and the function of the invention and two perceptual features was described. For example, children learned that a “nesh” is “used to shuffle cards”, is “made of metal and has two hands”. Children then completed activities requiring them to listen to and repeat the invention names and their functions, and were asked to try their best to remember both pieces of information. In the phonological only pre-exposure condition, inventions were presented orally by name only, with no picture referent and no information about their function. For example, children learned that a ‘nesh’ is one of Professor Parsnip’s inventions. Children then completed activities requiring them to listen to and repeat the invention names, and were asked to try their best to remember them. Phonology only and phonology plus semantic training sessions were matched for the number of phonological exposures to the novel oral vocabulary (50 per item in total across all sessions) and approximate session duration.

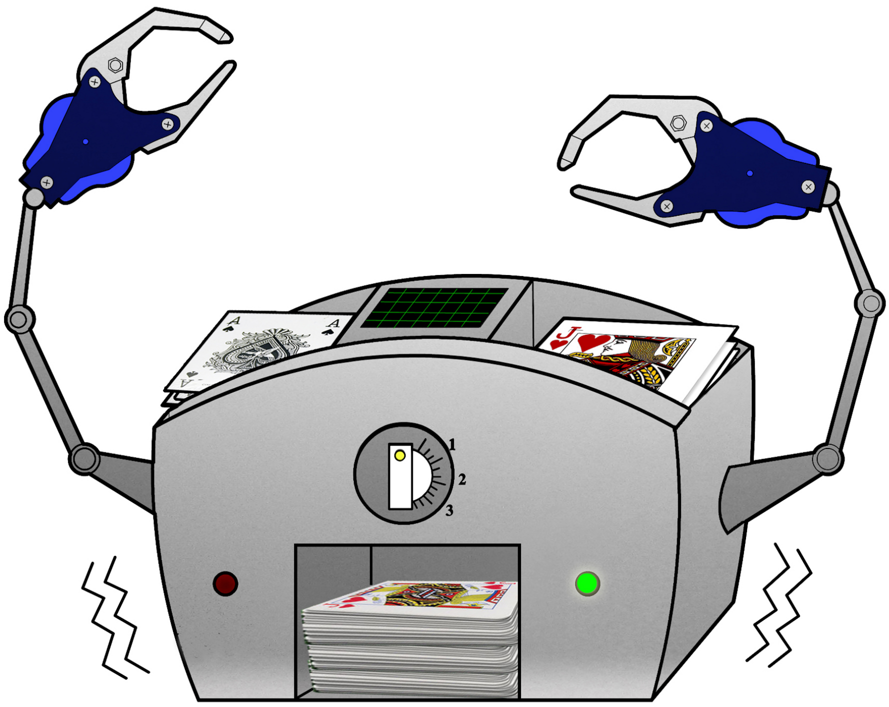

Figure B2. Sample picture: A 'nesh' is used to shuffle cards

Learning check. Following the completion of training but prior to the initial orthographic exposure, the children's oral vocabulary learning was assessed individually in a phonemic cued recall format. Children were provided with the following cue: "Which invention name starts with (insert initial phoneme)?". To equate the number of heard and produced phonological exposures, immediate feedback was provided regardless of accuracy. To assess how well children in the phonological plus semantic pre-exposure condition had learned the link between the invention name and its function, children were asked: "And what was that invention used for?".

Initial Orthographic Exposure. The children encountered the written form of the orally trained words for the first time between one and seven days following their final oral vocabulary training session. The mean delay between training and testing did not significantly differ across the two oral vocabulary training conditions (phonology plus semantics: $M = 2.38$, $SD = 1.27$; phonology only: $M = 2.58$, $SD = 1.33$; $t(81) = 0.720$, $p = 0.473$). All children silently read 40 experimental sentences: 16 sentences contained the inventions they had learned about; 16 contained inventions they had not learned about; and an additional four pairs of filler sentences included novel words not learned by any group. The sentences were interleaved and presented in a predetermined pseudorandom order. The carrier sentences were from Wegener and colleagues (2018). For the children who had received training in both phonology and semantics, carrier sentences were contextually rich. The same carrier sentences were read by the children who had received training in phonology only, and by virtue of this fact, were contextually neutral.

An Eyelink 1000 eye tracker (SR Research; Mississauga, Canada) in remote setup, with a sampling rate of 500Hz, was used to record children's eye movements as they read the sentences on a computer screen. The viewing distance was approximately 65cm and each character covered approximately 0.36 of horizontal visual angle. Sentences appeared in black Courier New font on a white background. Participants read binocularly but only the movements of the right eye were recorded. Following an initial calibration of the eye tracker, children read three practice sentences before progressing to the experimental sentences. The start and end of each trial was triggered by the experimenter when the children directed their gaze at specified fixation crosses. Children were required to answer a (yes/no) question after each trial as a means of promoting attention to task.

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 testing: reading aloud. Immediately following the initial orthographic exposure, a reading aloud task was administered in order to evaluate the accuracy and speed with which children could link the orthographic form of the inventions with their phonology. Both trained and untrained items were presented in an interleaved random order on a laptop using DMDX software (Forster & Forster, 2003). Responses were recorded using a voicekey and by the experimenter using a paper and pencil scoresheet. Words were displayed for 3500ms and remained on the screen for this period even if a response was recorded. CheckVocal (Protopapas, 2007) was employed to check accuracy and response times and accuracy was cross-checked with hand scoring. Children saw interleaved trained and untrained items over four blocked reading aloud trials but feedback regarding accuracy was never provided.

Post-exposure testing: Delayed spelling accuracy. To assess children's learning and retention of the orthographic forms of inventions, a surprise spelling task was administered at a whole class level. The children were told that they would be asked to spell all of the inventions they had read about while completing the eye-tracking task, including both those they had learned about orally in class and those the other class had learned. It was made clear that children should attempt to spell the invention names as they had seen them written in the context of the eye-tracking task. Items were interleaved and presented in a predetermined pseudorandom order. Responses were scored as correct or incorrect. The mean delay between the initial orthographic exposure and the spelling test was 7.52 days (range 1 to 9), and this did not significantly differ by vocabulary type (phonology plus semantics: M = 7.63, SD = 1.27; phonology only: M = 7.47 days, SD = 1.35 days; $t(81)$ = -0.55, p = 0.58).

Results

Learning check: Picture naming

Participants correctly recalled a mean of 9.12 of the 16 orally trained invention names (SD = 2.95). The number of items correctly recalled by children in the two vocabulary type conditions did not differ significantly (phonology plus semantics: M = 9.10, SD = 3.06; phonology only: M = 9.14, SD = 2.8, $t(81)$ = 0.061, p = 0.952). The difference in recall between participants who learned set 1 (M = 9.477, SD = 3.054) and set

2 ($M = 8.718$, $SD = 2.819$) was not significant ($t(81) = 1.172$, $p = 0.245$), nor was the difference in recall for items with predictable spellings ($M = 4.671$, $SD = 1.678$) and unpredictable spellings ($M = 4.458$, $SD = 1.677$; $t(81) = 1.116$, $p = 0.268$).

Eye movements

Data were analysed in the R computing environment (R Core Team, 2019). The lme4 package (Bates, Mächler, Bolker, & Walker, 2015) was used to construct linear mixed effects models. In order to ensure comparable interpretation of effects, consistent with the approach of Wegener and colleagues (2018) and other recent eye movement work (Joseph & Nation, 2018; Taylor & Perfetti, 2016), reading time data were log transformed to normalise the distributions of model residuals.

Models were run for each of the dependent variables of interest: first fixation duration, gaze duration, total reading time and regressions in. For the purpose of analysis, the area of interest was the invention name, or target word. If any of the three prespecified interest areas – target word, pre-target text, post-target text – were skipped during first pass reading, the trial was removed prior to analysis (5.0% of the experimental data).

Vocabulary type (phonology only vs. phonology plus semantics), training (trained vs. untrained), spelling (predictable vs. unpredictable) and their interaction were entered as fixed effects while participants and items were entered as random effects. Fixed effects were centred using deviation coding. When the full random effects structure was fitted, including random intercepts and slopes for subjects and items, singularity and/or nonconvergence were observed, suggesting that the models were over parameterized (Baayen, Davidson, & Bates, 2008). We therefore built models from the simplest to the most complex random effects structure and selected the highest nonsingular converging models. The hierarchy of random effects models are presented in the Supplementary Material as Table SB1. When an interaction was significant, the *phia* package (De Rosario-Martinez, 2015) was used to compute interaction contrasts. For ease of interpretation, arithmetic means and standard errors for each of the dependent variables appear in Figure B3.

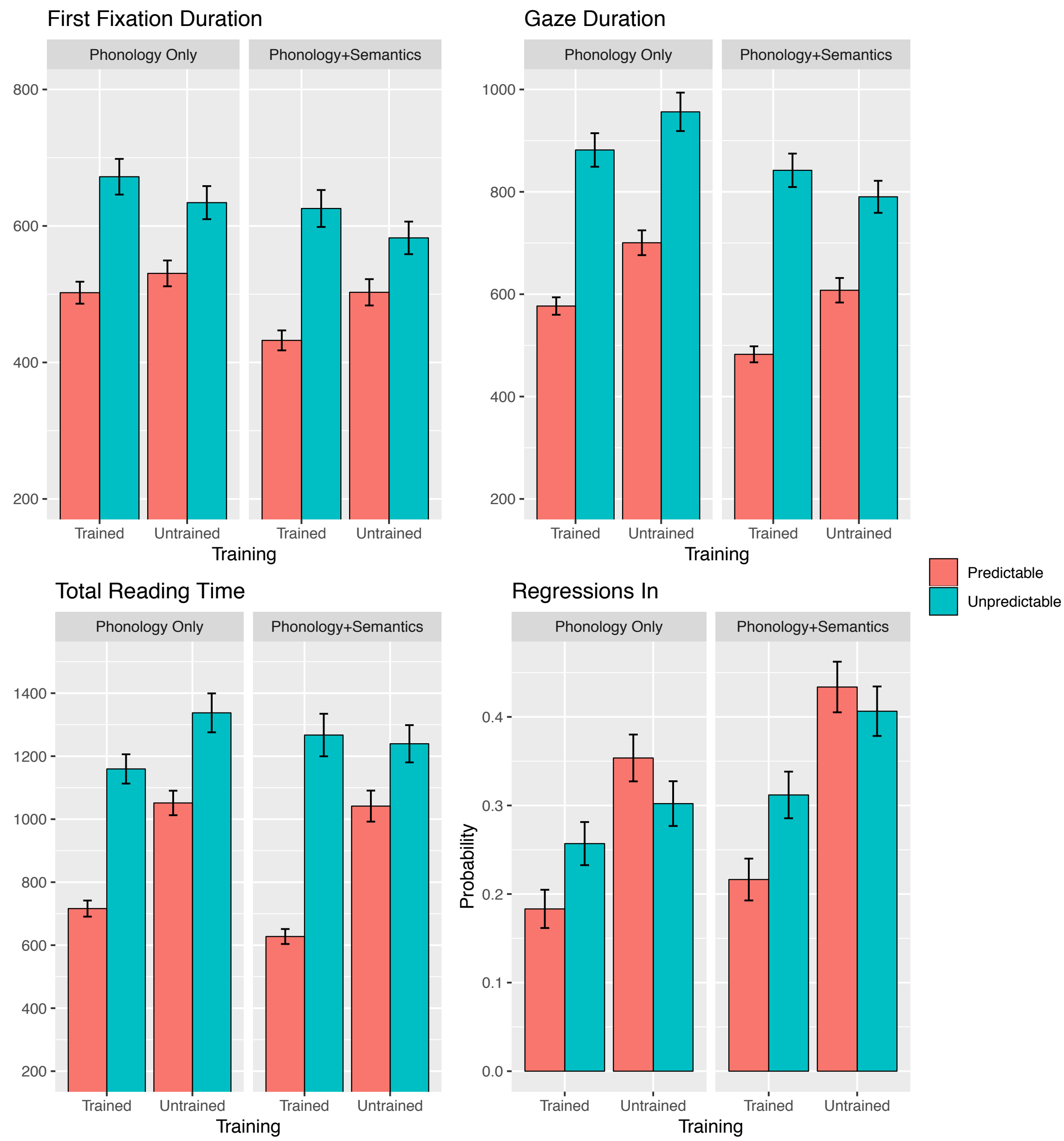

Figure B3. Arithmetic (untransformed) means and standard errors of eye movements in the target word interest area. First fixation duration, gaze duration and total reading time are expressed in milliseconds while regressions in reflects the likelihood of occurrence.

The model for first fixation duration revealed that the effect of spelling predictability was significant (β= -0.181, SE = 0.040, t = -4.512, p < 0.001), such that items with predictable spellings were fixated for a shorter period than items with unpredictable spellings. The effects of training (β= 0.003, SE = 0.025, t = -0.136, p =

0.892) and oral vocabulary training type (β= 0.091, *SE* = 0.058, *t* = 1.570, *p* = 0.120) were not significant. The two-way interactions between vocabulary type and training (β= 0.062, *SE* = 0.049, *t* = 1.265, *p* = 0.261) and between vocabulary type and spelling predictability (β= 0.016, *SE* = 0.059, *t* = 0.274 *p* = 0.785) were not significant, but the two way interaction between training and spelling predictability was significant (β= -0.119, *SE* = 0.049, *t* = -2.430, *p* = 0.015). Contrasts showed that the two-way interaction between training and spelling predictability was present for children in the phonology plus semantics condition (χ^2 = 5.210, *p* =0 .045) but not in the phonology only condition (χ^2 = 1.295, *p* = 0.255). The three way interaction between oral vocabulary type, training and spelling predictability (β= 0.083, *SE* = 0.098, *t* = -0.46, *p* = 0.398) was not significant, suggesting that the the interaction between training and spelling predictability did not significantly differ across the oral vocabulary training types.

The model for gaze duration revealed that each of the three fixed effects were significant. Specifically, the effect of spelling predictability (β= -0.354, *SE* = 0.052, *t* = -6.773, *p* < 0.001) indicated that items with predictable spellings were fixated for a shorter period than items with unpredictable spellings. The effect of training (β= -0.079, *SE* = 0.031, *t* = -2.573, *p* = 0.015) indicated that trained items were associated with shorter fixation durations than untrained items. The effect of oral vocabulary type (β= 0.156, *SE* = 0.057, *t* = 2.750, *p* = 0.007) suggested that when children were taught both pronunciations and meanings, fixation durations were shorter than when children were taught only pronunciations. The two-way interactions between vocabulary type and training (β= -0.028, *SE* = 0.044, *t* = -0.636, *p* = 0.525) and between vocabulary type and spelling predictability (β= 0.041, *SE* = 0.054, *t* = 0.772, *p* = 0.442) were not significant, but the two way interaction between training and spelling predictability was significant (β= -0.175, *SE* = 0.061, *t* = -2.867, *p* = 0.008). Interaction contrasts showed that the two-way interaction between training and spelling predictability was present for children in the phonology plus semantics condition ($\chi^2 = 10.604$, $p = 0.002$) but not in the phonology only condition ($\chi^2 = 1.903$, $p = 0.168$). However, the lack of three way interaction between oral vocabulary type, training and spelling predictability ($\beta = 0.145$, $SE = 0.088$, $t = 1.648$, $p = 0.099$) showed that the magnitude of the interaction between training and spelling predictability did not significantly differ across the oral vocabulary training types.

The model for total reading time revealed that two of the fixed effects were significant, whereas one was not. Specifically, the effect of spelling predictability was significant ($\beta = -0.374$, $SE = 0.043$, $t = -8.732$, $p < 0.001$), such that items with predictable spellings were fixated for a shorter period than items with unpredictable spellings. The effect of training ($\beta = -0.228$, $SE = 0.038$, $t = -6.023$, $p < 0.001$) was also significant such that trained items were fixated for shorter durations than untrained items. The effect of oral vocabulary type ($\beta = -0.078$, $SE = 0.073$, $t = -1.058$, $p = 0.293$) was not significant. The two-way interaction between vocabulary type and training ($\beta = -0.014$, $SE = 0.054$, $t = -0.264$, $p = 0.793$) was not significant. However, the two-way interaction between vocabulary type and spelling predictability ($\beta = -0.094$, $SE = 0.046$, $t = -2.043$, $p = 0.045$) was significant. Interaction contrasts showed that the two-way interaction between vocabulary type and spelling predictability was present for trained items ($\chi^2 = 9.266$, $p = 0.005$) but not for untrained items ($\chi^2 = 0.002$, $p = 0.968$). The two-way interaction between training and spelling predictability ($\beta = -0.345$, $SE = 0.066$, $t = -5.234$, $p < 0.001$) was again significant. Interaction contrasts showed that the two-way interaction between training and spelling predictability was present both for the children in the phonology plus semantics condition ($\chi^2 = 31.619$, $p < 0.001$) and for children in the phonology only condition ($\chi^2 = 11.066$, $p < 0.001$). The three-way interaction between vocabulary type, training and spelling predictability ($\beta = -0.182$, $SE = 0.079$, $t = -2.297$, $p = 0.022$) showed that the magnitude of the interaction between training and spelling predictability differed significantly across the vocabulary type conditions, with the two-way interaction being larger when children had been taught both phonology and semantics.

In the model reflecting the probability of regressions back to the target word, the effect of spelling predictability (β= -0.169, *SE* = 0.125, *t* = -1.348, *p* = 0.178) was not significant. However, the effect of vocabulary type (β= -0.368, *SE* = 0.177, *t* = -2.075, *p* = 0.038) was significant, such that when children were taught the pronunciations and meanings of novel words, they were more likely to reread the target words than when they had only been taught pronunciations. The effect of training (β= -0.717, *SE* = 0.111, *t* = -6.435, $p < 0.001$) was also significant such that children were less likely to reread items if they had received oral training. The two-way interactions between vocabulary type and training (β= 0.142, *SE* = 0.215, *t* = 0.662, *p* = 0.508) and between vocabulary type and spelling predictability (β= 0.095, *SE* = 0.186, *t* = 0.512, *p* = 0.609) were not significant. However, the two-way interaction between training and spelling predictability (β= -0.703, *SE* = 0.186, *t* = - -3.777, $p < 0.001$) was significant. Interaction contrasts showed that the two-way interaction between training and spelling predictability was present both for children in the phonology plus semantics condition (χ^2 = 6.5085, *p* = 0.011) and for children in the phonology only condition (χ^2 = 7.792, *p* = 0.011). To further unpack the two-way interaction between training and spelling predictability, we then conducted simple tests of training and spelling predictability collapsed across the oral vocabulary training type conditions. The effect of training was significant both for items with predictable (χ^2 = 0.256, $p < 0.001$) and unpredictable spellings (χ^2 = 0.410, *p* = 0.009); the effect of spelling predictability was significant for trained (χ^2 = 0.373, *p* = 0.003) but not untrained items (χ^2 = 0.546, *p* = 0.219). The lack of three-way interaction between oral vocabulary type, training and spelling predictability (β = -0.088, *SE* = 0.372, *t* = -0.236, *p* = 0.814) showed that the magnitude of the interaction between training and spelling predictability did not significantly differ across the vocabulary type conditions.

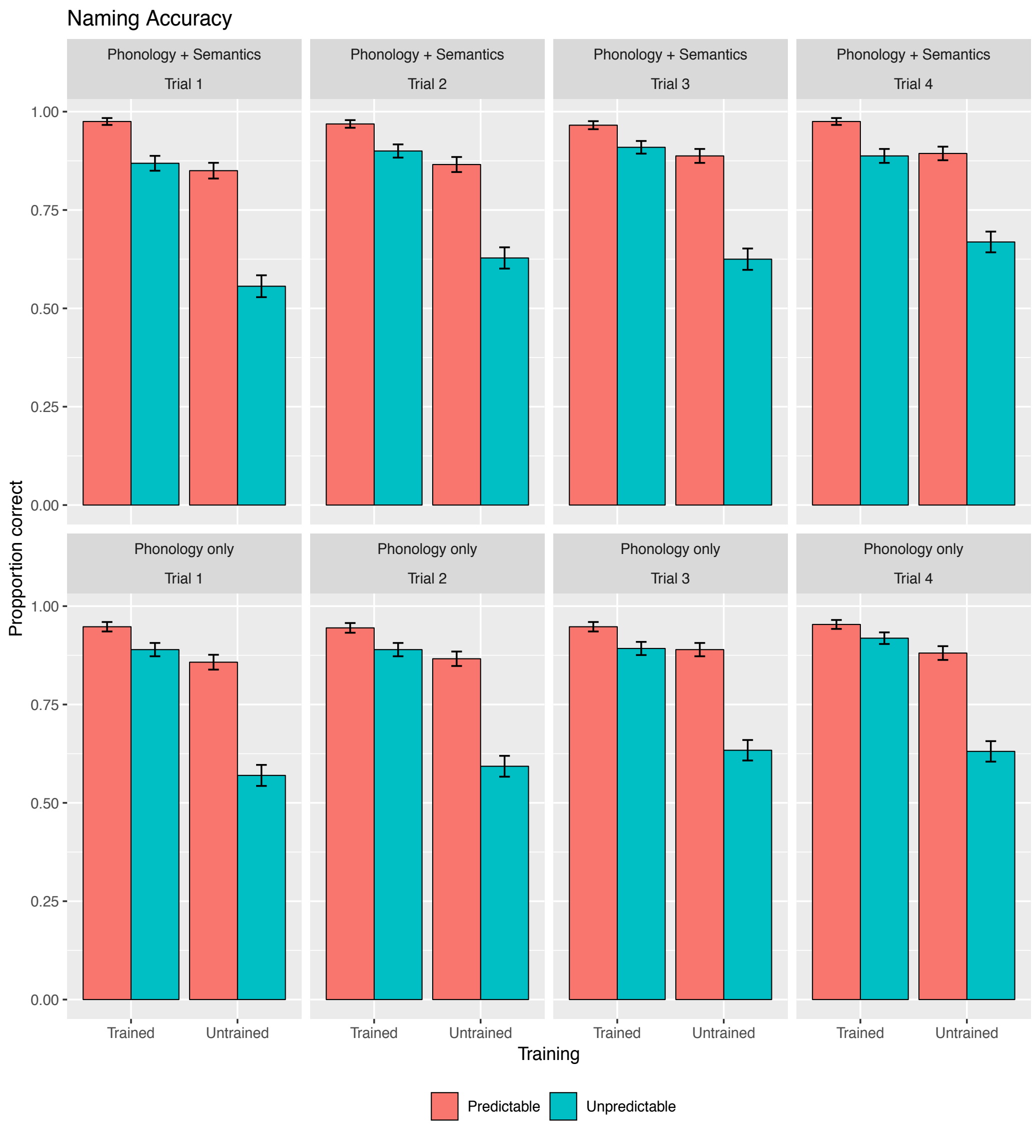

Figure B4. Means and standard errors of reading aloud accuracy, depicted as proportion correct.

Post-exposure tests of reading aloud and spelling

Linear mixed effects models were constructed using the lme4 package (Bates et al., 2015) to evaluate the children’s word reading accuracy, word reading latency and delayed spelling performance. All models included the fixed effects of vocabulary type (phonology plus semantics vs. phonology only), training (untrained vs. trained), spelling (unpredictable vs. predictable) and their interaction. In the two reading aloud models, the additional fixed effect of reading aloud *trial* and its interaction was entered. Because the fixed effect of reading aloud trial was ordered (from first to fourth reading aloud exposure), contrast coding was implemented for all fixed effects using the successive differences function from the *MASS* package (Ripley et al., 2019). This resulted in the implementation of three reading aloud trial contrasts that compared each trial with the preceding trial (2 vs. 1., 3 vs. 2, 4 vs. 3). We followed the same procedure for model selection and calculation of interaction contrasts as reported for the eye movement measures. The hierarchy of random effects models are presented in the Supplementary Material as Table SB2.

Reading aloud accuracy. Means and standard deviations of word reading accuracy appear in Figure B4. Due to the large number of comparisons in this model, here we focus on only the significant findings while referring the reader to Table B3 for a full list of model results. There was an overall effect of training (β = -2.466, SE = 0.323, z = -7.644, p < 0.001), with trained items more likely to be read accurately than untrained items. There was also an overall effect of spelling predictability (β = -1.742, SE = 0.400, z = -4.353, p < 0.001), with predictable spellings more likely to be read accurately than unpredictable spellings. The three-way interaction between oral vocabulary type, training and spelling predictability was also significant (β = 1.032, SE = 0.522, z = 1.977, p = 0.048). Interaction contrasts showed that the two-way interaction between training and spelling predictability was not present either for children who had been taught the pronunciation and meanings of the novel words (χ^2 = 0.459, p = 0.595), nor for children who had learned only the pronunciations (χ^2 = 0.523, p = 0.590). To further unpack the significant three-way interaction, we then conducted tests of the simple effects of training and spelling predictability separately for children who were taught under each of the two oral vocabulary training conditions. For children who had been taught the pronunciations and meanings, the effect of training was significant both for items with predictable (χ^2 = 26.092, p < 0.001) and unpredictable spellings (χ^2 = 26.965, p < 0.001); the effect of spelling predictability was also significant for both trained (χ^2 = 10.406, p = 0.003) and untrained items (χ^2 = 15.510, p < 0.001). For children who had been taught only pronunciations, there was a significant effect of training both for items with predictable ($\chi^2 = 16.821$, $p < 0.001$) and unpredictable spellings ($\chi^2 = 37.380$, $p < 0.001$); the effect of spelling predictability was significant for untrained items ($\chi^2 = 15.510$, $p < 0.001$) but not for trained items ($\chi^2 = 3.765$, $p = 0.052$). No other fixed effects or interactions were statistically significant.

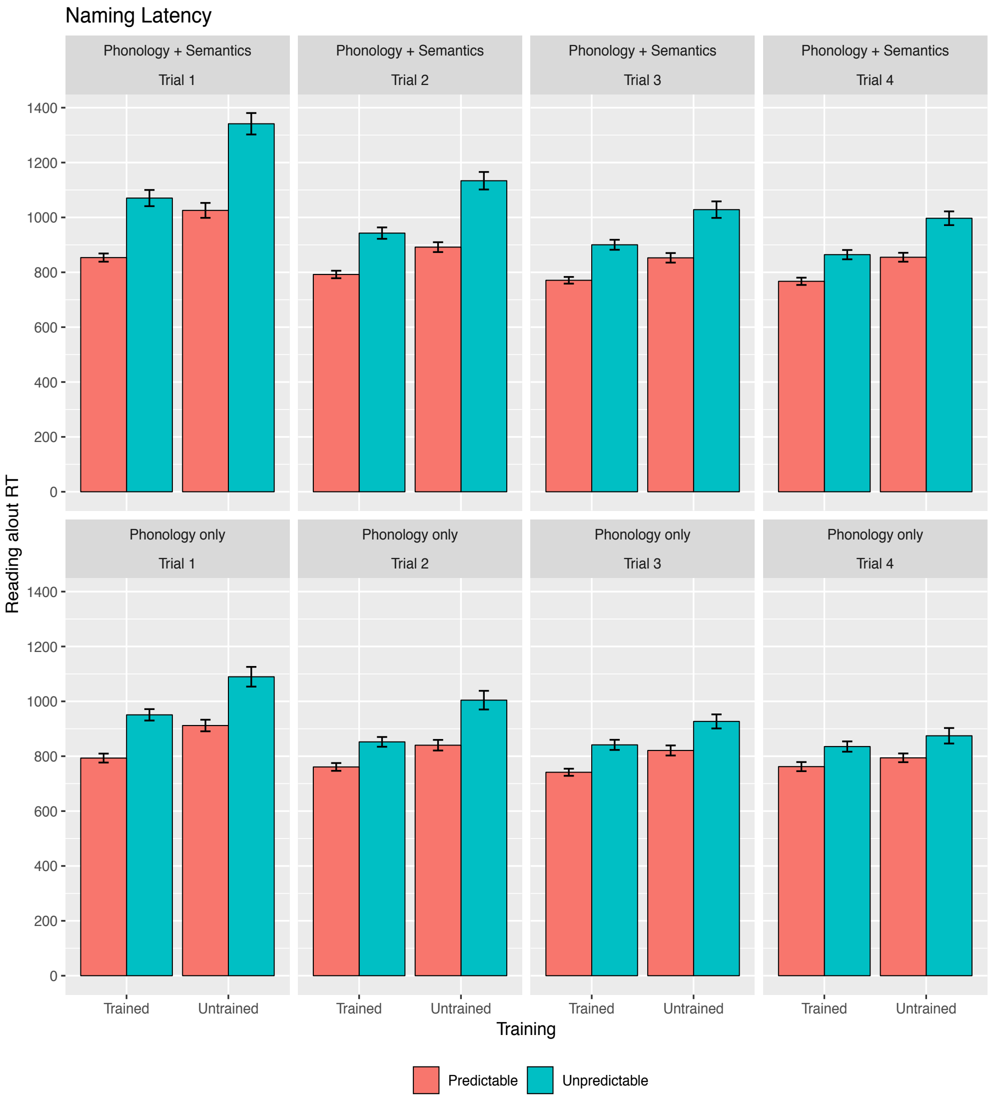

Figure B5. Arithmetic means and standard errors of reading aloud latency, reflecting time to the initiation of a verbal response, depicted in milliseconds.

Reading aloud latency. Only correct responses were included in this analysis. For ease of interpretation, arithmetic means and standard errors of reading aloud naming latency are presented graphically in Figure B5 but models are reported for log naming latency. Again due to the large number of comparisons in this model, here we focus on only the significant findings while referring the reader to Table B4 for a full list of model results. Naming latency reduced between trial 1 and 2 (β = -0.097, *SE* = 0.011, *t* = -9.023, *p* < 0.001), between trial 2 and 3 (β = -0.044, *SE* = 0.010, *t* = -4.640, p < 0.001) and between trial 3 and trial 4 (β = -0.017, *SE* = 0.008, *t* = -1.103, *p* = 0.038). There was a fixed effect of training (β = 0.153, SE = 0.020, *t* = 7.701, *p* < 0.001) such that children initiated a reading response to trained words more quickly than to untrained words. Predictable spellings were associated with a smaller naming latency than unpredictable spellings (β = 0.177, *SE* = 0.026, *t* = 6.865, *p* < 0.001). The two-way interaction between training and spelling predictability was significant (β = 0.089, *SE* = 0.033, *t* = 2.649, *p* = 0.013) such that the effect of spelling predictability was larger for untrained items than for trained items. Interaction contrasts showed that there was an effect of training for both predictable (χ^2 = 20.804, *p* < 0.001) and unpredictable spellings (χ^2 = 50.028, *p* < 0.001); there was also an effect of predictability for both trained (χ^2 = 33.051, *p* < 0.001) and untrained items (χ^2 = 35.931, *p* < 0.001). There was a two-way interaction between training and trial such that the benefit of training reduced between trial 1 and 2 (β = -0.035, *SE* = 0.015, *t* = -2.405, *p* = 0.016), and between trial 2 and 3 (β = -0.036, *SE* = 0.015, *t* = -2.507, *p* = 0.012). There was a two-way interaction between spelling predictability and trial such that the effect of spelling predictability reduced between trial 1 and 2 (β = -0.041, *SE* = 0.015, *t* = -2.809, *p* = 0.005), and between trial 3 and 4 (β = -0.029, *SE* = 0.014, *t* = -1.999, *p* = 0.046). No other fixed effects or interactions were statistically significant.

Delayed spelling accuracy. Means and standard deviations of immediate spelling accuracy are represented in Figure B6. A logistic linear mixed effects model was performed in which the dependent variable was delayed spelling accuracy. The model showed only a significant fixed effect of spelling predictability such that predictable items were more likely to be spelled accurately than unpredictable items (β = 4.541, *SE* = 0.343,

z = 13.234, p < 0.001). The fixed effects of training (β = 0.117, SE = 0.170, z = 0.686, p = 0.493) and vocabulary type were not significant (β = -0.119, SE = 0.201, z = -0.589, p = 0.556). The two-way interactions between training and spelling predictability (β = -0.490, SE = 0.343, z = -1.427, p = 0.154), between vocabulary type and training (β = 0.173, SE = 0.239, z = 0.728, p = 0.466) and between vocabulary type and spelling predictability (β = -0.548, SE = 0.382, z = -1.434, p = 0.151) were not significant; nor was the three-way interaction between vocabulary type, training and spelling predictability (β = -0.331, SE = 0.477, z = -0.694, p = 0.488).

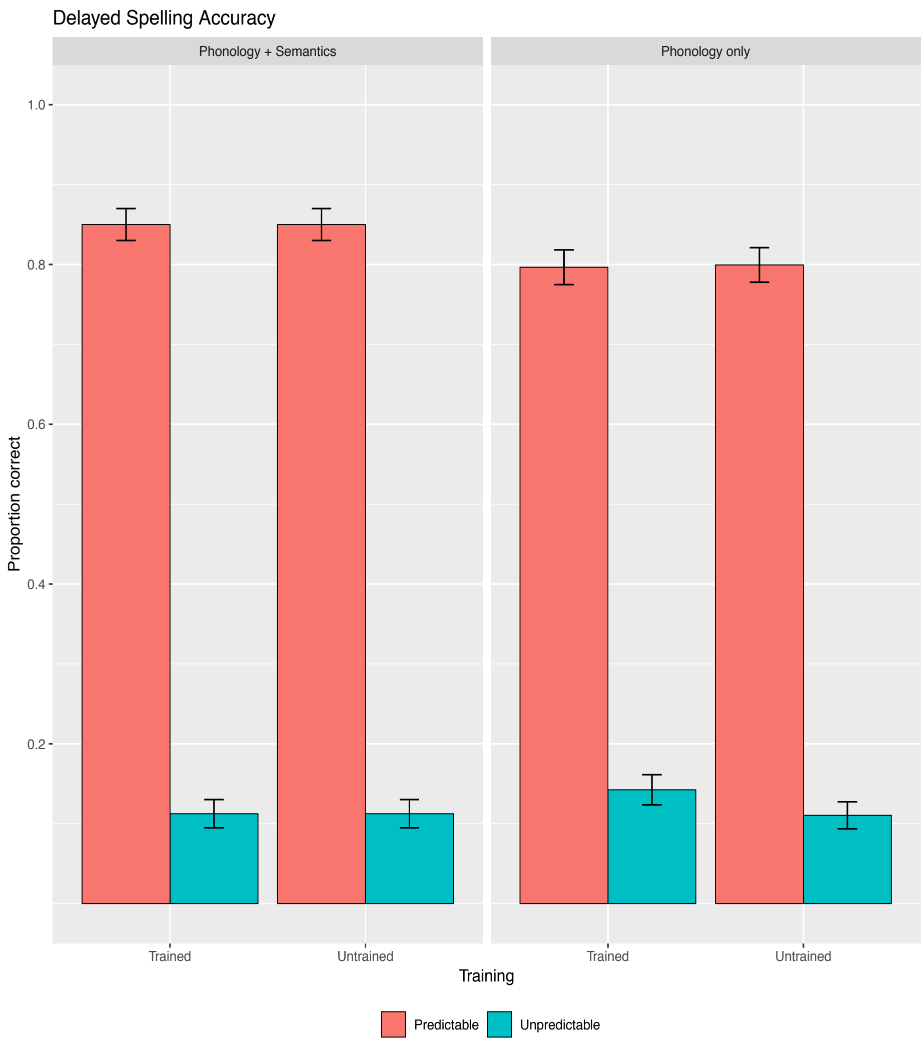

Figure B6. Means and standard errors of delayed spelling accuracy, depicted as proportion correct.

Table B3. *Results of the linear mixed effects model for reading aloud accuracy.*

		Training type	Training	Spelling predictability	Trial 2 vs. 1	Trial 3 vs. 2	Trial 4 vs. 3	
Main effects	*b*	0.096,	-2.466,	-1.742,	0.106,	0.109,	0.106,	
	SE	0.316,	0.323,	0.400,	0.104,	0.103,	0.107,	
	z	0.304,	-7.644,	-4.353,	1.026,	1.052,	0.996,	
	p	0.761	< 0.001*	< 0.001*	0.305	0.293	0.319	
		Training type x Training	Training type x Spelling	Training x Spelling	Training type x Trial 2 vs. 1	Training type x Trial 3 vs. 2	Training type x Trial 4 vs. 3	Training x Trial 2 vs. 1
Interactions	*b*	-0.305,	-0.454,	-0.144,	0.132,	-0.094,	-0.004,	0.184,
	SE	0.287,	0.352,	0.613,	0.207,	0.206,	0.214,	0.207,
	z	-1.064,	-1.289,	-0.235,	0.638,	-0.458,	-0.017,	0.888,
	p	0.287	0.197	0.814	0.524	0.647	0.987	0.375
		Training x Trial 3 vs. 2	Training x Trial 4 vs. 3	Spelling x Trial 2 vs. 1	Spelling x Trial 3 vs. 2	Spelling x Trial 4 vs. 3	Training type x training x spelling	Training type x training x Trial 2 vs. 1
Interactions	*b*	0.153,	-0.106,	0.259,	-0.013,	-0.042,	1.032,	0.068,
	SE	0.206,	0.214,	0.207,	0.206,	0.214,	0.522,	0.415,
	z	0.741,	-0.497,	1.247,	-0.064,	-0.198,	1.977,	0.164,
	p	0.459	0.619	0.213	0.949	0.843	0.048*	0.870
		Training type x training x Trial 3 vs. 2	Training type x training x Trial 4 vs. 3	Training type x spelling x Trial 2 vs. 1	Training type x spelling x Trial 3 vs. 2	Training type x spelling x Trial 4 vs. 3	Training x spelling x Trial 2 vs. 1	Training x spelling x Trial 3 vs. 2
Interactions	*b*	-0.098,	0.463,	0.398,	0.018,	-0.426,	-0.219,	-0.252,
	SE	0.413,	0.427,	0.415,	0.413,	0.427,	0.415,	0.413,
	z	-0.237,	1.085,	0.960,	0.044,	-0.998,	-0.529,	-0.610,
	p	0.813	0.278	0.337	0.965	0.318	0.597	0.542
		Training x spelling x Trial 3 vs. 4	Training type x training x spelling x Trial 2 vs. 1	Training type x training x spelling x Trial 3 vs. 2	Training type x training x spelling x Trial 4 vs. 3			
Interactions	*b*	0.352,	-0.399,	-0.531,	1.044,			
	SE	0.427,	0.829,	0.825,	0.854,			
	z	0.824,	-0.482,	-0.643,	1.223,			
	p	0.410	0.630	0.520	0.221			

Note. * denotes statistical significance

Table B4. *Results of the linear mixed effects model for log reading aloud latency.*

		Training type	Training	Spelling predictability	Trial 2 vs. 1	Trial 3 vs. 2	Trial 4 vs. 3	
Main effects	*b*	0.080,	0.153,	0.176,	-0.097,	-0.044,	-0.017,	
	SE	0.042,	0.020,	0.026,	0.011,	0.010,	0.008,	
	t	1.903,	7.701,	6.865,	-9.023,	-4.640,	-2.103,	
	p	0.061	< 0.001*	< 0.001*	< 0.001*	< 0.001*	0.038*	
		Training type x Training	Training type x Spelling	Training x Spelling	Training type x Trial 2 vs. 1	Training type x Trial 3 vs. 2	Training type x Trial 4 vs. 3	Training x Trial 2 vs. 1
Interactions	*b*	0.033,	0.036,	0.089,	-0.034,	-0.017,	0.003,	-0.035,
	SE	0.022,	0.022,	0.033,	0.021,	0.019,	0.016,	0.015,
	t	1.493,	1.616,	2.649,	-1.593,	-0.881,	0.204	-2.45,
	p	0.139	0.139	0.013*	0.115	0.381	0.839	0.016*
		Training x Trial 3 vs. 2	Training x Trial 4 vs. 3	Spelling x Trial 2 vs. 1	Spelling x Trial 3 vs. 2	Spelling x Trial 4 vs. 3	Training type x training x spelling	Training type x training x Trial 2 vs. 1
Interactions	*b*	-0.036,	-0.015,	-0.041,	-0.027,	-0.029,	0.020,	-0.033,
	SE	0.015,	0.014,	0.015,	0.015,	0.014,	0.026,	0.029,
	t	-2.507,	-1.025,	-2.809,	-1.999,	-1.999,	0.767,	-1.109,
	p	0.012*	0.306	0.005*	0.062	0.046*	0.445	0.267
		Training type x training x Trial 3 vs. 2	Training type x training x Trial 4 vs. 3	Training type x spelling x Trial 2 vs. 1	Training type x spelling x Trial 3 vs. 2	Training type x spelling x Trial 4 vs. 3	Training x spelling x Trial 2 vs. 1	Training x spelling x Trial 3 vs. 2
Interactions	*b*	-0.010,	0.047,	-0.005,	-0.012,	-0.003,	0.013,	-0.039,
	SE	0.029,	0.029,	0.029,	0.029,	0.029,	0.029,	0.029,
	t	-0.329,	1.646,	-0179,	-0.425,	-0.090,	0.435,	-1.359,
	p	0.742	0.100	0.858	0.670	0.929	0.664	0.174
		Training x spelling x Trial 3 vs. 4	Training type x training x spelling x Trial 2 vs. 1	Training type x training x spelling x Trial 3 vs. 2	Training type x training x spelling x Trial 4 vs. 3			
Interactions	*b*	-0.012,	-0.065,	0.010,	-0.004,			
	SE	0.029,	0.059,	0.058,	0.058,			
	t	-0.421,	-1.113,	0.268,	-0.073,			
	p	0.674	0.266	0.867	0.942			

Note. * denotes statistical significance

Discussion

This experiment investigated the roles of aspects of oral vocabulary knowledge – lexical phonology and semantics – within the process of the formation of children's spelling expectations. Replicating our previous findings (Wegener et al., 2018), when children had the benefit of both phonological and semantic information, a larger effect of spelling predictability for orally trained compared to untrained novel words was observed. This interaction was consistently present across the eye movement record from the first pass reading measures of first fixation duration and gaze duration to the later processing measure of total reading time. These results are consistent with the view that children had formed initial spelling expectancies on the basis of their spoken word knowledge, at least when the lexical entry included information about both pronunciation and meaning. Further, they lend weight to the proposal that theories of orthographic learning such as the self-teaching hypothesis (Share, 1995, 1999) and the lexical quality hypothesis (Perfetti, 1992; Perfetti & Hart, 2002) could be expanded to accommodate a complementary causal cognitive mechanism that allows oral vocabulary knowledge to benefit word reading prior to visual exposure via children's ability to translate from pronunciation to print.

Extending our previous work, even when children were taught only the phonological form of novel words, the effect of spelling predictability was numerically larger for orally trained compared to untrained items across all looking time measures. However, early and late measures of online processing revealed some nuance in this relationship. For the first pass reading measures of first fixation duration and gaze duration, although the interaction was in the expected direction, it did not reach significance. Interestingly though, the interaction was not statistically smaller than the corresponding interaction observed when semantic support was also present. This implies that these early measures of online processing may be capturing the formation of slightly weaker spelling expectancies than those that emerge with semantic support. Supporting this interpretation are findings from the late processing measure of total reading time. At this point in processing, the key interaction between training and spelling predictability was clearly present when children had learned only pronunciations, supporting the view that they had formed orthographic skeletons even without semantic support. However, the interaction was smaller when children had learned only pronunciations than when semantic information was also available, suggesting that semantic support may facilitate the generation of orthographic skeletons.

Taken together, findings from the looking time measures are consistent with the position that phonology is sufficient to give rise to orthographic skeletons, but semantic knowledge may convey some small further advantage within this process. One interpretation of this finding might attribute the small advantage to children's lexical semantic knowledge of the trained words. That is, when lexical phonology and lexical semantics are both present, these representations are of higher lexical quality than those that only include information about lexical phonology; this difference in lexical quality then gives rise to the observed differences in the strength of children's early orthographic expectancies. This interpretation is consistent with predictions arising from the lexical quality hypothesis (Perfetti, 1992; Perfetti & Hart, 2002), and with broader work suggesting a role of semantics in reading (Kearns & Al Ghanem, 2019; Ouellette & Fraser, 2009; Ricketts et al., 2016; Taylor, Duff, Woollams, Monaghan, & Ricketts, 2015). As alluded to previously, since the current study employed monosyllabic and monomorphemic stimuli, any such contribution from lexical semantics could not have acted directly on the formation of orthographic expectancies. Rather, a benefit arising from lexical semantics must contribute to the development of orthographic expectancies indirectly via connections between lexical semantics and lexical phonology. An alternative explanation might attribute the small advantage observed in the phonology plus semantics condition to the supportive role of context at the point of reading. On this view, orthographic skeletons are likely to be pre-activated when a constraining sentence context leads children to expect to see a word they learned about during training. Without the benefit of context, orthographic skeletons are less strongly activated initially so the effect is clearly observable only later in processing. It is certainly possible that contextual factors contributed to the current findings. We did not set out to disentangle these two possible interpretations but it will be important for future work to clarify whether the advantage observed here originates in lexical semantic knowledge or is the result of contextual facilitation or some combination of the two. An experiment in which children receive training in both the pronunciations and meanings of novel words prior to encountering them, along with untrained items, within contextually neutral sentences should shed light on this issue.

In line with our predictions, regardless of whether children had learned only pronunciations or pronunciations and meanings, we found that oral training was associated with a reduced probability of rereading. This is consistent with both our own prior findings and other work showing that novel words are more likely to be refixated than familiar words (Chaffin, Morris, & Seely, 2001; Taylor & Perfetti, 2016). However, two additional findings relating to the probability of rereading were unexpected. First, when children had been taught the spoken form of novel words, they were more likely to reread words with unpredictable spellings than those with predictable spellings. In contrast, when children had not been taught the spoken form of the novel words there was no difference in the probability of rereading according to the predictability of their spellings. The current findings imply that when children view an unexpected orthographic form for an orally familiar item, this might prompt more frequent rereading than encountering an expected orthographic form for an orally familiar word. The second unexpected finding concerned the influence of semantic information on the probability of rereading. Specifically, children were more likely to reread target words when semantic support was present than when it was absent. Again, while not an explicit prediction in the current experiment, in retrospect it seems reasonable. The processing and integration of meaning is one factor thought to influence rereading behaviour (Rayner, 1998) so the observation that rereading occurred more frequently when children had access to semantic information in the current experiment could be interpreted as aligning with this prior work.

Follow-up testing initially explored how well the children were able to establish orthography-to-phonology links over four reading aloud trials, both for words with and without oral pre-exposure. Consistent with predictions, oral training and predictable spellings conveyed a reading accuracy and latency advantage. An additional though unexpected finding for reading aloud latency indicated that the effect of spelling predictability was larger when items were *orally unfamiliar* than when items had been orally trained. This contrasts with the reading behaviour observed during the initial orthographic exposure: when items were *orally familiar* to children, their online processing was disproportionately affected by the spelling manipulation. Yet, when the children encountered the items again during the reading aloud task, latency data indicate that this interaction had reversed. This provides strong evidence that training benefited reading speed for all words regardless of whether their orthographic form was predictable or unpredictable on the basis of their phonology, and further suggests that the surprise afforded by misalignment of orthographic skeleton and its actual form can be resolved on subsequent reading measures. At the broadest level, these findings are consistent with other oral vocabulary training studies with children in showing that pre-existing spoken word knowledge boosts subsequent reading performance (Duff & Hulme, 2012; McKague et al., 2001).

The lexical semantic and contextual support provided to children during oral vocabulary learning and upon the first visual exposure did not exert a marked effect on either reading accuracy or latency on subsequent visual exposures. However, in the latency data there was a trend (p = 0.061) for items whose meanings had been taught to be read more *slowly* than items about which no semantic information was provided. The general absence of an effect of semantics in the reading aloud data contrasts with the pattern of results obtained during eye movement monitoring on the first visual exposure, which suggested a facilitatory role for semantics within the process of generating spelling expectancies of orally known words. Of course, the eye movement and reading aloud tasks have different properties and are encountered by children at different points in their learning. For example, during the initial orthographic exposure to the novel words both semantic and contextual support were available, which contrasts with the isolated presentation of target words that later occurs in the reading aloud task. This finding could therefore be interpreted as consistent with the notion that context, rather than lexical semantic knowledge, was driving the semantic benefit observed during the eye-tracking task. We have previously offered the view that context may serve to pre-activate orthographic skeletons online as children read. This explanation adopts the view that children had already formed skeletons during oral vocabulary training. An alternative possibility is that the orthographic expectancies were not generated during oral vocabulary training, but rather arose online as children read constraining sentences. Current data do not permit us to adjudicate between these accounts. However, a large body of existing data suggests that orthography penetrates spoken word processing (Chéreau et al., 2007; Pattamadilok et al., 2009, 2007; Taft et al., 2008; Ventura et al., 2008, 2007), which is more consistent with the notion that orthographic expectancies are generated automatically in response to spoken word forms rather than being driven by context during online reading.

Children were provided with multiple reading aloud exposures in order to provide them with some opportunity to acquire their orthographic form. Children received no corrective feedback during the reading aloud task, and consistent with our expectations, overall naming accuracy did not improve over trials but overall naming latency did.

Further, the reduction in reading aloud latency associated with oral familiarity was strongest at the first reading aloud trial, and weakened by the second and third trials. Similarly, the effect of spelling predictability on reading aloud latency was strongest at the first reading aloud trial, and weakened subsequently. Together, these findings for reading aloud latency suggest that visual experience with the target words gradually diminished the effects of our experimental manipulations, a finding that is consistent with view that visual encounters with novel words permits the incremental evolution of developing orthographic representations (Perfetti, 1992, 2007; Perfetti & Hart, 2002).

Since children had the opportunity to acquire the orthographic form of both trained and untrained items during multiple visual exposures, follow-up testing also explored children's delayed spelling performance. Consistent with predictions, items with spellings that were highly predictable from their pronunciations were spelled more accurately than those with spellings that were unpredictable from their pronunciations, and this effect was very large. However, contrary to predictions, children's spellings demonstrated no benefit of oral pre-exposure and no benefit of semantic support. Of note, children were able to retain a small proportion of the word-specific orthographic forms of the items with unusual spellings regardless of whether they had had pre-exposure to their spoken word form. While demonstrating that the repeated visual exposures resulted in at least some learning, the limited extent of this learning is striking and suggests that the task may simply have been too difficult. Indeed, children were not warned they would be tested on the spellings of the 32 invention names, and with half of these including unusual phoneme-to-grapheme correspondences, it would have been easy to confuse which unusual spelling went with which pronunciation, especially at a one week delay.

At present, we remain in the early stages of building an understanding of the novel cognitive mechanism that allows spoken word knowledge to influence reading prior to visual exposure. We have already highlighted a potential role for context which should be addressed in future work. A further issue concerns the form of the orthographic skeleton. In his lexical quality hypothesis, Perfetti (1992) proposes that early orthographic representations may take one of two forms: they might be partial representations constructed around a word's consonants; or they may be complete but transiently incorrect representations. Differentiating between these possibilities will have interesting implications for the development of instructional practices that might seek to improve children's literacy outcomes in part by building their capacity to form orthographic expectancies.

Conclusions

To conclude, the present study provides additional evidence consistent with the view that when children possess partial lexical knowledge about a word's pronunciation, with or without an associated meaning, they can use this information to generate expectations about the spellings of words they have heard before but never seen. These spelling expectancies are strongest when knowledge of word pronunciations is accompanied by semantic support from the lexical entry itself and from context during reading, suggesting that meaning may play a (likely indirect) role in facilitating their emergence. Although children's online processing showed evidence of disruption when viewing an unexpected orthographic form for a known spoken word, their subsequent reading aloud performance was boosted by oral familiarity regardless of the likely correspondence between the child's spelling expectation and the orthographic form at the first visual exposure, suggesting that orthographic expectations undergo a process of updating. However, there was no evidence for an ongoing role of semantic support in either children's reading aloud or delayed spelling performance leaving open the possibility that the semantic advantage observed at the initial orthographic exposure may have been at least partly driven by the supportive context in which they were read. Future work should attempt to directly address the roles of lexical semantic and contextual factors in the formation of the orthographic skeleton.

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Chapter 4

Partial or complete? The early form of orthographic expectancies

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This experiment was pre-registered with AsPredicted.org. Please see the Supplementary Materials section of this dissertation for further details.

Abstract

When children know a spoken word and understand phoneme-to-grapheme mappings, they form "orthographic skeletons", or expectations about the likely spellings of words they have previously heard but never seen (Wegener et al., 2018). Here, we asked whether skeletons are partial representations built around a word's consonants, or whether they are complete representations that may be transiently incorrect. Forty-one Grade 4 children received oral vocabulary training on one set of 18 novel words (e.g., "desh", "taff", "jorv") over four sessions, while another set were untrained. Spellings were either predictable from their phonology (e.g., *desh*), or included an unpredictable consonant (e.g., *taph)* or vowel (e.g., *jauv*). Orally trained and untrained items were subsequently shown in print for the first time, embedded in sentences, and children's eye movements were monitored. Trained items with predictable spellings were consistently fixated for shorter periods than untrained predictable spellings. Early processing measures (first fixation and gaze duration) showed that this benefit of oral training for predictable spellings was significantly larger than for both unpredictable consonant and unpredictable vowel spellings. Late in processing (total reading time), this pattern persisted only for unpredictable consonants. These results suggest that orthographic skeletons involve both consonants and vowels initially; with unpredictable vowel spellings possibly being more rapidly updated online than unpredictable consonant spellings. Children subsequently read and spelled trained words more accurately and read trained words more quickly than untrained words, suggesting that misalignment of the orthographic skeleton and its actual form can be resolved on later measures of orthographic processing.

Introduction

Evidence from cross-sectional (Nation & Cocksey, 2009; Nation & Snowling, 2004), longitudinal (Duff, Reen, Plunkett, & Nation, 2015; Lee, 2011) and training studies (Duff & Hulme, 2012; McKague, Pratt, & Johnston, 2001) converges on the view that children's oral vocabulary knowledge plays a causal role in reading development. That is, when a child possesses knowledge of a spoken word – its pronunciation with or without associated meaning – they are more likely to correctly read that word upon seeing it for the first time than another word that is similar but absent from their oral vocabulary. Since children enter school with a substantial number of known spoken words (Chall, 1987), there is potential to improve reading outcomes by leveraging the mechanism through which oral vocabulary knowledge supports reading acquisition. Yet comparatively little is known about the nature of the mechanism or mechanisms that underlie this association. We recently described and provided an initial demonstration of one such mechanism: children can draw on their knowledge of phoneme-to-grapheme correspondences to generate expectations of the spellings of known spoken words prior to viewing them in writing for the first time (Wegener et al., 2018). We called these initial spelling expectations *orthographic skeletons*. Here, we build on this work by describing the outcome of an experiment designed to investigate the form of the orthographic skeleton.

Oral vocabulary knowledge is generally thought of as assisting with *orthographic learning,* which refers to the process by which representations of written words are acquired (Castles & Nation, 2006; Nation & Castles, 2017). Mechanistic accounts of this association, however, diverge with respect to the proposed timing of the effect. Most theories view spoken word knowledge as providing assistance from the point a word is first seen in print. One such theory – the self-teaching hypothesis – holds that if a child's initial attempt to phonologically decode a newly encountered written word produces an unfamiliar pronunciation, the child may subsequently revise their decoding attempt in order to match it to a similar known pronunciation (Share, 1995, 2008). Consistent with this explanation, there is some evidence that the ability to resolve mismatches between two pronunciations may play a role in reading development (Dyson, Best, Solity, & Hulme, 2017; Elbro, de Jong, Houter, & Nielsen, 2012; Kearns, Rogers, Koriakin, & Al Ghanem, 2016; Savage, Georgiou, Parrila, & Maiorino, 2018; Tunmer & Chapman, 2012).

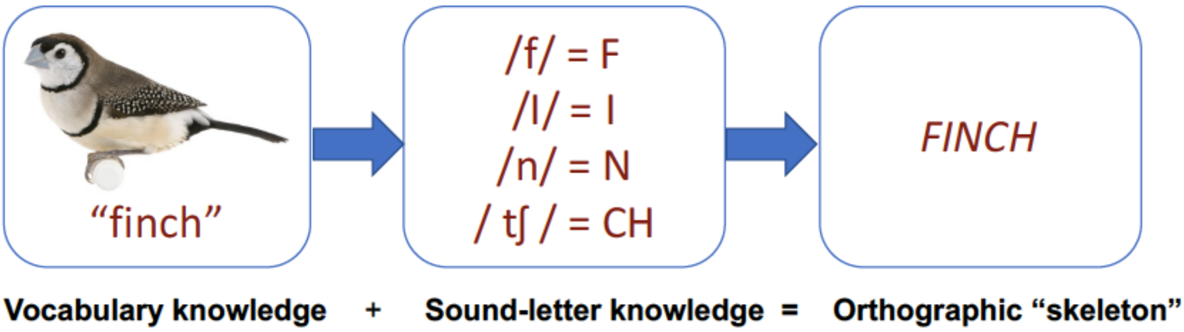

Figure C1. The orthographic skeleton hypothesis.

An alternative and potentially complementary view – the orthographic skeleton hypothesis (see Figure C1) – suggests that when oral vocabulary knowledge is accompanied by adequate knowledge of phoneme-to-grapheme correspondences, this can support reading acquisition *before* visual exposure by enabling children to generate initial expectations about the likely spellings of known spoken words. We tested this possibility for the first time with children in a novel word training study (Wegener et al., 2018). Following oral training on a set of novel words, children's eye movements were monitored as they read a series of simple sentences containing the items they had learned as well as the untrained items. Compared with untrained items, those that had received oral training and were shown in print with predictable spellings (e.g., the spoken word '*nesh*' written as *nesh*) were associated with shorter fixation durations, consistent with the notion that a match between the orthographic skeleton and the orthographic form facilitates online processing. Further, compared with untrained items, those that had received oral training but were presented with unpredictable spellings (e.g., the spoken word '*coib*' written as *koyb*) did not benefit from training, suggesting that the misalignment of the orthographic skeleton and the presented orthography takes time to resolve. Children's online processing of orally taught novel words therefore varied depending on the predictability of their spellings to a greater extent than orally untrained items, and this is in keeping with the operation of a causal mechanism that begins prior to visual exposure.

Our findings are consistent with evidence from skilled readers. For example, experiments employing a range of different experimental paradigms suggest that when adults listen to spoken words, this results in the automatic activation of orthographic information (Chéreau, Gaskell, & Dumay, 2007; Pattamadilok, Morais, De Vylder, Ventura, & Kolinsky, 2009; Pattamadilok, Morais, Ventura, & Kolinsky, 2007; Taft, 2011; Taft, Castles, Davis, Lazendic, & Nguyen-Hoan, 2008; Ziegler & Ferrand, 1998). Of particular interest are findings from McKague, Davis, Pratt and Johnson (2008), who taught adult participants the pronunciations and meanings of a set of novel words prior to presenting those words in print for the first time. The spelling consistency of the written words was manipulated such that items varied in the degree to which their spellings were predictable from pronunciations (Stone, Vanhoy, & Van Orden, 1997). Participants' visual word recognition was disrupted when spellings were inconsistent, suggesting that knowledge of pronunciations may have allowed participants to form an early orthographic representation.

While our findings suggest that children do generate orthographic skeletons of known spoken words, much remains to be learned about this novel mechanism. We coined the term 'orthographic skeletons' to denote our assumption that the spelling expectations children form on the basis of their oral vocabulary knowledge are not yet likely to have the properties of well-established orthographic representations. This statement raises the question of precisely what form these less than well-established orthographic representations might take.

The lexical quality hypothesis (Perfetti, 1992, 2007; Perfetti & Hart, 2002) proposes two alternative possibilities that could describe the form of early orthographic representations. Perfetti (1992) contrasted precise orthographic representations, which encode an exact spelling, with *variable* lexical representations. Variable lexical representations were described as imprecise because they include *free* variables in locations where fully specified representations include specific letters. These free variables reflect imprecision and may occur within early orthographic representations either because their spellings are partial and therefore *incomplete* or because they are complete but *transiently incorrect* (i.e., future reading experience might allow the child to either fill in one or more missing graphemes, or correct one or more erroneous graphemes).

One aspect of representational change that is thought to occur with experience concerns the consonant/vowel structure of the orthographic form. Specifically, Perfetti (1992) argues that early imprecision is most likely to be located within the vowel, because children tend to make more errors when reading aloud vowels. Indeed, the pronunciation of consonants have been referred to as “islands of reliability” in visual word recognition (Carr & Pollatsek, 1985, p. 36), while lexical statistics support this position by showing that grapheme-to-phoneme correspondences for English consonants are more reliable than for vowels (Kessler & Treiman, 2001). Masked priming work is also consistent with there being distinct representations of the consonant/vowel structure of orthographic representations, which can be extracted at an early prelexical stage (Chetail, Drabs, & Content, 2014; Chetail, Treiman, & Content, 2016).

But the orthographic skeleton hypothesis argues for a mechanism that operates in the reverse direction – from pronunciation to print – so arguably the reliability of phoneme-to-grapheme correspondences as used in spelling are of greater relevance in the operation of this causal mechanism. Here too, there tends to be a strong advantage for consonants. In an investigation of the consistency of English monosyllable spellings, Kessler and Trieman (2001) found that, regardless of whether a consonant is located at the onset (0.91) or coda (0.82), they have a higher degree of spelling predictability than vowels (0.53). Consistent with these lexical statistics, work with English speaking children suggests that more spelling errors are made with vowels than consonants (Treiman, 1993; Treiman, Berch, & Weatherston, 1993). Since consonants and vowels differ with respect to the predictability of their spellings, this might influence the initial form of the orthographic skeleton.

Building on the lexical quality hypothesis (Perfetti, 1992), one possibility is that children's orthographic expectancies begin as partial representations built around a word's consonants. Were this to be the case, then a known spoken word should initially include representations of the consonants, whereas the vowels would remain as free – or unspecified – variables until visual exposure. The reader is referred to Table C1 for examples of partial skeletons a child may generate on the basis of their spoken word knowledge. On this view, if a child knows a spoken word and is subsequently shown the orthographic form in print for the first time, they should be surprised if that form contains an unexpected *consonant* spelling because it conflicts with their expectation. In contrast, when the form contains an unexpected *vowel* spelling, the child should not be surprised because the vowel is not specified within their orthographic expectancy. In this case, visual exposure presumably provides an opportunity for the unspecified vowel information to be filled in, potentially without any additional cost associated with resolving misalignment between the expectancy and the form experienced in print.

To our knowledge, the possibility that early orthographic representations arising as a result of phonology-to-orthography connections might be partial and built around a word's consonants has not yet been tested with children. However, some initial evidence from skilled readers is consistent with this proposition. In another condition of the experiment conducted by McKague, Davis, Pratt and Johnson (2008), adults were taught the pronunciations and meanings of novel words. Participants were subsequently shown the written words for the first time in the context of a masked priming task. There was no disruption to visual word recognition when words contained unpredictable vowel spellings whereas disruption was obvious in the presence of an unexpected consonant spelling, consistent with the idea that early orthographic representations may be built around a word's consonants.

Table C1.

Examples of the possible form of early orthographic skeletons

Spoken word	Spelling	Partial skeleton	Complete skeleton
"porch"	Predictable vowel	p**ch	*porch*
"haunt"	Unpredictable vowel	h**nt	*hornt*
"chaff"	Predictable consonant	ch*ff	*chaff*
"graph"	Unpredictable consonant	gr*ff	*graff*

Note. The presence of an asterisk denotes an as yet unspecified letter.

An alternative possibility is that the orthographic skeleton may actually be a complete but potentially transiently incorrect representation of a word's spelling. On this view, an orthographic expectancy would include representations of both a word's consonants and vowels. As such, the expectancy could be the correct spelling, or it could take an incorrect form. The reader is referred to Table C1 for examples of complete skeletons a child may generate on the basis of their spoken word knowledge. Were it the case that orthographic expectancies are tentative but complete, then it would be predicted that a child should find any unexpected spelling surprising, regardless of its status as a consonant or vowel. This is because the requirement to resolve *any* conflict arising from misalignment between the orthographic skeleton and the actual orthographic form should be associated with a processing cost.

These two scenarios therefore give rise to different predictions about the likely processing that occurs at the first visual exposure. But what happens next? In the case that the early orthographic expectancy is partial and built around a word's consonants, then a visual encounter with the novel word will permit the vowel information to begin to be filled in. In the case that the initial orthographic skeleton includes representations of both consonants and vowels, then when a child sees the actual orthographic form, their expectancy is either confirmed when it matches the orthography, or is disconfirmed when it does not. In either case, the encounter with the novel written form permits the child to begin to update their initial spelling expectancy, which presumably renders the child's emerging orthographic representation closer to precision. Therefore, subsequent encounters with the orthographic form should show diminishing evidence of the processing cost associated with unexpected spellings of orally familiar items.

The current experiment

The current experiment investigated the form of the early spelling expectancies children generate on the basis of their oral vocabulary knowledge. In our original demonstration of the effect, the location of the spelling unpredictability was variable: sometimes it was located in the vowel position; sometimes in a consonant position; and sometimes in both. Here, we sought to differentiate the influence of spelling unpredictability arising from either the consonant or vowel. In line with the method we previously employed, Year 4 children received oral vocabulary training on of a set of novel words while they received no training on a second set (e.g., 'desh', 'taff', 'jorv'). All items, both trained and untrained, were then presented to children in written form for the first time in the context of a sentence reading task and their eye movements were monitored as they read silently. The spelling predictability of the novel words was manipulated such that a third of the items in each set had spellings that were highly predictable from phonology and therefore consistent with children's likely orthographic expectation (e.g., *desh*). The remaining two thirds of the items had spellings that were unpredictable from phonology and therefore inconsistent with children's likely expectations. The unpredictable spellings were allocated to two conditions: the unpredictability arose from the consonant (e.g., *taph*) in one condition, and from the vowel (e.g., *jauv*) in the other.

A key marker of the orthographic skeleton effect (Wegener et al., 2018) is facilitation of processing when the orthographic expectancy and the orthographic form actually seen in writing are congruent with each other. This is the case when spellings are predictable from their pronunciations. But what might happen when items are presented with spellings that contain an unpredictable phoneme-to-grapheme correspondence in a consonant or vowel position? Consonants are generally assumed to be present within early orthographic representations. Therefore, if spelling unpredictability arises from a consonant in the current experiment, this should create a surprise because it conflicts with children's orthographic expectancy. The effect of this conflict is a processing cost which should greatly reduce or remove any benefit associated with oral familiarity for these items. Thus, both accounts agree that predictable spellings should benefit from oral familiarity whereas this effect should be much smaller when items contain unpredictable consonant spellings. In other words, they should interact.

Whether vowels are also present in early orthographic representations is currently unclear. The partial account anticipates that because vowel representations are absent, they should be able to be rapidly filled in as a consequence of visual experience, suggesting that oral familiarity may still convey a benefit when items contain an unpredictable vowel spelling. The complete account anticipates that the vowel is present within the early representation, thereby permitting it to conflict with the orthographic expectancy in the event that the spelling contains an unpredictable vowel. Thus, only the complete account anticipates that the presence of an unpredictable vowel spelling should substantially reduce or remove any benefit of oral familiarity relative to items that have predictable spellings.

The two key tests relevant for disentangling these interpretations are interactions.

Specifically, does training interact with spelling: (a) when predictable spellings are compared with unpredictable consonant spellings; and/or (b) when predictable spellings are compared with unpredictable vowel spellings? If only (a) is observed, this would support the view that early orthographic expectancies are partial and built around a word's consonants. If on the other hand, both (a) and (b) are observed, this would support the view that early orthographic expectancies are tentative but complete representations.

Of secondary interest in the current experiment is the effect of our manipulations on the probability of rereading. Consistent with our previous findings and others suggesting that novel words are associated with a greater probability of rereading (Chaffin, Morris, & Seely, 2001), we expected that untrained items would be more likely to be refixated than trained items. Because all items had regular pronunciations, we did not anticipate observing either of the interactions between training and spelling predictability described above.

Follow-up testing was also conducted to investigate the effects of our manipulations on the children's ongoing reading and orthographic learning performance. Immediately following the initial orthographic exposure children read aloud and spelled all items, both trained and untrained. At a mean delay of approximately five days, children were required to spell all items again. It was anticipated that trained items would be read aloud more accurately and quickly, and spelled more accurately than untrained items. Further, it was anticipated that items with predictable spellings would be read more accurately and quickly, and spelled more accurately than items with either unpredictable consonant or unpredictable vowel spellings. Finally, we had no clear predictions about the presence or absence of interactions between training and spelling so we planned to explore these.

Method

Participants

A total of 42 children in Year 4 were recruited from a primary school in the metropolitan region of Sydney, Australia. No child who returned a consent form was excluded. Of the 42 recruited children, one was unable to be calibrated so we report data for the remaining 41 participants. Children were drawn from two (n = 22; n = 19) parallel mainstream classes (20 female; mean age: 9y;4m; range: 8y;10m -10y;5m). There was no significant difference in the ages of children from each of the two classes (class 1: $M = 112$ months; class 2: $M = 111$ months; $t(39) = 0.318$, $p = 0.7525$). The sample size was informed by previous investigations of orthographic learning (e.g., Wang et al., 2011; Share, 2004) and by our own prior work in which the basic orthographic skeleton effect was first demonstrated (Wegener et al., 2018).

Table C2.

Children's performance on standardized tests of spelling and vocabulary.

	M	SD	Min	Max
Spelling (DiST)				
Nonwords [a]	-0.14	0.90	-2.37	2.29
Irregular [a]	-0.47	1.26	-2.50	2.30
Oral Vocabulary (ACE)[b]	9.27	3.05	4.00	17.00

Note: DiST*, Diagnostic Spelling Test; ACE, Assessment of Comprehension and Expression 6-11.* [a] *Grade-based z scores (M = 0, SD = 1);* [b] *Age scaled score (M = 10, SD = 3).*

Standardized tests

Standardized measures of spelling and oral vocabulary were administered to characterize the sample. Irregular word and nonword spelling were assessed at a class level using the Diagnostic Spelling Test (Kohnen, Colenbrander, Krajenbrink & Nickels, 2015). Oral vocabulary knowledge was assessed with each child individually using the Naming subtest from the Assessment of Comprehension and Expression 6-11 (Adams, Cooke, Crutchley, Hesketh & Reeves, 2001). Summary data are presented in Table C2 and show that mean performance was within the average range across both measures.

Table C3.

Experimental target words.

	Set 1		Set 2	
	Phonology	Orthography	Phonology	Orthography
Predictable Items	/plɛv/	plev	/blIt/	blit
	/brIb/	brib	/snIg/	snig
	/smæg/	smag	/prʌp/	prup
	/dʒIʃ/	jish	/dɛʃ/	desh
	/ʃɛn/	shen	/tʃɒb/	chob
	/θʌb/	thub	/ʃæb/	shab
Unpredictable vowel spelling	/mɔɪp/	moyp	/lɑːb/	lahb
	/ləʊt/	loht	/dʒʊəv/	jauv
	/dɔːt/	dawt	/veIb/	vayb
	/vɜːm/	vurm	/jɛd/	yehd
	/tʃIv/	chyv	/θId/	thyd
	/juːm/	yewm	/mɜːb/	mirb
Unpredictable consonant spelling	/pɒk/	pocc	/vIk/	vikk
	/ræb/	rhab	/nɛn/	gnen
	/nId/	knid	/gʌb/	ghub
	/tɛzz/	tezz	/pʌm/	pumb
	/væm/	vamn	/tæf/	taph
	/wɛp/	whep	/rɒg/	wrog

Experimental materials

Two sets of 18 four-letter monosyllabic nonwords were constructed. Within each set, one third of the items were assigned spellings containing frequent phoneme to grapheme mappings (e.g., /s/ written as ‘s’) and were therefore highly predictable from their phonology. Another third of the items were assigned spellings in which the vowel was unpredictable because it was represented by a less common phoneme to grapheme mapping (e.g., /ɔː/ written as ‘au’ rather than the more common spelling ‘or’). The final third of the items were assigned spellings in which one consonant was unpredictable because it was represented by a less common phoneme to grapheme mapping (e.g., /f/ written as ‘ph’ rather than the more common spelling ‘f’). The unpredictable consonant spelling was located at the onset in half the items and in the coda position for the other half. Pilot testing confirmed the efficacy of the manipulation. Although the items varied in their spelling predictability, all items were regular for reading. That is, the correct pronunciations of all items employed the most common grapheme to phoneme mappings. The manner in which spelling predictability was manipulated meant that items could not be matched for number of phonemes (predictable spellings = 3.5, unpredictable consonant spellings = 3, unpredictable vowel spellings = 3) or bigram frequencies (predictable spellings > unpredictable consonant spellings > unpredictable vowel spellings), but these features are matched across item sets. A full list of items and their pronunciations appears in Table C3.

Procedure

Oral vocabulary training phase. Oral training was provided to each group of children, with information provided about both the phonology and semantics of one set of 18 nonwords at a class level, while the second set of items served as untrained items for that class. Item sets were counterbalanced across classes. The procedure was the same as that used by Wegener et al (2018). Following Wang and colleagues (Wang, Castles, Nickels & Nation, 2011), the children were informed that they would be learning about “Professor Parsnip’s Inventions”, and were shown picture referents paired with each invention name (additional pictures from Mimeau, Deacon, & Ricketts, 2018). The pronunciation of the invention was provided, along with a description of its appearance and function. For example, as shown in Figure C2, children learned that the “shab” is used for “polishing flowers” and that it “is has bristles and is electric”. Children were provided with opportunities to listen to and produce the invention names, and were instructed to attempt to learn both the name and function. The orthography of the invention names was never shown during this phase.

On four separate days children completed training sessions of approximately 20-

minutes duration. In the first session, nine inventions (three from each spelling predictability condition) were introduced; in the second session, the remaining nine inventions were introduced. During the third and fourth sessions, all 18 inventions were practiced. If a child was absent or missed a training session for any other reason, a catch-up training session was provided upon their return.

Figure C2. A sample invention: the "shab" is used for polishing flowers.

Learning check. Testing occurred between one and seven days after children's final oral vocabulary training session (M = 2.34; SD = 1.25). The mean delay for each class between training and testing did not differ significantly, $t(39) = 0.367$, $p = 0.716$ (class 1 = 2.40; class 2 = 2.26). The children's oral vocabulary learning was assessed individually using a picture-naming task. Children were asked to name pictures of the inventions and state their function. In order to ensure control over the number of phonological exposures to the invention names and functions, feedback was provided following every response, whether correct or incorrect.

Initial Orthographic Exposure. Immediately following the oral vocabulary learning check, children were exposed to the orthographic form of the invention names for the first time. The children silently read interleaved sentences referring to the 18 inventions they had learned about, the 18 inventions they had not learned about, and an additional four pairs of filler sentences that included novel words not previously encountered by either group.

A simple sentence frame was constructed for each pair of target nonwords, and were designed to provide contextual information relevant to the inventions learned by the children. An example is provided in sentences 1a and 1b (target words were not italicized during the experiment).

a. Pam put the dirty flowers under the *shab* to polish them.

b. Pam put the dirty flowers under the *thub* to polish them.

The children's eye movements were recorded using a remote Eyelink 1000 eye tracker (SR Research; Mississauga, Canada) sampling at 500Hz as they read sentences at a viewing distance of approximately 65cm. Each character subtended approximately 0.36 degrees of horizontal visual angle. Sentences were written 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, followed by three practice trials, and then the experimental sentences. The experimenter triggered the beginning and end of each trial when the participant looked at a fixation cross to indicate their readiness. To promote attention to task, children answered a (yes/no) question after each trial.

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 orthographic exposure: Reading aloud. Immediately following the initial orthographic exposure, children completed a reading aloud task in order to evaluate the accuracy and speed with which children could link the orthographic form of the inventions with their phonology. Children were asked to read aloud all invention names, both trained and untrained, as accurately and rapidly as possible. Words were presented in an interleaved 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 accuracy was cross-checked with hand scoring.

Post orthographic exposure: Immediate spelling and delayed spelling. To assess whether children had been able to learn and retain the fully specified orthographic forms of inventions, two spelling tasks were administered in which participants were asked to spell the invention names, both trained and untrained, to dictation. The children were told that they would be asked to spell all of the inventions they had read about while completing the eye-tracking task, both those they had learned about orally in class as well as those the other class had learned. Items were presented in a blocked fashion, with inventions the children had learned about orally being presented first, while inventions learned by the other class were presented next. Children were asked to try to spell the invention names in exactly the same way as they had seen them during the eye-tracking task. Responses were recorded as correct or incorrect. The first spelling task took place immediately following the orthographic exposure, and was therefore administered to each child individually. The second spelling test was conducted at a whole class level at a mean delay of 5.68 days (range 1 to 7) following the orthographic exposure. The length of the delay did not differ between classes ($t(38) = -0.746$, $p = 0.460$). One child was absent for the delayed spelling test so data are reported for 40 participants.

Results

Learning check: Picture naming

Participants correctly recalled a mean of 12 of the 18 orally trained invention names (*SD* = 4.66). The difference in recall between participants who learned set 1 (*M* = 12.86, *SD* = 4.68) and set 2 (*M* = 11.00, *SD* = 4.55) was not significant ($t(39) = 1.290$, $p = 0.21$). The difference in recall for items with predictable spellings (*M* = 3.78, *SD* = 1.917), unpredictable consonant spellings (*M* = 4.00, *SD* = 1.746), and unpredictable vowel spellings (*M* = 4.20, *SD* = 1.662) was not significant ($F(2,38) = 0.742$, $p = 0.479$).

Eye movements

Data were analysed in the R computing environment (R Core Development Team, 2019). Linear mixed effects models were constructed using the lme4 package (Bates, Maechler, Bolker, & Walker, 2019). In line with the basic effect upon which the current experiment builds (Wegener et al., 2018), reading time data were log transformed to improve the distributions of model residuals. This approach is also consistent with other recent eye movement work (Joseph & Nation, 2018; Taylor & Perfetti, 2016). Visual inspection of model residuals identified one large outlier; models were recalculated following its removal and these are reported below.

Models were run for each of the dependent variables of interest: first fixation duration, gaze duration, total reading time and regressions in. For the purpose of analysis, the area of interest was the invention name, or target word. If any of the three prespecified interest areas – target word, pre-target text, post-target text – were skipped during first pass reading, the trial was removed prior to analysis (13.1% of the experimental data).

Training (trained vs. untrained), spelling (unpredictable consonant vs. predictable vs. unpredictable vowel) and their interaction were entered as fixed effects while participants and items were entered as random effects. Fitting models with the full random effects structure (which included random intercepts and slopes for subjects and items) resulted in issues with singularity and nonconvergence, suggesting that the models were over parameterized (Baayen, Davidson, & Bates, 2008). We therefore built models from the simplest to the most complex random effects structure and selected the highest nonsingular converging models. The hierarchy of random effects models are presented in the Supplementary Materials as Table SC1.

Once the optimal random effects structure was determined, we tested only our specific pre-registered hypotheses (see Supplemental Material). For the looking time measures (first fixation duration, gaze duration and total reading time) there were two key questions. The first question was whether training and spelling predictability would interact when predictable spellings were compared with unpredictable consonant spellings. The second question was whether training and spelling predictability would interact when predictable spellings were compared with unpredictable vowel spellings. For the measure reflecting probability of return fixations on the target word (regressions in), there were three key questions. First, whether there was a fixed effect of training such that orally untrained items were more likely to be refixated than orally unfamiliar items. The second and third questions pertained to whether there was evidence of the two interactions between training and spelling as previously specified. These planned analyses were implemented using custom contrasts in the *lsmeans* package (Lenth, 2018) and applying the Holm-Bonferroni correction for multiple comparisons. When an interaction was significant, the *phia* package (De Rosario-Martinez, 2015) was employed to test the simple effect of training at each level of spelling. For ease of interpretation, arithmetic means and standard errors for each of the dependent variables appear in Figure C3.

The models for first fixation duration and gaze duration revealed that the interaction between training and spelling was significant both when predictable spellings were compared with unpredictable consonant spellings (first fixation duration: $\beta = -0.130$, $SE = 0.044$, $t = 2.973$, $p = 0.006$; gaze duration: $\beta = -0.150$, $SE = 0.043$, $t = 3.477$, $p =$

0.003) and when predictable spellings were compared with unpredictable vowel spellings (first fixation duration: β = - 0.148, *SE* = 0.044, *t* = 3.343, *p* = 0.004; gaze duration: β = - 0.127, *SE* = 0.043, *t* = 2.921, *p* = 0.006). Interaction contrasts showed that items with predictable spellings benefited from training (first fixation duration: $\chi^2 = 19.184$, $p < 0.001$; gaze duration: $\chi^2 = 23.146$, $p < 0.001$), whereas items with unpredictable consonant spellings (first fixation duration: $\chi^2 = 0.078$, $p = 1.000$; gaze duration: $\chi^2 < 0.001$, p = 0.988) and unpredictable vowel spellings (first fixation duration: $\chi^2 = 0.082$, $p = 1.000$; gaze duration: $\chi^2 = 0.567$, $p = 0.903$) did not.

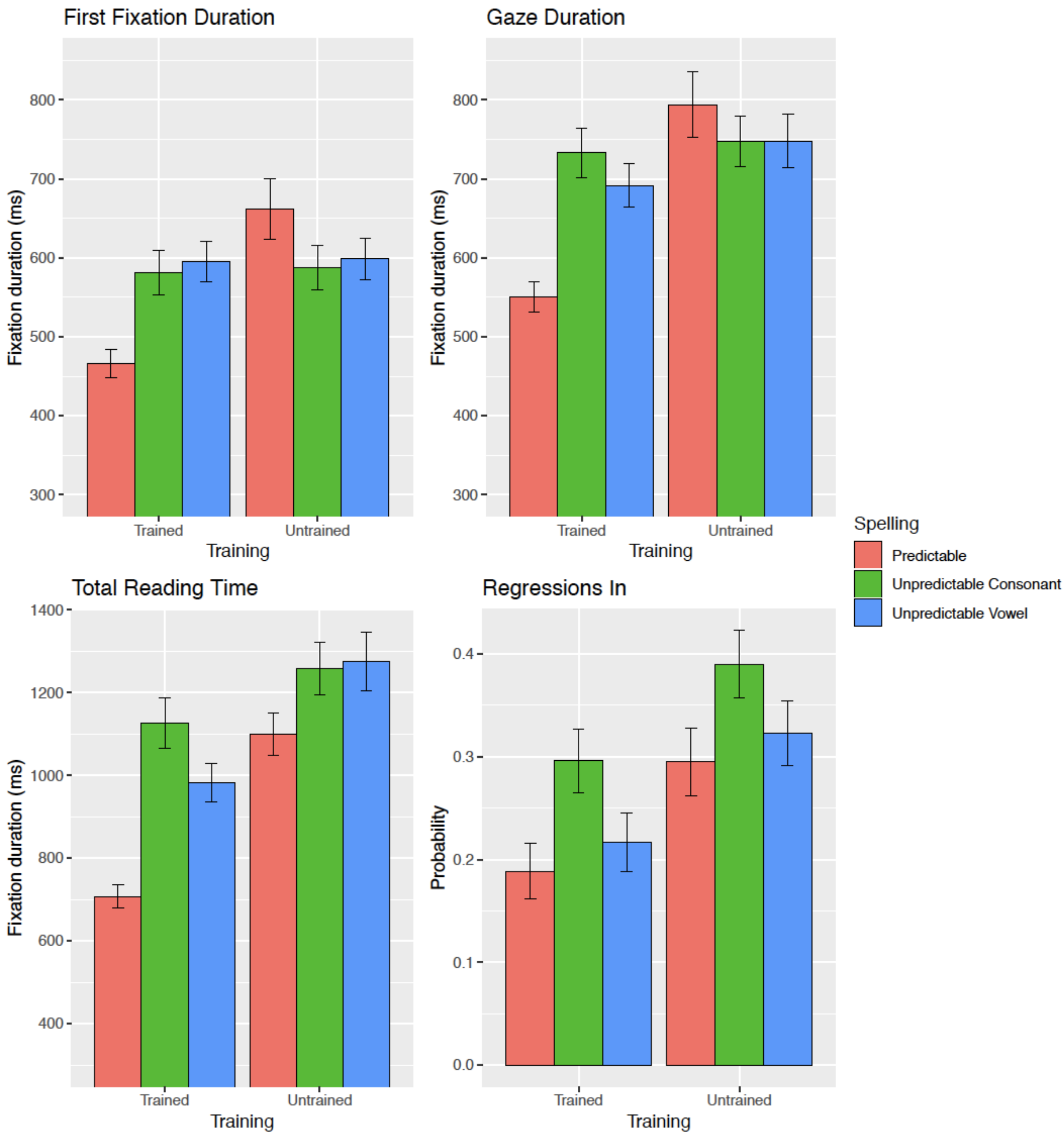

Figure C3. Arithmetic (untransformed) means and standard errors of eye movements in the target word interest area. First fixation duration, gaze duration and total reading time are expressed in milliseconds while regressions in reflects the likelihood of occurrence.

In the model for total reading time, the interaction between training and predictable spellings compared with unpredictable consonant spellings was significant (β = -0.159, *SE* = 0.057, *t* = 2.778, *p* = 0.018). However, the interaction between training and predictale spellings compared with unpredictable vowel spellings was not significant (β = -0.113, *SE* = 0.058, *t* = 1.963, *p* = 0.058). Interaction contrasts showed that items with predictable spellings benefited from training (χ^2 = 22.484, $p < 0.001$), while the effect of training was not significant for items with unpredictable vowel spellings (χ^2 = 4.764, *p* = 0.061) and unpredictable consonant spellings (χ^2 = 1.165, *p* = 0.280).

In the model reflecting the probability of regressions back to the target word, there was a significant effect of training (β = -0.656, *SE* = 0.178, *z* = -3.685, $p < 0.001$) such that children were more likely to return to the target word if they had not received training regarding its pronunciation and meaning. Training and spelling did not interact in this model, either when predictable spellings were compared with unpredictable consonant spellings (β = -0.110, *SE* = 0.178, *z* = 0.621, *p* = 1.000), nor when predictable spellings were compared with unpredictable vowel spellings (β = -0.028, *SE* = 0.182, *z* = 0.156, *p* = 1.000).

Post-exposure tests of reading and spelling

The same process of model construction and selection employed for analysing the eye movement data was also applied to each of the post exposure tests: reading aloud accuracy; reading aloud latency; immediate spelling accuracy; and delayed spelling accuracy. Once the optimal random effects structure was selected, we tested our specific pre-registered hypotheses. A fixed effect of training was anticipated such that orally trained items should be read more accurately and quickly and spelled more accurately than untrained items. It was anticipated that predictable spellings would be read more accurately and quickly and spelled more accurately than either unpredictable consonant or vowel spellings. Finally, we sought to explore the interactions between training and spelling specified in the eye movement analyses.

Reading aloud accuracy. Means and standard errors of reading aloud naming accuracy are presented graphically in Figure C4. A logistic linear mixed effects model was performed in which the dependent variable was naming accuracy. The model showed a fixed effect of training ($\beta = 2.622$, $SE = 0.456$, $z = 5.755$, $p < 0.001$) such that children read trained words more accurately than untrained words. Predictable spellings were more likely to be read accurately than unpredictable vowel ($\beta = 1.869$, $SE = 0.4991$, $z = 3.745$, $p < 0.001$) spellings, but this difference did not reach significance when predictable spellings were compared with unpredictable consonant spellings ($\beta = 1.145$, $SE = 0.498$, $z = 2.299$, $p = 0.065$). Neither the interaction between training and predictable spellings compared with unpredictable consonant spellings ($\beta = -0.038$, $SE = 0.377$, $z = -0.101$, $p = 0.920$), nor the interaction between training and predictable spellings compared with unpredictable vowel spellings ($\beta = -0.479$, $SE = 0.379$, $z = -1.264$, $p = 0.412$) were significant.

Reading aloud latency. Only correct responses were submitted to this analysis. Means and standard errors of reading aloud naming latency are presented graphically in Figure C4. Latency data were log transformed prior to analysis. The model showed a fixed effect of training ($\beta = -0.213$, $SE = 0.027$, $t = -7.911$, $p < 0.001$) such that children initiated a reading response to trained words more quickly than to untrained words. Predictable spellings were associated with a smaller response latency than either unpredictable consonant ($\beta = -0.147$, $SE = 0.049$, $t = -2.973$, $p = 0.017$) or unpredictable vowel ($\beta = -0.191$, $SE = 0.050$, $t = -3.800$, $p = 0.002$) spellings. Neither the interaction between training and predictable spellings compared with unpredictable consonant spellings ($\beta = 0.009$, $SE = 0.020$, $t = 0.431$, $p = 0.667$), nor the interaction between training and predictable spellings compared with unpredictable vowel spellings (β = 0.016, *SE* = 0.0213, *t* = 0.737, *p* = 0.923) were significant.

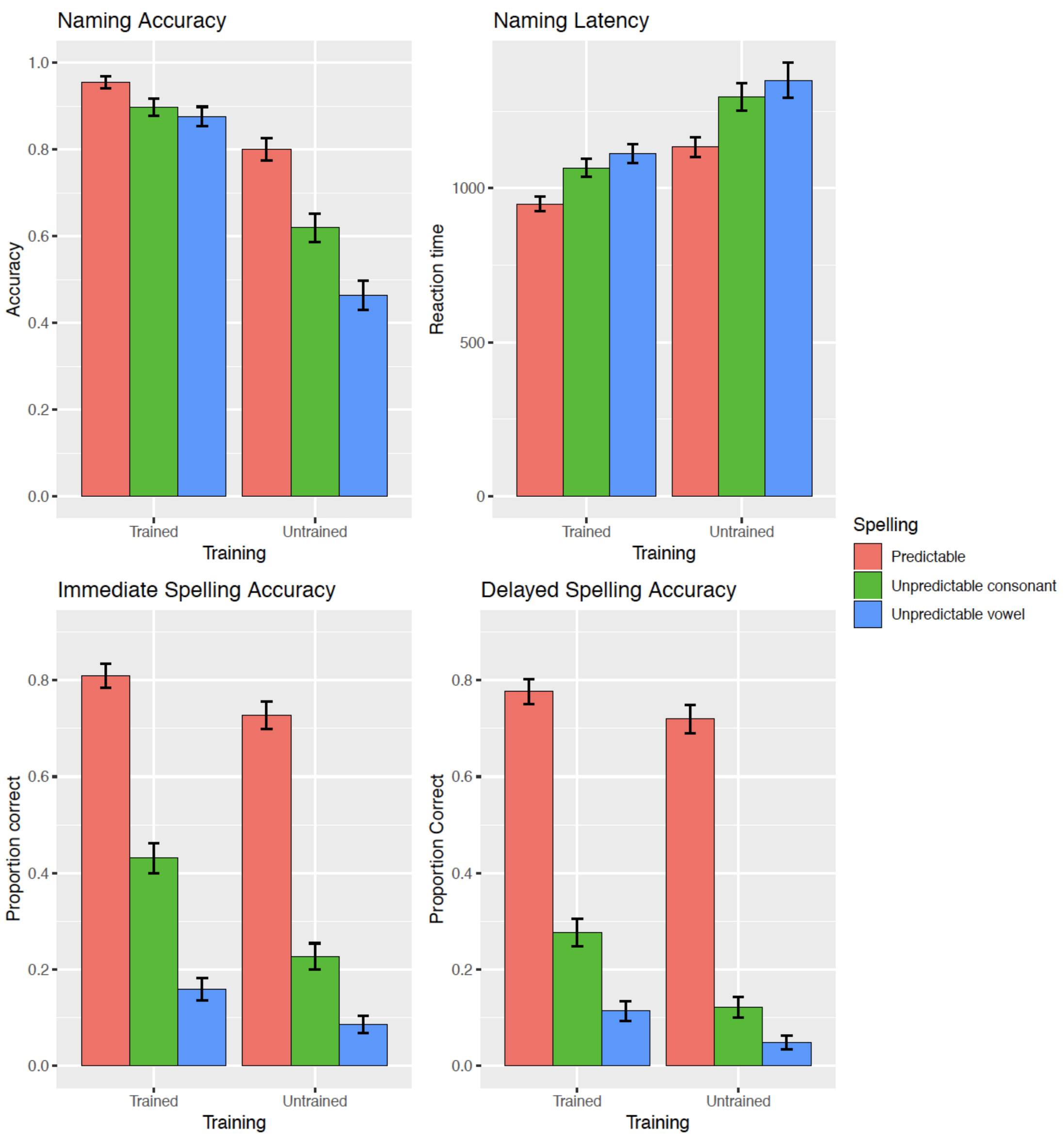

Figure C4. Means and standard errors of reading aloud accuracy, reading aloud latency, immediate spelling accuracy and delayed spelling accuracy. Accuracy measures are depicted as proportion correct, while latency is expressed in milliseconds.

Immediate spelling accuracy. Means and standard errors of immediate spelling accuracy are represented in Figure C4. A logistic linear mixed effects model was performed in which the dependent variable was spelling accuracy. The model showed a fixed effect of training (β = 0.982, *SE* = 0.197, *z* = 4.976, *p* < 0.001) such that children spelled trained words more accurately than untrained words. Predictable spellings were more likely to be spelled accurately than either unpredictable consonant ($\beta = 2.631$, $SE = 0.424$, $z = 6.204$, $p < 0.001$) or unpredictable vowel ($\beta = 4.318$, $SE = 0.455$, $z = 9.487$, $p < 0.001$) spellings. The interactions between training and predictable spellings versus unpredictable consonant spellings ($\beta = 0.386$, $SE = 0.218$, $z = 1.771$, $p = 0.153$) and between training and predictable spellings versus unpredictable vowel spellings ($\beta = 0.228$, $SE = 0.256$, $z = 0.892$, $p = 0.373$) were not significant.

Delayed spelling accuracy. Means and standard deviations of immediate spelling accuracy are represented in Figure C4. A logistic linear mixed effects model was performed in which the dependent variable was spelling accuracy. The model showed a fixed effect of training ($\beta = 0.980$, $SE = 0.234$, $z = 4.186$, $p < 0.001$) such that children spelled trained words more accurately than untrained words. Predictable spellings were more likely to be spelled accurately than either unpredictable consonant ($\beta = 3.718$, $SE = 0.529$, $z = 7.031$, $p < 0.001$) or unpredictable vowel ($\beta = 5.11$, $SE = 0.612$, $z = 8.353$, $p < 0.001$) spellings. The interactions between training and predictable spellings versus unpredictable consonant spellings ($\beta = 0.380$, $SE = 0.259$, $z = 1.466$, $p = 0.285$) and between training and predictable spellings versus unpredictable vowel spellings ($\beta = 0.280$, $SE = 0.300$, $z = 0.932$, $p = 0.352$) were not significant.

Discussion

In a previous experiment (Wegener et al., 2018) we proposed and found evidence consistent with the idea that when a child's spelling expectation matches the actual orthographic form at the first visual exposure to an orally known word, a processing advantage is observed relative to items that are not within the child's oral vocabulary. We expected to replicate this finding in the current experiment. Indeed, children did spend less time looking at orally trained items with predictable spellings than similar items that were orally untrained. The processing advantage for these items was consistently observed across each looking time measure of interest: first fixation duration, gaze duration, and total reading time. This finding is consistent with the view that children's oral vocabulary knowledge supports their online processing during reading, at least when spellings are highly predictable from a word's pronunciation.

Another key prediction of the orthographic skeleton hypothesis concerns the outcome of a mismatch between a child's initial spelling expectation and the actual orthographic form. Mismatches are viewed as resulting in a processing cost, the effect of which is to reduce or remove the benefit of oral familiarity. An interaction between training and spelling, wherein predictable spellings benefit more from training than unpredictable spellings, would be strong evidence that the orthographic skeleton includes a particular aspect of representation.

The lexical quality hypothesis (Perfetti, 1992) proposes that early orthographic representations might either be partial representations in which the consonants are specified while the vowels are not; or they may be complete but transiently incorrect representations which include both consonants and vowels. Both accounts agree that early orthographic representations should include consonants. Consistent with this prediction, an interaction between training and spelling was observed wherein predictable spellings benefited from training but unpredictable consonant spellings did not. This pattern was observed across the eye movement record from first pass reading measures (first fixation duration and gaze duration) to later measures (total reading time). The two accounts of the likely form of early orthographic representations differ with respect to whether or not these representations are likely to also encode information about vowels. Whereas the partial representation account proposes that early orthographic representations do not include vowels, the complete accounts proposes that early orthographic representations additionally include vowel representations. Contrary to the prediction that vowels might not be represented within initial orthographic skeletons, a second interaction was observed between training and spelling such that predictable spellings benefited from training but unpredictable vowels did not. This pattern of differential processing was clearly observed on first pass reading measures (first fixation duration and gaze duration). However, and most interestingly, it did not persist on the late processing measure of total reading time; the interaction comparing predictable spellings with unpredictable vowel spellings was no longer significant.

At the broadest level, children therefore do seem to demonstrate patterns of looking behaviour that vary depending on the correspondence between their orthographic expectancy and the actual orthographic form when it is seen in writing for the first time. This finding is consistent with our own prior work and provides further support for the idea that, via a mechanism that permits information to flow from phonology to orthography, oral vocabulary knowledge may confer an advantage within the process of orthographic learning that commences before written words are seen.

Differentiating the influence of spelling unpredictability associated with consonants and vowels allowed us to elucidate the form of these initial spelling expectancies. Early lexical identification processes are thought to be reflected in the eye movement measures of first fixation duration and gaze duration (Rayner & Liversedge, 2011). Results of the current experiment suggest that children's orthographic skeletons include representations of *both* consonants and vowels at these early time points, a finding that is inconsistent with the idea that early lexical representations are partial and built around a word's consonants (McKague et al., 2008; Perfetti, 1992). Rather, our findings are consistent with Perfetti's (1992) notion that very early lexical representations may be transiently incorrect, such that a complete but tentative initial orthographic representation is generated which is then either confirmed or disconfirmed upon visual exposure.

The late processing measure of total reading time is often interpreted as a general index of processing difficulty, reflecting the influence of both lexical factors and semantic integration processes (Liversedge, Paterson, & Pickering, 1998; Rayner, Chace, Slattery, & Ashby, 2006; Taylor & Perfetti, 2016). The pattern of findings obtained in the current experiment suggests that unpredictable vowel spellings seem to disrupt early but not late processing. This was unexpected and raises the intriguing possibility that the eye movement record may actually be capturing the early stages of children's online resolution of misalignment between their orthographic expectancies and orthographic forms that include unpredictable vowel spellings. We speculate that, because children typically encounter greater phoneme-to-grapheme unpredictability in the vowel position, this permits them to rapidly begin to integrate mismatches occurring in this position. Clearly further research is needed to evaluate the viability of this explanation.

For the looking time measures, we anticipated that the effect of training would differ according to the predictability of the spellings of the target words, so for this reason we did not predict or test for an overall effect of training. However, our predictions for the measure reflecting the likelihood of rereading were different. In this instance, we anticipated that training in a word's pronunciation and meaning would be associated with a reduced likelihood of rereading, and this is what we found. This is consistent with our own prior findings and with work from other groups showing that novel words are more likely to be refixated than familiar words (Chaffin et al., 2001; Taylor & Perfetti, 2016).

To explore the orthographic knowledge children had acquired during the initial exposure in the eye movement task, follow-up testing was undertaken. This consisted of reading aloud and spelling all items immediately following the initial orthographic exposure, and spelling all items again following a delay of approximately one week. Although children did not benefit from training when viewing unpredictable spellings in the context of the eye movement task, there was a clear advantage for orally familiar items across each of the follow-up tasks. As anticipated, children read and spelled trained words more accurately, and read trained words more quickly than untrained words. This finding replicates previous work showing children's reading aloud accuracy is improved by training in oral vocabulary (Duff & Hulme, 2012; McKague et al., 2001) and extends this accuracy advantage to spelling. Additionally, it provides further evidence suggesting that the processing cost associated with 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.

Many questions remain regarding the operation of the orthographic skeleton. Thus far we have only addressed the question of whether orthographic skeletons are observed at the first visual exposure to an orally known word. As yet, it is not known what happens to the orthographic skeleton over repeated visual exposures. One might expect visual exposure to result in some form of updating of the child's spelling expectation, but whether and when this occurs remains to be established in future work.

Conclusions

To conclude, the present study provides evidence that when children are in possession of partial lexical knowledge about a word's pronunciation and meaning, they can use this information to begin to create the missing aspect of representation – the orthography. Online measures of children's processing during the initial orthographic exposure to orally known words suggests that these representations appear to initially include information about both the consonants and vowel of a word, suggesting that children's early spelling expectations take the form of a complete but tentative spelling. However, late in the eye movement record there is evidence that unpredictable vowel spellings begin to be integrated online. Subsequent orthographic processing, as indexed by reading aloud and spelling, is also consistent with the view that following an initial visual exposure, children's orthographic expectancies undergo a process of updating that brings them closer to the form they experienced in print; thereby allowing items to benefit from training regardless of their spelling predictability.

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Chapter 5

Tracking the evolution of orthographic expectancies over building visual experience

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This experiment was pre-registered with AsPredicted.org. Please see the Supplementary Materials section of this dissertation for further details.

Abstract

When oral vocabulary knowledge is supported by knowledge of sound-to-letter mappings, children can generate expectations about the spellings of words they have not yet seen in print (Wegener et al., 2018). These initial spelling expectations, or *orthographic skeletons*, have previously been observed at the first orthographic exposure to known spoken words. Here, we asked what happens to the orthographic skeleton over repeated visual exposures. Grade 4 children (N=38) were taught the pronunciations and meanings of one set of 16 novel words while another set were untrained. Spellings of half the items were predictable from their phonology (e.g. *nesh*) while the other half were unpredictable (e.g. *koyb*). Trained and untrained items were subsequently shown in print, embedded in sentences, and eye movements were monitored as children silently read all items over three exposures. A larger effect of spelling predictability for orally trained compared to untrained items was observed at the first and second orthographic exposure, consistent with the notion that oral vocabulary knowledge had facilitated the formation of spelling expectations. By the third orthographic exposure this interaction was no longer significant, suggesting that visual experience had begun to update children's spelling expectations. Delayed follow-up testing revealed that, when visual exposure was equated, oral training provided a strong persisting benefit to children's written word recognition. Findings suggest that visual exposure can alter children's developing orthographic representations; here we show that this process can be captured online as children read novel words over repeated visual exposures.

Introduction

It is well known that children's spoken language skills and their emerging literacy skills are closely intertwined, with oral vocabulary knowledge likely playing a causal role in children's reading development (Duff & Hulme, 2012; Duff, Reen, Plunkett, & Nation, 2015; Lee, 2011; McKague, Pratt, & Johnston, 2001). Since virtually all children begin formal schooling in possession of knowledge about a substantial number of spoken words they cannot yet read (Chall, 1987), there may be potential to support reading acquisition through the implementation of oral vocabulary interventions. Understanding the nature of the mechanism or mechanisms that support the link between oral vocabulary and reading is an important but relatively overlooked prerequisite to this endeavour. In recent work we described one such mechanism: children may utilise their knowledge of the mappings between phonemes and graphemes to form expectations about the spellings of known spoken words they have not yet seen in writing (Wegener et al., 2018; presented here in Chapter 2). We found that these initial spelling expectations, or *orthographic skeletons*, influenced reading behaviour the first time words were seen in print. Here, we address the question of what happens to children's initial spelling expectancies over subsequent visual exposures and ask: do they remain evident with accumulating visual experience, or do they instead undergo an updating process which might serve to bring them closer to the written form?

Orthographic learning refers to the gradual acquisition of written word representations (Castles & Nation, 2006; Nation & Castles, 2017) and oral vocabulary is generally viewed as providing assistance within this process. Mechanistic accounts typically focus on how spoken word knowledge might assist children to make mappings between orthographic forms and their pronunciations. In so doing, they make the explicit prediction that oral vocabulary knowledge exerts an effect on word reading that begins upon exposure to a novel written word. A prominent example is the self-teaching hypothesis (Share, 1995, 2008), which positions phonological decoding as central to the process of orthographic learning. On this view, oral vocabulary knowledge is thought to provide top-down support during phonological decoding by assisting children to correct partial decoding attempts. Partial decodings might occur for a number of reasons. A child might have incomplete knowledge of the mappings between letters and sounds; they might make a decoding error for a mapping that they do know; or they might encounter a word with an irregular print-to-pronunciation mapping. Using the latter possibility as an example, if a child attempts to phonologically decode the written word *break*, they should produce an unfamiliar pronunciation rhyming with *peak*. If the child knows the spoken word 'break' and recognises that their phonological decoding attempt sufficiently resembles it, this may prompt the child to review their decoding attempt, thereby potentially aligning the two pronunciations. This idea resonates with related theories suggesting that the ability to match discrepant pronunciations of spoken words may contribute to reading development (Dyson, Best, Solity, & Hulme, 2017; Elbro, de Jong, Houter, & Nielsen, 2012; Kearns, Rogers, Koriakin, & Al Ghanem, 2016; Savage, Georgiou, Parrila, & Maiorino, 2018; Tunmer & Chapman, 2012).

An alternative possibility is that oral vocabulary knowledge may also exert an effect on word reading that begins prior to visual exposure, via children's ability to translate from pronunciation to print. Data from skilled readers suggests that the existence of such an alternative causal mechanism is plausible. For example, adults' processing of spoken words has been shown to automatically activate their orthographic knowledge (Chéreau, Gaskell, & Dumay, 2007; Pattamadilok, Morais, De Vylder, Ventura, & Kolinsky, 2009; Pattamadilok, Morais, Ventura, & Kolinsky, 2007; Taft, 2011; Taft, Castles, Davis, Lazendic, & Nguyen-Hoan, 2008; Ziegler & Ferrand, 1998). Notably, a similar effect has also been observed when adults received training on the pronunciation and meaning of novel words prior to encountering them in print for the first time

(McKague, Davis, Pratt, & Johnston, 2008), suggesting that participants' oral vocabulary knowledge may have resulted in the formation of early orthographic representations.

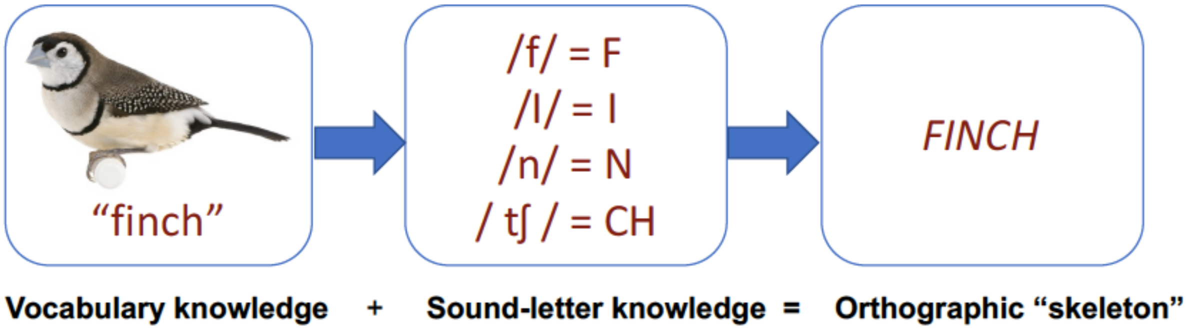

Figure D1. The orthographic skeleton hypothesis.

In the orthographic skeleton hypothesis (see Figure 1), we provide an account of how one's store of spoken word knowledge might support reading acquisition prior to visual exposure (Wegener et al., 2018). We suggest that when children know a spoken word and when they are also in possession of some knowledge about phoneme-to-grapheme mappings, they could be in a position to generate expectations about the spellings of words they have not yet seen in writing. We tested this possibility for the first time with developing readers in the context of a novel word training study. Children were taught the pronunciations and meanings of a set of novel words prior to reading sentences containing the trained items and another set of items they had not heard before. Children's eye movements revealed that, compared with untrained items, those that had received oral training and were shown in print with predictable spellings (e.g. the spoken word '*nesh*' written as *nesh*) were associated with shorter fixation durations. However, when orally trained items were presented with unpredictable spellings (e.g. the spoken word '*coib*' written as *koyb*) there was no benefit of training. These findings were interpreted as suggesting that children's online processing is facilitated when their orthographic expectancy matches the orthographic form; whereas there is an online processing cost associated with incongruence between children's orthographic expectancy and the orthographic form. This finding was interpreted as being consistent with the operation of a causal mechanism that begins prior to visual exposure.

The original investigation of the orthographic skeleton hypothesis addressed children's online processing at the first visual exposure to orally trained and untrained items on the assumption that the initial encounter should be particularly informative. This is because, if children do indeed form spelling expectations for orally known words, it should be most apparent at the earliest point in learning when phonology-to-orthography influences are likely to be strongest (see also McKague et al., 2008). Of course, in natural reading, written words are often encountered on more than one occasion. An important outstanding issue therefore concerns what happens to children's spelling expectations when the corresponding written form is experienced on subsequent occasions: do expectancies remain across visual exposures or is there evidence that visual experience permits them to be updated?

The frequency with which a spelling occurs in writing is associated with the speed with which it can be processed – frequently occurring written words require shorter processing times than less common written words. This so-called frequency effect is among the most robust findings in visual word recognition, occurring across a wide range of tasks such as reading aloud, lexical decision, semantic decision (for a review see Brysbaert, Mandera, & Keuleers, 2018) and fixation durations during sentence reading (Inhoff & Rayner, 1986; Joseph, Nation, & Liversedge, 2013). Indeed, models of skilled reading all offer an account of the word frequency effect (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Norris, 2006; Plaut, Seidenberg, McClelland, & Patterson, 1986), and while the specifics of the explanations differ, the effect is usually interpreted as reflecting the outcome of learning that has occurred during repeated visual exposures. Similarly, theories of orthographic learning all recognise a role for visual experience within the process of the acquisition of orthographic representations that extends beyond the initial visual exposure. The self-teaching hypothesis (Share, 1995, 1999, 2004), for example, proposes that each phonological decoding of a novel printed word provides an opportunity to learn its spelling, with the probability of subsequent word recognition depending at least in part on the frequency with which it has been seen. In a similar vein, the lexical quality hypothesis (Perfetti, 1992, 2007; Perfetti & Hart, 2002) proposes that knowledge about individual words is accrued gradually, with orthographic representations becoming increasingly robust and specific with building visual experience. Each of these theories predicts a role for multiple visual exposures within the process of written word learning.

Evidence for a direct role of repeated visual experience in reading acquisition is derived from learning paradigms that include a manipulation of exposure frequency. Notwithstanding substantial methodological differences between paradigms, evidence converges on the view that written word learning improves with increasing visual experience (but see Share, 2004). For example, naming accuracy improves (Duff & Hulme, 2012) while naming speed reduces (Bowey & Muller, 2005; Reitsma, 1983a, 1983b, 1989) as children encounter words over repeated exposures. More recent investigations favour orthographic choice as a more sensitive means of interrogating orthographic learning, with several studies showing that as trials increase so does children's ability to discriminate between learned and novel written forms that overlap with respect to pronunciation but differ in terms of their spellings (Bowey & Muller, 2005; Nation, Angell, & Castles, 2007). Further, eye movement work with both children (Joseph & Nation, 2018) and adults (Elgort, Brysbaert, Stevens, & Van Assche, 2018; Joseph, Wonnacott, Forbes, & Nation, 2014) suggests that as novel written words become increasingly familiar during the course of accrued visual experience, they require less online processing time during silent reading.

Both theoretical accounts and experimental evidence therefore converge on the view that the experience of reading a word over repeated exposures permits an individual to build their knowledge of that word – its spelling, pronunciation and meaning. Since orthographic representations are thought to develop over time, how might this occur? The lexical quality hypothesis (Perfetti, 1992, 2007; Perfetti & Hart, 2001) provides an account that is informative in this respect. On this view, the end-point of lexical knowledge acquisition is a *precisely* specified orthographic form that encodes an exact spelling. In contrast, developing orthographic representations are characterized by imprecision; this imprecision may arise either because the encoded spelling is incomplete, or because it contains one or more temporarily incorrect letters. The key consequence of imprecision, whether it arises from a partial or erroneous encoded spelling, is a representation that is unstable and subject to change (Perfetti, 1992). Since orthographic representations are conceived of as "evolving towards completeness" (Perfetti, 1992, p. 159), visual exposure during the initial stages of learning may provide an opportunity for developing orthographic representations to change, or be updated, in light of experience.

Extending this reasoning to the orthographic skeleton, two possible outcomes of an initial encounter with a known spoken word might be anticipated. In some instances, the child's spelling expectancy might match the orthographic form they experience in print. The effect of this encounter would be the provision of support for the orthographic skeleton, with the presumed effect that the initial orthographic representation is enhanced. In other cases, the orthographic skeleton will be misaligned in some way with the orthographic form. The consequence of such an encounter should be that one or more aspects of the orthographic skeleton is contradicted, presumably providing a prompt to alter the initial orthographic representation. In either event, the visual experience provides an opportunity for the reader to incrementally update their initial spelling expectancy, gradually bringing their initial spelling expectancy into alignment with the form they experienced in print. Eye movement monitoring during successive visual exposures has previously been shown to be sensitive to building visual experience with words (Elgort et al., 2018; Joseph & Nation, 2018; Joseph et al., 2014), suggesting that this approach may be a useful means of indexing the evolution of the orthographic skeleton across visual exposures.

The current experiment

The current experiment investigated the relationship between oral vocabulary knowledge and children's online processing over successive visual exposures to known and unknown spoken words. Two issues were of particular interest. First, we sought to determine whether oral vocabulary knowledge could be shown to permit children to form expectations of the spellings of known spoken words at the first visual exposure, a finding that if observed, would replicate that of Wegener and colleagues (2018). Second, if the effect was observed at the first visual exposure, we sought to determine whether it would remain as children read the words for a second and third time. Two groups of Year 4 children were taught the pronunciations and meanings of a set of novel words (e.g., 'nesh', 'coib') while a second set of items were untrained. All items, both trained and untrained, were embedded in contextual sentences which were presented to children over a series of three blocked exposure trials. The children's eye movements were monitored as they silently read the sentences. The spelling predictability of the novel words was manipulated such that half of the items in each set had spellings that were highly predictable from phonology and therefore consistent with children's likely orthographic expectations (e.g., *nesh*), while the remaining items had spellings that were unpredictable from phonology and therefore inconsistent with children's likely expectations (e.g., *koyb*).

In line with our initial findings (Wegener et al., 2018) we anticipated that if children do form spelling expectations for orally known words, this should be evident in looking times at target words during sentence reading. Specifically, when words are orally familiar, children should show a larger difference in time spent looking at items with predictable and unpredictable spellings than if the words are orally unfamiliar. This interaction between training and spelling predictability, which would be the key evidence in support of the position that children do form orthographic expectancies, should be observed across each of the looking time measures of interest (first fixation duration, gaze duration, total reading time). Extending our previous work, and drawing on the lexical quality hypothesis, we anticipated that visual exposure to known spoken words should provide an opportunity for children to update their initial spelling expectations, gradually aligning them with the written form experienced during reading. We elected to provide three orthographic exposures per target in view of prior work (e.g., Share, 1999, 2004) demonstrating that orthographic representations can be acquired over just a few visual exposures (ranging from 1 to 4 when assessed using orthographic choice). The notion that orthographic representations undergo a process of updating would be supported by diminishing evidence of the interaction between training and spelling predictability. Consequently, the key question addressed in this experiment is whether there is evidence of the orthographic skeleton at each visual exposure. Additionally, in line with prior work (Chaffin, Morris, & Seely, 2001; Wegener et al., 2018), we anticipated that oral familiarity would be associated with a reduced probability of rereading.

Follow-up testing investigated the influence of the orthographic skeleton on children's delayed orthographic learning as indexed by their performance on an orthographic recognition task. To this end, children completed a go/no-go lexical decision task in which they were required to respond to words they had seen during the eye-tracking task (both those that were orally familiar and those that were not), while inhibiting responses to a series of distractor items that had not been encountered previously. Based on prior work suggesting that oral vocabulary conveys an advantage within the process of orthographic learning, we expected to find an effect of training at follow-up. Less clear, however, are predictions relating to the influence of the spelling predictability manipulation. One possibility is that when the child's orthographic expectancy matches the orthographic form experienced in print, this correspondence might convey a particular benefit to orthographic learning because the requirement to alter the initial spelling expectation is greatly reduced. In the event that there is a mismatch between the child's orthographic expectancy and the orthographic form experienced in print, this incongruence might confer a smaller orthographic learning advantage because there is a greater requirement for adjustment. Alternatively, the incongruence might provide a strong cue to update the early orthographic representation, which may in turn drive a boost in performance for these items.

Method

Participants

A total of 40 children in Year 4 were recruited from a primary school in New South Wales, Australia. All children who returned a consent form were considered eligible. Of the total number of recruited children, one withdrew consent while another was unable to be adequately calibrated so data are reported for the remaining 38 participants. Children were drawn from two parallel mainstream classes (Class 1: n = 19; Class 2: n = 19; 17 males). The mean age of children was 10 years and 0 months (range: 9y;4m -10y;10m). There was no significant difference in the ages of children in each class (Class 1: M = 119.84 months, SD: 4.49; Class 2: M = 120.68 months, SD = 4.58; $t(36) = -0.572$, p = 0.571). The sample size was informed by previous investigations of orthographic learning (Share, 2004; Wang, Castles, Nickels, & Nation, 2011) and by our own prior work in which the basic orthographic skeleton effect was first demonstrated (Wegener et al., 2018).

Standardized tests

Standardized measures of spoken vocabulary knowledge, reading and spelling were administered to characterize the sample. Spoken vocabulary knowledge was assessed using the naming subtest from the Assessment of Comprehension and Expression 6-11 (ACE 6-11; Adams, Coke, Crutchley, Hesketh, & Reeves, 2001). Reading of regular, irregular and nonwords was assessed with each child individually using the Castles & Coltheart 2 (CC2; Castles et al., 2009). Spelling ability was assessed with the Diagnostic Spelling Test – irregular words (DiSTi; Kohnen, Colenbrander, Krajenbrink, & Nickels, 2015) and the Diagnostic Spelling Test – nonwords (DiSTn; Kohnen et al., 2015) with administration occurring at a group level. Summary data are presented in Table 1 and show that mean performance was broadly within the average range across all measures.

Table D1

Children's performance on standardized tests of spoken vocabulary, reading and spelling

	M	SD	Min	Max
Spoken vocabulary knowledge (ACE)[a]	8.71	2.73	3.00	16.00
Reading aloud (CC2)				
Regular [b]	-0.36	1.36	-2.37	2.99
Irregular [b]	-0.56	0.88	-2.29	1.67
Nonwords [b]	-0.43	1.09	-2.29	1.72
Spelling				
DiSTn [b]	-0.12	0.93	-1.71	1.75
DiSTi [b]	-0.05	0.93	-1.69	1.93

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

Items were taken from Wegener and colleagues (2018), and consisted of two sets of 16 three-phoneme, monosyllabic nonwords matched for consonant/vowel structure. All items were regular for reading: they employed the most common grapheme-to-phoneme correspondence (type frequency *M* = 94.23%, *SD* = 10.78%). Half of the items in each set were assigned spellings that were highly predictable from phonology because they contained frequent phoneme-to-grapheme mappings (e.g., 'f' for /f/). The other items were assigned spellings that were unpredictable from phonology because they contained less frequent phoneme-to-grapheme mappings (e.g., 'ph' for /f/). For details of the pilot testing that confirmed this manipulation, the reader is referred to Wegener and colleagues (2018). Of note, 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 item sets appear in Table D2.

Table D2.

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	/bɜːv/	birv
	/kɔɪb/	koyb	/dʒaɪf/	jayf
	/dʒiːb/	jeabb	/miːf/	meaph
	/fɜːf/	phirf	/gʌz/	ghuzz
	/gæk/	ghakk	/feg/	phegg
	/mɜːb/	mirbe	/veɪp/	vaype

Procedure

Oral vocabulary training. Children were taught one set of 16 novel spoken words at a class level, while the other set were untrained. Item sets were counterbalanced across classes. Children were introduced to the novel spoken words in sessions over a period of four days. Each session was of approximately 20-minutes duration. In the first session, eight items were introduced (four from each spelling predictability condition) while the remaining eight were introduced in the second session. All 16 items were rehearsed in the third and fourth training sessions. If a child was absent for any training session, a catch-up session was provided at the earliest opportunity. The procedure was identical to that employed by Wegener and colleagues (2018). Children were told that they would be learning about 'Professor Parsnip's Inventions' (Wang et al., 2011; Wang, Nickels, Nation, & Castles, 2013). Spoken invention names were paired with a picture referent (see Figure 2); information about the function of the invention and two perceptual features was also provided. For example, children learned that a 'nesh' is 'used to shuffle cards' and 'is made of metal and has two hands'. Children were asked to learn both the novel words and the function of each invention.

Figure D2. Sample picture: A "nesh" is used to shuffle cards.

Learning check. Following the completion of training but prior to the initial orthographic exposure, the children's oral vocabulary learning was assessed individually in a picture-naming task. Individual children were shown pictures of the inventions, one at a time, and were asked to provide both the name of the invention and its function. To control the number of phonological exposures, feedback was provided regardless of accuracy.

Orthographic Exposure. The children encountered the written form of the orally trained words for the first time between 1 and 7 days following their final oral vocabulary training session. The mean delay between training and testing did not significantly differ across the two classes (Class 1: M = 2.474, SD = 1.467; Class 2: M = 2.684, SD = 1.455; $t(36) = 0.444$, $p = 0.660$). Children silently read interleaved contextual sentences referring to the trained and untrained invention names over three blocked orthographic exposures. The first orthographic exposure took the same form as used by Wegener and colleagues (2018): children read sentences containing the 16 inventions they had learned; 16 sentences contained inventions they had not learned about; and eight filler sentences which contained novel words not learned by any group. On the second and third orthographic exposure, there were no filler sentences in order to limit the length of the testing session. Children read a total of 104 experimental sentences. The experimental sentences appear in Appendix D1.

An Eyelink 1000 eye tracker (SR Research; Mississauga, Canada) in head stabilized mode, with a sampling rate of 1000Hz, was used to record children's eye movements as they read the sentences on a computer screen. The viewing distance was 104cm and each character subtended approximately 0.25 degrees of horizontal visual angle. Sentences appeared in black Courier New font on a white background. Participants read binocularly but only the movements of the right eye were recorded. Following an initial calibration of the eye tracker, children read three practice sentences before progressing to the experimental sentences. The start of each trial was triggered by the experimenter when the children fixated a drift correct target, and recalibration was performed when necessary. The end of each trial was triggered when children directed their gaze towards a rectangle. Children were required to answer a (yes/no) question after each trial as a means of promoting attention to task.

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).

Delayed post-exposure testing: Go/no-go lexical decision. At a delay of between two and six days (*M* = 4.079; *SD* = 0.912) following the eye-tracking task, a go/no-go lexical decision task was administered in order to investigate the longer-term influence of the orthographic skeleton on children's delayed orthographic learning performance. The 16 trained items, the 16 untrained items, and set of 32 novel word foils were presented to children on a laptop using DMDX software (Forster & Forster, 2003). Items were interleaved and presented to each participant in a random order. Before commencing the task, children were reminded that they had read a number of novel words in the context of the eye-tracking task, some of which they had been taught orally while others they had never heard before. Children were told that they were going to see some more words one at a time on a computer screen, and that they were to press a button as quickly as possible if they recognized a word as being familiar to them from the eye-tracking task. It was emphasized that they should respond to these words if they had seen them before, even if they had not learned the word in spoken form. Children were instructed that they would also see other words that were not present in the eye-tracking task – these words would therefore be totally new to them, having never been seen or heard before. Children were instructed that when they did not recognise a word as being familiar to them from the eye-tracking task, they should do nothing and simply wait for it to disappear on its own. If a response button was not pressed, the words were displayed for a maximum duration of 4000ms.

Results

Learning check: Picture naming

Participants correctly recalled a mean of 10.474 of the 16 orally trained invention names (*SD* = 4.144). The difference in recall between participants who learned set 1 (*M* = 10.105, *SD* = 4.267) and set 2 (*M* = 10.842, *SD* = 4.100) was not significant ($t(36) = -0.543$, $p = 0.591$), nor was the difference in recall for items with predictable (*M* = 5.237, *SD* = 2.235) and unpredictable spellings (*M* = 5.237 *SD* = 2.085; $t(36) = 0.000$, $p = 1.000$).

Eye movements

Data were analysed in the R computing environment (R Core Development Team, 2019). Linear mixed effects models were constructed using the lme4 package (Bates, Maechler, Bolker, & Walker, 2019). In line with the basic effect upon which the current experiment builds (Wegener et al., 2018), reading time data were log transformed to improve the distributions of model residuals. This approach is also consistent with other recent eye movement work (Joseph & Nation, 2018; Taylor & Perfetti, 2016).

Models were run for each of the dependent variables of interest: first fixation duration, gaze duration, total reading time and regressions in. For the purpose of analysis, the area of interest was the invention name, or target word. If any of the three prespecified interest areas – target word, pre-target text, post-target text – were skipped during first pass reading, the trial was removed prior to analysis (7.18% of the experimental data).

Because exposure was ordered from first to third exposure, contrast coding was implemented for all fixed effects using the successive differences function from the *MASS* package (Ripley et al., 2019). Training (untrained vs. trained), spelling (unpredictable vs. predictable), exposure (2 vs. 1, 3 vs. 2) and their interaction were entered as fixed effects while participants and items were entered as random effects. Fitting the full random effects structure with random intercepts and slopes for subjects and items resulted in issues with singularity, suggesting that the models were over parameterized (Baayen, Davidson, & Bates, 2008). For this reason, models were built from the simplest to the most complex random effects structure and the highest nonsingular converging model is reported. The hierarchy of random effects models are presented in the Supplemental Material as Table

SD1. Our primary aim was to determine whether the two-way interaction was present at each visual exposure to the target words. To this end, we ran an overall model. Whenever the two-way interaction between training and spelling predictability was significant in the omnibus model, interaction contrasts were computed to determine whether the interaction was present at each visual exposure to the target words. Interaction contrasts were implemented using the *phia* package (Rosario-Martinez, 2015). For ease of interpretation, arithmetic means and standard errors for each of the dependent variables appear in Figure D3.

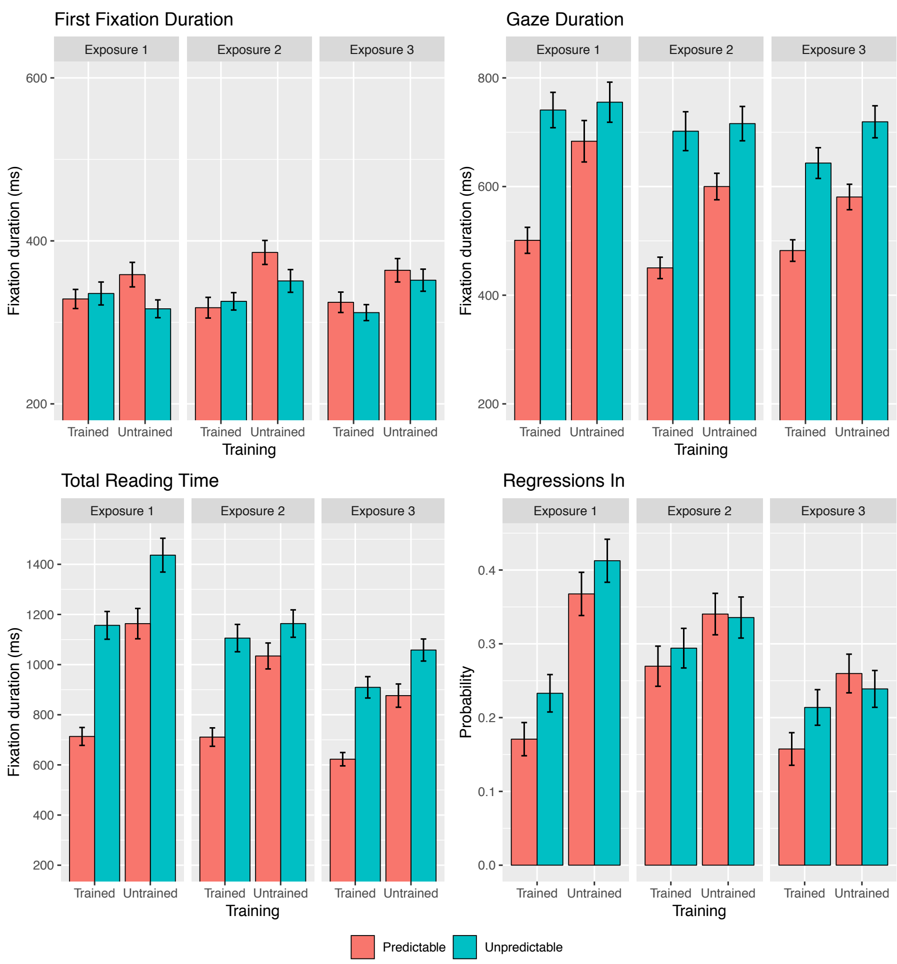

Figure D3. Arithmetic (untransformed) means and standard errors of target word fixation durations and probability of rereading. First fixation duration, gaze duration and total reading time are expressed in milliseconds while regressions in reflects likelihood of occurence.

Results of the model for *first fixation duration* are presented in Table D3. There were no fixed effects of spelling predictability or exposure. However, there was a significant fixed effect of training such that orally trained items were associated with shorter fixation durations than untrained items. There was also a significant two-way interaction between training and spelling predictability, suggesting that the effect of spelling predictability was larger for untrained items than for trained items. Contrasts showed that the interaction between training and spelling predictability was only present at the second exposure (χ^2 = -0.035, p = 0.038) but not at the first (χ^2 = -0.016, p = 0.493) nor third (χ^2 = -0.007, p = 0.636).

Table D3.

Results of the linear mixed effects model for first fixation duration.

		Training	Spelling	Exposure 2 vs. 1	Exposure 3 vs. 2	
Fixed effects	*b*	- 0.065	-0.029	0.034	-0.015	
	SE	0.016	0.025	0.020	0.020	
	t	4.008	-1.175	1.691	-0.766	
	p	< 0.001*	0.249	0.091	0.444	
		Training x Spelling	Training x Exposure 2 vs. 1	Training x Exposure 3 vs. 2	Spelling x Exposure 2 vs. 1	Spelling x Exposure 3 vs. 2
Two-way Interactions	*b*	-0.078	0.110	-0.024	0.039	-0.000
	SE	0.033	0.040	0.039	0.040	0.040
	t	-2.383	2.510	-0.595	0.979	-0.008
	p	0.017*	0.012*	0.552	0.328	0.994
		Training x Spelling x Trial 2 vs. 1	Training x Spelling x Trial 3 vs. 2			
Three-way Interactions	*b*	-0.075	0.114			
	SE	0.080	0.080			
	t	-0.938	1.432			
	p	0.349	0.152			

Note. * denotes statistical significance

There was also an incidental and unexpected finding observed at first fixation. Specifically, the effect of training was larger at the second exposure compared to the first exposure; however, the interaction did not persist when the third exposure was compared to the second. Interaction contrasts showed that the effect of training was not significant at the first visual exposure (χ^2 = 0.492, p = 0.824) but it was significant at the second (χ^2 = 14.305, p < 0.001) and the third (χ^2 = 8.710, p = 0.006) . No other two-way or three-way interactions were significant.

Table D4.

Results of the linear mixed effects model for gaze duration.

		Training	Spelling	Exposure 2 vs. 1	Exposure 3 vs. 2	
Fixed effects	*b*	0.138	0.258	-0.046	0.015	
	SE	0.029	0.042	0.024	0.024	
	t	4.824	6.103	-1.870	0.607	
	p	< 0.001*	< 0.001*	0.062	0.544	
		Training x Spelling	Training x Exposure 2 vs. 1	Training x Exposure 3 vs. 2	Spelling x Exposure 2 vs. 1	Spelling x Exposure 3 vs. 2
Two-way Interactions	*b*	-0.173,	0.061,	-0.026,	0.025,	-0.050,
	SE	0.053,	0.049,	0.049,	0.049,	0.049,
	t	-3.293,	1.253,	-0.537,	0.506,	-1.035,
	p	0.003*	0.210	0.591	0.613	0.301
		Training x Spelling x Trial 2 vs. 1	Training x Spelling x Trial 3 vs. 2			
Three-way Interactions	*b*	-0.038,	0.160,			
	SE	0.098,	0.097,			
	t	-0.393,	1.653,			
	p	0.694	0.098			

Note. * denotes statistical significance

Results of the model for *gaze duration* are presented in Table D4. There was no significant fixed effect of exposure. However, there was an effect of training such that trained items were fixated for shorter durations than untrained items. There was also a significant effect of spelling, such that items with predictable spellings were fixated for a shorter duration than items with unpredictable spellings. Training and spelling predictability also interacted, with the effect of spelling predictability being larger for orally trained compared to untrained items. Contrasts showed that the interaction between training and spelling predictability was only present in the first (χ^2 = 6.77, p = 0.019) and second exposure (χ^2 = 9.695, p = 0.006) but not in the third (χ^2 = 1.062, p = 0.303). No other two-way or three-way interactions were significant.

Table D5.

Results of the linear mixed effects model for total reading time.

		Training	Spelling	Exposure 2 vs. 1	Exposure 3 vs. 2	
Fixed effects	*b*	0.252	0.321	-0.066	-0.129	
	SE	0.037	0.042	0.024	0.024	
	t	6.729	7.630	-2.725	-5.373	
	p	< 0.001*	< 0.001*	0.006*	< 0.001*	
		Training x Spelling	Training x Exposure 2 vs. 1	Training x Exposure 3 vs. 2	Spelling x Exposure 2 vs. 1	Spelling x Exposure 3 vs. 2
Two-way Interactions	*b*	-0.233	-0.074	-0.011	-0.091	0.025
	SE	0.058	0.048	0.048	0.048	0.048
	t	-4.002	-1.537	-0.223	-1.889	0.513
	p	< 0.001*	0.124	0.824	0.059	0.608
		Training x Spelling x Trial 2 vs. 1	Training x Spelling x Trial 3 vs. 2			
Three-way Interactions	*b*	-0.077	0.221			
	SE	0.096	0.096			
	t	-0.804	2.305			
	p	0.421	0.021*			

Note. * denotes statistical significance

Results of the model for *total reading time* are presented in Table D5. A fixed effect of exposure was observed such that fixation durations reduced from the first to the second exposure and from the second to the third exposure. An effect of training was again observed such that trained items were fixated for shorter durations than untrained items. The effect of spelling predictability was also significant such that items with predictable spellings were fixated for a shorter duration than items with unpredictable spellings. Training and spelling predictability interacted, with the effect of spelling predictability being larger for orally trained compared to untrained items. Contrasts showed that the interaction between training and spelling predictability was only present in the first (χ^2 = 9.975, $p = 0.003$) and second exposure (χ^2 = 17.109, $p < 0.001$) but not in the third (χ^2 = 1.933, $p = 0.164$). A three-way interaction was also observed, which suggested that the interaction between training and spelling predictability was significantly smaller at the third exposure compared to the second exposure. No other interactions were significant.

Table D6.

Results of the linear mixed effects model for regressions in.

		Training	Spelling	Exposure 2 vs. 1	Exposure 3 vs. 2	
Fixed effects	*b*	0.547	0.174	0.098	-0.529	
	SE	0.109	0.101	0.097	0.101	
	t	5.033	1.722	1.011	-5.266	
	p	< 0.001*	0.085	0.312	< 0.001*	
		Training x Spelling	Training x Exposure 2 vs. 1	Training x Exposure 3 vs. 2	Spelling x Exposure 2 vs. 1	Spelling x Exposure 3 vs. 2
Two-way Interactions	*b*	-0.2901	-0.724	0.119	-0.260	0.090
	SE	0.190	0.195	0.201	0.195	0.201
	t	-1.531	-3.721	-0.592	-1.334	0.447
	p	0.126	< 0.001*	0.554	0.182	0.655
		Training x Spelling x Trial 2 vs. 1	Training x Spelling x Trial 3 vs. 2			
Three-way Interactions	*b*	0.023	-0.366			
	SE	0.389	0.401			
	t	0.059	-0.913			
	p	0.953	0.361			

Note. * denotes statistical significance

Results of the model reflecting the *probability of regressions* back to the target word are presented in Table D6. There was no significant effect of spelling predictability. There was no significant difference in the probability of rereading between the first and second visual exposures, but the probability of rereading did reduce significantly between the second and third exposures. An effect of training was observed such that trained items were less likely to be reread than untrained items; this training effect reduced from the first to the second exposure, but not from the second to third exposure. No other interactions were significant.

Follow-up testing

Models reflecting accuracy and latency were run for the delayed go/no-go lexical decision task. Fixed effects were training, spelling predictability and their interaction. The same process of model construction and selection as described above was also applied to the analysis of the follow-up task data.

Go/no-go lexical decision accuracy. On average, participants correctly inhibited responding to 81.9% of the distractor items. These data were removed prior to analysis and do not appear in Figure D4, which depicts the means and standard errors of lexical decision accuracy for orally trained and untrained items. A logistic linear mixed effects model with lexical decision accuracy as the dependent variable showed a fixed effect of training ($\beta = -4.710$, $SE = 0.562$, $z = -8.384$, $p < 0.001$) such that children recognized trained words with greater accuracy than untrained words. There was no effect of spelling predictability ($\beta = 0.043$, $SE = 0.285$, $z = 0.152$, $p = 0.880$) and no interaction between training and spelling predictability ($\beta = 0.274$, $SE = 0.5010$, $z = 0.537$, $p = 0.591$).

Go/no-go lexical decision latency. Only correct ‘yes’ responses were submitted to this analysis. In line with the analysis of eye movement data, lexical decision latency data was log transformed. Means and standard errors of lexical decision latency are presented graphically in Figure 4. The model showed a fixed effect of training ($\beta = 0.389$, $SE = 0.040$, $t = 9.611$, $p < 0.001$) such that children initiated a reading response to trained words more quickly than to untrained words. Predictable spellings were associated with a smaller response latency than unpredictable spellings ($\beta = 0.112$, $SE = 0.036$, $t = 3.098$, $p = 0.005$). The interaction between training and spelling predictability was not significant ($\beta = -0.075$, $SE = 0.058$, $t = -1.305$, $p = 0.198$).

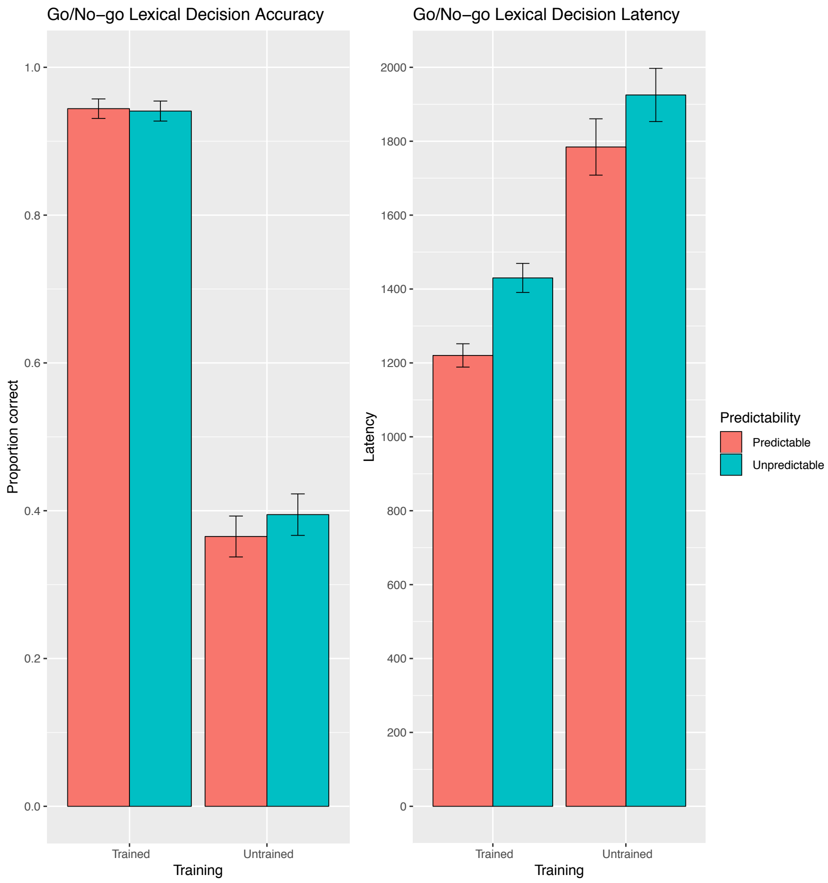

Figure D4. Means and standard errors of go/no-go lexical decision accuracy and latency. Accuracy is depicted as proportion correct while latency is expressed in milliseconds.

Discussion

The current experiment sought to replicate the orthographic skeleton effect at the first visual exposure, and then asked whether spelling expectations continue to be evident as children encounter these words in writing for a second and third time, or whether with increasing visual experience, they might be observed to undergo a process of updating which may serve to bring them closer to the form experienced in print.

The eye movement signature of orthographic expectancies is a larger effect of spelling predictability for orally trained compared to untrained items (Wegener et al., 2018). At the first visual exposure, the anticipated pattern was observed on the eye movement measures of gaze duration and total reading time (but not first fixation duration, which is discussed later). Since children's online processing differed according to the correspondence between their orthographic expectancies and the actual orthographic form experienced in print, both at first pass and on subsequent looking time measures, this largely replicates our initial work. These findings provide additional support for the existence of a causal mechanism that contributes to orthographic learning prior to visual exposure by permitting a flow of information from phonology to orthography. As such, these findings imply that existing theories of orthographic learning (Perfetti, 1992; Perfetti & Hart, 2002; Share, 1995, 2008) could reasonably be extended to accommodate this complementary causal mechanism through which oral vocabulary might support reading acquisition.

Having observed orthographic expectancies at the first visual exposure, we asked whether the effect remained evident on subsequent visual exposures. At the second visual exposure, oral training and spelling predictability continued to interact on the looking time measures of gaze duration and total reading time, with trained items demonstrating a larger effect of spelling predictability than untrained items. Although this interaction was numerically larger at the second compared to the first visual exposure, the difference did not reach significance. Findings at the second visual exposure are thus consistent with those observed at the first orthographic exposure. We, like McKague and colleagues (2008), have argued that influences on orthographic processing measures arising from phonology are likely to be strongest at the first visual exposure. According to theories of orthographic learning (Perfetti, 1992, 2007; Perfetti & Hart, 2002; Share, 1995, 1999, 2008), each visual exposure to a novel written word provides an opportunity for children to make mappings between orthography and phonology. On this basis, accumulating visual experience might be viewed as resulting in growing influences flowing from orthography to phonology. Therefore, we interpret the persistence of the orthographic skeleton effect at the second visual exposure as likely reflecting residual influences from phonology to orthography, in combination with increasing influences running from orthography to phonology.

Findings from the third orthographic exposure support the view, as espoused in theories of orthographic learning (Perfetti, 1992, 2007; Perfetti & Hart, 2002; Share, 1995, 1999, 2008), that building visual experience provides opportunities for children to make mappings between orthography and phonology. At this point in processing, training and spelling predictability did not interact on any looking time measure. For gaze duration there was a non-significant trend ($p = 0.098$) suggesting that the training by spelling predictability interaction diminished between the second and third orthographic exposures. At total reading time, the diminishing size of the training by spelling predictability interaction reached significance between the second and third orthographic exposures. Together, these findings suggest that when children are provided with opportunities to build orthography-phonology mappings, their initial spelling expectancies begin to undergo an updating process in light of this visual experience. The onset of this process is able to be captured in measures of online moment-to-moment processing as visual exposures unfold over time, with clear evidence of updating occurring between the second and third encounters.

As already alluded to, the pattern of results obtained on the eye movement measure of first fixation duration differed from that observed on the other measures of looking time. At the initial visual exposure there was no significant effect of our experimental manipulations on the children's first fixations. By the second exposure, a benefit of training emerged which was maintained at the third exposure. However, at no point was the interaction between training and spelling predictability observed in the predicted direction; rather, there was either no interaction at all (on the first and third orthographic exposure), or there was an interaction observed that was the reverse of our expectations (at the second exposure) with untrained items showing a larger effect of spelling predictability than trained items. We speculate that these findings, which unexpectedly differ from the pattern observed in Wegener and colleagues (2018) and two other forthcoming experiments, simply reflect some degree of variability across experiments. In the current experiment, the addition of subsequent first pass fixations (as in gaze duration) yields clear effects in the expected direction for the first and second orthographic exposures, which we suggest lends support to this interpretation.

As anticipated, an advantage for trained words was apparent in a measure reflecting the probability of regressions, demonstrating that children were less likely to reread orally familiar than unfamiliar words. This is consistent with the finding that novel words are more likely to be refixated than familiar words (Chaffin et al., 2001). It also aligns with our own prior work suggesting that oral familiarity is a more important determinant of rereading behaviour than the predictability of target word spellings (Wegener et al., 2018). Two other aspects of the current findings are of interest, both of which suggest that rereading behaviour is modified by visual experience. First, the training benefit was strongest at the first visual exposure to the novel target words, implying that for the probability of rereading, there may be a diminishing role of oral familiarity with building visual experience. Future work might test this possibility more directly by providing further visual exposures and asking at what point oral familiarity ceases to influence rereading behaviour; doing so will expand our understanding of how online processing evolves with building visual experience. Second, the overall probability of rereading reduced between the second and third visual exposures, regardless of whether the items had been trained. This latter finding resonates with others showing that that as reading experience accrues, participants engage in less rereading of new word forms (Joseph & Nation, 2018).

Follow-up testing addressed the question of the longer term influence of the orthographic skeleton on children's delayed orthographic form recognition. It was anticipated that orally trained items would be more likely to be correctly recognized as visually familiar and would be responded to more quickly than items that were orally unfamiliar. However, it was not entirely clear what role spelling predictability might play. Based on the idea that children's orthographic expectancies were likely to match the written form of trained items with predictable spellings, we anticipated that the need to update the initial orthographic expectancy for these items should be substantially reduced or removed, potentially placing them at an advantage in the delayed word recognition task. In the event of misalignment of the child's orthographic expectancy and the orthographic form, the incongruence could either confer a smaller subsequent visual word recognition advantage because there is a greater requirement for adjustment; or, the incongruence might drive learning by providing a strong cue for updating the early orthographic representation. Results with respect to recognition accuracy revealed a very large effect of training only, with performance being essentially at ceiling for all trained items. Latency data similarly showed a strong effect of training and an additional effect of spelling predictability, but no interaction between them. The finding of a strong effect of training is consistent with our predictions and with the growing experimental literature demonstrating that spoken word knowledge conveys an advantage within the process of written word learning (Duff & Hulme, 2012; McKague et al., 2001; Nation & Cocksey, 2009). Current findings build on existing work by additionally showing that the benefit of oral familiarity persists over time, extending over a period of at least several days regardless of the spelling predictability of the written form. The current experiment cannot allow us to draw conclusions about the processes underlying the training advantage. It may be that a single process underlies the training effect, or it may be the case that trained items with predictable and unpredictable spellings benefited from training in different ways, perhaps as outlined above. The general advantage for orally trained items suggests that some updating, particularly of incongruent orthographic representations, occurred during the learning trials that was sufficient to subsequently support children's visual word recognition at a delay. By this, we do not mean to suggest that the updating process was complete to the extent that it was stable and encoded a precise spelling in the manner Perfetti (1992, 2007; Perfetti & Hart, 2002) describes. Indeed, we did not test children's spelling so data from the current experiment cannot speak to this issue.

Models of skilled reading (Coltheart et al., 2001; Plaut et al., 1996) and orthographic learning (Perfetti, 1992, 2007; Perfetti & Hart, 2002; Share, 1995, 1999, 2008) predict that the accrual of experience with written words should influence visual word recognition and the acquisition of written word forms respectively. Findings from the eye movement monitoring task in the current experiment suggest that orthographic knowledge can be brought to bear on the task of reading even prior to an initial visual encounter with an orally known word. Further, these early orthographic representations were found to begin to be updated by the third orthographic exposure. The initiation of an updating process observable during moment-to-moment processing during repeated reading of novel words is consistent with Perfetti's notion that building visual experience allows orthographic representations to "evolve towards completeness" (Perfetti, 1992, p. 159). Further, the finding that prior oral vocabulary knowledge supports the delayed recognition of previously encountered written word forms also supports the lexical quality hypothesis, insofar as it predicts that reading behaviours should be influenced by variations in the types (form and meaning) of available lexical information (Taylor & Perfetti, 2016).

Future work should seek to build on our current understanding of the orthographic skeleton and the conditions that support it. For example, our investigations have so far been limited to questions surrounding children's ability to form spelling expectations for monosyllabic, monomorphemic words. Of future interest will be whether children might also be able to form spelling expectations for polysyllabic or polymorphemic words. Another important question concerns the issue of whether orthographic skeletons are generated automatically upon hearing a spoken word, or strategically as a form of mnemonic aid to assist children to encode the novel oral vocabulary.

Conclusions

The current experiment provides further evidence consistent with the view that spoken word knowledge, in combination with knowledge about mappings between phonemes and graphemes, permits children to form expectations about the likely spellings of words that have not been encountered in print. These spelling expectancies were observed at the first visual exposure, consistent with prior work. Persisting evidence of spelling expectancies was observed at the second but not at the third visual exposure, suggesting that visual experience permits updating of the orthographic representation that is observable in online processing measures. Children's performance on delayed follow-up testing suggested a substantial ongoing advantage for all orally trained items, implying that when the initial orthographic expectancy is misaligned with the orthographic form experienced in writing, it is able to be sufficiently updated so as to support subsequent orthographic learning performance.

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Appendices

Appendix D1.

Experimental sentences.

	First exposure	Second exposure	Third exposure
1.	Rick put his dirty socks into the xxx to clean them.	His socks were so dirty he did not think the xxx could get them clean.	He was happy when white socks fell out of the xxx and into the basket.
2.	Diana put the best orange on the xxx to juice it.	The juice quickly filled the cup as the xxx sucked on the orange.	When the orange had been juiced she rinsed the xxx and put it away.
3.	Pam put the dirty flowers under the xxx to polish them.	The flower looked brighter as soon as the xxx touched its petals.	When the flowers looked clean she turned off the xxx and put it away.
4.	Max put his food in the xxx to remove the peas.	After his food was sorted by the xxx he sat down to enjoy his dinner.	He took the peas out of the xxx and put them in the bin.
5.	Sara put her soaking wet hat on the xxx to dry it.	The hat was dry after the xxx had been spinning for two minutes.	The girl took her hat off the xxx and put it into her school bag.
6.	Lucy loaded the rubbish into the xxx to sort it for recycling.	She put rubbish bins under each spout of the xxx before turning it on.	When the rubbish had been sorted by the xxx it was put out for collection.
7.	Lucas put his sore tummy beside the xxx and he felt better.	When his tummy pain was gone the boy told his Mum that the xxx had worked.	The next time the boy had a tummy pain he used the xxx straight away.
8.	Jennifer put her soggy chips under the xxx to make them crispy.	The chips quickly became brown as the xxx blew hot air on them.	Before the girl ate her crispy chips she put the xxx back in its box.
9.	Nick put the deck of playing cards into the xxx to shuffle them.	He watched the playing cards as the xxx mixed them up.	After the cards had been well shuffled the xxx turned itself off.
10.	Rex put the tennis ball back into the xxx to keep playing fetch.	The tennis balls were thrown by the xxx very quickly.	The dog just had time to return the ball before the xxx threw another one.
11.	James put the girl's picture into the xxx to find out her name.	When the boy saw the name on the xxx he recognized it straight away.	The boy often had trouble remembering names so he used the xxx quite a lot.
12.	Jane put her cold and sore feet into the xxx to warm them.	Her feet felt like ice until the xxx heated up.	Her feet became so warm in the xxx that she had to turn it off.
13.	Matt put his feet into the xxx so he could climb up the wall.	The boy looked at the wall and then at the xxx on his feet.	It was so easy to climb the wall when the xxx was turned on.
14.	Sam waited for the birds to land on the xxx to hear them sing.	Three birds landed on the xxx as it played music.	The birds sang along with the xxx as it played its tune.
15.	Ben picked up the fish	The fish swam away from	When the fish tank was

	tank and the xxx to clean the dirty glass.	the xxx as it scrubbed the glass.	clean he turned off the xxx and put it away.
16.	Pip waited while the brushes on the xxx removed the sand from his body.	Before leaving the beach he used the xxx to brush the sand off his skin.	When all the sand was gone he turned off the xxx and went home.

Chapter 6

General Discussion

General Discussion

Knowledge of the spoken form of a word is thought to assist children to learn to read that specific word (Duff & Hulme, 2012; McKague, Pratt, & Johnston, 2001), yet little is known about how this presumed causal relationship might operate (Duff, Reen, Plunkett, & Nation, 2015). Whereas most theoretical accounts attribute the oral vocabulary advantage to the operation of a causal mechanism that begins from the point of visual exposure (e.g., Ehri, 2014; Perfetti, 1992; Share, 2008), this dissertation made the case that interactivity between spoken and written language might permit the operation of an additional complementary cognitive mechanism which begins to influence learning prior to visual exposure.

Two overarching aims have been addressed in the body of work presented in this dissertation. The first aim was to elucidate a theory of a novel cognitive mechanism through which oral vocabulary knowledge might benefit word reading prior to visual exposure. To this end, Chapter 1 reviewed the literature pointing to the viability of such a cognitive mechanism while Chapter 2 (not presented for examination) built on this to advance the *orthographic skeleton hypothesis*, according to which children draw both on their knowledge of spoken words and their appreciation of the mappings between sounds and letters to form expectations of the spellings of known spoken words before a word has even been seen in print.

The second aim was to use this initial work as the theoretical foundation for further empirical investigation of this proposed cognitive mechanism, with a view to building an elaborated account of the generation of orthographic skeletons and how they influence ongoing written word learning. To this end, three further empirical studies are reported. Chapter 3 investigated the roles of lexical phonology (pronunciations) and semantics (meaning) within the formation of the orthographic skeleton. In Chapter 4, the form of children's initial spelling expectancies was investigated by asking whether spelling expectancies are best characterised as partial representations built around a word's consonants, or complete but tentative representations. Chapter 5 investigated the question of whether children's initial spelling expectancies remain evident over subsequent visual exposures, or whether they might instead begin to evolve with building visual experience during the early stages of orthographic learning. Chapters 3 to 5 additionally investigated the influence of the orthographic skeleton on one or more subsequent tasks – reading aloud, spelling, or lexical decision – which assess ongoing orthographic learning.

The remainder of this chapter will summarize the major findings and implications of the experiments presented in this dissertation. Following this will be a discussion of the contributions and limitations of the dissertation as a whole, and drawing on these, directions for future research will be outlined.

Summary of findings

Eye movements and the orthographic skeleton

Children can form orthographic skeletons of orally known words. Chapter 2 reviewed evidence suggesting that children's oral vocabulary and reading skill are causally related, with spoken word knowledge exerting a direct influence on written word learning (Duff & Hulme, 2012; Duff et al., 2015; Lee, 2011; McKague et al., 2001). Drawing on evidence that an individual's knowledge of their writing system automatically penetrates their spoken word processing (see Taft, 2011 for a review), it was proposed that this interactivity between spoken and written language might permit the operation of a cognitive mechanism which begins to influence learning prior to visual exposure. The *orthographic skeleton hypothesis* was described, which suggests that children can draw on both their oral vocabulary and their knowledge of phoneme-to-grapheme mappings to form expectations about the likely spellings of words they have heard before but never seen. To test this possibility, a training paradigm was employed in which Year 4 children were first pre-exposed to the pronunciations and meanings of a set of novel words, while never encountering their written form. Subsequently, these words were embedded in simple sentence frames and children read them, along with another set of items that had not been pre-exposed, while their eye movements were monitored. At the point of reading, the spelling predictability of the novel words was manipulated so that some had spellings that were highly predictable from their pronunciations (e.g., the spoken word ‘nesh’ written as *nesh*) while others had spellings that were unpredictable from their pronunciations (e.g., the spoken word ‘coib’ written as *koyb*). This manipulation was applied with a view to creating conditions in which children’s orthographic expectancies, if they had indeed been formed, either matched (predictable spellings) or did not match (unpredictable spellings) the orthographic form they saw in writing. The results showed that children’s online processing of orally taught novel words varied according to the predictability of their spellings to a greater extent than was observed for orally untrained words. This interaction between training and spelling predictability was present across the eye movement record and was interpreted as support for the position that children can form orthographic expectancies of orally known words prior to visual exposure. These ‘orthographic skeletons’ are evident at the first visual exposure, and are particularly beneficial when words have spellings that are highly predictable from their pronunciations.

The contributions of lexical phonology and semantics to the generation of orthographic expectancies. In Chapter 3, distinctions were drawn between influences arising from lexical phonology and semantics (either from the lexical representation itself or from the context in which it appears). Drawing on these distinctions, novel predictions arising from the orthographic skeleton hypothesis were described. First, possession of knowledge about a word’s phonological form was thought a necessary and likely sufficient prerequisite to the formation of orthographic skeletons because the spoken word form can be decomposed into its constituent phonemes, and then mapped onto corresponding graphemes. Second, drawing on the lexical quality hypothesis (Perfetti, 1992, 2007;

Perfetti & Hart, 2002), it was proposed that the availability of lexical semantic information in addition to lexical phonology may confer an indirect benefit in the process of generating orthographic skeletons because the addition of semantic information renders it a higher quality representation. Third, it was proposed that contextual semantic support might assist children to activate their skeletal orthographic representation online during reading. To test these hypotheses, the same manipulations of oral vocabulary training and spelling predictability employed in Chapter 2 were retained. Extending this work, one group of Year 4 children were taught only the pronunciations of a set of novel words, while another group were taught both pronunciations and meanings. Children later read the trained items and a matched set of untrained items as their eye movements were monitored. Sentence contexts were supportive for children who had received instruction in lexical semantics but neutral for children who had only learned pronunciations.

The condition in which children were taught both pronunciations and meanings permitted a direct replication of Chapter 2. As expected, the results of Chapter 3 were consistent with those reported in Chapter 2, and provided converging evidence of a larger effect of spelling predictability for orally trained compared to untrained items across the eye movement record in this condition. When the children had only learned pronunciations, the results suggested that this knowledge was sufficient to give rise to orthographic skeletons that were weak early in processing but clearly evident late in processing. When the group of children who had been taught both pronunciations and meanings was compared to the group of children who had been taught only pronunciations, semantic knowledge did seem to convey some advantage to the generation of the orthographic skeleton. The finding that semantics boosts children's orthographic expectancies is potentially consistent with two explanations. One gives weight to the role of increased lexical quality conferred by the addition of lexical semantic knowledge, while the other gives weight to the role of contextual support during reading. The respective contributions of lexical semantics and contextual facilitation remain to be established in future research.

The form of early orthographic expectancies. Chapter 4 reports the outcome of an experiment designed to probe the form of the initial spelling expectancies that children can generate on the basis of their oral vocabulary knowledge. Drawing on the lexical quality hypothesis (Perfetti, 1992; Perfetti & Hart, 2002, 2002), we asked whether orthographic skeletons are partial representations built around a word's consonants, or whether they are complete representations that may be transiently incorrect. These possibilities were evaluated by applying the same oral vocabulary training manipulation as employed in Chapter 2. A modified spelling predictability manipulation was employed, which distinguished between spellings that were highly predictable from pronunciations and spellings that contained either an unpredictable consonant or vowel spelling.

Consistent with findings reported in Chapters 2 and 3, there was clear evidence that children formed orthographic skeletons on the basis of their oral vocabulary knowledge. Across the eye movement record, items with predictable spellings benefited from oral training. First pass reading measures showed that this benefit of oral training for predictable spellings was significantly larger than for both unpredictable consonant and unpredictable vowel spellings, suggesting that children's orthographic skeletons initially include both consonants and vowels. Late in processing, this pattern persisted only for unpredictable consonants, raising the possibility that unexpected vowel spellings may be able to be more rapidly resolved online than unexpected consonant spellings. These results were interpreted as consistent with the view that orthographic skeletons are initially complete but tentative orthographic representations.

The evolution of orthographic expectancies over accumulated visual experience. Findings from Chapters 2, 3 and 4 suggest that children can draw on their oral vocabulary knowledge to form initial expectations about the spellings of words they have not seen in writing before. The experiment reported in Chapter 5 employed the same manipulations of oral familiarity and spelling predictability as reported in Chapter 2. The specific aims of Chapter 5 were: (a) to determine whether the orthographic skeleton effect would replicate at the first visual exposure; and (b) extend these findings to address the question of what happens to the orthographic skeleton over repeated visual exposures. Drawing particularly on the lexical quality hypothesis (Perfetti, 1992, 2007; Perfetti & Hart, 2002; Reichle & Perfetti, 2003), it was anticipated that visual experience should provide an opportunity for the initial orthographic skeleton to become closer to the form experienced in writing. It was proposed that if orthographic skeletons do undergo a process of updating, this would be supported by diminishing evidence of the interaction between training and spelling predictability. Consequently, the key question addressed in this experiment was whether orthographic skeleton effect is present at each visual exposure.

Children's eye movements were monitored as they read both trained and untrained items in supportive contexts over three blocked exposures. The orthographic skeleton effect was observed on measures of gaze duration and total reading time at the first and second orthographic exposure, consistent with the notion that oral vocabulary knowledge had facilitated the formation of spelling expectations. By the third orthographic exposure this interaction was no longer significant for any measure of fixation duration, suggesting that as predicted, visual experience had begun to update children's spelling expectations.

The orthographic skeleton effect across experiments. There is high degree of alignment between the experimental chapters in terms of the eye movement signature of the orthographic skeleton effect: having a word in oral vocabulary facilitates online processing when spellings are highly predictable from pronunciations, but not when spellings are unexpected. This pattern is observed throughout Chapters 2 to 5, and consistently supports the view that children generate expectations of the spellings of orally known words prior to visual exposure. While this basic finding replicates both directly and conceptually across each of four different experiments, there are some subtle differences in the eye movement record across experimental chapters that are worthy of mention.

In Chapters 2 to 4 the orthographic skeleton effect was consistently present on both measures of first pass reading (first fixation duration and gaze duration), suggesting that spelling expectations impact on early lexical identification processes. The results of Chapter 5, on the other hand, showed evidence of the effect on only one of the measures of first pass reading (gaze duration). While reassuring in terms of the general interpretation that the orthographic skeleton is evident early in processing, the failure to find the effect at first fixation duration raises the question of why this might be. In the relevant experimental chapter we suggested that the inconsistency likely reflects some degree of expected variation across experiments, and we continue to believe that this is the most parsimonious explanation. We further suggest that such variability was most likely to be observed on first fixation duration rather than gaze duration because the orthographic skeleton effect tends to increase between these two measures (as signalled by the lower p values for gaze duration than first fixation duration across all experimental chapters).

In Chapters 2, 3 and 5 the orthographic skeleton effect persisted on the late processing measure of total reading time. Notably, the same stimuli were used in Chapters 2, 3 and 5. This is important because the location of the spelling unpredictability in these items was variable: sometimes it arose from a consonant, sometimes from the vowel, or sometimes both. In Chapter 4, different stimuli were used to separate out the influence of unpredictability arising from either the consonant or the vowel. Findings from Chapter 4 raised a possible reason for the persistence of the orthographic skeleton effect late in processing in Chapters 2, 3 and 5. Specifically, the results of Chapter 4 showed that only spelling unpredictability in the consonant position continued to give rise to the orthographic skeleton effect late in processing, whereas unexpected vowel spellings did not. Thus, the persistence of the effect observed in Chapters 2, 3 and 5 might be due, at least in part, to the presence of unpredictable consonant spellings in some of these stimuli.

The influence of the orthographic skeleton on subsequent orthographic learning

Chapters 3 to 5 each addressed the influence of the orthographic skeleton on subsequent measures of orthographic learning. Findings relating to each follow-up task are discussed below.

Reading aloud accuracy and latency. Chapters 3 and 4 both included assessment of the children's reading aloud accuracy and latency immediately following the initial orthographic exposure which occurred in the context of the eye tracking task. In Chapter 3, children completed four reading aloud trials. The results showed significant effects of training and spelling predictability on accuracy and latency, with trained items and those with predictable spellings being read more accurately and quickly than untrained items and those with unpredictable spellings. Increasing visual exposure was associated with decreasing reading aloud latency, and reductions in the effects of both training and spelling predictability.

In Chapter 4, children completed one reading aloud trial. The results again showed that trained items were read more accurately and quickly than untrained items. Spelling predictability again exerted an effect on accuracy, with predictable spellings more likely to be read correctly than unpredictable vowel, but not unpredictable consonant spellings. Similarly, spelling predictability also influenced reading aloud latency, with predictable spellings read faster than either unpredictable consonant or vowel spellings.

Chapters 3 and 4 both showed that, on these follow-up reading aloud measures, while there was a clear effect of training, it no longer interacted with spelling predictability. This is consistent with broader findings suggesting that spoken knowledge conveys an advantage within the process of written word learning (Duff & Hulme, 2012; McKague et al., 2001). Further, it suggests that the surprise afforded by the presentation of an unpredictable spelling at the first visual exposure (in the context of the eye movement monitoring task) is able to be resolved on subsequent measures of processing. This implies, along with findings reported in Chapter 5, that visual exposure permits orthographic skeletons to undergo some process of updating that presumably serves to bring them closer to the form experienced in print. This improvement is sufficient to support subsequent reading aloud performance, and is consistent with predictions arising from the lexical quality hypothesis.

Spelling. The children's ability to learn and retain fully specified orthographic forms was assessed in both Chapters 3 and 4, albeit using slightly different methods. In Chapter 3, children were required to spell all items at a single time point. Trained and untrained items were interleaved when they were presented for spelling to dictation at a delay of approximately one week following five orthographic exposures to all items. These exposures included the initial visual encounter in which children read the target words in sentence contexts while their eye movements were monitored, and four visual exposures occurred in a reading aloud task in which target words were presented in isolation. Although the results revealed a strong effect of spelling predictability, there was no effect of training. The lack of a training effect in Chapter 3 prompted some modification of the method of orthographic exposures in subsequent experiments.

In Chapter 4, children were forewarned that they would be required to spell all items to dictation, and testing occurred at two time points. Children had experienced two visual encounters with the novel word forms. The initial visual exposure occurred when children's eye movements were recorded as they read the target words within sentence contexts, and the second exposure was in the context of a reading aloud task in which the target words were presented in isolation. Items were presented in blocks of trained followed by untrained items, and took place immediately following these visual exposures and again at a time delay of approximately five days. Consistent with findings from Chapter 3, there was a strong effect of spelling predictability. However, unlike the findings reported in Chapter 3, a small effect of training was also observed.

Chapters 3 and 4 provided divergent estimates of the effects of training on longer-term orthographic learning as indexed by spelling performance. Methodological differences between the experiments mean that it is not possible to provide an account of the conditions that give rise to a training effect on subsequent spelling performance. Several factors could conceivably play a role, but this remains to be clarified in future work. Specifically, what is the role of forewarning of an upcoming spelling test; does the blocking of trained and untrained items make a difference; and what is the role of the number of orthographic exposures (i.e., might increasing visual experience be associated with reduced effects of training)?

Chapters 3 and 4 consistently observed a large effect of spelling predictability. The children's performance on items with predictable spellings was consistently high regardless of whether they had been trained (accuracy across both experiments and all time points ≈ 80%). This accuracy rate well exceeds that observed for trained items in prior studies of orthographic learning which have employed items with regular print-to-pronunciation mappings but that have other plausible homophonic spellings (e.g., spelling accuracy of ≈ 50% in Wang, Castles, Nickels, & Nation, 2011). One interpretation of this finding is that children found it easier to remember the word-specific orthography of these items. An alternative interpretation is that knowledge of phoneme-to-grapheme mappings should be sufficient to support spelling accuracy for predictable items. Indeed, this is the basis upon which the items with predictable spellings were constructed. Predictable items were designed to correspond with children's likely spelling expectations. This being the case, the high accuracy rate for predictable spellings may well have resulted from reliance on phoneme-to-grapheme mappings rather than on recall of the word-specific orthography.

The children were able to retain a small proportion of the precise orthographic forms of items with unpredictable spellings. These items all had other plausible, and indeed, more likely homophonic spellings. The finding that children were able to recall such a small number of these unusual spellings might be interpreted as implying that children may also have relied on their knowledge of phoneme-to-grapheme mappings while responding to most of these items. Because the items have unusual spellings, such reliance should lead them to arrive at an incorrect target word spelling. In Chapter 3 accuracy for unpredictable spellings was ≈ 12% when averaged across training conditions. In Chapter 4, a similar level of performance was observed when items had unpredictable vowel spellings (accuracy ≈ 10% when averaged across training conditions), while performance was a little better when items had unpredictable consonant spellings (accuracy ≈ 30% when averaged across training conditions). The generally low level of spelling performance suggests that the task was likely too difficult on the whole. Indeed, there were a large number of spellings for children to recall (32 in Chapter 3 and 36 in Chapter 4) and while all items had regular print-to-pronunciation mappings, half contained one (Chapter 4) or more (Chapter 3) unusual phoneme-to-grapheme correspondence. Therefore, at least in the context of these experiments, spelling does not appear to be a particularly sensitive measure of children's orthographic learning. This being the case, it remains difficult to draw conclusions about the influence of oral vocabulary knowledge and the orthographic skeleton on children's subsequent orthographic learning.

Lexical decision. Motivated by the observation that the indices of orthographic learning adopted in Chapters 3 and 4 were relatively insensitive to the effects of training, Chapter 5 adopted a different approach to the assessment of longer-term orthographic learning. Specifically, children completed a delayed go/no-go lexical decision task in which they were required to rapidly endorse items they had previously encountered during the eye movement monitoring task, while inhibiting responses to distractor items they had never encountered before. This task had several advantages: (a) unlike reading aloud and spelling, children were not required to produce either a spoken or written response; and (b) relative to the standard yes/no lexical decision task, the go/no-go task makes fewer demands on processing and is associated with faster and more accurate responding (Perea, Rosa, & Gómez, 2002). As anticipated, the go/no-go lexical decision task was highly sensitive to the effects of training, showing a very large benefit of oral pre-exposure on delayed orthographic recognition accuracy and latency, while spelling predictability only influenced response latencies but not accuracy.

It was anticipated that the requirement to update initial spelling expectancies of predictable spellings would be minimal, whereas the need to update spelling expectancies for unpredictable spellings would be obvious. On this basis, it was anticipated that predictable spellings might be associated with a particular recognition advantage over unpredictable spellings. However, trained items were at ceiling in terms of accuracy, regardless of their spelling predictability. It is not possible to draw any conclusions about the processes underlying the training advantage, but future work might seek to clarify whether the training advantage observed for predictable and unpredictable spellings arises in the same or different ways.

Learning metrics matter. The studies presented in this dissertation suggest that the method of learning assessment matters. Because eye movements are thought to be sensitive to partial knowledge and incremental learning (Joseph & Nation, 2018; Joseph, Wonnacott, Forbes, & Nation, 2014; Nation & Castles, 2017), this metric was consistently adopted at the first visual exposure and revealed reliable evidence of the basic orthographic skeleton effect. Continued use of this metric at the second and third visual exposures in Chapter 5 provided clear evidence of updating between the second and third visual exposures. When reading aloud was employed as a metric of learning in Chapters 3 and 4, there was evidence of updating that occurred at the second visual exposure. Therefore, while both assessment methods suggest that visual experience permits incremental updating of early orthographic representations, they provide slightly different estimates of the timing of this change.

The importance of learning metrics is reinforced when one considers the widely divergent estimates of learning obtained from the spelling and word recognition tasks. Chapters 3 and 4 both found that when indexed by spelling, estimates of learning are very low, a finding which is broadly consistent with prior reports (e.g., Wang, Castles, Nickels, & Nation, 2011). Conversely, estimates are very high when learning is indexed by an orthographic recognition task. Together, these observations highlight the importance of task demands; they matter and will influence the conclusions that are drawn about what has been learned and when. In weighing up decisions about the choice of learning metric, an orthographic learning researcher might be guided by deciding whether their aim is to provide converging evidence that *some* learning has occurred, or whether the goal is instead to provide a unified (and possibly continuous) metric of learning as indexed by one specific task.

Contribution

The major contributions of this dissertation to the broad field of reading research are threefold.

A novel theory of the association between oral vocabulary and reading acquisition

Results from the four experiments reported in this dissertation are consistent with the view, advanced by the orthographic skeleton hypothesis, that children can draw on their knowledge of correspondences between phonemes and graphemes to form expectations about the spellings of words they know in spoken form but have never seen in print. Although the orthographic skeleton hypothesis is not the first to suggest that oral vocabulary might exert an influence on written word learning prior to visual exposure (McKague, Davis, Pratt, & Johnston, 2008; Stuart & Coltheart, 1988), it is the first to have shown evidence for its operation in children, establishing it as one developmentally plausible mechanism via which vocabulary knowledge might benefit reading acquisition, at least once children are in possession of some sound-to-letter knowledge and phonological awareness. Further, the approach adopted is unique in demonstrating the operation of this causal mechanism dynamically as children read novel words for the first time.

An elaborated account of the generation of orthographic skeletons and their influence on longer-term orthographic learning

Building on the initial theory proposed in Chapter 2, the subsequent experimental papers have together offered an elaborated account of the formation of orthographic skeletons and their influence on longer-term orthographic learning. For instance, it has been shown that knowledge of pronunciations promotes the generation of orthographic skeletons, but the presence of semantics (either from the lexical representation itself or from the context in which it appears) provides an additional boost. Additionally, orthographic skeletons appear likely to initially take the form of complete but tentative orthographic representations. Further, these tentative representations demonstrate evidence of evolution with accumulating visual experience. Finally, orthographic skeletons and prior oral vocabulary knowledge in general confer an ongoing benefit to children's subsequent reading aloud and orthographic form recognition regardless of the alignment of the orthographic expectancy and the orthographic form.

Broader implications

The findings reported in this dissertation contribute to several existing bodies of work. First, they corroborate data that points to a causal relationship between oral vocabulary and reading acquisition (Duff & Hulme, 2012; Duff et al., 2015; Lee, 2011; McKague et al., 2001). Second, they extend the growing literature demonstrating interactivity between spoken and written language in adulthood (Chéreau, Gaskell, & Dumay, 2007; Petrova, Gaskell, & Ferrand, 2011; Taft, 2011; Taft, Castles, Davis, Lazendic, & Nguyen-Hoan, 2008) and during childhood (Ventura, Kolinsky, Pattamadilok,

& Morais, 2008; Ventura, Morais, & Kolinsky, 2007). And third, they confirm the utility of adopting a training paradigm in combination with eye movement monitoring for investigating the effects of lexical quality on reading, as originally suggested by Taylor and Perfetti (2016). Here, the basic paradigm has been extended to investigate issues related to the development of reading skill in child populations.

Limitations

A limitation of this dissertation concerns the manipulation of spelling predictability applied to the target words in each of the reported experiments. During the design of the manipulation of spelling predictability, the primary intention was to develop an item set which would maintain print-to-pronunciation regularity while exerting a high degree of control over the likely alignment of children's orthographic expectancies, should they exist, and the orthographic form viewed in print. Specifically, orthographic expectancies should have a high probability of aligning with the predictable spellings, while having a low probability of aligning with the unpredictable spellings. Pursuit of this goal had the consequence that the item sets were not matched with respect to the number of letters (Chapters 2, 3, and 5) or the number of phonemes (Chapter 4) and bigram frequency (Chapters 2 to 5), a fact which was reflected in children's fixation durations on untrained items in Chapter 2. These baseline differences in looking time, however, cannot account for the observed interaction between training and spelling predictability. For this reason, and to ensure tight links between each experiment, the strong manipulation of spelling predictability was retained through this dissertation.

Each experimental chapter has argued that the key interaction between training and spelling predictability should be interpreted as reflecting the operation of processes that begin prior to visual exposure. As alluded to in Chapter 2, another interpretation is possible: it could instead be attributed to the operation of processes that occur from the point of visual exposure. That is, when a child ordinarily sees a word with a more common spelling, this facilitates phonological decoding. But, when that common spelling relates to a word that is orally familiar, the facilitatory effect of the common spelling is somehow enhanced. Chapter 2 offers a rationale for the view that the orthographic skeleton effect is more compatible with an interpretation that attributes it to the operation of processes that begin prior to visual exposure, but acknowledges that the test of the orthographic skeleton hypothesis cannot definitively rule out this alternative explanation. Given that each of the subsequent experiments adopt the same or similar stimuli, the point equally applies to them.

It will be important for future work to address this issue by attempting to match predictable and unpredictable spellings more closely. The challenge in this respect will be to concurrently maintain print-to-pronunciation regularity along with strong control over the likelihood that the orthographic skeleton is either congruent or incongruent with the actual orthographic form. Maintaining print-to-pronunciation regularity is essential because when words contain irregularities in these mappings, assembled pronunciations will not align with any word held in oral vocabulary and should therefore require the use of some form of post-hoc matching process (Share, 1995, 2008).

While achieving better matching of stimulus properties, manipulations of predictability applied elsewhere (e.g., Perry, 2003; Ziegler, Petrova, & Ferrand, 2008) may not offer the desired level of control over the correspondence between orthographic skeletons and their actual form. To illustrate this point, imagine there are two or three plausible spellings for a given phonology (/sɜːd/) that maintain print-to-pronunciation regularity (*sird, serd, surd)*. If selecting items for an unpredictable spelling condition, the option with the most common phoneme-to-grapheme correspondences would be avoided (the *ur* spelling has the highest type frequency). But what if the other options were only slightly or somewhat less common, as is the case for *serd* and *sird*? This would presumably result in a fairly high likelihood that a child's orthographic expectancy might actually match the orthographic form that was selected to be unpredictable, which would be highly undesirable. There may be potential to obtain some advantage in the process of stimuli selection by exploiting the well-established finding that the spelling of vowel sounds, which are notoriously variable, become more predictable when the preceding and following consonants are considered (Kessler & Treiman, 2001; Treiman, Berch, & Weatherston, 1993; Treiman & Kessler, 2006). Specifically, if the consonantal context of a spoken word biases the form of children's orthographic expectancies, this could be exploited by choosing a spelling that runs counter to this bias. For example, the initial phoneme /k/ is most frequently spelled with the grapheme *c* as in the word *coast* unless it is followed by the /ɛ/ phoneme. In this case, it is more often spelled with the grapheme *k* as in the word *kept*. Therefore, if the target pronunciation were /kɛt/, then an unpredictable spelling might take the form *cet*.

An entirely different approach would be to employ the same basic paradigm while explicitly setting out to test the idea that oral vocabulary knowledge supports reading acquisition from the point of visual exposure. Such an experiment might provide training in novel oral vocabulary and subsequently manipulate the print-to-pronunciation regularity of the novel words at the point of visual exposure. The eye movement signature of this effect should more strongly index processes occurring from the point of visual exposure, and this could be compared with the eye movement signature of the orthographic skeleton effect as reported in this dissertation.

Future Directions

The role of context

The results of Chapter 3 pointed to a potential role of semantics within the formation of the orthographic skeleton. However, it was not possible to determine whether the observed advantage originated in lexical semantic knowledge, or as a consequence of contextual facilitation, or some combination of the two. Future studies should attempt to disentangle the contributions of lexical semantics and context. One possible method of exploring this issue would be to provide children with training in both the pronunciations and meanings of novel words but later present those items, along with untrained items, within contextually neutral sentences. If the orthographic skeleton effect is still present in first pass reading measures under these conditions, it would imply that it is driven largely by lexical semantic knowledge rather than by contextual support during reading.

The potential role of strategy

The experiments reported in this dissertation did not address the issue of whether orthographic skeletons arise automatically or strategically at the point of oral vocabulary learning. The finding that orthography is automatically activated during spoken word processing (Chéreau et al., 2007; Pattamadilok, Morais, De Vylder, Ventura, & Kolinsky, 2009; Pattamadilok, Morais, Ventura, & Kolinsky, 2007; Petrova et al., 2011; Taft et al., 2008; Ventura et al., 2008, 2007; Ziegler & Ferrand, 1998) implies that orthographic skeletons could arise automatically as children listen to the novel oral vocabulary during training. On the other hand, findings suggesting that orthography can act as a potential mnemonic aid for assisting children to remember novel phonology (Jubenville, Sénéchal, & Malette, 2014; Ricketts, Bishop, & Nation, 2009; Rosenthal & Ehri, 2008) suggests that there may be some benefit associated with deliberately adopting a strategy of generating predictions about the spellings of words during oral training. A third possibility is that the orthographic skeleton is generated automatically, but it can be boosted by the application of strategic efforts.

There are several approaches future work might adopt to shed light on this issue. First, children could simply be asked whether they adopted any explicit strategies to assist them to remember the novel oral vocabulary. Second, an experiment might contrast the orthographic skeleton effect observed after children are instructed to adopt an explicit strategy of imagining what the spoken words might look like in print, and when no such instruction is provided (as in the current experiments). Third, oral vocabulary training could be altered so that the learning task itself becomes more implicit (cf. the highly explicit nature of the oral vocabulary training provided in each of the experiments reported here).

Orthographic skeletons of polysyllabic words?

Each of the investigations reported in this dissertation has addressed the issue of whether children can form orthographic skeletons using monomorphemic words. Given the precedence of monosyllables in computational models of word reading (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Plaut, Seidenberg, McClelland, & Patterson, 1996) together with our focus on reading development, we viewed this as a sensible starting point. Yet monosyllables represent only a fraction of words in English (Mousikou, Sadat, Lucas, & Rastle, 2017). An outstanding issue therefore relates to the question of whether children might be able to form orthographic skeletons of polysyllabic words containing one or more units of meaning.

Monomorphemic polysyllabic words. Polysyllables make spelling in English more difficult due to associated increases in length and complexity. As mentioned in Chapter 4, vowels present particular issues for spelling in the English orthography in part because there is greater variability in vowel spellings (Treiman, 1993; Treiman, Berch, & Weatherston, 1993). Polysyllables additionally introduce potential difficulties arising from stress placement, and associated differences in the fullness of spoken vowels. For instance, if a spoken English syllable is stressed then its vowel is likely to be fully articulated. In turn, full articulation of the vowel should facilitate detection of the phoneme-grapheme relationship. This contrasts with unstressed syllables, for which the vowels are typically reduced. When a spoken vowel is reduced, it tends to be quieter and shorter in duration. This is exemplified by the schwa phoneme /ə/ (as in the *e* in *frozen*), which can take the place of any vowel in writing and can be spelled in as many as 16 different ways (Treiman, 1993). Whether children might be able to form orthographic skeletons for monomorphemic polysyllabic words remains an empirical question. The prior discussion raises interesting possibilities regarding the design of potential stimuli, particularly those with unpredictable spellings. Conceivably, the unpredictability might arise either by selecting an uncommon phoneme-to-grapheme correspondence (e.g., the spoken word /zɔːˈwIb/ being written as *zauwib*) or by situating the unpredictability in the spoken word form itself, perhaps by including a schwa phoneme (e.g., the spoken word /zəˈwIb/ being written as *zorwib*).

Morphologically complex words. Many, perhaps most, polysyllabic words are morphologically complex in that they contain more than one unit of meaning (morphemes). For example, the word *fighter* contains two units of meaning: the stem *fight* and the suffix *-er*. As alluded to in Chapter 3, meaning-to-spelling cues are absent in monomorphemic words (Rastle, 2019). Morphologically complex spoken words, in contrast, frequently carry clear cues regarding spelling (e.g., the suffix *-er* in *fighter*). Indeed, children have been shown to exploit such morphological cues during spelling (Bourassa, Treiman, & Kessler, 2006; Pacton & Deacon, 2008; Treiman, 2017; Treiman & Cassar, 1996). These findings imply that children may well be able to form orthographic expectancies for morphologically complex words. If this proves to be the case, it would suggest that the formation of the skeleton may potentially obtain some additional benefit from morphological semantic cues.

Conclusions

Oral vocabulary knowledge has been causally linked to the development of children's word reading but little work has addressed the nature of the cognitive mechanism or mechanisms that permit this influence. Most theories have focused on influences that enable oral vocabulary knowledge to support word reading from the point at which a word is seen in print (Ehri, 2014; Perfetti, 1992; Share, 2008). The work presented in this thesis concentrated on the possibility that an alternative complementary causal mechanism might exist that enables oral vocabulary to influence written word learning prior to visual exposure. To support this position, the orthographic skeleton hypothesis was proposed which offers a novel theory of one such mechanism. The findings of this thesis suggest that this alternative cognitive mechanism is developmentally plausible, and have provided important insights into how orthographic skeletons are formed and their influence on longer-term orthographic learning.

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Supplementary Materials

Chapter 2

Additional detail about the training protocol

Nonwords were presented along with a picture referent in the form of "Professor Parsnip's Inventions" after the method developed by Wang et al. (2011). For example, "This invention is called *nesh*. It is used to shuffle cards. It is made of metal and vibrates".

Children were encouraged to remember the invention names and functions. Training occurred over four days, with a weekend between the third and fourth sessions. The items in each session were presented to the groups sequentially in a predetermined pseudorandom order via PowerPoint presentation. During the first and second training sessions, eight items (four from each spelling predictability 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 group repeated the correct name. The other four items were then presented. 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 group 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 group. 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 group 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 50 exposures were given for each item.

Table SA1.

Justified-by-the-design model comparisons

M1 <- lmer([D.V.] ~ [full fixed structure] + (1|subj) + (1|itemN) + group

M2 <- lmer([D.V.] ~ [full fixed structure] + (training|subj) + (1|itemN) + group

M3 <- lmer([D.V.] ~ [full fixed structure] + (predict|subj) + (1|itemN) + group

M4 <- lmer([D.V.] ~ [full fixed structure] + (training+predict|subj) + (1|itemN) + group

M5 <- lmer([D.V.] ~ [full fixed structure] + (training*predict|subj) + (1|itemN) + group

M6 <- lmer([D.V.] ~ [full fixed structure] + (training*predict|subj) + (training|itemN) + group

Chapter 3

Table SB1.

Procedure for selecting the optimal random effects structure for eye movement measures and delayed spelling.

M1 [D.V.] ~ [full fixed structure] + (1|sid) + (1|item)
M2 [D.V.] ~ [full fixed structure] + (training|sid) + (1|item)
M3 [D.V.] ~ [full fixed structure] + (spell|sid) + (1|item)
M4 [D.V.] ~ [full fixed structure] + (training+spell|sid) + (1|item)
M5 [D.V.] ~ [full fixed structure] + (training*spell|sid) + (1|item)
M6 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training|item)
M7 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (spell|item)
M8 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training+spell|item)
M9 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training*spell|item)

Table SB2.

Procedure for selecting the optimal random effects structure for reading aloud accuracy, latency and delayed spelling accuracy.

M1 [D.V.] ~ [full fixed structure] + (1|sid) + (1|item)
M2 [D.V.] ~ [full fixed structure] + (training|sid) + (1|item)
M3 [D.V.] ~ [full fixed structure] + (training+spell|sid) + (1|item)
M4 [D.V.] ~ [full fixed structure] + (training*spell|sid) + (1|item)
M5 [D.V.] ~ [full fixed structure] + (training+spell+trial|sid) + (1|item)
M6 [D.V.] ~ [full fixed structure] + (training*spell+trial|sid) + (1|item)
M7 [D.V.] ~ [full fixed structure] + (training*spell*trial|sid) + (1|item)
M8 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training|item)
M9 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training+spell|item)
M10 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training*spell|item)
M11 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training+spell+trial|item)
M12 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training*spell+trial|item)
M13 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training*spell*trial|item)

Pre-registration of the experiment reported in Chapter 3: The contributions of lexical phonology and semantics to the generation of orthographic skeletons

AsPredicted
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You are logged in as: **signy.wegener@hdr.mq.edu.au** (Log out (logout.php))

HOME (index.php) BACK (see_list.php)
Make Suggestion (mailto:larry@AsPredicted.org?Subject=I have a suggestion for AsPredicted) Change my email (update_email1.php)

As Predicted:"*How does oral vocabulary knowledge enhance children's novel word reading?*" (#3475)

Created: 03/21/2017 06:01 PM (PT)

Author(s)
Signy Wegener (Macquarie University) - signy.wegener@hdr.mq.edu.au
Hua-Chen Wang (Macquarie University) - huachen.wang@mq.edu.au
Kate Nation (University of Oxford) - kate.nation@psy.ox.ac.uk
Anne Castles (Macquarie University) - anne.castles@mq.edu.au

1) Have any data been collected for this study already?
No, no data have been collected for this study yet

2) What's the main question being asked or hypothesis being tested in this study?
This study builds on a previous experiment (Wegener, Wang, de Lissa, Robidoux, Nation & Castles, submitted) and asks: what oral vocabulary knowledge is needed for children to generate expectations of the spellings of words they are familiar with orally? Children in Year 4 will be taught the oral form of novel words. Vocabulary training type (phonology+semantics vs. phonology only), training (trained items vs. untrained items) and spelling predictability (predictable vs. unpredictable) will be manipulated. Children will then read the novel words, embedded in sentences, and their eye movements will be monitored. Carrier sentences at test will be contextual for children receiving training in phonology and semantics but neutral for children receiving training only in phonology. A second question is: how do orthographic expectancies impact on children's subsequent reading aloud and delayed spelling performance?
First orthographic exposure: Eye movements. Consistent with Wegener et al. (submitted) we predict: trained items will have shorter looking times and will be less likely to be refixated than untrained items; predictable spellings will have shorter looking times than unpredictable spellings; there will be a larger effect of spelling predictability for trained than untrained items. The latter prediction, if supported, is the key evidence that children draw on their oral vocabulary knowledge and their knowledge of sound-to-letter mappings, to form expectations of the spellings of words before those words are seen in print. Extending our previous work, we predict that semantic knowledge at the point of oral learning and via contextual support during reading should give rise to stronger orthographic expectations than phonological knowledge alone.
Second to fifth orthographic exposures: Reading aloud. Trained items will be read more accurately and quickly than untrained items; predictable items will be read more accurately and quickly than unpredictable items; there will be no trainingXpredictability interaction.
Delayed spelling accuracy. Trained items and items with predictable spellings will be spelled more accurately than untrained items and items with unpredictable spellings; semantic information will convey a spelling advantage compared to phonological information alone.
Relationship between spelling predictability and literacy. The size of the spelling predictability effect will be

positively correlated with children's literacy skills.

3) Describe the key dependent variable(s) specifying how they will be measured.
Target word = written form of the novel words (trained and untrained).
Eye movements: First fixation duration; gaze duration; total reading time; regressions in.
Reading aloud: Reading accuracy (correct vs. incorrect) and latency (ms).
Spelling: Accuracy (correct vs. incorrect).
The spelling predictability effect and literacy: The size of the spelling predictability effect for each child will be calculated like this: [(trained unpredictable/trained predictable)-(untrained unpredictable/untrained predictable)].
Reading (Castles & Coltheart 2); spelling (Diagnostic Spelling Test).

4) How many and which conditions will participants be assigned to?
The design is 2x2x2: oral vocabulary training type (phonology+semantics vs. phonology only, between Ss); training (trained vs. untrained, within Ss); spelling predictability (predictable vs. unpredictable, within Ss). Participants will be children in Year 4 classes. Oral vocabulary training will be at a class level on 16 novel words. A matched set will serve as untrained items. Vocabulary training type and item sets will be counterbalanced across classes. Half of the items in each list will have spellings that are predictable from phonology; the others will be unpredictable.

5) Specify exactly which analyses you will conduct to examine the main question/hypothesis.
Eye movements: If time data residual distributions are skewed, log transformation will be applied. Linear mixed effects models will be used separately for each DV (Gaussian/logistic). Fixed effects will be oral vocabulary training type, training and spelling predictability. We will fit the maximal model, which will include by-subject and by-item random intercepts and slopes for the within Ss factors of training and spelling predictability, but no random slopes for the between Ss factor of instruction type. If the maximal model does not converge we will employ a data driven approach to model selection (Matuschek et al., 2015).
Reading aloud: The same procedure as applied to eye movements will be used, but trial will be added as a fixed effect (4 levels).
Spelling: The same procedure as applied to eye movements will be used.
The spelling predictability effect and literacy: By-participant Pearson product-moment correlations will be calculated.

6) Any secondary analyses?
After training but before orthographic exposure, the children's level of learning of oral vocabulary items will be assessed. Oral vocabulary learning will be the DV in a 2x2x4 mixed ANOVA with vocabulary training type, spelling predictability and class membership as IVs. Children's raw scores on literacy tasks will be DVs in a series of ANOVAs. The IV will be class membership. If an effect of class is present it will be entered as a fixed effect within the analyses specified under Q4.

7) How many observations will be collected or what will determine sample size?
No need to justify decision, but be precise about exactly how the number will be determined.
We will recruit Year 4 students. With one vocabulary training type, we previously recruited two classes. As vocabulary training type will be a between Ss factor with two levels, we will recruit from four classes. Total N≈72 but will vary depending on the consent rate.

8) Anything else you would like to pre-register?
(e.g., data exclusions, variables collected for exploratory purposes, unusual analyses planned?)
Eye movements: Participants will be excluded if they cannot be calibrated, if they have eye issues preventing accurate tracking, or in the event of equipment failure. If an interest area is skipped (target, pre-target, post-target) the trial will be removed. Outliers will be identified by visual inspection and then removed (Baayen, 2008).
Reading Aloud: Outliers will be treated as above. Correct latency responses will be analysed.

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Chapter 4

Table SC1.

Procedure for selecting the optimal random effects structure.

M1 [D.V.] ~ [full fixed structure] + (1|sid) + (1|item)
M2 [D.V.] ~ [full fixed structure] + (training|sid) + (1|item)
M3 [D.V.] ~ [full fixed structure] + (spell|sid) + (1|item)
M4 [D.V.] ~ [full fixed structure] + (training+spell|sid) + (1|item)
M5 [D.V.] ~ [full fixed structure] + (training*spell|sid) + (1|item)
M6 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training|item)
M7 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (spell|item)
M8 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training+spell|item)
M9 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training*spell|item)

Pre-registration of the experiment reported in Chapter 4: Partial or complete? The early form of orthographic expectancies

AsPredicted
Pre-Registration made easy

Spelling expectations arising from oral vocabulary: what form do they take (#)

Author(s)
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Created: 03/12/2018 11:36 AM (PT)
Public: ?????

1) What's the main question being asked or hypothesis being tested in this study?
When children draw on their oral vocabulary knowledge to generate expectations of the spellings of those words, what form do those expectations take? Are they built around consonants or vowels, or are both represented? Year 4 children will be taught new spoken words. Training (trained vs. untrained items) and spelling predictability (predictable vs. unpredictable consonants vs. unpredictable vowels) will be manipulated. Children will read the novel words, embedded in sentences, and eye movements will be monitored. Carrier sentences will have supportive contexts. A second question is: how do orthographic expectancies impact children's subsequent reading aloud and spelling?
Eye movements. Training should benefit children's reading of predictable spellings (shorter fixation times). If orthographic expectations are built around consonants, when a child has a word in oral vocabulary and the orthographic form contains an unpredictable consonant spelling, children's reading should be perturbed (longer fixation times) relative to their reading of trained items with predictable spellings. We expect a training by spelling predictability interaction (predictable spellings and unpredictable consonant spellings): the effect of training is greater for items with predictable spellings than those with unpredictable consonant spellings. If orthographic expectations are built around vowels, when a child has a word in oral vocabulary, and the orthographic form contains an unpredictable vowel, children's reading will be perturbed (longer fixation times) relative to their reading of trained items with predictable spellings. We expect a training by spelling predictability interaction (predictable spellings and unpredictable vowel spellings): the effect of training is greater for items with predictable spellings than those with unpredictable vowel spellings. If both are observed, it would suggest that both consonants and vowels are represented within spelling expectations. Consonants are more orthographically predictable than vowels (Kessler & Treiman, 2001), raising the possibility that consonants may be dominant within orthographic expectations: the interaction between training and spelling predictability might be present only when predictable spellings are compared with unpredictable consonant spellings.
Reading aloud and spelling. Children will read and spell all items following the eye-tracking task. We anticipate main effects of training (trained items will be read more accurately and quickly, and spelled more accurately than untrained items) and spelling predictability (predictable spellings will be read more accurately and quickly, and spelled more accurately than unpredictable spellings). We will explore training by spelling predictability interactions (predictable vs. unpredictable consonant spellings; predictable vs. unpredictable vowel spellings).

2) Describe the key dependent variable(s) specifying how they will be measured.
Target word = written form of the novel words (trained and untrained). Eye movements: First fixation duration; gaze duration; total reading time; regressions in. Reading aloud: Accuracy (correct vs. incorrect) and latency (ms). Spelling: Accuracy (correct vs. incorrect).

3) How many and which conditions will participants be assigned to?
The design is 2x3 within-Ss: training (trained vs. untrained); spelling predictability (predictable vs. unpredictable consonants vs. unpredictable vowels). Subjects will be children in Year 4. Oral vocabulary training will be at a class level on 18 novel words (6 per spelling predictability condition). A matched set will serve as untrained items. Item sets will be counterbalanced across classes.

4) Specify exactly which analyses you will conduct to examine the main question/hypothesis.
Eye movements: If time data are skewed, log transformation will be applied. Linear mixed effects models will be used separately for each DV (Gaussian/logistic). Fixed effects will be training and spelling predictability. We will fit the maximal model, which will include by-subject and by-item random intercepts and slopes for training and spelling predictability. If the maximal model does not converge we will employ a data driven approach to model selection (Matuschek et al., 2015). Planned contrasts will be conducted comparing the effect of training for predictable items vs. unpredictable consonant spellings; and comparing the effect of training for predictable items vs. unpredictable vowel spellings. Reading aloud and spelling: The same procedure as applied to eye movements will be used.

5) Describe exactly how outliers will be defined and handled, and your precise rule(s) for excluding observations.
Eye movements: Participants will be excluded if they cannot be calibrated, if they have eye issues preventing accurate tracking, or in the event of equipment failure. If an interest area is skipped (target, pre-target, post-target) the trial will be removed. Outliers will be identified by visual inspection and then removed (Baayen, 2008). Reading Aloud: Outliers will be treated as above. Correct latency responses will be analysed.

6) How many observations will be collected or what will determine sample size? No need to justify decision, but be precise about exactly how the number will be determined.
We will recruit two Year 4 classes. Total N≈40 but this will vary depending on consent rate.

7) Anything else you would like to pre-register? (e.g., secondary analyses, variables collected for exploratory purposes, unusual analyses planned?)
Before orthographic exposure, the children's level of learning of oral vocabulary items will be assessed. Oral vocabulary learning will be the DV in a 3x2

ANOVA with spelling predictability and class membership as IVs. Children's raw scores on literacy tasks will be DVs in a series of ANOVAs. The IV will be class membership. If an effect of class is present it will be entered as a fixed effect within the analyses specified under Q5.

8) Have any data been collected for this study already?
No, no data have been collected for this study yet.

Chapter 5

Table SD1.

Procedure for selecting the optimal random effects structure.

M1 [D.V.] ~ [full fixed structure] + (1|sid) + (1|item)
M2 [D.V.] ~ [full fixed structure] + (training|sid) + (1|item)
M3 [D.V.] ~ [full fixed structure] + (spell|sid) + (1|item)
M4 [D.V.] ~ [full fixed structure] + (training+spell|sid) + (1|item)
M5 [D.V.] ~ [full fixed structure] + (training*spell|sid) + (1|item)
M6 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training|item)
M7 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (spell|item)
M8 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training+spell|item)
M9 [D.V.] ~ [full fixed structure] + (optimal random effects structure|sid) + (training*spell|item)

Pre-registration of the experiment reported in Chapter 5: Tracking the evolution of orthographic expectancies with over building visual experience

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Pre-Registration made easy

Multiple visual exposures to orally trained words (#)

Author(s)
Signy Wegener (Macquarie University) - signy.wegener@students.mq.edu.au
Hua-Chen Wang (Macquarie University) - huachen.wang@mq.edu.au
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Anne Castles (Macquarie University) - anne.castles@mq.edu.au

Created: 11/08/2018 12:38 AM (PT)
Public: ?????

1) What's the main question being asked or hypothesis being tested in this study?
We expect to replicate our previous work showing that, at the first visual exposure, children have formed orthographic skeletons (or spelling expectations) of orally trained words (Wegener et al., 2018). We extend this by asking: does evidence of the orthographic skeleton persist over a second and third orthographic exposure? A second question is: when the number of visual exposures to trained and untrained items is matched, does oral training (which affords the opportunity to form an orthographic skeleton) convey a further benefit to delayed visual word recognition assessed via lexical decision? Year 4 children will be taught new spoken words. Oral training (trained vs. untrained items), spelling predictability (predictable vs. unpredictable), and exposure number (first vs. second vs. third) will be manipulated. Children will read the novel words, embedded in single line contextually supportive sentences, and eye movements will be monitored. Visual exposures to the target words will be distributed; all items (trained and untrained) will be read prior to being encountered again. Eye movements: It is hypothesised that, at the first visual exposure, there will be a training by spelling predictability interaction with a larger effect of spelling predictability for orally trained words. If the orthographic skeleton persists, then the interaction will continue to be observed at the second and third visual exposures. However, it is possible that with repeated visual exposures, children will be able to update their orthographic representations of orally trained items with unpredictable spellings. If this were to be the case, then the interaction observed at the first visual exposure may change over subsequent exposures. At the second exposure, there will be main effects of training and spelling predictability, and a numerically smaller interaction between them (in the same direction). By the third visual exposure, the direction of the interaction might reverse: there may be a larger effect of spelling predictability for orally untrained items. Planned contrasts to test these hypotheses are specified in Q4. We also expect that, at the first visual exposure, orally trained items will be reread less often than orally untrained items. Delayed visual lexical decision: Children will have read both the orally trained and untrained items three times in the context of the eye-tracking task. At a delay (approx. 3 to 5 days following the eye-tracking task) children will complete a go/no-go visual lexical decision task. Here, children will press a button to indicate that they have read an item in the eye tracking task and will not respond when they see a word they have never encountered. We anticipate that orally trained items will be recognised with greater accuracy and speed than orally untrained items.

2) Describe the key dependent variable(s) specifying how they will be measured.
Target word = written form of the novel words (trained and untrained). Eye movements: First fixation duration; gaze duration; total reading time; regressions in. Lexical decision: Accuracy (correct vs. incorrect) and latency (ms).

3) How many and which conditions will participants be assigned to?
The design is 2x2x3 within-Ss: training (trained vs. untrained); spelling predictability (predictable vs. unpredictable); exposure number (1 vs. 2 vs.3). Subjects will be children in Year 4. Oral vocabulary training will be at a class level on 16 novel words (8 per spelling predictability condition). A matched set will serve as untrained items. Item sets will be counterbalanced across classes.

4) Specify exactly which analyses you will conduct to examine the main question/hypothesis.
Eye movements: If time data model residuals are skewed, log transformation will be applied. Linear mixed effects models will be used separately for each DV (Gaussian/logistic). Fixed effects will be training and spelling predictability. We will fit the maximal model, which will include by-subject and by-item random intercepts and slopes for training and spelling predictability. If the maximal model does not converge we will employ a data driven approach to model selection (Matuschek et al., 2015). Planned contrasts will be conducted: the interaction between training and spelling predictability at exposure 1 will be greater than zero (one tailed); the interaction for exposure 1 will be greater than the interaction for exposure three (negative interaction, one-tailed); the interaction for exposure 2 will not be larger than exposure 1 or smaller than exposure 3 (one-tailed). Delayed visual lexical decision: The same procedure as applied to eye movements will be used for latencies.

5) Describe exactly how outliers will be defined and handled, and your precise rule(s) for excluding observations.
Eye movements: Participants will be excluded if they cannot be calibrated, if they have eye issues preventing accurate tracking, or in the event of equipment failure. If an interest area is skipped (target, pre-target, post-target) the trial will be removed. Outliers will be identified by visual inspection and then removed (Baayen, 2008). Delayed visual lexical decision latency: Correct latency responses will be analysed. Outliers will be treated as above.

6) How many observations will be collected or what will determine sample size? No need to justify decision, but be precise about exactly how the number will be determined.
We will recruit two Year 4 classes. Total N≈40 but this will vary depending on consent rate

7) Anything else you would like to pre-register? (e.g., secondary analyses, variables collected for exploratory purposes, unusual analyses planned?)
After training but before orthographic exposure, the children's level of learning of oral vocabulary items will be assessed. Oral vocabulary learning will be

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the DV in a 2x2 ANOVA with spelling predictability and class membership as IVs. Children's raw scores on literacy tasks will be DVs in a series of ANOVAs. The IV will be class membership. If an effect of class is present it will be entered as a fixed effect within the analyses specified under Q4. Data for this project has begun - we have 16 eye tracking datasets but no other data. The data has not been looked at.

8) Have any data been collected for this study already?
It's complicated. We have already collected some data but explain in Question 8 why readers may consider this a valid <u>pre</u>-registration nevertheless.

Ethics Approvals

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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Education
Public Schools

DOC17/1232846
SERAP 2016560

Ms Signy Wegener
16 University Avenue
Macquarie University NSW 2109

Dear Ms Wegener

I refer to your application to conduct a research project in NSW government schools entitled *Investigating how vocabulary knowledge helps children learn to read*. I am pleased to inform you that your application has been approved.

You may contact principals of the nominated schools to seek their participation. **You should include a copy of this letter with the documents you send to principals.**

This approval will remain valid until 12-Dec-2017.

The following researchers or research assistants have fulfilled the Working with Children screening requirements to interact with or observe children for the purposes of this research for the period indicated:

Researcher name	**WWCC**	**WWCC expires**
Signy Wegener	WWC0709706E	13-May-2020
Dr Hua-Chen Wang	WWC0094129E	10-Sep-2018
Julianne Pascoe	WWC0450660E	05-Aug-2018

I draw your attention to the following requirements for all researchers in NSW government schools:

- The privacy of participants is to be protected as per the NSW Privacy and Personal Information Protection Act 1998.
- School principals have the right to withdraw the school from the study at any time. The approval of the principal for the specific method of gathering information must also be sought.
- The privacy of the school and the students is to be protected.
- The participation of teachers and students must be voluntary and must be at the school's convenience.
- Any proposal to publish the outcomes of the study should be discussed with the research approvals officer before publication proceeds.
- All conditions attached to the approval must be complied with.

When your study is completed please email your report to: serap@det.nsw.edu.au
You may also be asked to present on the findings of your research.

I wish you every success with your research.

Yours sincerely

Dr Robert Stevens
Manager, Research
12 December 2016

School Policy and Information Management
NSW Department of Education
Level 1, 1 Oxford Street, Darlinghurst NSW 2010 – Locked Bag 53, Darlinghurst NSW 1300
Telephone: 02 9244 5060 – Email: serap@det.nsw.edu.au

NSW GOVERNMENT | Education Public Schools

Ms Signy Wegener
Macquarie University
16 University Avenue
Macquarie University NSW 2109

DOC17/904302
SERAP 2016560

Dear Ms Wegener

I refer to your application for variation to the research project being conducted in NSW government schools entitled *Investigating how vocabulary knowledge helps children learn to read*. I am pleased to inform you that your application has been approved.

This approval will remain valid until 12-Dec-2017.

The following researchers or research assistants have fulfilled the Working with Children screening requirements to interact with or observe children for the purposes of this research for the period indicated:

Researcher name	WWCC	WWCC expires
Signy Wegener	WWC0709706E	13-May-2020
Dr Hua-Chen Wang	WWC0094129E	10-Sep-2018
Julianne Pascoe	WWC0450660E	05-Aug-2018

When your study is completed please email your report to serap@det.nsw.edu.au.

Yours sincerely

Dr Robert Stevens
Manager, Research
29 August 2017

School Policy and Information Management
NSW Department of Education
Level 1, 1 Oxford Street, Darlinghurst NSW 2010 – Locked Bag 53, Darlinghurst NSW 1300
Telephone: 02 9244 5060 – Email: serap@det.nsw.edu.au

NSW GOVERNMENT | Education Public Schools

Ms Signy Wegener
16 University Avenue
MACQUARIE UNIVERSITY NSW 2109

DOC17/1127583
SERAP 2016560

Dear Ms Wegener

I refer to your application for extension to the research project being conducted in NSW government schools entitled *Investigating how vocabulary knowledge helps children learn to read*. I am pleased to inform you that your application has been approved.

This approval will remain valid until 02-Nov-2018.

The following researchers or research assistants have fulfilled the Working with Children screening requirements to interact with or observe children for the purposes of this research for the period indicated:

Researcher name	**WWCC**	**WWCC expires**
Signy Wegener	WWC0709706E	13-May-2020
Dr Hua-Chen Wang	WWC0094129E	10-Sep-2018
Julianne Pascoe	WWC0450660E	05-Aug-2018

When your study is completed please email your report to serap@det.nsw.edu.au.

Yours sincerely

Dr Robert Stevens
Manager, Research
2 November 2017

School Policy and Information Management
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