

How Children Learn to Read

Dissecting the Process of Orthographic Learning

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Thesis summary

Learning to read new words is one of most important skills that a child has to master in order to become a proficient reader. The transition from laboriously sounding out a new word to the automatic recognition of the word is referred to as ‘orthographic learning’. In this thesis, I break down the process of orthographic learning and examine the components involved in this process with both typically-developing and dyslexic readers, in the framework of the self-teaching hypothesis (Share, 1995) and the dual route model of reading. Across 5 papers, I used two novel orthographic learning paradigms to explore the role of phonological decoding, context, vocabulary knowledge, orthographic knowledge, and paired-associate learning ability in the process of orthographic learning.

The first paper investigated the effect of context on orthographic learning of regular and irregular words. The second paper directly tested the self-teaching hypothesis and the role of phonological decoding in orthographic learning using regular and irregular novel words. The third paper examined the predictors in orthographic learning of regular and irregular words. The fourth and fifth papers explored orthographic learning with two specific subtypes of dyslexic readers.

The principal findings of this thesis were: contextual information and the meaning of a novel word only assisted orthographic learning when the novel word to be learned had irregular letter-sound mapping; orthographic learning was less effective when the novel word was irregular and decoding could only be partial; the relationship between orthographic learning and phonological decoding did not hold at an item-level; vocabulary knowledge assisted orthographic learning of irregular words only; and different impairments in the reading process affect orthographic learning differently. These findings suggest that the relationship between phonological decoding skills and orthographic learning is not as straightforward as proposed in the literature, and provides support for the involvement of additional components.

Statement

I certify that the work in this thesis entitled “How children learn to read: Dissecting the process of orthographic learning” has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree to any other university or institution other than Macquarie University.

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

In addition, I certify that all information sources and literature used are indicated in the thesis. The research presented in this thesis was approved by Macquarie University Ethics Review Committee, reference number: **HE24AUG2007-R05406** on 12th September 2007.

Signed:

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5th April 2012

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General Introduction

One of the most important skills in reading development is learning to read new words. The transition from slowly and laboriously sounding out an unfamiliar word to rapidly and automatically recognising that word has been referred to as ‘orthographic learning’ (Castles & Nation, 2006). This transition must occur in order for a child to read fluently and efficiently, without having to use letter-sound correspondences to decode every word encountered in text. The five papers presented in this thesis focus on how orthographic learning takes place and what factors are involved in this process for both typically developing and low-progress readers.

In this general introduction, I will review models and research in single word reading, reading development and finally orthographic learning. Subsequently, I will discuss orthographic learning in the context of a model of reading (the dual route model) and identify the factors that might be involved in the process of orthographic learning. Finally, the specific research questions pursued by each paper within this thesis are outlined.

Single Word Reading

In order to understand how text may be read fluently, it is first necessary to understand the processes that occur when reading single words. The dual route theory has been one of the most influential theories of how reading takes place at a single word level (e.g., Coltheart, 1978; Coltheart, Curtis, Atkins & Haller, 1993) and is implemented computationally in the Dual Route Cascaded model (DRC; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). According to this theory, when a skilled reader sees a word in print, two routes simultaneously process that word. One route is nonlexical in which words are read via phonological decoding, and the other is lexical in which words are read as a whole unit. These two routes can be broken down into six basic components (see Figure 1), with the first and the last components shared by both routes.

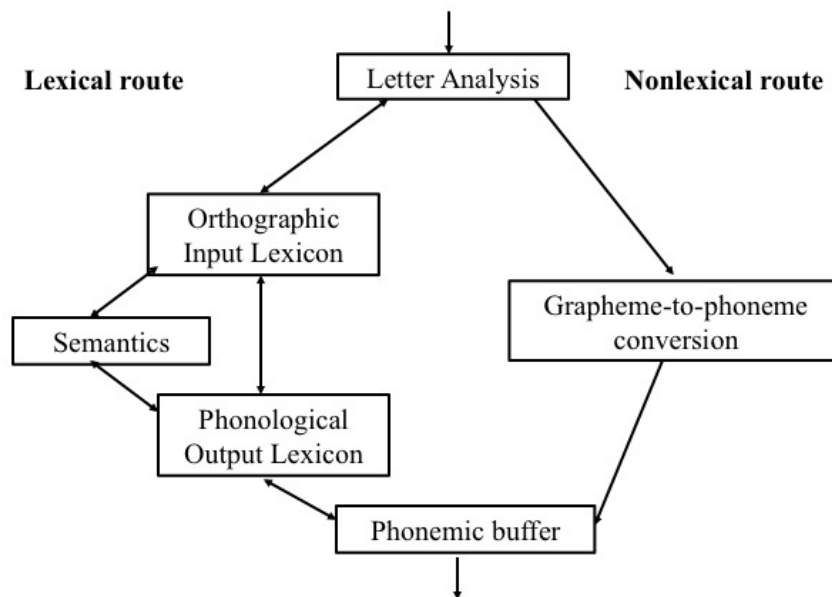


Figure 1. The dual route model of reading aloud (e.g., Coltheart et al., 2001).

The first component is *letter analysis*, in which letters are analysed and identified.

Letters are represented at this level as abstract entities such that no matter what font or case a letter is presented in, it will activate the same letter representation. In the nonlexical route, the component that follows letter analysis is *grapheme-to-phoneme conversion*. Here, letters or letter strings such as ‘f’ or ‘th’ are converted into their corresponding phonemes based on the reader’s letter-sound knowledge. Subsequently, these phonemes are activated and temporarily stored in the *phonemic buffer* before they are spoken.

In the lexical route, the letters activate the print form, or the orthographic representation of the word in the *orthographic lexicon* directly as a whole unit. Subsequently, the meaning of the word is activated in the *semantic system* and the sound of the word is activated in the *phonological lexicon*. In turn, the phonemes of the word are activated and temporarily stored in the *phonemic buffer* before the word is articulated, as in the nonlexical route.

According to the dual route model, a skilled reader processes a word with both routes simultaneously; however, certain types of words can only be read correctly by one route and

not the other. For example, when a word has an irregular letter-sound mapping (e.g., *yacht*), it can only be read correctly via the lexical route as a whole unit. This is because processing via the nonlexical route would result in each grapheme being converted into sounds using the most common rules of the language and would consequently arrive at the incorrect pronunciation of the irregular word (“y-a-ch-t”). On the other hand, when a letter string is unfamiliar in print, an orthographic representation does not exist in the orthographic lexicon, and hence, the letter string can only be read via the nonlexical route using one’s letter-sound knowledge. However, once a word has become familiar, a representation will be formed in the orthographic lexicon, and it can then be read via the lexical route. This route is a more efficient and rapid way of reading (e.g., Coltheart, Curtis, Atkins & Haller, 1993).

Although the dual route model explains how skilled reading takes place, it is not a learning model and does not explain how a word transfers from being unfamiliar to familiar and from being successfully processed only via the nonlexical route to being processed quickly and accurately via the lexical route.

Another highly influential framework has a stronger focus on learning. The triangle model proposes that the essential elements in reading - semantics, phonology, and orthography - are all connected via a learning mechanism that simulates the connections of the neural network (Seidenberg & McClelland, 1989; Plaut, McClelland, Seidenberg & Patterson, 1996). Hence, the triangle model explains lexical learning as enhanced connections between the three elements following reading experiences. Reading in this model also involves dual routes: one being orthography to phonology, and the other including connections between orthography, semantics and orthography. In this connectionist model, learning occurs by training of the neural net using back propagation between orthography and phonology. Back propagation refers to the changing of the weights on the connections between units when they are simultaneously active. If the two units are associated (a correct response) the connections will be strengthened, but if they are not (an

incorrect response) the connections will be weakened. Each change in weight is very gradual, therefore learning a word requires many trials of feedback and instructions. In contrast, as suggested by many studies in children, learning to read can and often does happen uninstructed, with even a single exposure of the word (e.g., Share, 2004a).

While these two dominant theories address how single word reading occurs, it seems that neither can sufficiently explain how learning to read takes place. Nevertheless, the dual route model explicitly outlines the specific components that are involved in this reading process that are not addressed in the triangle model.¹ In addition, as noted above, while the triangle model includes a learning mechanism, this mechanism of constant feedback and instruction seems implausible in the context of human word learning. Therefore, in this thesis, I adopt the dual route framework to conceptualise the process of learning to read and the components that are involved in this process. In the next section, I will turn to discuss the important theories from the perspective of reading development.

Reading Development

Studies in reading development suggest that a skilled reader progresses through a number of stages (e.g., Gough & Hillinger, 1980; Frith, 1985; Seymour & Duncan, 2001; for a review, see Ehri 2005), and that this sequence often begins with home education, well before any formal instruction in reading (Adams, 1990; Pressley, 1998), and continues until the reading system is fully developed.

One of the most influential theories in reading development is Ehri's (1998, 1999; 2002) four-phase theory. This theory accounts for the development of a reading system from the very beginning to its completion. The first, *pre-alphabetic reading* phase, usually takes place in pre-school when children read words using visual cues, particularly salient ones, to

¹ The triangle model includes similar components as the dual-route model, however, the components are not explicitly outlined and are addressed as 'hidden units' mediating between phonology, semantics and orthography.

remember words (e.g., *yellow* is the word with two sticks). At this stage, word recognition is merely visual and may rely on the context in which the word was encountered. In addition, no letter sound knowledge or phonological decoding skill is used. This phase is also described as logographic (Frith, 1985) or rote association and linguistic guessing (Marsh, Friedman, Wekch & Desberg, 1981).

As children gradually learn more letter names and some letter-sound mappings, they move on to the second, *partial alphabetic* phase. In this stage, children have not yet developed phonological decoding skills but have started using phonetic cues rather than visual cues. Ehri and Wilce (1985) found that for partial alphabetic readers, items with phonetic cues (e.g., *JRF* for *giraffe*, where the letter names allude to the sound of the word) are easier to learn than items with visual cues (e.g., *wBc* for *giraffe*, where the letter string's shape alludes to the shape of the word). However, because children at this stage have not yet acquired phonological decoding skills, errors are often made with words that have similar letters (e.g., *men* as *man*).

As children receive instruction in letter-sound correspondences and acquire phonological decoding skills, they move on to the *full alphabetic* phase. In this phase, children use their phonological decoding skills to build connections between graphemes and phonemes and build word-specific orthographic knowledge of each word. In doing so, children rapidly establish their sight word vocabulary. The last phase is the *consolidated alphabetic* phase, which begins during the full alphabetic phase and eventually replaces the full alphabetic phase. In this phase, reading is more fluent and involves graphophonemic units including morphemes, onsets, and rimes. Hence, reading involves utilising larger chunks of letter patterns rather than using just grapheme-to-phoneme correspondences as in the full-alphabetic phase.

Another highly influential theory in reading development is proposed by Frith (1985). According to Frith, there are three phases: first, the logographic phase (which is

similar to Ehri's pre-alphabetic phase) where words are recognised on the basis of distinct visual features; second, the alphabetic phase (which is similar to Ehri's full alphabetic phase) where words are read according to letter-sound knowledge; and the last, orthographic phase (which is similar to Ehri's consolidated phase) where words are recognised with their unique spelling patterns. Similar to Ehri's phase theory, Frith also proposes a transition from nonlexical decoding to direct word recognition as a process of skilled reading.

These theories provide an excellent foundation for studies in reading development, and explain how a beginner readers progresses to becoming a skilled reader. From here on, this thesis will be aimed at pinpointing the exact processes involved in the transition from alphabetic decoding to the consolidated or orthographic stage of direct word recognition. In other words, the focus is on the acquisition of orthographic representations at a single word level. In the next section, a theory with this focus will be discussed.

Orthographic Learning

Rather than explaining learning to read in sequences of developmental phases or stages, Share (1995) proposed a self-teaching hypothesis that focuses on orthographic learning at an item level. The move away from developmental phases is motivated by the fact that readers continue to add new items to their print vocabularies throughout their lives, and not simply when they are first learning to read.² Furthermore, at an item level, the process of learning a new word can occur within a few exposures. According to the self-teaching hypothesis, orthographic learning, that is, the transition whereby an unfamiliar word becomes familiar, takes place via the phonological decoding of that word. When a novel word is encountered, a reader will use their knowledge of orthography to phonology mappings (including letter-sound mappings) to generate the phonology of that word, since

² Consider the example of names of new children's television characters (e.g., Iggle Piggle, MakkaPakka, Tombliboo, from "In the night garden") or politicians (Obama; Ahmadinejad; Shevardnadze).

the word is novel and cannot be accessed lexically. This process of phonological decoding serves as a self-teaching mechanism that draws a reader's attention to the graphemic form of the word and thus provides the opportunity to build up the orthographic representation of the word. With a few print exposures, the orthographic representation of the word will be established in the orthographic lexicon, and subsequently, lexical access and rapid recognition of the word is possible (Share, 1995; Share & Jorm, 1987).

The self-teaching hypothesis considers phonological decoding as the key to reading acquisition, and the role of teaching instruction and contextual guessing as insufficient for orthographic learning. Share (1995) stresses that the process of orthographic learning is self-directed and does not rely on instruction. According to Nagy and Herman (1987), a child in fifth grade may encounter about 10,000 new words per year. Hence, it is unlikely that every new word can be taught to the child. In addition, context is not a reliable means of recognising an unfamiliar print word since contextual information is often either ambiguous or unpredictable in natural text (Share, 1995; Gough, 1983; Nicholson & Hill, 1985). Therefore, phonological decoding is thought to be the only reliable way of learning novel words.

The self-teaching hypothesis has attracted much attention and resulted in a growing body of empirical evidence. Share (1999) presented the first experimental test of the self-teaching hypothesis. In that study, Hebrew speaking second graders were asked to learn novel words presented in short stories (e.g., "Yait is the hottest town in the world"). Subsequently, orthographic learning was measured with three tasks: orthographic choice, naming speed, and spelling. In the orthographic choice task, the children were asked to choose the correct spelling of those words from distractors (e.g., YAIT, YATE, YOIT, YOYT). The results of the orthographic choice task showed that children were more likely to choose the target words (e.g., *yait*) than to choose distractors that were spelled differently but with the same pronunciation (pseudohomophones, e.g., *yate*) or words that looked similar

(visual distractors, e.g., *yoit*, *yoyt*). The results from naming speed and spelling showed that they were faster at reading the target items aloud than pseudohomophones, and produced more target spellings than homophonic spellings. Therefore, it was concluded that orthographic learning had taken place. The learning paradigm used in this experiment has since been implemented in many studies examining orthographic learning and across languages such as Hebrew (e.g., Share, 1999, 2004a), Dutch (e.g., de Jong & Share, 2007; de Jong, Bitter, van Setten & Marinus, 2009), and less transparent reading systems such as English (e.g., Cunningham, Perry, Stanovich & Share, 2002, Cunningham, 2006; Bowey & Muller, 2005; Byrne et al., 2008; Nation, Angell & Castles, 2007).

Although the self-teaching hypothesis provides a seemingly straightforward and simple explanation of how orthographic learning takes place, precisely how the process operates and what factors are involved nevertheless remains unclear. The following sections of this chapter will conceptualise the processes involved in the self-teaching hypothesis and discuss factors that might be involved in orthographic learning.

Conceptualising Orthographic Learning

In this thesis I will be adopting the dual-route framework, as discussed above, to better explain the process of orthographic learning according to the self-teaching hypothesis.

As mentioned previously, Share (1995) argues that children acquire orthographic representations via a self-teaching mechanism, the cornerstone of which is the phonological decoding of a novel word. Phonological decoding results in the assembly of the spoken form of the word, which in turn allows for the bonding between phonology and orthography via some form of paired associate learning. This process is repeated on subsequent presentations of the word until the orthographic form and its mapping to phonology is learned. However, when phonological decoding is compromised, such as in the case of reading irregular words, contextual information may be important to arrive at the correct phonology of the word.

To provide a more explicit account of this learning process, it is helpful to conceptualise it more explicitly, breaking it down into its sub-components in the context of the dual route model (see Figure 2). In this model, when an unfamiliar written word is encountered, there will be no representation of this word in the orthographic lexicon so the only pathway to successful pronunciation will be via grapheme-phoneme conversion in the sublexical route (① in Figure 2). This conversion results in the activation of a series of phonemes in the phonemic buffer, which, if the novel word is already in the child's spoken vocabulary, will activate the corresponding phonological representation of this word in the phonological lexicon (② in Figure 2). The phonology of the novel word will then be linked with the orthography via some form of paired-associate learning (③ in Figure 2). This process is repeated until the orthographic representation of the novel word is firmly established in the orthographic lexicon (④ in Figure 2). At this point, the word can be read via the lexical route (orthographic lexicon to phonological lexicon), allowing rapid automated reading.

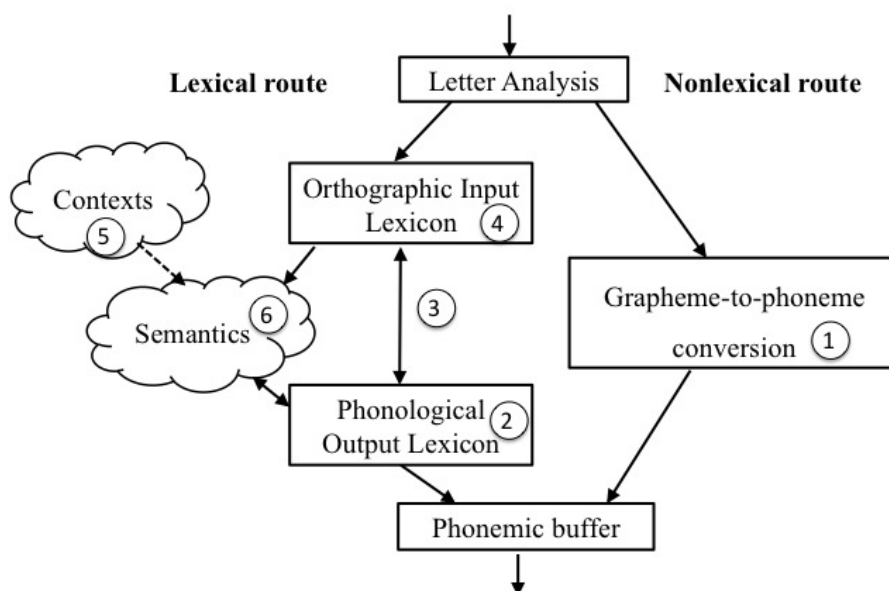


Figure 2. The dual route model of reading aloud. The numbers indicate the components of orthographic learning that this thesis investigates.

However, when grapheme-phoneme conversion can only generate partially correct decoding, such as in the case of irregular words, or when the sublexical route is not fully functioning (early in development or in poor readers), not all the correct phonemes will be activated in the phonemic buffer. For example, if the novel word STEAK is presented, the grapheme-conversion rules would result in the activation of "s" "t" "ee" and "k". In this case, the representation "steak" will not be fully activated in the phonological lexicon since the incorrect pronunciation "steek" does not exist in the child's vocabulary. However, information from the context (e.g., "He ordered rump...", ⑤ in Figure 2) can (pre)activate the meaning of STEAK in the semantic system (⑥ in Figure 2). This will in turn activate the spoken form in the phonological lexicon (② in Figure 2) which, when combined with the (partial) activation from the phonemic buffer (i.e., the correct conversion of s, t & k), will result in sufficient activation of the phonological form for paired associate learning with the orthography to occur. Hence, 'contextual guessing' is proposed to be particularly important in providing information that feeds in to the semantic system and eventually leads to the correct phonology of the word.

Components of Orthographic Learning

Having defined more precisely the potential mechanisms underlying orthographic learning, the next section will discuss the individual factors involved in more detail.

Phonological Decoding

The importance of phonological decoding skill in reading development has been broadly agreed and widely discussed (e.g., Brady & Shankweiler, 1991; Byrne, 1992, 1998; Goswami & Bryant, 1990). The self-teaching hypothesis suggests that phonological decoding is not only important, but that it is the predominant means by which orthographic learning takes place. Share (1999) conducted a series of experiments examining the role of phonological decoding in orthographic learning. As described above, in the first experiment,

Hebrew speaking second graders were asked to read short stories with novel words (e.g., “Yait is the hottest town in the world”). The results of orthographic learning tasks three days later suggested that the children had indeed learned those novel words. In the subsequent experiments, the availability of phonological decoding process was minimised by using shorter exposure durations and the results showed that when the opportunity for phonological decoding was reduced, orthographic learning was also compromised. Kyte and Johnson (2006) investigated the role of phonological decoding in a similar way. They manipulated the opportunity for phonological decoding in two conditions: reading aloud, in which phonological decoding is maximised, and silent reading with concurrent articulation (repeatedly saying ‘La’ aloud whilst reading), in which phonological decoding is reduced. The results showed that orthographic learning was advantaged when phonological decoding was not hindered.

In line with this idea, studies have also found that there is a positive correlation between correct phonological decoding and success in orthographic learning (Bowey & Miller 2007; Cunningham, et al., 2002; Kyte & Johnson, 2006; Cunningham, 2006). However, Nation et al. (2007) found that correct decoding of a novel word does not directly transfer to orthographic learning of the same novel word with an item-level analyses, suggesting that the relationship between phonological decoding and orthographic learning might not be as straightforward as initially indicated. In addition, in English, there are many, so called irregular, words with unpredictable letter-to-sound correspondences (e.g., words such as *yacht*), and consequently, orthographic representations of these words are unlikely to be able to be acquired using phonological decoding alone. Hence, it appears that further exploration of the role of phonological decoding in orthographic learning is required, particularly with irregular words.

Orthographic Knowledge

In addition to phonological decoding skills, other pre-existing reading skills such as word-specific orthographic knowledge have also been suggested to be important in orthographic learning (Cunningham et al., 2002; Cunningham, 2006; Connors, Loveal, Moore, Hume & Maddox, 2010). Cunningham et al. (2002) used the self-teaching paradigm with second-grade English speaking children. Novel words were presented in short stories and children were asked to read aloud the stories by themselves. The results showed that the novel words that were read correctly were also more likely to be recognised correctly in an orthographic choice task. Moreover, further analysis revealed that pre-existing word-specific orthographic knowledge (measured with an orthographic choice task requiring selection from a word and a pseudohomophone, e.g. *sleep-sleap*) explained unique variance in orthographic learning even after phonological decoding ability was accounted for.

Share (2004b) has also suggested that the importance of orthographic knowledge for orthographic learning may differ depending on the transparency of writing scripts. In a transparent writing system such as Hebrew, phonological decoding skill is sufficient for beginning readers to learn to read. However, for a less transparent writing system such as English, orthographic knowledge might be more important as letter-sound knowledge is not always reliable to read and learn words correctly. Hence, English-speaking children may be more practiced, and therefore better, at acquiring word-specific orthographic knowledge. In support of this view, Share (2004b) found that Hebrew-speaking first-graders showed little or no evidence of orthographic learning, whereas Cunningham (2006) demonstrated orthographic learning in English-speaking children of the same age. In light of this discrepancy, a prediction that has not yet been tested is that the importance of orthographic knowledge should not only differ across scripts, but may also differ for different word types within a script. That is, orthographic knowledge may be more important in acquiring irregular novel words than regular novel words.

Context

As mentioned previously, orthographic learning cannot depend solely on context, as information provided from natural text is often insufficient (Share, 1995). For example, while the sentence we used above "He ordered rump...." appears relatively unambiguous, it is not only "steak" that could be appropriate here: "cooked rare" "with salad" "as a main course" are also possible. Indeed, several studies have found little effect of context on orthographic learning (Nation, Angell & Castles, 2007; Cunningham, 2006). In fact, Landi, Perfetti, Bolger, Dunlap and Foorman (2006) even suggested that context may have a negative effect on orthographic learning. In their study, children were asked to learn real words that they were not able to read at pretest. The words were presented to them either in sentence context or in isolation. The results showed that the children used contextual information to assist in decoding when the words were first exposed. However, orthographic learning measured a week later showed that reading accuracy was higher for the words learned in isolation. This is suggested to be because when novel words are presented in sentences, the context may draw attention away from the novel words compared to when the novel words are presented in isolation. Further analyses suggested that this negative effect of context could be particularly true for less skilled readers, as they might require more attention or effort when learning to read novel words.

However, all the above studies used items with regular letter-sound mappings. Share (1995, footnote 3, p.154) has noted that "contextual information may play an important developmental role in supplementing partial or incomplete decoding stemming from weak phonological decoding skill or phonetically recalcitrant ("irregular") words". In other words, he suggests that contextual information is more likely to be important in assisting orthographic learning when decoding is compromised. Therefore, further research is

required to investigate the effect of context on orthographic learning with irregular words, and with poor readers that have insufficient phonological decoding skill.

Vocabulary Knowledge

Vocabulary knowledge has been considered as an important language factor in reading acquisition (e.g., Perfetti & Hart, 2002; Nation & Snowling, 2004). Vocabulary knowledge is defined here as knowledge of both the phonology and meaning of spoken words. Although previous studies have found that vocabulary knowledge is associated with reading ability (e.g. Nation & Snowling, 1998; 2004), the effect of vocabulary knowledge on orthographic learning is not well understood.

McKague, Pratt and Johnston, (2001) broke down vocabulary knowledge into the meaning and sound components and manipulated the provision of those two components separately. Year 1 children were first exposed to either the meaning or the sound of novel words, and were subsequently given the print form of those words. The results showed that children learned the novel words that were pre-exposed with sounds better than those that were not. Semantic pre-exposure, however, had no effect on learning the print form of the novel words. Similarly, Duff and Hulme, (Experiment 2, 2012) also found no effect of word meaning on orthographic learning of regular novel words. Ouellette and Fraser (2009), on the other hand, found some evidence that semantics affects orthographic learning. In their experiment, 9 year-old children were taught novel words. Half of the words were presented along with semantic information (drawings and descriptions of different creatures) and half were not. They found that the children recognised words presented with semantic information better in an orthographic choice task, but semantics had no effect on spelling accuracy of those words.

One potential explanation for the weak effect of semantics could be similar to that of context on orthographic learning. That is, vocabulary knowledge might only be important

when phonological decoding is less effective. In support of this, previous studies have found that vocabulary knowledge is particularly associated with reading irregular words (e.g., Bowey & Rutherford, 2007; Nation & Snowling, 1998; Ouellette, 2006; Ricketts, Nation & Bishop, 2007; Nation & Cocksey, 2009). Two word learning studies with adults (McKay, Davis, Savage & Castles, 2008; Taylor, Plunkett & Nation, 2011) have found that vocabulary knowledge contributes to orthographic learning only when the words to be learned have irregular letter-sound mappings.

The only study to date that has investigated the effect of word meaning on orthographic learning of irregular words with children is a very recent experiment by Duff and Hulme (2012, Experiment 1). In this study, 5-year-old children were taught to read words with consistent and inconsistent spelling-sound correspondences (broadly equivalent to regular and irregular words). Their results showed that the words that had higher imageability (which is suggested to be related to richer semantic information) were also learned better by the children. However, the effect of imageability was not affected by word consistency (or regularity). While this seems to argue against semantics playing a larger role in the learning of irregular (or inconsistent) words, a possible explanation as suggested by the authors may be that the 5 year-old participants had limited letter-sound knowledge. In other words, phonological decoding was compromised for both consistent and inconsistent words and hence semantic information assisted orthographic learning of all novel words for these participants.

Therefore, further and more direct investigation of how vocabulary knowledge affects orthographic learning of both regular and irregular words would seem to be required, particularly with older children that have better phonological decoding skills.

Paired-Associate Learning

The self-teaching hypothesis suggests that the process of orthographic learning

begins with phonological decoding, and follows by linking the spoken form and the orthography of the word. The process of linking the spoken form and the orthography of the word could be considered as a form of verbal-visual paired-associate learning. Previous studies have found that paired associate learning ability accounts for unique variance in word reading (Windfuhr & Snowling, 2001; Hulme, Goetz, Gooh, Adams & Snowling, 2007). In addition, children with dyslexia have more difficulty in learning associations, particularly when there is a verbal component involved (Gascon & Goodglass, 1970; Vellutino, Steger, Harding & Philips, 1975; Messbauer & de Jong, 2003).

It remains unclear, however, whether orthographic learning is only associated with visual-verbal paired associate learning or a more general paired-associate learning mechanism. Byrne et al. (2008) conducted a longitudinal twin study exploring genetic and environmental factors in orthographic learning. They found a high genetic influence on orthographic learning and suggested that the relationship with decoding is not as straightforward as the self-teaching hypothesis posits. Byrne et al. concluded that there may be a more global learning-rate factor which most directly influences orthographic learning. Measuring paired-associate learning skill may be one possible way to tap into this learning-rate factor. Therefore, it seems necessary to investigate the role of paired-associate learning across modalities in relation to orthographic learning.

Orthographic Learning in Poor Readers

Investigating orthographic learning in poor readers can not only help us to understand the difficulties they encounter in learning to read and thus allowing targeted assistance, but it can also contribute to identifying the underlying mechanisms of orthographic learning by indicating which processes may not be adequately functioning.

Unsurprisingly, previous studies have found that children with reading difficulties also show difficulties in learning novel words (e.g., Ehri & Saltmarsh, 1995; Manis, 1985;

Reitsma, 1983; 1989; Share, 2004b). Share (2004b) examined orthographic learning of poor readers in Hebrew with the standard self-teaching paradigm. The results showed that poor readers were worse than age-matched controls at orthographic learning as measured by spelling and orthographic choice tasks, and that the success of orthographic learning was linked to the correct decoding of target words. Therefore, the results also supported the importance of phonological decoding in orthographic learning for poor readers

However, the fact that there are two broad subtypes of developmental dyslexia suggests there may be other factors beyond phonological decoding skills involved in orthographic learning. As phonological decoding is suggested to be the key to acquiring orthographic representations, proficient phonological decoding processes should lead to success in orthographic learning, and impaired phonological decoding processes should lead to difficulties in orthographic learning. However, a large body of evidence on heterogeneity within the dyslexic population and on the existence of different subtypes of dyslexia (Castles & Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang & Petersen, 1996; Stanovich, Siegel & Gottardo, 1997; Valdois, Bosse, Ans, Carbonnel, Zorman, David & Pellat, 2003), and this suggests that the relationship between phonological decoding skills and orthographic learning might not be straightforward. Children with *surface dyslexia* have difficulty in reading irregular words (e.g. *yacht*) but are unimpaired at reading nonwords (e.g. *grep*), indicating that their phonological decoding skills have been acquired normally but that they are impaired in their ability to acquire orthographic representations and their mapping to phonology³. Conversely, children with *phonological dyslexia* show impairments in nonword reading but not irregular word reading, suggesting normal orthographic representations but difficulties with phonological decoding. In other words, despite the fact that children with phonological dyslexia have impaired phonological decoding processes, they appear to be able to build up orthographic lexical knowledge within the normal range;

³ It should be noted that there are studies suggesting that surface dyslexia is normal delayed reading, resulting from impoverished reading (e.g., Stanovich et al., 1997)

in contrast, children with surface dyslexia have normal phonological decoding processes, but yet have difficulties in acquiring orthographic representations.

Therefore, the dissociation between phonological decoding and orthographic learning in these two subtypes of dyslexia suggests that the impairment in orthographic learning may occur in components of orthographic learning other than phonological decoding. As outlined earlier (Figure 2), the second proposed component of orthographic learning is the association of phonology and orthography. As mentioned in the previous sections, earlier studies have found that dyslexic children may be impaired in learning paired-associations (Gascon & Goodglass, 1970; Vellutino, Steger, Harding & Philips, 1975; Messbauer & de Jong, 2003). However, these studies were all with an unselected group of dyslexic readers who may differ in their reading profiles. According to the selective reading impairment of the two specific subtypes of dyslexia children, we predict that only the surface dyslexic children would be impaired in paired-associate learning abilities and the phonological dyslexic children would not.

Outline of Experimental Papers

This thesis is organised according to the “thesis by publication” format. Each chapter is an independent manuscript with common overarching questions. Therefore, chapters include overlapping information. Paper 1 has been published in the *Journal of Experimental Child Psychology* and Paper 2 has been accepted for publication in the *Quarterly Journal of Experimental Psychology*. The remaining papers have been prepared and formatted for submission to specific journals.

The five papers included in this thesis explore orthographic learning and the components in the process of orthographic learning with typically developing and impaired readers. The aim of the thesis is to paint a full picture of how orthographic learning takes

place, building on the current literature of reading acquisition and orthographic learning. In the following section the specific research questions addressed by each paper are outlined.

Paper 1: Context and Orthographic Learning

Paper 1 examines the role of context in orthographic learning. As discussed previously, the self-teaching hypothesis proposes that although orthographic learning mostly takes place in sentence context, contextual information is only important when phonological decoding is partial. However, little research has directly explored this hypothesis. The current study looked at the effect of context on orthographic learning using both regular and irregular novel words. A novel paradigm was developed to explore the effect of context on orthographic learning of both regular and irregular words in a self-teaching environment where the learning is self-directed. In this paradigm, children were exposed to the sound and meanings of novel words. Subsequently, they were presented with those words in written form in short stories.

The effect of context was examined with two experiments, one with irregular novel words and one with regular novel words. In each experiment, the novel words were presented either with context (in stories) or without context (in a list). The results of this experiment provide a better understanding of how context contributes to the process of orthographic learning.

Paper 2: Word Regularity and Orthographic Learning

Paper 2 aimed to directly test the key feature of the self-teaching hypothesis: the role of phonological decoding in orthographic learning. The self-teaching hypothesis proposes that orthographic representations are acquired via phonological decoding. Therefore, word regularity should have an effect on the number and quality of word-specific orthographic representations that children acquire. A similar paradigm as Paper 1 was used in this study,

in which children were first provided with vocabulary knowledge of the novel words before they saw the words in print. The results of this paper provide new insight into the role of phonological decoding in orthographic learning.

Paper 3: Predictors of Orthographic Learning

Paper 3 examines predictors of orthographic learning, with particular interest in three reading- and language-related factors: phonological decoding skill, orthographic knowledge and vocabulary knowledge. Phonological decoding is considered the key to orthographic learning (e.g., Share, 1995, 1999; Bowey & Miller); orthographic knowledge has been found to be important in orthographic learning even after controlling for phonological decoding skills (Cunningham et al., 2002); and vocabulary knowledge is suggested to be an important language factor in reading acquisition (e.g., Nation & Snowling, 1998, 2004).

Building on Paper 1 and Paper 2, this paper explores these effect of the three factors mentioned above on orthographic learning of regular and irregular words, and whether the effects interact with word regularity in the process of orthographic learning. The results of this paper allow us to better understand the process of orthographic learning of regular and irregular words in relation to those three factors.

Paper 4: Tracking Orthographic Learning in Two Subtypes of Dyslexia

Paper 4 examines orthographic learning in children with two subtypes of dyslexia: phonological and surface dyslexia. The existence of these two types of developmental dyslexia suggests the relationship between phonological decoding skills and sight word learning is not straightforward. Children with surface dyslexia have normal phonological decoding skill but are impaired in their whole-word recognition skills, and children with phonological dyslexia show the opposite reading profile. The first aim of the study was to examine the role of phonological decoding in orthographic learning with these two subtypes

of dyslexia using a novel paradigm that tracks orthographic learning of regular and irregular words. The second aim of the study was to explore the predictors of orthographic learning with a larger group of poor readers.

This study contributes to the understanding of the role of phonological decoding in orthographic learning with dyslexic readers. In addition, investigation of the predictors of orthographic learning in poor readers allows us to explore how low-progress readers learn to read and whether there is a difference in the processes of orthographic learning between poor readers and typically developing readers.

Paper 5: Dissecting the Components of Orthographic Learning

The last paper of the thesis aimed to investigate orthographic learning in one case of phonological dyslexia and one case of surface dyslexia. Building on the findings of Paper 4, Paper 5 further breaks down the possible process of orthographic learning and explores each subprocess in greater detail. Three processing components were the main focus of interest: phonological decoding skill, paired-associate learning ability, and the use of context.

This paper is the first to document orthographic learning in detail across phonological and surface dyslexia. By breaking down the process of orthographic learning for these two cases of dyslexia, it is possible to localise where difficulties in orthographic learning occur, and in turn shed light on processes of orthographic learning of normally developing readers.

Summary

In this General Introduction, previous research relating reading and reading acquisition has been reviewed in relation to how orthographic learning takes place. The components that may be involved in the process of orthographic learning have been addressed and specific research questions of each of the five papers have been outlined.

Across these five papers, this thesis aims to further understanding the process of orthographic learning.

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Paper 1

Context Effects on Orthographic Learning of Regular and Irregular words

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Abstract

The self-teaching hypothesis (Share, 1995) proposes that orthographic learning takes place via phonological decoding in meaningful texts, that is, in context. Context is proposed to be important in learning to read, especially when decoding is only partial. However, little research has directly explored this hypothesis. The current study looked at the effect of context on orthographic learning and examined whether there were different effects for novel words given regular and irregular pronunciations. Two experiments were conducted using regular and irregular novel words, respectively. Second-grade children were asked to learn eight novel words either in stories or in a list of words. The results revealed no significant effect of context for the regular items. However, in an orthographic decision task, there was a facilitatory effect of context on irregular novel word learning. The findings support the view that contextual information is important to orthographic learning, but only when the words to be learned contain irregular spelling-sound correspondences.

Word count: 155

Keywords: orthography, reading development, word recognition process, orthographic learning, self-teaching hypothesis, word regularity

How reading abilities develop has generated immense research interest. A widely accepted conclusion from this wealth of research is that, at least in alphabetic writing systems such as English, the ability to match a letter or string of letters to its correct sound is a fundamental skill during the early stage of reading. The importance of this phonological decoding skill in reading has been supported by many studies (e.g., Brady & Shankweiler, 1991; Byrne, 1992, 1998; Goswami & Bryant, 1990).

However, less is known about the developmental transition from phonological decoding to fluent and proficient reading. It has been argued that proficient readers must have high-quality lexical representations that are sufficient for automatic and rapid word recognition (Perfetti & Hart, 2002). The progression from an early stage of reading words, in which they are laboriously sounded out, to this advanced stage, in which words are recognised and read as individual units, is a transition referred to as orthographic learning (Castles & Nation, 2006).

The most influential theory of orthographic learning is the self-teaching hypothesis (Share, 1995), where orthographic learning is proposed to depend primarily on phonological decoding. The self-teaching hypothesis posits that by using letter-to-sound rules to translate letter strings to the correct pronunciation, readers gradually build up a lexical representation that enables rapid, automatic orthographic recognition. This process of learning is self-directed and independent and does not require instruction, thereby being defined as self-teaching. In one influential experiment (Share, 1999), second-grade children learning to read Hebrew were asked to read aloud novel words in context (e.g., “*Yait* is the hottest town in the world”). Three days later, the children were asked to choose the correct spelling in an orthographic choice task. They were more likely to choose the target words (e.g., *yait*) than to choose words spelled differently but with the same pronunciation (homophones, e.g., *yate*) or words that looked similar (visual distractors, e.g., *yoit*, *yoyt*). Share (1999) suggested that because the children were able to identify the target items, orthographic learning had taken

place.

However, orthographic learning is likely to be modulated by factors beyond phonological skill. In a language such as English, there are many irregular words (e.g., *yacht*) that are not pronounced according to regular letter-to-sound rules. Children clearly cannot depend entirely on the rules to correctly pronounce such words. The self-teaching hypothesis posits that, during the process of orthographic learning, contextual information is important where decoding is only partial (Share, 1995, 1999). Partial decoding is where the reader does not have sufficient phonological decoding skill to sound out the word or where the word has an irregular spelling that cannot be pronounced correctly with the common sounding out rules. Thus, contextual information would assist in the decoding attempt by linking the word's meaning to a correct pronunciation.

According to Share's self-teaching hypothesis, the sentence context in which a new written word is presented is particularly important during the early stages of learning to read and in cases where only a partial decoding of the word is possible. Context provides the information that will allow anticipation of the coming word and that coactivates the sound and meaning of the novel word together with the written exposure. This is proposed to lead to the building up of stronger associations among phonology, semantics, and orthography. However, there is surprisingly little direct evidence that the presence of contextual information does facilitate orthographic learning in this way. In most experiments using the self-teaching paradigm, novel words have always been presented in a sentence context, so the effect of this factor cannot be determined (Cunningham, Perry, Stanovich & Share, 2002; Share, 1999, 2004). Of those studies that have manipulated context, evidence for a positive effect of context is weak. For example, Nation, Angell, and Castles (2007) found no difference between nonword learning in context and nonword learning in isolation with second graders, measured using an orthographic choice task. Cunningham (2006) used real words that were found, in a pilot study, to be familiar in oral vocabulary but novel in written

form to first graders (e.g., prince). Using a new group of first graders, Cunningham presented the target words either in a story or in a scrambled passage and found that the children decoded more accurately when the words were presented in context. However, no effect of context was found when measuring the acquisition of orthographic representations themselves using orthographic choice and spelling tasks.

In contrast to Share (1995), Landi, Perfetti, Bolger, Dunlap, and Foorman (2006) suggested that context could have a negative effect on orthographic learning because it draws attention away from the novel word during decoding. Children ranging in age from kindergarten to second grade were asked to learn real words that they were not able to read at pretest. The words were presented either in sentence context or in isolation. The results showed that the children used contextual information to assist in decoding when the words were first exposed. However, orthographic learning, as measured by reading accuracy a week later, was superior when the words had been learned in isolation.

All of the studies mentioned above either used novel words (nonwords) with regular letter-to-sound rules or used real words without controlling for regularity. As Share (2009) also noted, there is a lack of studies examining the role of context and how it interacts with word regularity on orthographic learning. As outlined above, the self-teaching hypothesis predicts that contextual information should be more important when only partial decoding is obtained and, hence, should play a larger role when learning irregular words than when learning regular words. Therefore, the aim of the current study was to explore this possibility by looking at the effect of context on orthographic learning and, in particular, by exploring how context interacts with word regularity.

For contextual information to assist in partial decoding in a self-teaching environment as Share proposed, readers need to possess some prior oral vocabulary knowledge of the word, and indeed this is typically the case when children encounter new written words. However, in most studies using Share's paradigm, readers have had no oral

exposure to the novel words and, thus, had no semantic information about the words before reading them (Nation et al., 2007; Share, 1999, 2004). In other words, the readers could only extract semantic information about the word to be learned from the surrounding text and could not rely on their oral vocabulary for support. Other studies have used real words but without full control for preexisting oral vocabulary knowledge (e.g., Cunningham, 2006; Landi et al., 2006). Irregular words cannot be correctly pronounced by using letter-to-sound rules. Thus, on the first occasion an irregular word is encountered in print, correct reading requires contextual information from the sentence together with preexisting vocabulary knowledge.

In summary, the goal of the current study was to examine whether children's orthographic learning proceeds better in context in the way suggested by the self-teaching hypothesis. Previous studies using the self-teaching paradigm have found either no effect of context (Cunningham, 2006; Nation et al., 2007) or a negative effect of context (Landi et al., 2006). However, none of these studies specifically used irregular words or looked at whether contextual assistance is sensitive to word regularity. The study reported here comprised two experiments manipulating the presence of context in orthographic learning, the first using regular novel words and the second using irregular novel words. Moreover, we used a more natural learning environment than is typically the case in self-teaching experiments by providing a preexposure phase during which children were familiarised with the pronunciations and meanings of the novel words before they saw them in written form. This also allowed us to make the nonwords "irregular" by mismatching the oral pronunciations of the words with those produced by the phonological decoding of the words. Finally, as Bailey, Manis, Pedersen, and Seidenberg (2004) have also noted, it is important to control for potential influences of the visual resemblance of the word form to other words in a child's vocabulary. Hence, in this study, the target items used had the same written forms but were given regular and irregular pronunciations in Experiments 1 and 2, respectively.

Two alternative hypotheses are suggested by previous research. According to Landi and colleagues (2006), the use of contextual information in novel word learning should lead to poorer performance on measures of orthographic learning because it draws attention away from the details of the written form of the word. They proposed that when a reader needs to rely more on context, less attention can be given to building up orthographic representations. According to this hypothesis, therefore, we would expect to find better orthographic learning of novel regular words presented in isolation as opposed to in context. Because irregular words rely more on context for decoding, more attention should be diverted from building up orthographic representations; therefore, the negative effect of context is predicted to be even larger for irregular novel words. On the other hand, the self-teaching hypothesis predicts the opposite results, where irregular novel words should be learned better in context, compared with in isolation, due to the assistance provided by context in resolving partial decoding. The current study attempted to adjudicate between these two competing hypotheses.

Each experiment involved three phases. During the first (*preexposure*) phase, the participants were presented with the phonology and meanings of the new words. During the second (*orthographic exposure*) phase, the participants were exposed to the written forms of the new words, presented either in contextually rich stories or in lists of words, using a within-participant manipulation. During the last (*orthographic test*) phase, the success of orthographic learning was assessed both immediately after orthographic exposure and after a 10-day delay.

During the preexposure phase, oral vocabulary knowledge was instantiated using drawings and oral definitions. Previous studies have provided semantic information by giving drawings of imaginary creatures and verbal descriptions of their attributes (McKague, Pratt & Johnston, 2001; Ouellette & Fraser, 2009). In the current study, the stimuli were “new inventions” from a factory. Hence, the picture showed the invention and the definition

reiterated the information in the picture. For example, one of the new inventions is something used to clean fish tanks; it has a sponge and is shaped like an arm.

In Experiment 1, children learned novel regular words in stories and lists. In Experiment 2, the items were in the same written form as in Experiment 1 but were assigned irregular pronunciations.

Experiment 1

Method

Participants. A total of 19 children in second grade (third year of schooling) participated in this experiment. The mean age of the participants was 7 years 6 months (ranging from 6 years 11 months to 8 years 3 months). Children were recruited from a class in a mainstream primary school in the Sydney, Australia, metropolitan region. Second graders were chosen because they have typically acquired basic phonological decoding skills but still have much to acquire in terms of orthographic representations. Because 1 of the participants was not able to complete the last session, data from 18 participants were analysed.

To ensure that the children's word reading ability and phonological decoding skills were within the normal range, two assessments were used. The Castles and Coltheart 2 (CC2) (Castles et al., 2010) demonstrated that the children's accuracy in reading regular words (mean z score = 0.37, SD = 1.13), irregular words (M = 0.48, SD = 0.79), and nonwords (M = 0.08, SD = 0.89) was within the range of normal readers. None of the children had a z score lower than -1.5. The Test of Word Reading Efficiency (TOWRE) (Torgesen, Wagner & Rashotte, 1999) showed that the children had average to above average reading accuracy and fluency (words: mean standard score = 116.06, SD = 11.90; nonwords: M = 109.33, SD = 10.09).

Materials and procedure. The provision of contextual information was manipulated

within participants such that each child learned half of the novel words in context and the other half in lists. The three phases (preexposure, orthographic exposure, and orthographic test) were conducted over six sessions for each child. All sessions were carried out in a quiet room of the school library.

The target items were eight homophonic pairs of pronounceable monosyllabic nonwords of four or five letters (e.g., *cleap/cleep*; see Appendix A). All items were given pronunciations that were regular in the sense that the graphemes were pronounced according to a set of typical grapheme–phoneme correspondence (GPC) rules (Rastle & Coltheart, 1999). In addition, the body (vowel and final consonant) was always pronounced in the same way when it occurred in a real word (e.g., *eep* is always pronounced as /i:p/ such as in *keep*, *sheep*, or *sleep*) (CELEX database: Baayen, Piepenbrock & van Rijn, 1993). Finally, the pronunciation of the vowels of the stimuli was checked using the Children’s Printed Word Database (CPWD) (Masterson, Stuart, Dixon & Lovejoy, 2003), and all vowels were regular according to this database, with the vowels being pronounced in the same way as the target words in more than 50% of occurrences. To control for any preference for one spelling over the other (e.g., a preference for spelling /kli:p/ as *cleep* rather than *cleap*), the items were counterbalanced such that half of the children saw the nonword items as targets and the other half saw their homophone twins. The items were also counterbalanced across the *context* and *no-context* conditions so that all items appeared in both conditions. All children saw half of the novel words in context and half in lists.

Preexposure phase. During this phase, the participants were presented with the target items in oral form (note that no written forms of the novel words were exposed during this phase) along with pictures representing them. To create a setting that was child-friendly and similar to a normal classroom activity, the nonwords were presented as ‘‘Professor Parsnip’s’’ novel inventions. Each nonword was given a function and two perceptual features (e.g., ‘‘This invention is called *cleap*. It is used to clean fish tanks. It has a sponge

and is shaped like an arm’’). Cartoon-style colored pictures were created depicting the function and features of each invention. A sample of a drawing can be found in Appendix B.

Children were familiarised with the spoken phonology of eight novel words and with the meanings of the words in the form of inventions. Children also saw pictures that depicted items and their features. They were encouraged to remember the invention names and the semantic information related to the names. This familiarisation continued for four sessions over 4 days, with a total of 22 phonological exposures for each item.

Four items were introduced in Session 1 and four were introduced in Session 2. The experimenter started by saying the name of the invention, asking the participants to repeat the name, and then introducing the semantic features with both the picture and verbal descriptions (e.g., ‘‘This invention is a *cleap*. It has a sponge and is shaped like an arm. It is used to clean fish tanks’’). Participants then heard the item name again and were asked to repeat the name once more, and finally they were asked to say what the invention was used for. After all four items were introduced, a picture naming task was conducted with feedback, followed by the experimenter saying the features and the function of the items once more.

Sessions 3 and 4 included all eight items and started with the experimenter showing the picture and saying the features and function of the invention. Participants were then asked whether they could recall the name of that invention. Whether or not they correctly recalled the name, the children were then provided with the name and asked to repeat it. To simulate a natural condition of children’s vocabulary knowledge and assist the participants in learning the items better, the participants were 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 _____’’.

A picture naming task was conducted at the end of each preexposure session to measure how well the participants had learned to associate the semantic information with the phonology of the items and was scored for accuracy. After scoring, if the children could not recall the name correctly, the initial sound of the word was provided as a cue. If the children

still could not produce the correct word, the experimenter would then provide the correct answer. The picture naming task was conducted again immediately before the orthographic exposure phase and again 10 days after orthographic exposure, but without any feedback or phonemic cues.

Orthographic exposure phase. During the orthographic exposure phase, the children were asked to read aloud the materials presented to them. To see the effect of context in a self-teaching paradigm, no feedback was provided during reading. The stimuli were presented to the children for the first time in written form, with half appearing in context and half appearing without context. Children were told that they were now going to see the invention names that they had been learning about in written forms and that there would be questions about those words for them to answer afterward.

In the *context* condition, the nonword items were presented in stories. Each item appeared four times in a short story, averaging 57 words in length. The stories were presented on an A4 size paper (similar to a US letter size paper) in a 22-point font size. Two comprehension questions related to the content of each story were created to make sure that the participants read carefully.

In the *no-context* condition, the target items were presented four times in lists of words. Each list contained the same number of words as the story in the context condition. The words in the no-context lists were matched with the words in the context condition for frequency in CPWD, length, and word class. The items in lists were presented in a table format rather than on individual flash cards so that items in the lists and the stories were presented in a visually similar display.

Orthographic test phase. Orthographic learning was assessed using three tasks: spelling, orthographic choice, and orthographic decision. These tests were carried out immediately after orthographic exposure and again 10 days after orthographic exposure.

Spelling task. Children were first reminded that what they had just read was how the

invention names were written down and that now it was time to see how well they could remember them. The children were instructed to write down the words when the experimenter said them aloud and to write them exactly as they had seen them in printed form.

Orthographic choice task. The target item was presented together with its homophone and two visual distractors (e.g., *cleap*, *cleep*, *cleak*, *cleek*). The two visual distractors were also homophones. In this way, the target and homophone (e.g., *cleap*, *cleep*) had the same vowel pronunciation, and the other two items (e.g., *cleak*, *cleek*) also shared the same vowel pronunciation, ensuring that there was no outstanding pronunciation that might influence the decision in making the orthographic choice. The four options were presented horizontally on an A4 size paper. Children were told that only one of the four options was the correct spelling of the invention name.

Orthographic decision task. A previous study looking at aphasic patients found that a multiple-choice task was less sensitive than a verification task at identifying language impairments in auditory comprehension (Breese & Hillis, 2004). Multiple-choice tasks such as orthographic choice could induce strategic decision making and possibly more interference from the distractors when making the decision. In the orthographic choice task, children are restricted to choosing one option and, moreover, would know that one of the options is the correct target. If children have no representation of the target item at all, there will be a 25% chance of choosing the correct target. On the other hand, if children have a relatively strong phonological representation compared with the orthography, the chance of getting the correct target will be 50% (between the correct target and its homophone foil). Therefore, in a variation on the orthographic choice task, we developed an orthographic decision task to provide a more sensitive measure of orthographic representations, where children are not restricted to choosing only one option. All target items, homophones of the target items, and visual distractors were randomised and presented one at a time on flash

cards. Children were asked to look at each card carefully and to answer “yes” if the word on the card was an invention name with the correct spelling or “no” if the word was not a correctly spelled invention name.

Children received no feedback on their performance on any of the test measures.

Results

Oral vocabulary learning. The training of oral vocabulary was carried out over four sessions; four of the items were trained in Session 1, the other four were trained in Session 2, and all eight items were trained again in Sessions 3 and 4. Hence, each item received three training sessions. As noted above, a picture naming task was conducted after every session during the preexposure phase, then immediately before the orthographic exposure phase, and again 10 days after the orthographic exposure phase to provide a measure of the maintenance of the children’s semantic knowledge and its link to the phonology of the items. Note that during the preexposure phase, picture naming was cued with the initial sound of the word if the children could not recall the name. Only uncued correct responses were scored and are reported here. The accuracy of the task with cued responses was even higher.

In addition to saying the names of the inventions on the pictures, the children were also asked to give the functions of the inventions to provide a more detailed indication of their semantic knowledge for the items. When asked to recall the functions of the inventions with the pictures being available, none of the participants made any errors. This is perhaps unsurprising given that a picture provides clear cues as to an invention’s function.

The mean proportion of correct responses in the picture naming task increased across the training sessions (Sessions 1 and 2, $M = .39$, $SD = .25$; Session 3, $M = .48$, $SD = .25$; Session 4, $M = .74$, $SD = .25$) and remained roughly the same immediately before the orthographic exposure phase ($M = .74$, $SD = .21$) and again 10 days after the exposure phase ($M = .77$, $SD = .22$). To see whether the participants improved their vocabulary knowledge

about the novel words during the preexposure training, a repeated measures analysis of variance (ANOVA) with the factors of time (Sessions 1 and 2, Session 3, Session 4) and context (context, no-context) was conducted. The results showed that, as predicted, the participants performed significantly better on the picture naming task as the training progressed, $F(2, 34) = 34.18$, $\eta_p^2 = .67$, $p < .01$, with a significant linear trend, $F(1, 17) = 71.20$, $\eta_p^2 = .01$, $p < .01$. There was no effect of context, $F(1, 17) = 0.18$, $\eta_p^2 = .01$, $p = .68$. Note that although the analyses were done by separating the items into those that were to be assigned to the context and no-context conditions during the orthographic exposure phase, during the preexposure phase there was no difference between the way these items were trained.

A repeated measures ANOVA with the factors of time (Session 4, before the orthographic exposure, 10 days after the exposure) and context (context, no-context) showed no effect of time, $F(2, 34) = 0.37$, $\eta_p^2 = .02$, $p = .70$, or context, $F(1, 17) = 0.20$, $\eta_p^2 = .01$, $p = .66$, indicating that vocabulary knowledge did not change between the end of the training sessions, immediately before orthographic exposure, and after a 10-day delay and also did not differ between conditions. No interaction was found between the two factors, $F(2, 34) = 0.55$, $\eta_p^2 = .03$, $p = .58$.

Orthographic exposure phase. During the orthographic exposure phase, the children read aloud the items either in stories (context condition) or in lists (no-context condition). Each item was scored four times over the four exposures; the mean accuracy in reading the novel words in the context and no-context conditions over four exposures is presented in Table 1. Overall, 92% of the items were read correctly.

Table 1.

The Mean Accuracy in Reading Aloud During the Orthographic Exposure Phase in Experiment 1

	1st exposure	2nd exposure	3rd exposure	4th exposure
Context	.94 (.11)	.96 (.10)	.96 (.10)	.97 (.08)
No Context	.83 (.17)	.88 (.20)	.90 (.15)	.88 (.21)

Note: standard deviations are in parentheses.

An ANOVA with the factors of exposure (first, second, third, fourth) and context (context, no-context) showed that there was a main effect of exposure, $F(3, 51) = 3.21$, $\eta_p^2 = .16$, $p = .03$, with a significant linear trend, $F(1, 17) = 6.36$, $\eta_p^2 = .27$, $p = .02$. The main effect of context approached significance, $F(1, 17) = 3.98$, $\eta_p^2 = .19$, $p = .06$, and no interaction was found, $F(3, 51) = 1.22$, $\eta_p^2 = .07$, $p = .31$. Children showed a strong tendency toward an advantage for reading the novel words when presented in the context condition. Post hoc analyses revealed that this was significant for the first exposure to the novel item, $t(1, 17) = 2.68$, $d = .78$, $p = .02$.

Orthographic test phase. The analyses for this phase compared the accuracy rates on the spelling, orthographic choice, and orthographic decision tasks as a function of context (context, no-context) and time (immediately after orthographic exposure, after a 10-day delay).

Spelling. Responses were scored as correct only when the participants spelled the exact written form that they saw during the orthographic exposure phase. Alternative homophonic spellings of the target items (e.g., target: *cleap*; homophone: *cleep*) were recorded as “homophonic misspellings,” and other responses were grouped as “other misspellings.” Fig. 1 illustrates the proportion of responses of each type on the task both immediately after the exposure and after a 10-day delay.

On average (combined across conditions), the children spelled .53 ($SD = .21$) of the

target items correctly immediately after the exposure and spelled .49 ($SD = .17$) correctly in the delayed test. In addition, the participants produced .22 ($SD = .11$) homophonic misspellings immediately after the exposure; the mean proportion increased to .31 ($SD = .13$) when the spelling task was conducted again 10 days later (combined across conditions).

For the correct spelling responses, there was no main effect of context, $F(1, 17) = 2.06$, $\eta_p^2 = .11$, $p = .17$, or time, $F(1, 17) = 0.80$, $\eta_p^2 = .05$, $p = .38$, and there was no interaction between time and context, $F(1, 17) = 0.70$, $\eta_p^2 = .04$, $p = .41$.

In analysing the homophonic misspelling responses, a main effect of time was found, $F(1, 17) = 5.39$, $\eta_p^2 = .24$, $p = .03$, but there was no main effect of context, $F(1, 17) = 0.85$, $\eta_p^2 = .05$, $p = .37$, and no interaction, $F(1, 17) = 0.46$, $\eta_p^2 = .03$, $p = .51$. The participants produced significantly more homophonic misspellings in the delayed test compared with the test immediately after the exposure, $t(1, 17) = -2.32$, $d = -.74$, $p = .03$.

Orthographic choice. This required the participants to choose the target item (e.g., *cleap*) over its homophone foil (e.g., *cleep*) and two visual distractors (e.g., *cleak*, *cleek*). The pattern of responses produced by the participants immediately and 10 days after the exposure is illustrated in Fig. 2.

Combined across conditions, the overall proportion where the target was correctly chosen over its homophone foil and visual distractors was .73 ($SD = .18$) immediately after the exposure. This dropped to .64 ($SD = .18$) in the delayed test. Instead of choosing the target items, the participants chose the homophone .22 ($SD = .18$) of the time combined across conditions; after 10 days delay, the mean increased to .35 ($SD = .20$). A repeated measures ANOVA showed a main effect of time, $F(1, 17) = 5.39$, $\eta_p^2 = .24$, $p = .03$, reflecting the fact that participants chose the correct target items significantly more often immediately after the exposure compared to the delayed test. There was no main effect of context, $F(1, 17) = 0.57$, $\eta_p^2 = .03$, $p = .46$ and no interaction between context and time, $F(1, 17) = 1.8$, $\eta_p^2 = .10$, $p = .20$.

The mean rate of homophone foil choice also showed a main effect of time, with participants choosing the homophone foil significantly more often in the delayed test than in the immediate test, $F(1, 17) = 9.76$, $\eta_p^2 = .37$, $p = .01$. There was no main effect of context, $F(1, 17) = 1.05$, $\eta_p^2 = .06$, $p = .32$, and no interaction, $F(1, 17) = 3.15$, $\eta_p^2 = .16$, $p = .09$.

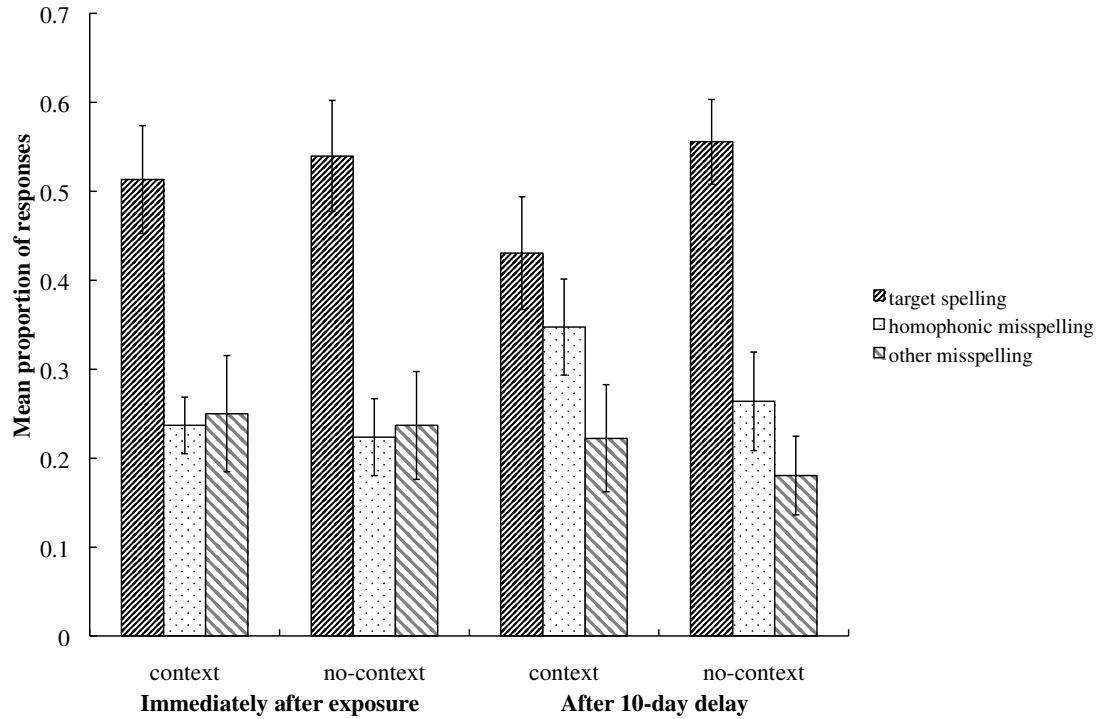


Fig. 1. Mean responses from the spelling task in Experiment 1.

Orthographic decision. Children were asked to say “yes” to the correctly spelled invention name, and “no” to homophone foils and visual distractors. The mean proportion of occasions participants correctly said “yes” to the target, and incorrectly said “yes” to the homophone foils and the visual distractors, immediately after and 10 days after the exposure, is presented in Fig. 3.

CONTEXT EFFECTS ON ORTHOGRAPHIC LEARNING

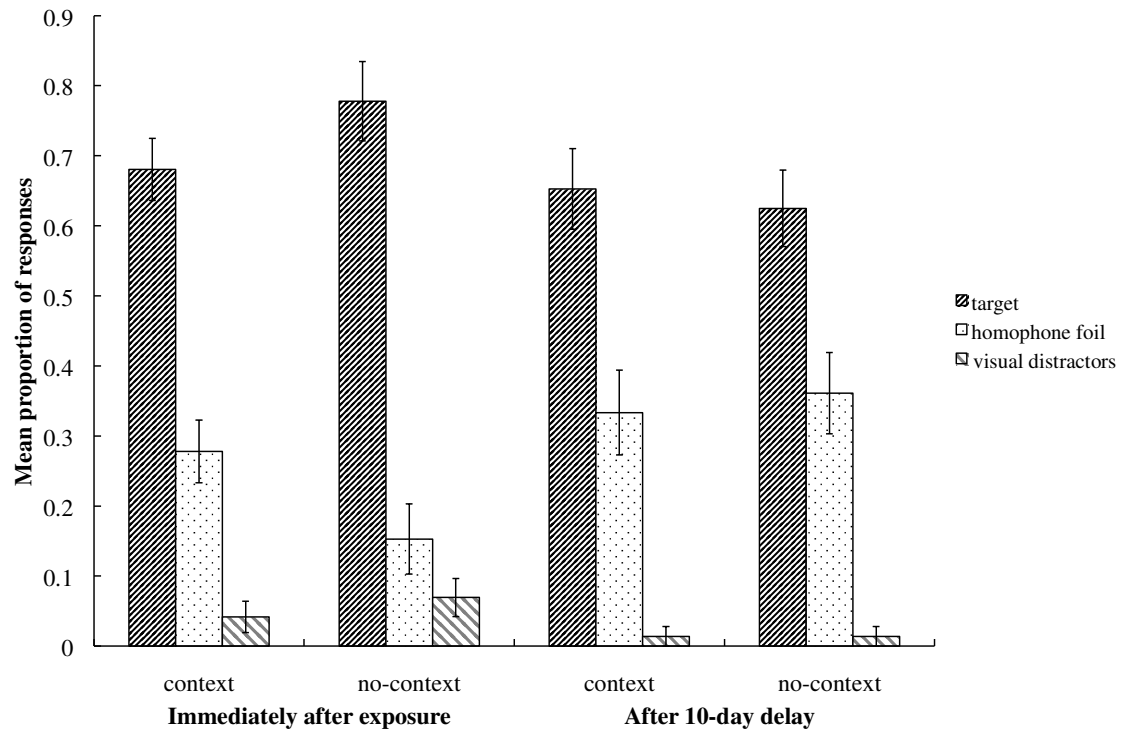


Fig. 2. Mean responses from the orthographic choice task in Experiment 1.

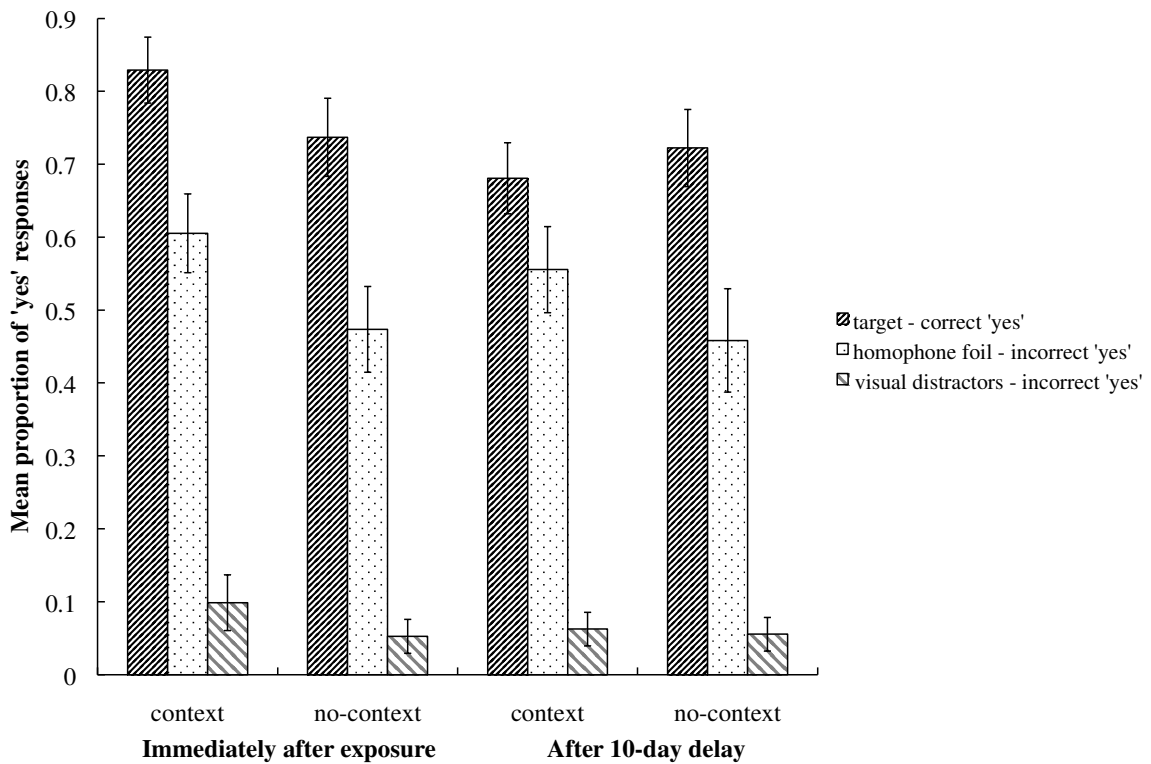


Fig. 3. The “yes” responses from the orthographic decision task in Experiment 1.

The overall mean proportion of targets correctly accepted combined across conditions was .79 ($SD = .16$) immediately after the exposure, dropping slightly to .70 ($SD = .14$) 10 days later. A main effect of time was found, $F(1, 17) = 4.75$, $\eta_p^2 = .22$, $p = .04$, indicating that this decrease in performance was significant. There was no main effect of context, $F(1, 17) = 0.12$, $\eta_p^2 = .01$, $p = .73$, and no interaction, $F(1, 17) = 2.89$, $\eta_p^2 = .15$, $p = .11$.

There were no main effects of time, $F(1, 17) = 0.57$, $\eta_p^2 = .03$, $p = .46$) or context, $F(1, 17) = 2.71$, $\eta_p^2 = .14$, $p = .12$ for incorrectly accepting the homophonic foil.

Discussion

Experiment 1 looked at the effect of context on orthographic learning of regularly pronounced novel words. The results showed no evidence for better learning of the orthography of these novel words in context, either in the short term or in the longer term.

The preexposure phase aimed to simulate children's typical experience in learning to read new words by providing semantic and phonological vocabulary knowledge prior to written exposure. After 4 days of training, the children were able to associate the sound of the novel word with its meaning more than 70% of the time. This knowledge was retained over time, suggesting that children not only learned the vocabulary and semantic information but also were able to retain this knowledge for the duration of the experiment.

The results from the orthographic exposure phase showed that the participants tended to read the novel words more accurately when they were presented in sentence contexts than when they were presented as single words in lists, particularly at the first written exposure. This result is consistent with previous findings suggesting that the presence of contextual information assists in word identification, allowing "contextual guessing" (Landi et al., 2006; Nation & Snowling, 1998). Although the effect was small, it should be noted that performance was close to ceiling in both the context and no-context conditions, and so it is

possible that this disguised any stronger beneficial effects of context.

Results from all three measures of orthographic learning—spelling, orthographic choice, and orthographic decision—showed evidence of orthographic learning but no effect of context both immediately after the exposure and after a 10-day delay. Although there was a weak trend favoring the items learned without context in the spelling test, which is similar to the findings of Landi and colleagues (2006), this was not significant in our experiment.

The participants tended to benefit from context in correctly reading the novel words when they encountered them for the first time, but we did not find evidence that contextual information either inhibited or facilitated orthographic learning. Consistent with Nation and colleagues (2007), we found that regularly pronounced novel words presented in context were learned just as well as those presented without context. Nevertheless, the results from the current study did show a trend favoring novel words learned without context. Landi and colleagues (2006) argued that learning a new word in context reduces the amount of attention focused on the word compared with words in isolation and, thus, results in less effective word retention. However, in their study, word regularity was not controlled, and (as discussed earlier) it is likely that more assistance might be needed from context to decode the word when the unfamiliar words are irregular. Hence, it is possible that in Landi and colleagues' study, the need for more contextual guessing due to the inclusion of irregular words resulted in more attention being diverted from orthographic learning in the context condition and, therefore, in words presented in isolation being better learned. However, the current study used only regular novel words, requiring less focus on contextual information and, therefore, potentially more attention to orthographic detail. Thus, word regularity may be an important factor modulating the effect of context on orthographic learning.

According to Share's (1995) self-teaching hypothesis, contextual information is important for supporting weak phonological recoding or for identifying words that can be only partially decoded. Participants in Experiment 1 were second graders with sufficient

phonological skills to decode the regular letter-to-sound novel words used in this experiment. To test the hypothesis of a greater facilitation effect of context for partial decoding, Experiment 2 used irregular novel words that could not be fully decoded with regular letter-to-sound rules.

Experiment 2

Method

Participants. A total of 22 children in second grade participated in this experiment. The mean age of the participants was 8 years (ranging from 7 years 2 months to 8 years 8 months). Children were recruited from a class in a mainstream primary school in the Sydney metropolitan region. None of the participants in this experiment also participated in Experiment 1. Because 1 of the participants was not able to complete the last session, data from 21 participants were analysed.

Children were again normal range readers, as indicated by the CC2 (Castels et al., 2010) (regular words: mean z score = 0.30, SD = 1.02; irregular words: M = 0.21, SD = 0.86; nonwords: M = 0.32, SD = 1.05) and the TOWRE (Torgesen et al., 1999) (words: mean standard score = 111.77, SD = 15.37; nonwords: M = 108.50, SD = 15.93).

Materials and procedure. In this experiment, all aspects of the design were the same as in Experiment 1 except that the novel words were given irregular pronunciations and some adjustments were made accordingly. The target items used in Experiment 1 were regular in the sense that the pronunciations of the words followed GPC rules, the vowels were pronounced in the same way in more than 50% of words in the CPWD based on the token frequency, and the body was consistent in reading. The target items used in Experiment 2 were spelled the same as the target items used in Experiment 1 but were irregular in that the pronunciations did not follow GPC rules, the vowels were pronounced in this form in fewer than 50% of words in the CPWD, and the body in real words is never

pronounced the way it was in the experiment. However, it is important to note that the irregular pronunciations were possible for each vowel; they just were not frequent pronunciations for that certain form, nor were they pronunciations that occurred in the context of that final consonant (i.e., that body). For example, the participants in both experiments saw the target spelling *cleap* in written form during the orthographic exposure phase; in Experiment 1 the children heard the target pronunciation as *cleap* (/kli:p/) during the preexposure phase when learning the name for the invention, whereas in Experiment 2 they heard the pronunciation as *clape* (/kleIp/).

During the test phase, for the orthographic choice and orthographic decision tasks, a set of three distractors was created based on each target spelling. Rather than using a homophone of the target item as in Experiment 1, a “regularised” spelling distractor was created. The regularised spelling foil was matched with the target pronunciation by using GPC rules. For example, the participants heard the target as *clape* during the preexposure phase but saw *cleap* during the exposure phase, and the regularised spelling foil would be *clape*. The regularised foil, therefore, was the only option that matched the phonology of the novel word according to the children’s prior vocabulary knowledge. There were also two visual distractors (e.g., *cleak*, *clake*). One of the visual distractors was created by changing one letter of the target item, and the other one was created by changing one letter of the regularised foil. In addition, two of the four choices had their vowels pronounced in the same way (*cleap/cleak*, *clape/clake*) using GPC rules so that one pronunciation did not outnumber the other and induce strategic choices.

The instructions before the orthographic exposure were modified for the irregular items used in this experiment. In addition to the instructions given in Experiment 1, the children were also told the following by the experimenter:

Some of these invention names will not look exactly like the way they sounded. For example, Professor Parsnip has a dog named “Dord,” and this is what is written on his

name tag: ‘‘Dard’’ [show Dard on a card]. And this will sometimes happen when you are learning to read new words as well; for example, this word is ‘‘blood’’ [show blood on a card] but not ‘‘blued’’ (/blud/). So now your job is to use what you know about the invention names to help you with reading them and remembering them.

Results

Preexposure phase. The picture naming task was carried out across the four training sessions, before the orthographic exposure phase, and 10 days after the exposure phase. Note that during the training sessions (Sessions 1-4), the items were presented identically across context and no context conditions.

By the end of the preexposure training session, the participants could correctly name the picture .67 ($SD = .19$) of the time, improved from Session 1 and 2, .36 ($SD = .22$), and Session 3, .50 ($SD = .23$). Combined across conditions, the mean proportion of correct picture naming responses was .64 ($SD = .23$) before the orthographic exposure phase; this dropped slightly to .57 ($SD = .17$) 10 days after the exposure phase. A repeated measures ANOVA with factors of time (Sessions 1 and 2, Session 3, or Session 4) and context showed that participants improved in their performance on the task with time. There was a significant effect of time, $F(2, 40) = 29.57$, $\eta_p^2 = .59$, $p < .01$, with a significant linear trend, $F(1, 20) = 104.10$, $\eta_p^2 = .83$, $p < .01$, but no effect of context, $F(1, 20) = 1.39$, $\eta_p^2 = .06$, $p = .25$.

A second repeated measures ANOVA explored whether naming performance decreased after the training sessions, before the orthographic exposure and 10 days after the exposure. This revealed a main effect of time (Session 4, before the exposure, 10 days delay), $F(2, 40) = 3.40$, $\eta_p^2 = .15$, $p = .04$, but no main effect of context (context, no-context), $F(1, 20) = 0.003$, $\eta_p^2 = .00$, $p = .96$, or interaction, $F(2, 40) = 0.22$, $\eta_p^2 = .01$, $p = .80$. The main

effect of time was due to the accuracy in Session Four being significantly higher than the accuracy 10 days after the exposure phase, $t(1, 20) = 2.58$, $d = .58$, $p = .02$.

Orthographic exposure phase. Children read the target items in stories or lists, each item was repeated four times. Items were scored as correct only if the participants pronounced them as they had heard them in the pre-exposure phase. Table 2 shows the mean rate of correct reading across four exposures in both conditions:

Table 2.

The Mean Accuracy in Reading Aloud During the Orthographic Exposure Phase in Experiment 2

	1st exposure	2nd exposure	3rd exposure	4th exposure
Context	.71 (.36)	.71 (.32)	.71 (.30)	.71 (.30)
No Context	.50 (.33)	.56 (.37)	.57 (.35)	.58 (.34)

Note: standard deviations are in parentheses.

Overall, .63 ($SD = .28$) of the items were read as the target pronunciations, with the mean proportion of .71 ($SD = .31$) in the context condition and .55 ($SD = .34$) in the no-context condition (combined across the four exposures). A repeated measure ANOVA with the factors of exposure (first, second, third, fourth) and context (context, no-context) revealed a main effect of context, $F(1, 20) = 5.00$, $\eta_p^2 = .19$, $p = .04$, with mean reading accuracy across all four exposures being significantly higher when the items were presented in context condition than in the no-context condition. There was no main effect of exposure, $F(3, 60) = 1.44$, $\eta_p^2 = .06$, $p = .24$, and no interaction between the factors, $F(3, 60) = 1.31$, $\eta_p^2 = .06$, $p = .28$.

Orthographic test phase. Three tasks were conducted to assess the success of orthographic learning immediately, and 10 days after the exposure phase.

Spelling. The written forms of the target items presented in the orthographic exposure phase were considered as the correct spellings. Incorrect misspellings were categorised as regularised misspellings when the participants used sound-to-letter rules to produce spellings corresponding to the pronunciations they heard during the preexposure phase (e.g., target: *cleap*; regularised spelling: *clape*). The remaining incorrect responses were grouped as ‘other misspelling’. Fig. 4 illustrates the responses produced by the participants immediately after the exposure phase and after a 10-day delay.

Combined across conditions, children spelled .15 ($SD = .14$) of the target items correctly immediately after the written exposure. The correct spelling rate 10 days after the exposure dropped to .10 ($SD = .10$). For the regularised misspelling responses, the mean combined across conditions was .51 ($SD = .24$) immediately after the exposure, and this increased to .58 ($SD = .23$) 10 days after the exposure (combined across conditions).

For correct spelling production, there was a main effect of time with participants producing significantly more correct target spellings immediately after the exposure than at the delayed test, $F(1, 20) = 6.92$, $\eta_p^2 = .26$, $p = .02$. There was no main effect of context, $F(1, 20) = 0.02$, $\eta_p^2 = .001$, $p = .89$, and no interaction, $F(1, 20) = 1.72$, $\eta_p^2 = .08$, $p = .20$.

The regularised misspelling responses showed the same pattern: a main effect of time, $F(1, 20) = 4.71$, $\eta_p^2 = .19$, $p = .04$, but no main effect of context, $F(1, 20) = 0.80$, $\eta_p^2 = .04$, $p = .38$, and no interaction between the two factors, $F(1, 20) = 3.40$, $\eta_p^2 = .15$, $p = .08$.

Orthographic choice. The orthographic choice task required the participants to choose the target item (e.g., *cleap*) over its regularised foil (e.g., *clape*) and two visual distractors (e.g., *cleak*, *clake*). Fig. 5 shows the responses circled by the participants immediately after exposure and after a 10-day delay.

Combined across conditions, the overall accuracy for choosing the correct target was .52 ($SD = .25$) immediately after the exposure phase, dropping to .46 ($SD = .22$) in the delayed test. The largest proportion of errors were when, instead of choosing the target item,

the participants chose the regularised foil. This occurred on .42 ($SD = .25$) of responses immediately after the exposure, increasing to .52 ($SD = .21$) of responses in the test 10 days later (combined across conditions).

In analysing the correct target responses, there was no main effect of context, $F(1, 20) = 1.02$, $\eta_p^2 = .05$, $p = 0.33$, or time, $F(1, 20) = 1.77$, $\eta_p^2 = .08$, $p = .20$. There was also no interaction between context and time, $F(1, 20) = 1.63$, $\eta_p^2 = .08$, $p = .22$, despite the apparent trend towards worse performance in the no-context condition in the delayed test.

For the mean responses choosing the regularised foil, there was a main effect of time, $F(1, 20) = 4.53$, $\eta_p^2 = .19$, $p = .046$, with participants choosing this foil more often in the delayed test than immediately after orthographic exposure. But once again there was no main effect of context, $F(1, 20) = 0.64$, $\eta_p^2 = .03$, $p = .43$, nor interaction of the two factors, $F(1, 20) = 0.95$, $\eta_p^2 = .05$, $p = .34$.

Orthographic decision. In this task, the children were asked to say “yes” to the correct invention name, and “no” to regularised foils and visual distractors. The mean proportions for correctly accepting the targets and for incorrectly accepting the regularised foil and the visual distractors immediately after the exposure and after a 10-day delay are illustrated in Fig. 6.

The overall mean combined across conditions showed that the participants correctly accepted the target item immediately after the exposure phase on a proportion of .58 ($SD = .16$) of occasions, dropping slightly to .55 ($SD = .23$) 10 days later. However, combined across time and condition, the participants also incorrectly accepted the regularised foil a proportion of .59 ($SD = .22$) of the time and incorrectly accepted the visual distractors .08 ($SD = .09$) of the time.

In analysing only the correct acceptance of the target item, a main effect of context was found, with participants performing better in the context condition than in the no-

CONTEXT EFFECTS ON ORTHOGRAPHIC LEARNING

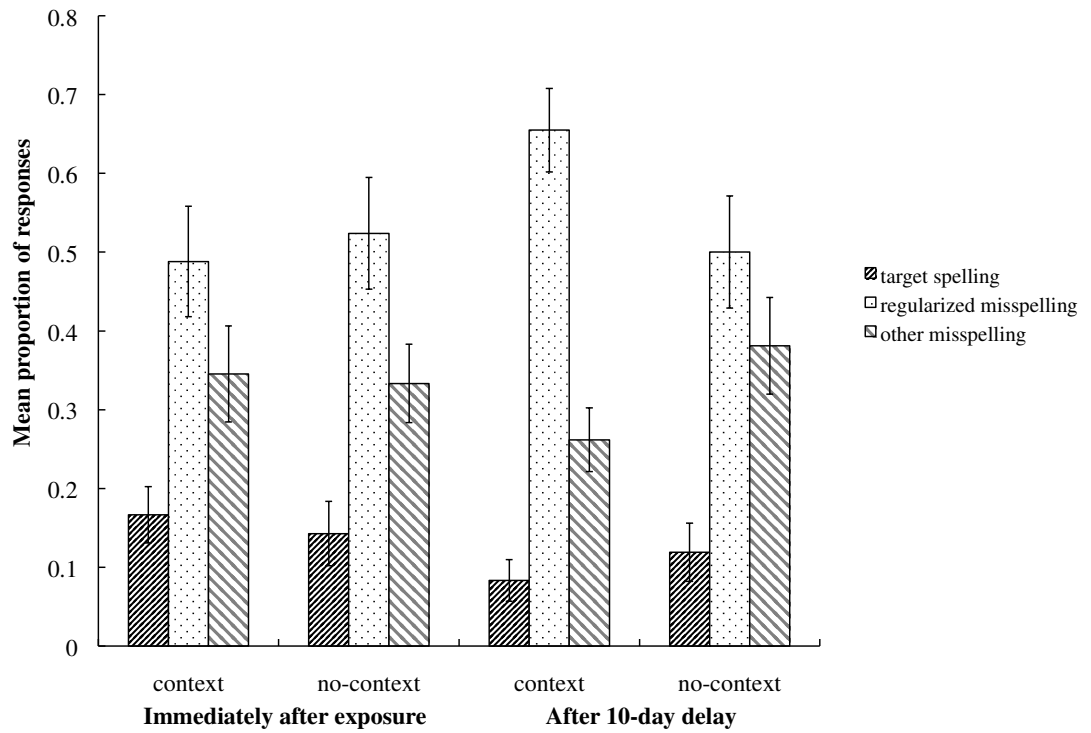


Fig. 4. Mean responses from the spelling task in Experiment 2

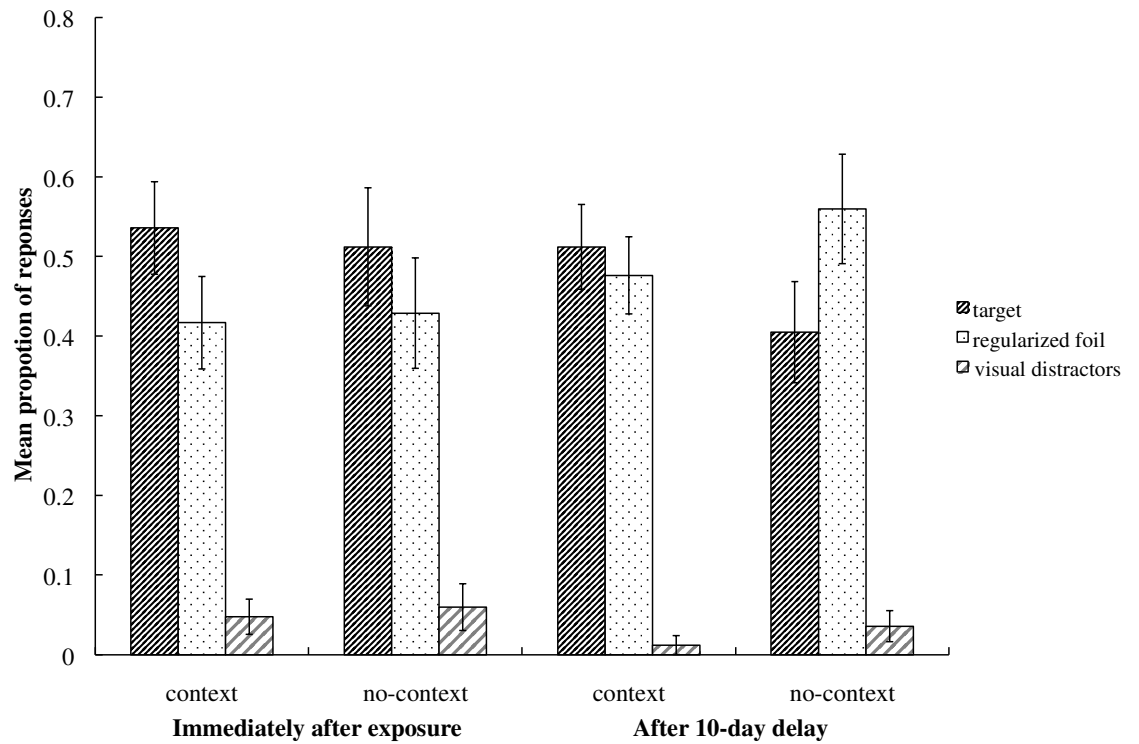


Fig. 5. Mean responses from the orthographic choice task in Experiment 2.

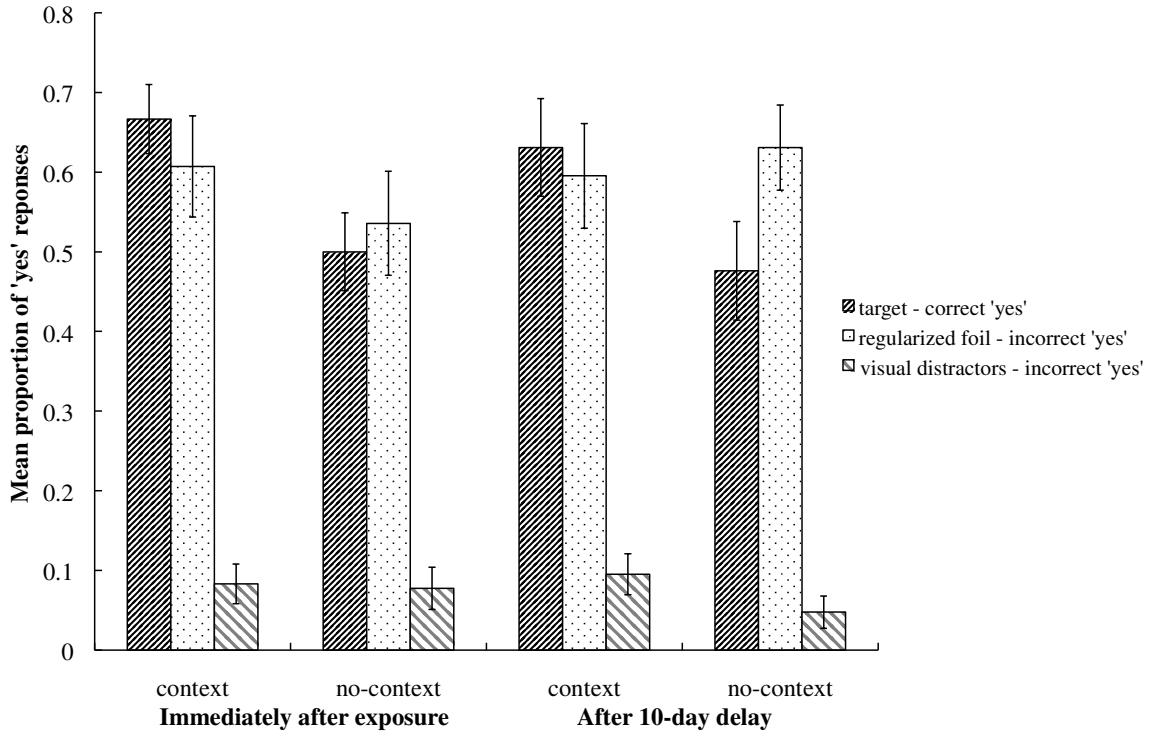


Fig. 6. The 'Yes' responses from the orthographic decision task in Experiment 2.

context condition, $F(1, 20) = 8.65$, $\eta_p^2 = .30$, $p = .01$. There was no main effect of time, $F(1, 20) = 0.25$, $\eta_p^2 = .01$, $p = .62$, and no interaction, $F(1, 20) = 0.02$, $\eta_p^2 = .001$, $p = .88$.

Finally, for falsely accepting regularised foils, there was no main effect of time, $F(1, 20) = 0.89$, $\eta_p^2 = .04$, $p = .36$, context, $F(1, 20) = 0.13$, $\eta_p^2 = .01$, $p = .72$, or interaction between the two factors, $F(1, 20) = 1.40$, $\eta_p^2 = .07$, $p = .25$. Considering the higher rate of correct reading attempts in the context compared with that in the no-context condition during the orthographic exposure phase, one possible explanation for the context effect found in this task could be that the higher target acceptance in context was simply a reflection of the higher reading accuracy. Therefore, the analysis was repeated with correct reading of the first exposure as a covariate and the effect of context remained significant, $F(1, 19) = 5.89$, $\eta_p^2 = .24$, $p = .03$.

Although the effect of context was only significant in the target acceptance compared to the regularised foil acceptance, the high rate of accepting both the targets and the

regularised foils called for further analysis. A supplementary analysis of beta (β) based on signal detection theory (SDT) (Green & Swets, 1966) was used to measure response bias. For the orthographic decision task, we calculated β combined across participants based on the mean hit (HR, -correctly saying “yes” to the target) and the false alarm rate (FR, incorrectly saying “yes” to the regularised foil): $\beta = -[z(\text{HR}) + z(\text{FR})] / 2$. This analysis allowed us to examine whether the responses were biased towards saying “yes” or “no” as a function of the context and no-context conditions.

The results showed that in the context condition, β was significantly less than 0 both immediately after exposure ($\beta = -0.43$, $SD = .60$), $t(1,20) = -3.57$, $p = .002$, and after a 10-day delay ($\beta = -0.42$, $SD = .80$), $t(1,20) = -2.42$, $p = .03$, indicating that children tended to accept both targets and the regularised foils. In contrast, the results from the no- context condition showed that β was not significantly different from 0 either immediately after exposure ($\beta = -0.09$, $SD = .72$), $t(1,20) = -0.62$, $p = .54$, or after a 10-day delay ($\beta = -0.17$, $SD = .58$), $t(1,20) = -1.42$, $p = .17$. This indicates that when the novel words were read in context, the children possibly acquired some form of representation (phonological and/or orthographic), albeit partially specified. Thus, the children were more likely to accept the target as well as its homophonic foil.

Discussion

Experiment 2 looked at the effect of context on orthographic learning of novel words assigned irregular pronunciations, where the participants could not fully decode the novel words by using letter-to-sound rules. The results showed that correct initial reading of the novel words was strongly facilitated by the presence of contextual information and that there was a moderate beneficial effect of context on orthographic learning.

The results from the orthographic exposure phase showed that the participants read more irregular novel words correctly when the words were presented in a sentence context

than when they were presented in lists. The participants appeared to use contextual information to provide top-down support to resolve decoding ambiguity, as suggested by Share (1995). On the other hand, when the irregular novel words were presented without context, the rate of correct pronunciation was much lower and the incorrect productions were mostly the alternative regularised pronunciations derived by using letter-to-sound rules.

Overall spelling accuracy in Experiment 2 was a lot lower than that in Experiment 1. Instead of correct spellings, the participants produced the regularised spellings about half of the time both immediately after exposure and in the delayed test. Context did not play a role in the likelihood of producing the correct spellings across time. It should be noted that the performance in the spelling task was close to floor level (the overall accuracy across time and conditions was just above 10%), reducing the chance of observing statistically significant results. However, there was a significant context effect in the production of regularised misspellings, which was found to be higher in the 10-day delayed test for the words presented in context compared with those presented without context.

As would be expected, the results from the orthographic choice task showed a higher accuracy in choosing the correct targets compared with the production of correct targets in the spelling task. The results from this task appeared to show a tendency for performance to be better maintained when the words had been learned in a sentence context.

An effect of context was observed in the orthographic decision task, where the participants correctly accepted more target items when the target items had been learned in sentence contexts compared with when they had been learned in lists of words. Context facilitation was strong and was maintained at the posttest 10 days later. In contrast, there was no effect of context on the likelihood of falsely accepting the regularised misspellings. Further analysis of response bias showed that the children were more inclined to accept both the target and its regularised foil when the novel words were learned in context. This suggested that novel words learned in context were better acquired in the lexicon and that

this was manifested in a higher rate of acceptance of both the orthographic and phonological representations of the words.

In summary, the availability of contextual information assisted children as they irregularly pronounced novel words, drawing on pronunciations associated with their newly learned vocabulary knowledge. The results from the orthographic decision task showed that the irregular novel words were learned better in context. However, the effect of contextual facilitation was not as strongly evident in the spelling and orthographic choice tasks - the tasks used by most of the previous studies to measure orthographic learning. The orthographic decision task appeared to be more sensitive in measuring weak orthographic representations. The discrepant results among the tasks are discussed further in the General Discussion.

General discussion

This study aimed to explore the effect of context on orthographic learning in a self-teaching environment and to see whether the effect of context interacts with word regularity. The findings from the two experiments suggest that the effect of context on orthographic learning was modulated by word regularity.

In both experiments, children read novel written words more accurately when they were presented in meaningful sentence contexts than when they were presented in lists. However, assistance from contextual information was stronger for irregular novel words than for regular words (where it primarily affected the first exposure to the orthographic form).

To measure the success of orthographic learning, three tasks were conducted both immediately after the orthographic exposure and again 10 days later: spelling, orthographic choice, and orthographic decision. In Experiment 1, where the novel words to be learned were regular, no facilitatory effect of context was seen on any of these measures of

orthographic learning. The results from Experiment 2, in which the novel words to be learned were assigned irregular pronunciations, showed a different pattern; better orthographic learning was seen in the context condition, and this was most evident in the orthographic decision task.

The findings from Experiment 1 are consistent with previous findings in which context has not been found to have an effect on orthographic learning for words with regular pronunciations (Cunningham, 2006; Nation et al., 2007). Nation and colleagues (2007) suggested that the failure to find an effect of context might be due to the lack of vocabulary knowledge prior to print exposure; their novel words were not already instantiated in the participants' oral vocabularies and, thus, the participants might not have been able to use top-down assistance even in the context condition. In the current study, however, children were first given the opportunity to acquire novel words in their oral vocabulary prior to orthographic exposure. The results showed that even with preexisting oral vocabulary knowledge that was strong and robust over time, children did not show better learning of these regular target words when presented in context. Indeed, similar to Landi and colleagues (2006), there was a trend favoring novel words learned without context, although this was evident only in the spelling test.

The findings from Experiment 2, using irregular novel words, paint a different picture of context effects on orthographic learning. Compared with regular word learning in Experiment 1, contextual facilitation was stronger for the initial reading of these irregular words, and for these items contextual facilitation also appeared to be evident in the acquisition of orthographic representations. The results from this study showed that context provided support in correctly reading both regular and irregular novel words during print exposure; however, only irregular words learned in context were better retained. It is important to note that the effect of context on orthographic learning of irregular words was shown most clearly in the orthographic decision task rather than in spelling or orthographic

choice.

Discrepancies in results for different measures of orthographic learning seem paradoxical; however, they have often been found in other studies (e.g., Nation et al., 2007; Ouellette & Fraser, 2009). The higher accuracy rate in orthographic recognition compared with spelling might be related to the strength of the new orthographic representations. Correct spelling is possible only with a complete and fully specified orthographic representation (Frith, 1980, 1985). In contrast, in orthographic choice and orthographic decision, a relatively weak representation of the word might be sufficient to perform the task correctly. The high rate of accepting the target items as well as their homophonic foils is consistent with the idea that fairly weak orthographic representations can support performance in orthographic recognition tasks. Across the two orthographic recognition tasks used in this study, the effect of context on irregular word learning was found only in the orthographic decision task and not in the orthographic choice task. The orthographic decision task allowed the children to make independent judgments on all targets and their foils rather than being restricted to only one option as in the orthographic choice task. Hence, the orthographic decision task might be a measure that is more sensitive to weaker representations of the novel word form and less susceptible to the effects of children's strategies on their decisions.

Our findings support Share's self-teaching hypothesis that contextual support helps with initial reading, especially when decoding is only partial. In the current study, both regular and irregular novel words were read better when they were presented in context. Nevertheless, there appeared to be different effects of contextual information on orthographic learning between regular and irregular novel words. Despite better reading performance, context did not lead to better retention of the orthographic representation for regular words (and appeared to favor words learned without context), but context was shown to facilitate irregular word learning. Our results from Experiment 2 with irregular words are

somewhat inconsistent with Landi and colleagues' (2006) account of the nature of context effects. Those authors suggested that the need for assistance from context diverts attention from building up an orthographic representation of the words and results in poorer learning for the words presented in context. Hence, the fact that more assistance was required from context for irregular word reading should induce a stronger negative effect of context compared with regular word learning. However, the reverse was found, with context benefiting irregular orthographic learning.

Our study refined the self-teaching paradigm in a number of important ways. First, the experiments were designed to have a training phase of vocabulary knowledge before the participants saw the words to be learned in print, with semantic information provided in the form of pictures depicting functional features of the novel words. Having oral vocabulary knowledge prior to encountering the word form not only is closer to children's everyday learning experience but also made it possible for the participants to correctly read out the irregular words unassisted by providing top-down information to assist in correct reading.

Second, to control the processing demands for orthographic learning of regular and irregular words (Bailey et al., 2004), we used the same spelling for the regular and irregular novel words and simply altered the assigned pronunciations.

Third, in many previous studies exploring the role of context in orthographic learning, words in the no-context condition were presented individually on flash cards. Landi and colleagues (2006) argued that this allows the participants to have more focused attention on the words to be learned than is the case for words presented in sentences or stories. Therefore, in the current study, the novel words in the no-context condition were presented embedded in a list of real words matched for length, frequency, and word class with the real words used in the context condition, ensuring that the two conditions were as closely matched as possible.

Finally, in addition to the spelling and orthographic choice tasks typically used to

assess orthographic learning, we included an orthographic decision task. Our results suggested that this seemed to be a more sensitive measure, tapping learning even when orthographic representations are weak. However, it is important to conduct further studies comparing the results among different measures of orthographic learning. In addition, considering the low spelling performance of the irregular novel words in the current study, future research with older students may be called for to enable better distribution of performance on the spelling measure.

In summary, our findings have demonstrated evidence of orthographic learning via self-teaching in 7- and 8-year-olds learning to read regular and irregular words in English. The results support the view that contextual information is important for orthographic learning but that its effect is restricted to when the words to be learned are irregular. Context does not seem to have an effect on novel word learning when mappings between orthography and phonology are regular.

Acknowledgments

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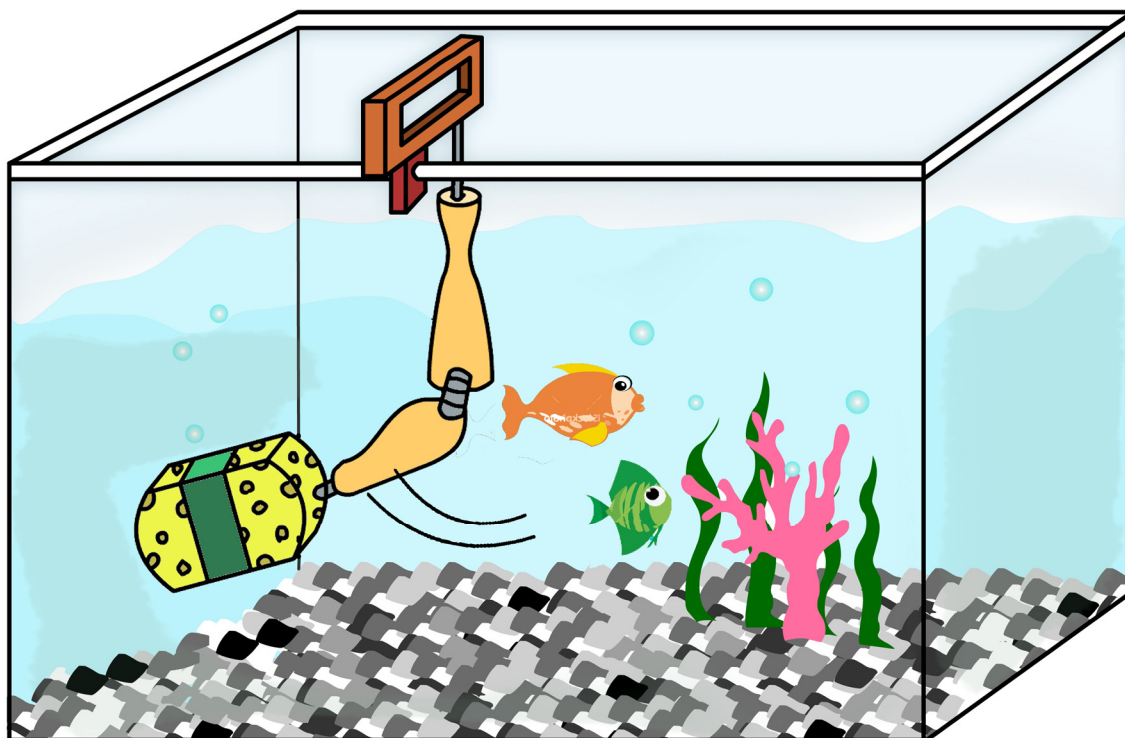
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Appendix A

An example of the picture used in the pre-exposure phase.



Appendix B

Target items used in the orthographic exposure phase		
	Regular (Exp1) pronunciation	Irregular (Exp2) pronunciation
vack	/væk/	/va:k/
smope	/sməʊp/	/smɒp/
praif	/preɪf/	/præf/
broon	/bru:n/	/brʌn/
jape	/dʒeɪp/	/dʒæp/
cleap	/cli:p/	/cleɪp/
doud	/daʊd/	/dəʊd/
ferb	/fɜ:b/	/fa:b/

Paper 2

Word Regularity Affects Orthographic Learning

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Abstract

Share's (1999) self-teaching hypothesis proposes that orthographic representations are acquired via phonological decoding. A key, yet untested, prediction of this theory is that there should be an effect of word regularity on the number and quality of word-specific orthographic representations that children acquire. Thirty-four Grade two children were exposed to the sound and meaning of eight novel words, and were then presented with those words in written form in short stories. Half the words were assigned regular pronunciations and half irregular pronunciations. Lexical decision and spelling tasks conducted 10 days later revealed that the children's orthographic representations of the regular words appeared to be stronger and more extensive than those of the irregular words.

Word count: 114

Keywords: orthography, word recognition, orthographic learning, self-teaching hypothesis, word regularity

Phonological decoding skill, or the ability to map letters to sounds, is widely agreed to be important in reading acquisition (e.g., Brady & Shankweiler, 1991; Byrne, 1992, 1998). However, being a proficient reader also requires the acquisition of word-specific knowledge to allow rapid, automatic recognition of individual words. Here, we test the hypothesis that there is an effect of word regularity on the number and quality of word-specific orthographic representations that children acquire. Such a regularity effect is clearly predicted by the most influential theory of orthographic learning– the self-teaching hypothesis (Share, 1995) - yet has not been directly experimentally tested to date.

According to the self-teaching hypothesis, orthographic learning takes place via phonological decoding of a novel printed word. When a word is encountered, the attempt to phonologically decode it functions as a self-teaching mechanism that builds its orthographic representation. In Share (1999), second grade Hebrew children were asked to read novel words in context (e.g. *Yait is the hottest town in the world.*). Three days later, the children were more likely to choose the target word (*yait*) than words spelled differently but with the same pronunciation (homophones, e.g., *yate*) or visual distractors, (e.g., *yoit*), suggesting that word-specific orthographic learning had taken place. Success of orthographic learning was also shown to be reduced when phonological recoding was minimised by reducing exposure duration and including concurrent articulation, suggesting that phonological decoding plays a direct role in building orthographic representations.

All of the novel words in Share’s experiments were regularly spelled. When a word’s letter-to-sound mapping is not regular (e.g., *yacht*), the relationship between phonological decoding and orthographic learning is less clear. Share (1995) argues that orthographic learning will still depend on decoding to some extent, since the letter-to-sound mappings are not completely unpredictable, even in English.⁴ However, if phonological decoding is indeed the primary mechanism by which orthographic representations are acquired, it should

⁴ Some theorists describe English as quasi-regular, as higher level regularities can be found even in irregular words (e.g., Plaut, McClelland, Seidenberg & Patterson, 1996).

nevertheless be harder for children to acquire orthographic representations of irregular words than of regular words, and the orthographic representations should be less precise. That is, a *regularity effect* should be observed in the acquisition of word-specific orthographic representations.

Although the self-teaching hypothesis predicts that orthographic learning of regular words will be more effective than irregular words, an alternative perspective might predict the opposite. It could be argued that regular words can be easily decoded and do not require much attention or effort to read, whereas irregular words require closer attention and so may provide more focus on the letters and the order of the letters of the word, thus supporting orthographic learning. Cross-linguistic studies have provided some support for this view, with indications that orthographic learning in writing systems that have regular orthographies may be less efficient than in writing systems that are less regular. Share (2004) found that Hebrew speaking first graders showed little or no evidence of orthographic learning, whereas Cunningham (2006) demonstrated orthographic learning in English speaking children of the same age.⁵

Surprisingly, there has been no direct test of this key prediction of the self-teaching hypothesis. Although regularity effects have been demonstrated in both reading (Laxon, Masterson & Coltheart, 1991) and word learning (Manis, 1985; Rack, Hulme, Snowling & Wightman, 1994; Nilsen & Bourassa, 2008) tasks with children, the dependent measure in these studies focused on reading aloud. If a child is more accurate in reading aloud a regular word than an irregular word, this may not be due to them having a more precise or accurate orthographic representation of the regular than the irregular word. Rather, the advantage may be due to the fact that the regular word can be read aloud accurately purely by phonological decoding, even if the child has no word-specific orthographic representation at all, whereas the irregular word cannot. Indeed, regularity effects in adult reading aloud are typically

⁵ We thank an anonymous reviewer for this suggestion.

attributed to the influence of sublexical phonological decoding processes on responses (e.g., Coltheart, Rastle, Perry, Langdon & Ziegler, 2001; Jared, 2002), not to differences in the quality or extent of orthographic representations.

To examine regularity effects in orthographic representations themselves, tasks such as lexical decision are needed, which tap these representations directly without the influence of online phonological decoding. Spelling tasks may also be used, assuming the correct answer cannot be arrived at purely by decoding. Interestingly, the few studies that have examined regularity effects using such tasks in developing readers, have reported some advantage for regular words, particularly when they are low in frequency (e.g., Waters, Seidenberg & Bruck, 1984).

In this study, we directly tested the hypothesis of regularity effects in the acquisition of orthographic representations. We exposed Grade two children to regular and irregular novel written words in a self-teaching context, and then assessed the extent and quality of the resulting representations through tasks that were not subject to the influence of online phonological decoding. Specifically, we used an orthographic decision task, in which the target word had to be successfully distinguished from phonological and visual distractors, and a spelling task, in which the correct spelling had to be produced instead of a phonologically plausible alternative.

The standard self-teaching paradigm developed by Share (1995) can only be used to examine orthographic learning of novel regular words, since no prior phonology of the items is provided. In order for a novel written word to be “irregular”, the pronunciation obtained through phonological decoding must be different from the word’s existing known pronunciation. To achieve this, we used a variation of the self-teaching paradigm recently developed by Wang, Castles, Nickels and Nation (2011), in which prior phonology and meanings for novel words are provided, allowing regularity to be manipulated on subsequent presentation of the orthography. Based on Share’s hypothesis that the primary mechanism by

which orthographic representations are established is through phonological decoding, we expected that, after exposure to the two word types, the children would perform better on the orthographic decision and spelling tasks for regular than for irregular words.

Method

Participants were thirty-four children aged 6;10 to 8;3 ($M = 7;6$), from Grade 2 of a mainstream Sydney primary school.

The design of the experiment was similar to Wang et al., (2011). There were three consecutive phases, conducted over 15 days for each child. In the first *preexposure* phase, participants were given the phonology and meaning of a set of new words (Days 1- 4). In the second *orthographic exposure* phase, the written forms of the new words were presented in contextually-rich stories (Day 5). The novel words were either regular, where the written form, when read according to letter-sound rules, matched the phonology of the word provided in the pre-exposure phase, or irregular, where there was a mismatch. In the final *orthographic test* phase, 10 days after orthographic exposure, the acquisition of orthographic representations was assessed (Day 15).

All children were exposed to a mix of both regular and irregular novel words. The regular target items were four, 4-5 letter pronounceable monosyllabic nonwords (e.g., *vack*). For all regular items, the graphemes were pronounced according to a set of typical grapheme-phoneme correspondence rules (Rastle & Coltheart, 1999); the body (vowel and final consonant) always had the same pronunciation in real words, (e.g., *-eep* is always pronounced /i:p/; CELEX database: Baayen, Piepenbrock & van Rijn, 1993); and all vowels were regular, with the target pronunciation in over 50% of occurrences in the Children's Printed Word Database (CPWD; Masterson, Stuart, Dixon & Lovejoy, 2003).

The irregular novel words had pronunciations that did not follow typical grapheme-phoneme conversion rules. As is most common for English, the irregularity occurred on the

vowel, where the allocated pronunciation of the vowel in the target word occurred in fewer than 50% of words in the CPWD. The stimuli also had irregular bodies, with no real word body having the target pronunciation. Nevertheless all of the irregular pronunciations were possible, in that the assigned grapheme-phoneme correspondences do occur, though not frequently and not in the context of the final consonants (bodies). The regular and irregular items were also matched for bigram frequency (regular items: $M = 7992$, $SD = 3848$; irregular items: $M = 8348$, $SD = 3536$). Limitations on item selection meant that we could not disentangle grapheme-phoneme regularity and body consistency in this study; however, as reading using both units would generally be considered as phonological decoding, we felt this was not essential for testing the hypothesis.

Pre-exposure Phase

Vocabulary knowledge for the novel words was provided using drawings and oral definitions in the context of “Professor Parsnip’s inventions”. Each picture conveyed target function and key perceptual features, which were also provided orally by the experimenter (see Appendix 1). Each child received four 10-minute training sessions over four days. Four items were introduced in Session 1 and four in Session 2. Sessions 3 and 4 trained all eight items. The experimenter first introduced the invention names and their functions (e.g., “A ‘ferb’ is used to take out the food you don’t like”), then the child repeated the names and functions, and then recalled the names from the pictures by themselves, with feedback. In sessions 3 and 4, the child was additionally asked to use the invention names in new sentences (e.g., “If I had a ‘ferb’, I would use it for...”). For further details see Wang et al. (2011).

Picture naming accuracy at the end of each session was used to measure growth in vocabulary knowledge. It was also assessed immediately before the orthographic exposure phase, and at the orthographic test phase.

Orthographic Exposure Phase

Here, the stimuli were presented for the first time in written form, half with regular and half with irregular spellings. The two conditions were manipulated within participant and stimuli were presented in a random order. Each novel word was presented four times in a short story about the invention, which the children read aloud without feedback. Two comprehension questions were administered to ensure the participants read carefully. Each novel word was scored for reading accuracy on each of the four occurrences in the story. Only the pronunciation that matched the phonology that the participants had been exposed to during the pre-exposure training phase was considered correct.

At the beginning of the orthographic exposure phase, the children were instructed to use what they had learned about the invention names to assist their reading. They were also told that some of the invention names might not look quite how they expected them to. This was modeled with an example of an irregular novel word (“Professor Parsnip has a dog named “Dord” and *Dard* is how he spells it”).

Orthographic Test Phase

Orthographic learning was assessed using two tasks on Day 15 (10 days after orthographic exposure).

Orthographic decision task. The most widely used test for measuring acquisition of word-specific representations is the orthographic choice task (Share, 1999). Here, children are presented simultaneously with the target as well as phonological and visual distractors and must choose the correct one. In the present study, we adapted this into a decision task, where children were presented with the target and distractors one at a time and made individual decisions on each. As argued by Wang et al. (2011), this task is potentially more

sensitive and also provides more information about the children's knowledge, as the responses to the target and distractors are independent of each other.

One phonologically-related foil and two visual distractors were created for each target item. For the regular novel words (e.g., *ferb*), the phonological foil was the homophone of the target item (e.g., *furb*) and the two visual distractors were one letter different from the target and the phonologically-related foil (e.g., *ferd*, *furd*). The two visual distractors were also homophone pairs. For the irregular novel words, the phonological foil was the 'regularised' spelling of the target item. For example, the participants heard the target as 'clape' during the pre-exposure phase, but saw *cleap* during the exposure phase, and the regularised foil was *clape*. Therefore, if the child did not acquire the orthographic representation of a novel word, he or she would be likely to accept the phonologically-related foil. The two visual distractors (e.g., *cleak*, *clake*) were created in the same way as for the regular items, where each visual distractor was one letter different from the target and the phonological foil (see Appendix 2).

All target items, homophones of the target items, and visual distractors were randomised and presented one at a time on flash cards. The children were asked to look at each card carefully and say "Yes" if the word on the card was an invention name with the correct spelling, and "No" if it was not.

Spelling task. The children were asked to write the novel words exactly as they had seen them in the stories. Responses were categorised as 'correct' (e.g., *ferb* / *cleap*), 'regular misspelling' (e.g., *furb* / *clape*), or 'other misspelling'.

Results

Oral Vocabulary Learning

Picture-naming task. The mean proportions of correct responses on the picture-naming task (carried out at the end of each session) were: Sessions 1 and 2 (combined since

each session introduced half of the novel words), $M = .56$ ($SD = .36$); Session 3, $M = .59$ ($SD = .26$), and Session 4, $M = .76$, ($SD = .23$). The participants improved over the sessions with a significant linear trend, $F(1,33) = 9.75$, $\eta_p^2 = .23$, $p < .01$.

Immediately before the orthographic exposure phase (Day 5), mean picture naming accuracy was $.79$ ($SD = .22$), and $.77$ ($SD = .20$) at orthographic test on Day 15. A repeated measures analysis of variance (ANOVA) with time (Day 5, Day 15) and regularity (regular, irregular) showed no effect of time, $F(1,33) = 2.26$, $p = .14$, indicating that the vocabulary knowledge of the novel words was retained throughout the experiment. There was no main effect of word-regularity, $F < 1$, indicating no difference in vocabulary retention for the items assigned regular or irregular spellings. There was also no interaction between factor time and word-regularity, $F < 1$.

Orthographic Learning

Reading accuracy. During the orthographic exposure phase, the children read aloud stories in which each of the novel words appeared four times. Responses were scored as correct if they read the novel words according to their pronunciation in the pre-exposure phase. Table 1 shows the mean proportion correct for both conditions across the exposures.

Table 1.

Mean Proportion Correct in Reading Aloud Regular and Irregular Novel Words in the Orthographic Exposure Phase (with SDs in brackets).

	1st exposure	2nd exposure	3rd exposure	4th exposure
Regular	.97 (.08)	.96 (.11)	.98 (.07)	.96 (.09)
Irregular	.76 (.25)	.78 (.22)	.79 (.25)	.82 (.23)

An ANOVA revealed that accuracy for regular items was significantly higher than for irregular items, $F(1,33) = 31.68$, $p < .01$. There was no main effect of exposure, $F(3,30)$

= 1.03, $p = .39$, and no interaction between exposure and word-regularity, $F(3,30) = 1.26$, $p = .29$.

Orthographic Test Phase

Orthographic decision. Children were asked to say “Yes” to correctly spelled invention names, and ‘no’ to three other foils. The mean proportion of occasions participants correctly said “Yes” to the target, and incorrectly said “Yes” to the phonologically-related foils and the visual distractors is illustrated in Figure 1. The proportion of correct “Yes” responses to regular targets was significantly higher than to irregular targets, $F(1,33) = 35.06$, $p < .01$. There was no effect of regularity on incorrect “Yes” responses to phonologically-related foils, $F < 1$.

In order to provide a very stringent measure of acquisition of orthographic representations, comparable across the regular and irregular words, a single correct score for each target word was created, based on it being correctly accepted and all three phonological and visual foils being correctly rejected. The mean proportion of correct scores was .38 ($SD = .29$) higher for the regular items and .25 ($SD = .25$) than for the irregular items, which was significant, $F(1,33) = 5.77$, $p = .02$.

Spelling task. The overall mean proportion correct for target spelling combined across conditions was .28 ($SD = .19$). The pattern of responses on the spelling task for the correct target spelling, regular misspelling, and other misspelling is illustrated in Figure 2.

Mean accuracy for regular items was significantly higher than for irregular $F(1,33) = 25.50$, $\eta_p^2 = 0.42$, $p < .01$.⁶ There were more phonologically-related misspellings (alternative homophonic spelling for regular items, regularised misspellings using sound-to-letter rules

⁶ The scores for the orthographic decision and spelling tasks were negatively skewed. Although ANOVA is considered to be robust to normality violation when the sample size is large (Field, 2009), we reran the analyses with nonparametric tests and the results were the same: there was a main effect of regularity for spelling, $Z = 3.81$, $p = .00$; and for orthographic decision task, $Z = 2.28$, $p = .02$.

WORD REGULARITY AFFECTS ORTHOGRAPHIC LEARNING

for irregular items) for the irregular items than the regular items, $F(1,33) = 79.20$, $\eta_p^2 = 0.71$, $p < .01$.

The results of the experiment and regularity analyses are summarised in Table 2.

Table 2.

Summary of Mean Proportion Correct and Regularity Analyses.

		Regular items		Irregular items		Regularity effect		
		<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>F</i> (1,33)	<i>p</i>	Effect size
Phase 1	<i>Picture naming</i> (before exposure)	.77	.26	.81	.23	1.09	.30	.03
Phase 2	<i>Reading accuracy</i> (averaged across exposures)	.97	.07	.79	.20	31.68	$p < .01$.49
Phase 3	<i>Orthographic decision</i>	.38	.29	.25	.25	35.06	$p < .01$.52
	<i>Spelling</i>	.40	.30	.16	.17	23.50	$p < .01$.42

Phase 1 = pre-exposure phase; Phase 2 = orthographic exposure phase; Phase 3 = orthographic test phase.

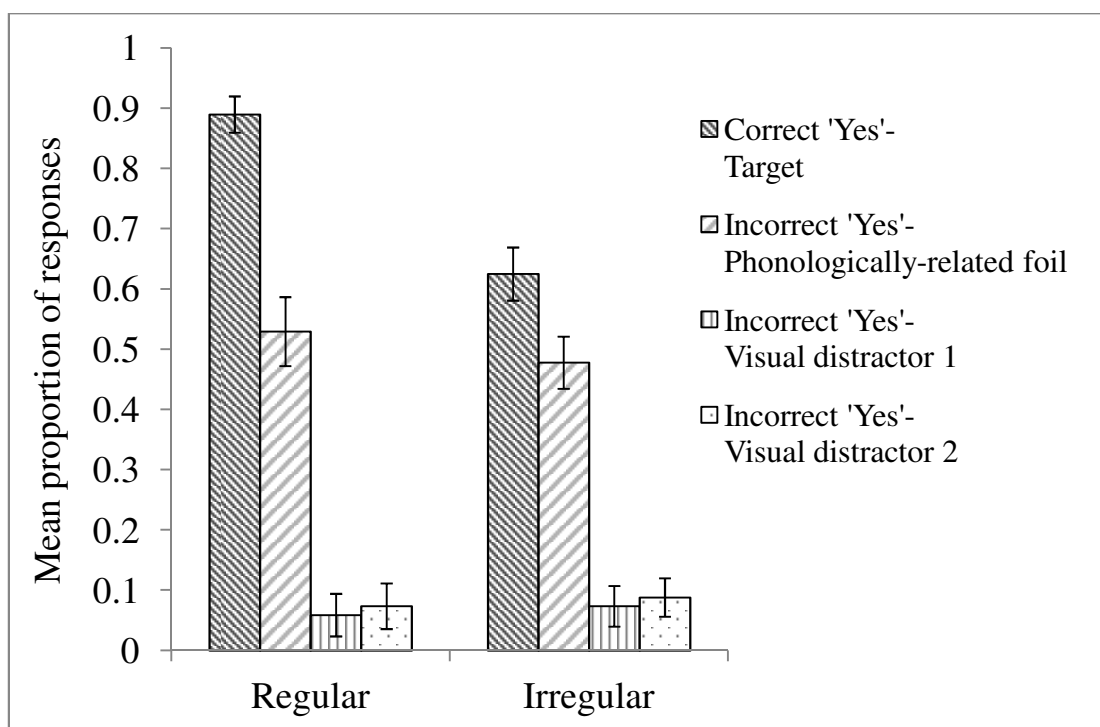


Figure 1. Mean proportion of “Yes” responses on the orthographic decision task. Phonologically-related foils refer to homophonic foils for regular words, and regularised foils for irregular words (with the error bars indicating standard errors).

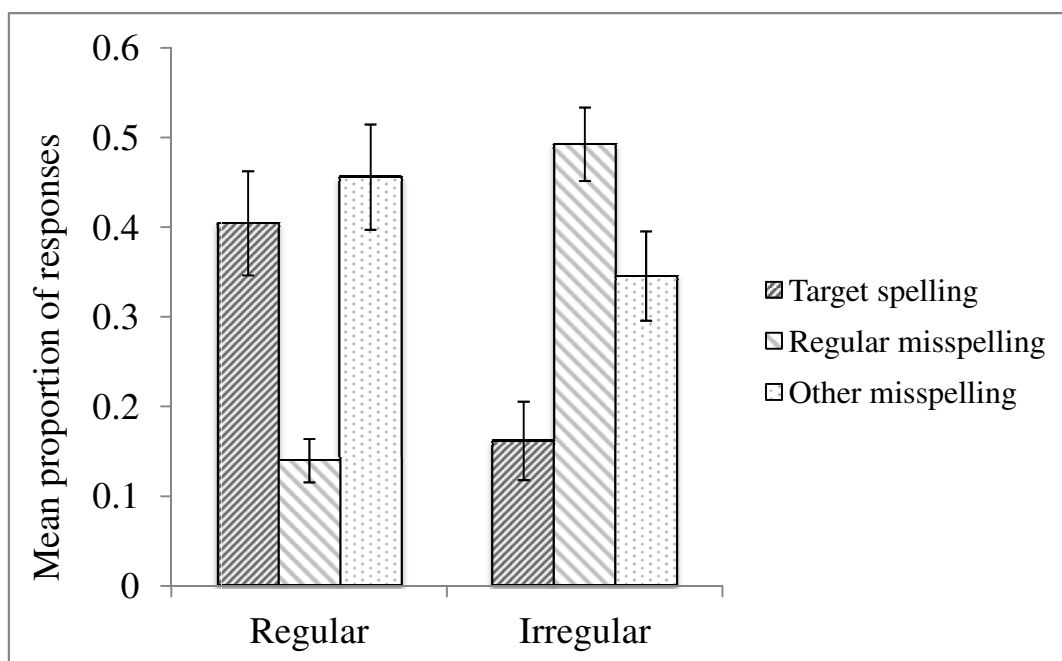


Figure 2. Mean proportion of each type of spelling response: “regular” misspelling refers to homophonic spellings for regular words, and regularised misspellings for irregular words (with the error bars indicating standard errors).

Discussion

This study directly tested a key prediction of Share's (1999) self-teaching hypothesis: that there would be an effect of the regularity of a word on how quickly and successfully an orthographic representation of that word would be formed. Specifically, we expected that, since irregular words cannot be phonologically decoded as readily as regular words, orthographic acquisition for these items would be reduced.

The results supported this hypothesis. As expected, the children were less successful at reading aloud irregular words when they first saw them in print than they were regular words, indicating that their opportunity for self-teaching via phonological decoding was compromised in the former case. This disadvantage in initial decoding performance then carried through 10 days later, to measures of the number and quality of orthographic representations that the children had acquired.

Importantly, these measures directly tapped orthographic representations themselves, independently of the effects of online phonological decoding. Although, arguably, spelling performance could be influenced to some degree by phonological decoding skills, we ensured that all the regular words used in the experiment had at least two sound to letter mappings (e.g., *ferb* can also be spelled as *furb*), meaning that accuracy required access to word-specific knowledge. As such, this finding goes beyond previous reports of regularity effects in children's reading aloud (e.g., Laxon et al., 1991) in showing that these effects do not necessarily derive only from the influence of online phonological decoding on output, but may be an effect of stronger regular word representations within the orthographic lexicon itself.

An alternative explanation of the regularity effect found in the study could be that orthographic learning was affected by sound-spelling consistency (Burt & Blackwell, 2008; McKague, Davis, Pratt & Johnston, 2008; Rastle, McCormick, Bayliss & Davis, 2011;

Ziegler & Ferrand, 1998). When the readers were exposed to the phonology of the novel words, they might have pre-established an orthographic representation of them. Thus, when the novel words were presented for the first time in print, the regular items were more likely to match the orthographic representations that had been established than the irregular items, assisting orthographic learning. Further research is required to disentangle feed-forward versus feedback effects of regularity and consistency on orthographic learning in children.

These findings also deserve consideration in relation to the adult literature, where regularity effects are typically not found in lexical decision tasks (e.g., Coltheart, Besner, Jonassen & Davelaar, 1979; Seidenberg, Waters, Barnes & Tanenhaus, 1984; but see Parkin, 1982). It may be that, with sufficient exposure to words, the gap in lexical acquisition between regular and irregular words gradually reduces, such that effects are no longer observable in skilled adult readers. Consistent with this hypothesis is the finding that regularity effects in lexical decision for children are typically most robust for low frequency words (Waters et al., 1984).

In sum, this research is the first to demonstrate that irregular words are not only *decoded* less accurately but also *encoded* less well. This important finding will provide a basis for future research.

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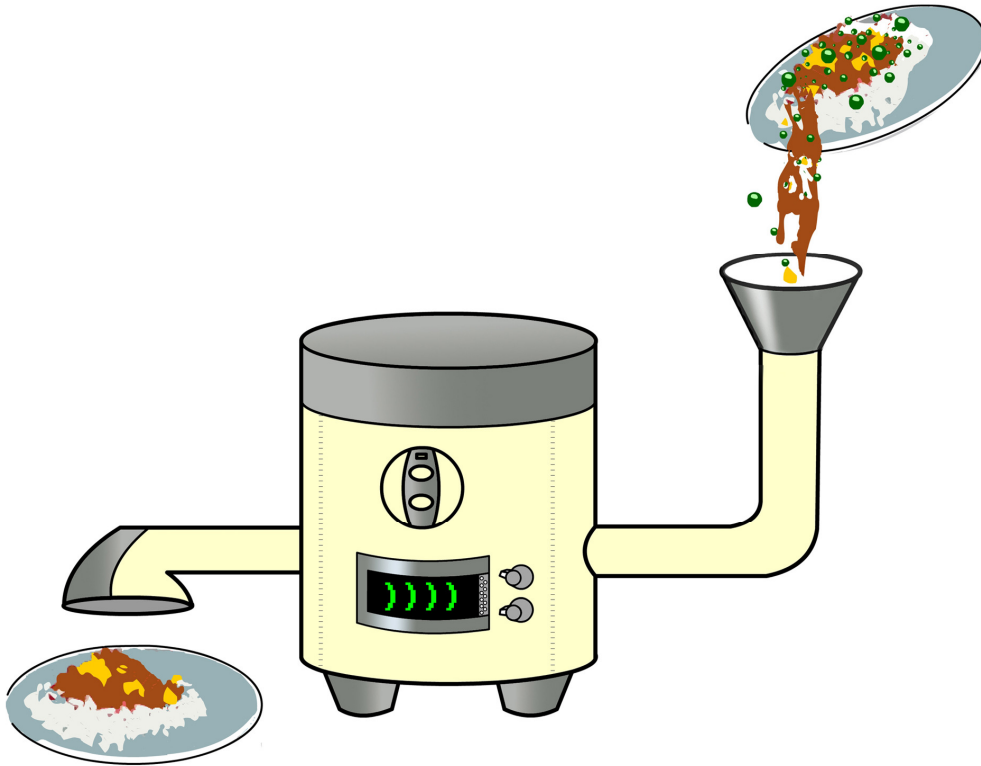
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Appendix 1

An example of the picture used in the preexposure phase.

“A *ferb* is used to take out the food that you don’t like on your plate. It has a tube and two open ends”.



Appendix 2

<u>Target items and foils for the orthographic decision task</u>					
<i>Word type</i>	<i>Target items</i>		<i>Phonologically - related foils</i>	<i>Visual Distractor 1</i>	<i>Visual Distractor 2</i>
Regular	vack	(/væk/)	vakk	vock	vokk
Regular	doud	(/daʊd/)	dowd	dowf	douf
Regular	praif	(/preɪf/)	prafe	prait	prate
Regular	broon	(/bru:n/)	brune	broop	brupe
Irregular	jape	(/dʒæp/)	japp	jate	jatt
Irregular	cleap	(/cleɪp/)	clape	cleak	clake
Irregular	ferb	(/fa:b/)	farb	ferg	farg
Irregular	smope	(/smɒp/)	smopp	snope	snopp

Paper 3

Predictors of Orthographic Learning for Regular and Irregular Words

This paper was submitted for publication as:

Wang, H.-C., Castles, A., Nickels, L. & Nation, K. (in preparation). Predictors of
orthographic learning for regular and irregular words. *Scientific Studies of Reading*.

Abstract

The aim of this study was to explore the reading and language skills that are associated with orthographic learning and to examine whether the effects of these factors are influenced by word regularity. Grade 2 and 3 children learned the phonology and meaning of novel words and were subsequently exposed to their orthography, with either regular or irregular mappings. The children's overall level of phonological decoding skill, orthographic and vocabulary knowledge were associated with orthographic learning for both word types. However, at an item level, only vocabulary knowledge was a predictor of success in orthographic learning, and only for irregular words.

Word count: 101

Keywords: orthography, reading development, word recognition, orthographic learning, self-teaching hypothesis, oral vocabulary

How children progress from slowly sounding out novel words to rapidly recognizing them as lexical items has generated much research interest (e.g., Share, 1995; 1999; Castles & Nation, 2006; Cunningham, Perry, Stanovich & Share, 2002). In this study, we focus on how this transition takes place and what factors might be involved in the process of the acquisition of word-specific orthographic knowledge.

One of the most commonly agreed factors to be important in reading acquisition is the ability to map letters to sounds, or phonological decoding skills (e.g., Brady & Shankweiler, 1991; Byrne, 1992, 1998; Goswami & Bryant, 1990). However, in English, there are many words with unpredictable letter-to-sound correspondences (e.g., *yacht*); consequently, orthographic representations of these words are unlikely to be able to be acquired using phonological decoding alone. The aim of this study was to directly explore the factors associated with the orthographic learning of irregular words and to determine to what degree these factors are the same as, or different from, those associated with the orthographic learning of regular words. We focused on both reading-related factors and other language factors previously shown to be important in reading acquisition. Furthermore, we examined the extent to which the effects held at an item level.

With reference to reading-related factors, although phonological decoding cannot solely account for orthographic learning in English, the most prominent theory in the field, the self-teaching hypothesis (Share, 1995), proposes that this reading subskill nevertheless plays a very important role for both regular and irregular words. Share argues that the process of phonological decoding draws the readers' attention to the order of the letters and the details of the graphemes in the word. The successful outcome of decoding then provides the reader with a spoken form of the word that binds with the visual form and the semantics of the word. Thus, phonological decoding functions as a self-teaching mechanism that builds up the orthographic representation of the word (e.g., Share, 1995, 1999, 2011). In line with

this idea, there is a positive correlation between correct phonological decoding and success in orthographic learning (Bowey & Miller 2007, Cunningham et al., 2002, Share, 1999).

In addition to the importance of phonological decoding for establishing orthographic representations, pre-existing reading skills such as orthographic knowledge may also affect orthographic learning. Cunningham et al. (2002) examined orthographic learning using the self-teaching paradigm and, as expected, found that decoding accuracy correlated with orthographic learning when second grade English speaking children were asked to learn novel words in short stories. However, a further regression analysis suggested that pre-existing orthographic knowledge (measured with an orthographic choice task requiring selection from a word and a pseudohomophone, e.g., *sleep-sleap*) was a better predictor of orthographic learning than decoding accuracy of the target words. Similarly, Conners, Loveal, Moore, Hume, and Maddox (2010) also suggested that orthographic knowledge is important to the process of orthographic learning. Conners et al. assessed orthographic knowledge, phonological decoding (nonword reading) and word identification (a mix of regular and irregular real word reading) of 40 grade two and three children. Orthographic knowledge was measured with an orthographic choice (e.g., *rume-room*), a homophone choice task (e.g., *for-four* “which is a number?”) and a lexical decision task (e.g., *filk-filv*). The results showed that phonological decoding predicted word identification after controlling for IQ and orthographic knowledge. Moreover, orthographic knowledge also predicted word identification after controlling for IQ and phonological decoding. Conners et al. concluded that good decoders acquire better orthographic knowledge and as a result, this benefits their word reading.

Beyond phonological skills, another language factor associated with reading acquisition is vocabulary knowledge, that is, knowledge of the phonological form and meaning of spoken words (Nation & Snowling, 2004). This appears to be particularly the case for the reading of irregular words (e.g., Bowey & Rutherford, 2007; Nation & Snowling,

1998; Ouellette, 2006; Ricketts, Nation & Bishop, 2007; Nation & Cocksey, 2009). This finding has been accounted for in terms of the lexical quality hypothesis (Perfetti & Hart, 2002), which proposes that connections between phonology, semantics and orthography are jointly formed to build up a word-specific lexicon. In the case of irregular words, the connection between phonology and orthography is somewhat compromised, and so good vocabulary knowledge becomes especially important.

Several studies have looked at whether knowledge about the meaning of a word, in addition to its phonological form, assists orthographic learning in children and have found little (Ouellette & Fraser, 2009) or no evidence (McKague, Pratt & Johnston, 2001; Duff & Hulme, Experiment 2, 2012) to support this view. However, these studies all used regular novel words. As mentioned above, word meaning in addition to phonology could be particularly important when learning irregular novel words, potentially explaining why these studies did not find an effect of knowledge of word meanings for regular novel word learning.

Studies with adults have indeed found that prior knowledge of word meaning can affect orthographic learning of irregular but not regular novel words (McKay, Davis, Savage & Castles, 2008; Taylor, Plunkett & Nation, 2011). There is only one study that has investigated the effect of word meaning (in addition to phonology) on orthographic learning of irregular words with children. Duff and Hulme (2012, Experiment 1) taught 5-year-old children to read words with consistent and inconsistent spelling-sound correspondences (broadly equivalent to regular and irregular words). They also manipulated the semantically-related variable of imageability, finding that high imageability words were learned better at an item level. However, there was no difference in the imageability effect across consistent and inconsistent words. While this seems to argue against semantics playing a larger role in learning of irregular (or inconsistent) words, the authors suggest that perhaps their 5-year-old participants were too young and were only able to make limited use of letter-sound

correspondences. If so, then both regular and irregular words would be learned using a similar mechanism and both helped equally by semantic knowledge – the pattern found in the study.

In summary, despite the fact that there are reasons to expect reading and language factors to be associated with orthographic learning of regular and irregular words differently, little research has directly examined this. The first aim of the current study was therefore to examine how phonological decoding skills, pre-existing orthographic knowledge, and vocabulary knowledge associate with the orthographic learning of regular and irregular words separately. It was predicted, based on previous studies, that both decoding skills (indexed by nonword reading) and word-specific orthographic knowledge (indexed by irregular word reading) would be associated with regular word learning. We predicted that orthographic knowledge might show a stronger association with irregular word learning than regular word learning. Decoding skills could potentially play a less important role in irregular word learning since decoding alone is insufficient to derive the correct phonology of irregular words. Moreover, we predicted that vocabulary knowledge might be a stronger predictor of irregular word learning compared to regular word learning.

One of the key features of the self-teaching hypothesis is that orthographic learning is considered to be item based, not stage based. These transitions from processing novel words as unfamiliar to being familiar are proposed to happen from very early on, as a beginner reader first starts to read, and to continue throughout life, since even skilled readers encounter new words on occasion. Hence, under this hypothesis there should be a one-to-one mapping between the success of reading accuracy and orthographic learning at an item level. By the same token, if vocabulary knowledge of a novel word assists learning of the orthography, as suggested by both the self-teaching and lexical quality hypotheses, this relationship should also be seen at an item level. Therefore, the second aim of the current study was to test the relationship between initial reading accuracy, vocabulary knowledge,

and orthographic learning at an item level. In other words, we examined whether being able to successfully read aloud a novel word, or having item-specific vocabulary knowledge for that novel word, are linked to the success of orthographic learning of the same novel word.

To address these questions, we used a variation of the self-teaching paradigm we have developed that allows learning of irregular as well as regular novel words (see Wang, Castles, Nickels & Nation, 2011; Wang, Castles & Nickels, 2012). In this paradigm, we provide children with the vocabulary knowledge of novel words first, subsequently allowing regularity to be manipulated on presentation of the written form. Children first have several learning sessions in which they are exposed to the meanings and pronunciations of a set of novel words. For example, the experimenter says: “Professor Parsnip has invented many products in his factory; one of the inventions is called a “ferb”, which is used to clean fish tanks” and one is called a “claip” which is used to take out the food bits you don’t like.” Later, the children see the novel words in print for the first time with either regular (e.g., “ferb” written as *ferb*) or irregular (e.g., “claip” written as *cleap*) spellings. Orthographic learning is then tested.

In a recent study (Wang, Castles & Nickels, 2012), we used this paradigm to directly explore regularity effects in orthographic learning. Thirty-four Grade 2 children were exposed to the sound and meaning of eight novel words, and were then presented with those words either in regular or irregular written form in short stories. Lexical decision and spelling tasks conducted 10 days later revealed that the children’s orthographic representations of the regular words appeared to be stronger and more extensive than those of the irregular words. Here, we build on this basic experimental work by reporting the results of correlational and item-based regression analyses examining reading and language predictors of the orthographic learning outcomes. For this purpose, we draw on data from Wang et al. but also collected data from an additional set of Grade 3 children. This served to

provide a sufficiently large sample for the regression analysis and also to provide a wider range of reading and orthographic learning abilities.

Method

Participants

A total of 45 children, aged from 6 years 10 months to 9 years 7 months (Mean: 8 years, 6 months), from grades two and three (third and fourth year of schooling), participated in the experiment. The children were recruited from two classes in a mainstream primary school in a metropolitan region of Sydney, Australia. These two grades were chosen because children of this age are typically learning large numbers of new words, and there is a wide range of individual differences in their reading skills. Consent forms were sent out to two classes and children who returned the forms participated in the study. No child who returned the forms was excluded. Wang et al. (2012) report data from a subset of Grade 2 children.

Materials and Procedure

Orthographic learning paradigm. The design of the orthographic learning task was similar to Wang et al., (2011). There were three consecutive phases, conducted over 15 days for each child. In the first *vocabulary-training* phase (Days 1-4), participants were given vocabulary knowledge (sound and meaning) for eight novel words. Success of the training was tracked using a picture-naming task, which was used as the item-specific vocabulary knowledge measure. In the second *orthographic-exposure* phase, the written forms of the eight new words were presented in contextually-rich stories (Day 5). The novel words were either regular, where the written form when read according to sound-to-letter rules matched the phonology of the word provided in the vocabulary-training phase, or irregular, where there was a mismatch. The accuracy of reading aloud the novel word on the first encounter was used as the item-specific initial reading measure. In the final *orthographic-test* phase, 10

days after orthographic exposure (Day 15), the acquisition of orthographic representations was assessed using spelling and orthographic decision tasks. The results from this phase were used for all analyses of regular and irregular orthographic learning.

All children were exposed to a mix of both regular and irregular novel words. The regular target items were four, 4-5 letter pronounceable monosyllabic nonwords (e.g., *vack*). For all regular items, the graphemes were pronounced according to a set of typical grapheme-phoneme correspondence rules (Rastle & Coltheart, 1999). In this case, the allocated pronunciation of the vowel occurred in more than 50% of words containing that vowel grapheme in both the CELEX database (Baayen, Piepenbrock & van Rijn, 1993) and the Children's Printed Word Database (CPWD; Masterson, Stuart, Dixon & Lovejoy, 2003). The irregular novel words had pronunciations that did not follow typical grapheme-phoneme conversion rules. The allocated pronunciation of the vowel in the target word occurred in fewer than 50% of words in the CELEX and the CPWD. Nevertheless, all of the irregular pronunciations were possible, in that the assigned grapheme-phoneme correspondences do occur in English words, though not frequently and not in the context of the final consonants (bodies).

Vocabulary-training phase: During this phase, vocabulary knowledge for the novel words was provided using drawings and oral definitions in the context of “Professor Parsnip’s inventions”. Each picture conveyed the function and the key perceptual features that were also provided orally by the experimenter. Each child received four 10-minute training sessions over four days. Four items were introduced in Day 1 and four in Day 2. Days 3 and 4 trained all eight items. The procedures were as follows:

1. The experimenter presented the picture to the child and said the name of the invention (e.g., “This is a ferb”) and the child repeated it.

2. The experimenter introduced the semantic features of the invention (e.g., “A ferb is used to clean fish tanks. It has a sponge and is shaped like an arm.”). The child repeated the invention name again.
3. The child repeated the invention name and definition (e.g., “ferb, a ferb is used to clean fish tanks”).
4. Picture-naming task: the child recalled the name of the invention when prompted by the picture.
5. In sessions three and four, the child also made up a sentence with the invention name in it starting with ‘If I had a...(the invention name), I would use it for...’.

Picture-naming was also assessed immediately before the orthographic-exposure phase (Day 5), and at the orthographic-test phase (Day 15).

Orthographic-exposure phase: In this phase, the stimuli were presented to the children for the first time in written form, half with regular and half with irregular pronunciations. The regular and irregular conditions were manipulated within participants and were presented to the children in a random order. All novel word items were presented in stories, which the children read aloud without feedback. Each item appeared four times in one short story. Each novel word was scored for reading accuracy on each of the four occurrences in the story. Reading accuracy on the first occurrence was used as the initial reading accuracy measure. Only the pronunciation that matched the phonology that the participants had been exposed to during the vocabulary-training phase was considered as correct reading.

At the beginning of the exposure phase, the children were told the following by the experimenter:

“Remember the inventions we have been learning about? Now we are going to read some stories about them. Some of these invention names will not look exactly like the way they sounded. For example, Professor Parsnip has a dog named “Dord” and

this is what is written on his name tag: *Dard* [show *Dard* on a card]. This sometimes happens when you are learning to read new words as well; for example, this word is “blood” [show *blood* on a card], but not “blued” (/blud/). So now your job is to use what you know about the invention names to help you with reading them and remembering them. Read clearly and carefully and I will ask you questions about them later.”

Orthographic-test phase: Orthographic learning was assessed using two tasks on Day 15 (10 days after orthographic exposure): a spelling task and an orthographic decision task. In the spelling task, the novel words were spoken aloud to the children and they were asked to try and write them exactly as they had seen them in the stories. The orthographic decision task was an adaptation of the most widely used test for measuring acquisition of word-specific representations: the orthographic choice task (Share, 1999). In the orthographic choice task, children are presented simultaneously with the target as well as phonological and visual distractors and must choose the correct one (e.g., *yait*, *yate*, *yoi*, *yoyt*). In the decision task, children were presented with the target or distractors one at a time and made individual decisions on each. As argued by Wang et al. (2011), this task is potentially a more sensitive measure than the choice task and provides more information about the children’s knowledge as the responses to the target and distractors are independent of each other.

One phonologically-related foil and two visual distractors were created for each target item in the orthographic decision task. For the regular novel words, the phonological foil was the homophone of the target item (e.g., *ferb*, *fur*) and the two visual distractors were one letter different from the target and the phonologically-related foil (e.g., *ferd*, *furd*). The two visual distractors were also homophone pairs. For the irregular novel words, the phonological foil was the ‘regularized’ spelling of the target item. For example, the

participants heard the target as ‘clape’ during the vocabulary-training phase, but saw *cleap* during the exposure phase, and the regularized foil was *clape*. The two visual distractors (e.g., *cleak*, *clake*) were created in the same way as for the regular items, where each visual distractor was one letter different from the target and the phonological foil (see Appendix 1).

All target items, homophones of the target items, and visual distractors were randomized and presented one at a time on flash cards. The children were asked to look at each card carefully and say “Yes” if the word on the card was an invention name with the correct spelling, and “No” if the word was not a correctly spelled invention name.

Standardized reading and language measures. To assess children’s orthographic knowledge, phonological decoding skills and general vocabulary knowledge for the purposes of examining how well they might predict orthographic learning, each participant completed three sets of tests: the Castles and Coltheart 2 (CC2; Castles et al., 2010), the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner & Rashotte, 1999), and a shortened version of the Peabody Picture Vocabulary Test (PPVT-III; Dunn & Dunn, 1997).

Orthographic knowledge was measured by CC2 irregular word reading accuracy as irregular words can only be read correctly using one’s word-specific knowledge.

Phonological decoding skill was measured by both CC2 nonword reading accuracy and TOWRE nonword reading fluency. Vocabulary knowledge was assessed using PPVT.

Item-specific reading and language measures. We used measures derived from the orthographic learning paradigm to obtain item-specific indices of vocabulary knowledge and initial reading accuracy. Specifically, accuracy in picture-naming on Days 3-5 was used as a measure of item-specific vocabulary knowledge and accuracy in reading the novel words at first written exposure on Day 5 was used as a measure of initial reading accuracy. These measures were then used in the item-specific analyses to explore how well they predicted orthographic learning of the target items measured on Day 15.

Results

In this section, we first report a summary of results from all three phases of the experiment: vocabulary-training, orthographic-exposure, and orthographic-test. This is followed by a summary of the children's performance on the standardized reading and language measures and correlational analyses reporting the relationship between these skills and orthographic learning of regular and irregular words separately. Finally, we report the item-level analyses exploring whether item-specific vocabulary knowledge and initial reading accuracy predict orthographic learning of regular and irregular words.

Results of the Orthographic Learning Experiment

The basic results the orthographic learning experiment were consistent with those of Wang et al. (2012), who report on this experiment in a subset of the current sample of children (see Table 1).

Vocabulary-training phase. A picture-naming task was used to evaluate how well the children had acquired the vocabulary knowledge of the novel words. This was administered between the end of training sessions and before the orthographic-exposure phase and once again 10 days after orthographic exposure. An analysis comparing vocabulary knowledge on Day 5 and Day 15 showed no main effect of time, $F < 1$, indicating that the vocabulary knowledge of the novel words was retained throughout the experiment. There was no main effect of word-regularity, $F < 1$, indicating no significant difference in accuracy prior to orthographic exposure between the items that were later to be assigned either regular or irregular spellings. There was also no interaction between time and word-regularity, $F < 1$.

Orthographic-test phase. For the spelling task, there was a main effect of word regularity, $F(1,44) = 26.77$, $p < .01$, $\eta_p^2 = 0.38$, reflecting the fact that mean accuracy for regular items was significantly higher than for irregular items.

In the orthographic decision task, children were asked to say “Yes” to the correctly spelled invention name, and “No” to three other foils. The proportion of correct “Yes” responses to regular targets ($M = .86$; $SD = .21$) was significantly higher than irregular targets ($M = .60$; $SD = .23$), $F(1, 44) = 40.59$, $p < .01$, $\eta_p^2 = .48$. There was no effect of regularity on incorrect “Yes” responses to phonologically-related foils (regular: $M = .47$, $SD = .28$; irregular: $M = .46$, $SD = .26$), $F < 1$). Children very rarely accepted the visual distractors (combined across regular and irregular items: $M = .05$ ($SD = .12$)).

In order to provide a more stringent measure of orthographic learning and take both correct and incorrect responses into consideration, a single correct score for each target word was created. This score was based on a target being correctly accepted and all three of its foils being correctly rejected (see Table 1), and was hence lower than the proportion of correct “Yes” responses. This score was used in the correlational and regression analyses in the following sections.

Table 1

Mean Proportion of Correct Responses in all Three Phases for Regular and Irregular Words (with SDs in brackets).

	Vocabulary-training Phase (Day 3-5)				Orthographic-exposure Phase (Day 5)				Orthographic-test Phase (Day 15)	
	Picture Naming				Reading Accuracy				Spelling	Orthographic Decision
	Day 3	Day 4	Day 5	Day 15	1st	2nd	3rd	4th		
Regular	.64	.79	.81	.79	.97	.97	.98	.97	.43	.42
(SD)	(.32)	(.26)	(.24)	(.27)	(.08)	(.10)	(.06)	(.09)	(.30)	(.29)
Irregular	.68	.81	.83	.79	.78	.81	.81	.84	.21	.28
(SD)	(.29)	(.23)	(.22)	(.24)	(.24)	(.21)	(.23)	(.21)	(.19)	(.24)

Correlational Analysis: The Relationship Between Standardized Measures of Language and Reading Skills and Orthographic Learning

Table 2 reports a summary of the results for reading and language skill measures.

Table 2.

The Mean Raw Scores and Standardized Scores for Reading and Language Assessments (with SDs in Brackets).

	<i>Raw scores</i>		<i>Standardized scores</i>	
Orthographic knowledge: CC2 irregular word reading ¹	16.29	(5.90)	0.30	(0.81)
Phonological decoding: CC2 nonword reading ¹	19.89	(11.84)	0.06	(-0.06)
Phonological decoding: TOWRE nonword reading ²	24.78	(14.11)	106.38	(14.41)
Vocabulary knowledge: shortened PPVT ³	20.84	(4.77)	NA	NA

NA: Not available

¹ The Castles and Coltheart Test (CC2; Castles et al., 2010), raw score /40, standardized score = z-score; ² Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner & Rashotte, 1999), number of items read in 45 seconds, standardized score: mean = 100, SD = 15; ³ A shortened version of the Peabody Picture Vocabulary Test (PPVT-III; Dunn & Dunn; 1997), raw score /40.

In order to investigate which reading and language skills were associated with orthographic learning of regular and irregular words, correlations and partial correlations of raw scores controlling for age were conducted (see Table 3). The results and discussion will be focused on the correlations between raw scores and the outcome measures of orthographic learning (but not partial correlations) as the aim of the analyses was to directly examine the associations between reading and language skills and orthographic learning.

Table 3

Correlations (above diagonal) and Partial Correlations Controlling for Age (below diagonal) Between Orthographic Learning of Regular and Irregular Words and Orthographic Knowledge, Phonological Decoding Skill, and Vocabulary Knowledge.

		1.	2.	3.	4.	5.	6.	7.	8.
<i>Orthographic Learning</i> (mean of raw score /4)	1. Spelling: Regular	-	.38*	.61**	.29⁺	.59**	.59**	.57**	.51**
	2. Spelling: Irregular	.26 ⁺	-	.30*	.64**	.57**	.58**	.64**	.40**
	3. Orthographic decision: Regular	.57**	.18	-	.31*	.50**	.39**	.38**	.36*
	4. Orthographic decision: Irregular	.18	.55**	.21	-	.56**	.52**	.59**	.22
<i>Predictors</i>	5. CC2-Irregular	.52**	.40**	.42**	.44**	-	.77**	.81**	.38*
	6. CC2- Nonword	.53**	.44**	.30*	.40**	.68**	-	.92**	.38*
	7. TOWRE- Nonword	.50**	.52**	.29 ⁺	.48**	.75**	.90**	-	.36*
	8. PPVT	.45**	.28 ⁺	.29 ⁺	.10	.25	.26 ⁺	.24	-

**indicates $p < .01$; * indicates $p < .05$; ⁺ indicates $p < .10$

Orthographic learning of regular and irregular words moderately correlated within both the spelling ($r = .38$) and orthographic decision ($r = .31$) measures. However, orthographic learning of the different word types were highly correlated across the two measures. Regular words measured by spelling accuracy was highly correlated with orthographic learning of regular words measured by the orthographic decision task ($r = .61$), and this was also true for orthographic learning of irregular words ($r = .64$).

For orthographic learning measured by the spelling task, both regular and irregular word learning was correlated with orthographic knowledge, indexed by irregular word reading accuracy (CC2). The learning of both types of novel words was also correlated with phonological decoding skill, indexed by nonword reading accuracy (CC2) and fluency (TOWRE). Vocabulary knowledge was significantly correlated with orthographic learning of both regular and irregular words.

For orthographic learning measured by the orthographic decision task, the pattern was very similar to the spelling task. The main exception was that vocabulary knowledge was not significantly correlated with orthographic learning of irregular words. However, the difference between these two correlations was not significant ($z = 0.70$, $p = .48$, using the Fisher r -to- z transformation).

Item-level Analysis: The Relationship Between Orthographic Learning and Item-Specific Vocabulary Knowledge and Reading Accuracy.

In order to assess the relationships between the factors at the item level, we used a logistic linear mixed-effects model (e.g., Baayen, 2008). This model predicts orthographic learning with two fixed factors including initial reading accuracy (raw score out of 1) and vocabulary knowledge (picture-naming accuracy, raw score out of 3), as a function of word type (regular and irregular). Participants and items were included as random factors. Initial reading accuracy was used because accuracy was generally high and most errors were made

when the child encountered the word at the first exposure, hence using summed accuracy across exposures did not add further sensitivity or change the pattern of the results. The item-specific vocabulary knowledge measure was the sum of correct picture-naming responses across the vocabulary-training phase after all items were introduced (Days 3-5) to provide a more sensitive measure of the extent of item-specific vocabulary knowledge.

Figure 1 illustrates the proportion of correct spelling responses as a function of item-specific vocabulary knowledge and reading accuracy, subdivided by regularity.

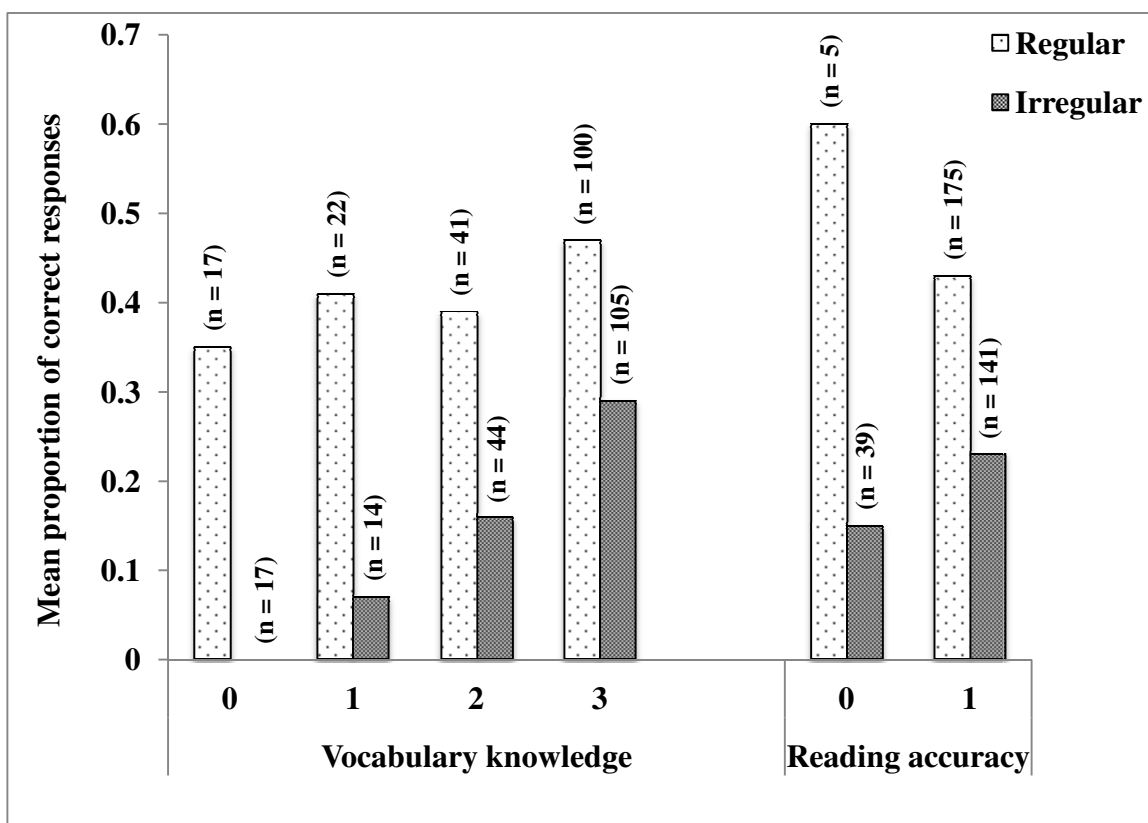


Figure 1. Mean proportion of correct spelling as a function of word regularity, vocabulary knowledge and reading accuracy (parentheses indicate total number of trials).

For correct target spelling, initial reading accuracy was not a significant predictor, $X^2 = 1.60$, $p = 0.21$, whereas both word type, $X^2 = 3.96$, $p = .05$, as well as vocabulary knowledge (picture-naming), $X^2 = 6.24$, $p = .04$, were significant factors. The interaction

between word type and vocabulary knowledge was also significant, $X^2 = 4.28$, $p = .04$. The interaction reflected the fact that for irregular items, vocabulary knowledge was a significant predictor, $X^2 = 8.58$, $p = .003$, but it was not for the regular items, $X^2 = .48$, $p = .49$.

Results from the orthographic decision task showed a similar pattern as the spelling task (see Figures 2), however, none of the predictors in the model reached significance (word type, $X^2 = 1.61$, $p = .20$; vocabulary knowledge, $X^2 = 2.09$, $p = .15$; reading accuracy, $X^2 = .001$, $p = .97$).

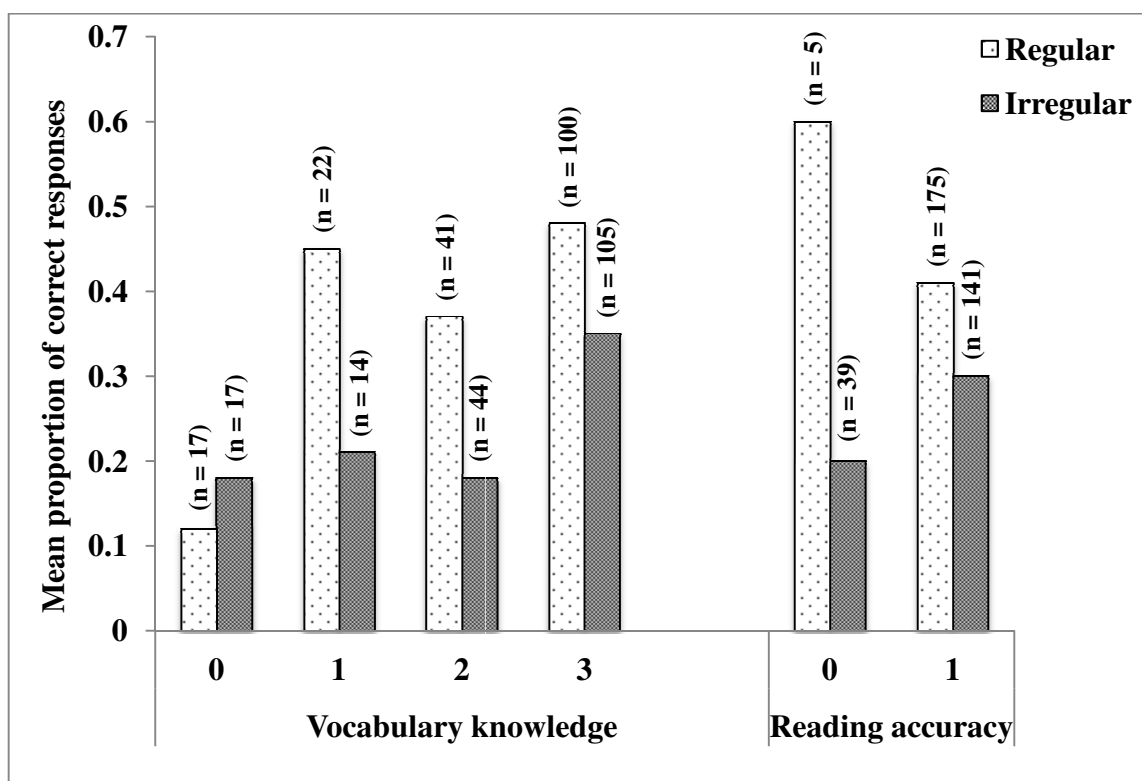


Figure 2. Mean proportion of correct responses of the orthographic decision task as a function of word regularity, vocabulary knowledge and reading accuracy (parentheses indicate total number of trials).

Discussion

In this study, we examined the role of three important reading and language factors in orthographic learning of both regular and irregular words: phonological decoding skill, orthographic knowledge, and vocabulary knowledge. The second part of the study examined the relationship between reading accuracy, vocabulary knowledge and the success of

orthographic learning at an item level. The findings suggested that overall, phonological decoding skill, orthographic knowledge and vocabulary knowledge are all associated with regular and irregular orthographic learning. However, at an item level, correct reading of the novel word did not predict the success of the orthographic learning of the same novel word. Finally, item-specific vocabulary knowledge predicted successful orthographic learning of irregular words only; it did not predict learning of regular words.

The first aim of the study was to examine the reading and language skills that are associated with orthographic learning and explore whether the effects of these factors are influenced by word regularity. Given the evidence from previous research (Share 1995, 1999; Cunningham et al., 2002; Conners et al., 2010), it was predicted that both orthographic knowledge and phonological decoding skill would be associated with orthographic learning of regular words. Our results were consistent with this prediction: orthographic learning of regular words was highly correlated with orthographic knowledge (as indexed by irregular word reading accuracy and word reading fluency), as well as phonological decoding skill (as indexed by nonword reading accuracy and fluency). Similar results were found for the orthographic learning of irregular words, where both phonological decoding skill and orthographic knowledge were associated with orthographic learning. The association of these pre-existing reading skills with orthographic learning is consistent with reports that poor readers often also struggle with learning novel words (Share, 2004; Reitsma 1983, 1989, Manis, 1985).

Although we predicted that the relationship between orthographic and phonological skills and orthographic learning would be modulated by word regularity, the results of the correlational analyses did not support this view. Orthographic knowledge, as measured by our standardized reading task, did not show a stronger association with orthographic learning of irregular words compared with that of regular words; and phonological decoding skill appeared to be no less strongly linked to orthographic learning of irregular words compared

to regular words. However, it is important to note that orthographic knowledge and phonological decoding skills were highly correlated with each other; that is, children with better orthographic knowledge were also better phonological decoders. The high correlation between these two factors could explain why there was no difference in their effects on orthographic learning of regular and irregular words. These correlations may also relate to general factors which affect all three skills, as discussed below.

The correlational analyses also revealed that although pre-existing reading scores of irregular and nonword reading are highly correlated with each other, orthographic learning of regular and irregular words, were, surprisingly, only moderately correlated. This result may suggest that orthographic learning of regular and irregular words might involve the application of different learning mechanisms. It is also possible that the moderate correlation is due to the fact that during the experiment, the children adopted a particular, and perhaps atypical strategy, to learn the irregular novel words but not the regular words. However, this explanation seems relatively unlikely given that the regular and irregular novel words were presented intermixed in this experiment. This design was used precisely to minimize strategic artifacts and to simulate a more typical experience that children have when they learn to read (where regular and irregular words are intermingled). It should be noted that in the orthographic learning task, the children were alerted about the word regularity, which might not always happen in children's silent reading experiences. Nevertheless, in our view it is reasonable to assume that teachers may similarly warn the children about word regularity when teaching new words.

This study also examined the effect of general vocabulary knowledge (indexed by PPVT score) on orthographic learning as vocabulary knowledge is suggested to be particularly important for reading or learning irregular words (Bowey & Rutherford, 2007; Nation & Snowling, 1998; Ouellette, 2006; Ricketts, Nation & Bishop, 2007; Nation & Cocksey, 2009). Vocabulary knowledge here referred to a combination of the children's

knowledge of a word's phonology and its meaning, as this is the knowledge children would most typically have prior to seeing a word in written form. Different from previous findings (McKague et al., 2001; Duff & Hulme, 2012), we found vocabulary knowledge correlated with orthographic learning of both regular and irregular words when learning was measured by a spelling task. When orthographic learning was measured by the orthographic decision task, only orthographic learning of regular words was correlated with vocabulary knowledge (although the differences between the two correlations was not significant). One explanation for this finding that differs from previous studies could be due to the lack of sensitivity of the measure for vocabulary knowledge (the shortened version of PPVT).

The correlation between reading skills and orthographic learning suggests that children with better reading and language skills are better able to acquire orthographic representations of both regular and irregular words than those children with less good reading and language skills. However, it could be argued that these associations were produced by general participant-level factors rather than the actual recruitment of pre-existing reading skills to perform orthographic learning tasks; that is, more able students tended to be better readers and also to perform better on the orthographic learning task than less able students. Therefore, in order to examine whether the reading skills we assessed were utilized directly during the process of orthographic learning, we performed an item-level analysis: If reading a particular novel word correctly directly transfers to the success of acquiring the representation of that word, it would be a stronger evidence of the relationship between initial reading ability and orthographic learning.

The second aim of the study, therefore, was to investigate the effect of item-specific vocabulary knowledge and initial reading accuracy on subsequent orthographic learning of those same regular and irregular words. The results showed that the accuracy of initial reading was not a predictor of acquisition of the orthographic representations for either regular or irregular items. In other words, being able to accurately “decode (or partially

decode)'' a novel word when encountered for the first time in written form, did not lead to greater success in acquiring the orthographic representation of that same word. This result is consistent with the findings of Nation, Angell and Castles (2007) who found that while correct phonological decoding and the success of orthographic learning of novel regular words were moderately correlated, this relationship did not hold at an item-level. Thus, our results do not support the item-based predictions of the self-teaching hypothesis (Share, 1995), which proposes that phonological decoding serves as a self-teaching mechanism that builds up an orthographic representation of a newly encountered word. Moreover, this self-teaching mechanism is proposed to take place every time the reader encounters the word; hence, the process is not stage based, but item-based. The current study confirmed an association between general measures of phonological decoding skill and orthographic learning for both regular and irregular novel words, but suggests that this association may not be a direct one.

However, there are alternative explanations for not finding reading accuracy as a significant predictor of orthographic learning. First, reading accuracy was at ceiling for regular items, hence, the lack of variability of the data might have reduced statistical power for the analysis. This issue does not apply to irregular items, as the mean proportion of irregular items read correctly was .78, and yet reading accuracy was still not a significant predictor of orthographic learning. Secondly, Share (2011) suggested that although phonological decoding was necessary for successful orthographic learning, the smoothness or speed during the process of decoding could also play an important role in orthographic learning. One of the limitations of the present study is therefore, using only the reading accuracy measure as a predictor of orthographic learning, and not using the reading times needed to read the novel words as a predictor. Future study is required to explore the speed of decoding or reading and its relationship to forming orthographic representations.

The item-level analysis also revealed that the effect of item-specific vocabulary

knowledge was modulated by word regularity, which is consistent with the literature examining the effect of word meaning on orthographic learning in adults (McKay et al, 2008; Taylor et al., 2011). For orthographic learning of irregular words, knowledge of the pronunciation and meaning of a particular novel word predicted the success of orthographic learning of that word, whereas for irregular words, item-specific vocabulary knowledge did not predict the success of orthographic learning of those words. This suggests that when phonological decoding can only be partially successful, as was the case with irregular words in this study, orthographic learning was assisted by factors such as vocabulary knowledge. On the other hand, when phonological decoding is not compromised, vocabulary knowledge does not appear to provide additional assistance to acquiring orthographic representations. It is important to note that the role of feedback consistency could also be crucial in the interaction between word regularity and the phonology component of vocabulary knowledge. When a child was exposed to the phonology of the novel word, an orthographic representation of the word may have been already established before seeing its print form and this feedback from phonology may be involved in the early stages of orthographic learning (McKague, Davis, Pratt & Johnston, 2008). Therefore, when the novel words were presented for the first time in print, the regular items may have been more likely to match the orthographic representations that had been established than the irregular items. As a result, vocabulary knowledge became more important for resolving the mismatch for the irregular items than for the regular items.

It should also be noted that the effect of vocabulary knowledge on orthographic learning was found only in the spelling task and not in the orthographic decision task. A discrepancy in results across different measures of orthographic learning has been found in many studies (e.g., Nation et al., 2007; Ouellette & Fraser, 2009, Wang et al., 2011). One possible explanation is that vocabulary knowledge of a novel word assists and consolidates the acquisition of the orthographic representation of this novel word, and this was

manifested in the spelling task, which requires a complete and fully specified orthographic representation for accuracy. On the other hand, in the orthographic decision task, a weaker orthographic representation can support successful performance. Therefore, the mapping between vocabulary knowledge and orthographic learning was not evident in the orthographic decision task.

In summary, there are three main findings from this research. First, orthographic learning of both regular and irregular words was highly correlated with pre-existing word-specific orthographic knowledge, phonological decoding skill, and vocabulary knowledge. Second, reading a novel word correctly did not directly transfer to the successful acquisition of the representation of that novel word. This suggests that while phonological decoding is important in orthographic learning, it is likely there are other factors also involved in the process of acquiring orthographic representations. Finally, this study was the first to demonstrate that the effect of vocabulary knowledge on children's orthographic learning is modulated by word regularity. When a child is learning irregular novel words, where phonological decoding can only be partial, orthographic learning is assisted by vocabulary knowledge of those words. On the other hand, when learning regular novel words, where phonological decoding is not compromised, vocabulary knowledge does not provide additional contribution to the acquisition of orthographic representations. This may have important implications on the use of different methodology in assisting children to read regular and irregular words. Taken together, the relatively low correlation between orthographic learning of regular and irregular words, and the finding that vocabulary knowledge only assists orthographic learning of irregular words provides some initial evidence that orthographic learning of regular and irregular words may involve recruitment of different processes.

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Appendix 1

<u>Target items and the foils for the orthographic decision task</u>				
<i>Word type</i>	<i>Target items</i>	<i>Phonologically - related foils</i>	<i>Visual Distractor 1</i>	<i>Visual Distractor 2</i>
Regular	vack (/væk/)	vakk	vock	vokk
Regular	doud (/daʊd/)	dowd	dowf	douf
Regular	praif (/preɪf/)	prafe	prait	prate
Regular	broon (/bru:n/)	brune	broop	brupe
Irregular	jape (/dʒæp/)	japp	jate	jatt
Irregular	cleap (/cleɪp/)	clape	cleak	clake
Irregular	ferb (/fɜ:b/)	farb	ferg	farg
Irregular	smope (/smɒp/)	smopp	snope	snopp

Paper 4

Tracking Orthographic Learning in Children with Different Types of Dyslexia

This paper was prepared for publication as:

Wang, H.-C., Castles, A., Nickels, L. & Marinus, E. (in preparation). Tracking Orthographic learning in children with different types of dyslexia. *NeuroPsychologia*.

Abstract

The ability to map letters to sounds, or phonological decoding skill, is considered the key means by which sight words are learned (Share, 1995). However, two types of developmental dyslexia groups suggest the relationship between phonological decoding skills and sight word learning is not straightforward. Children with surface dyslexia have normal phonological decoding skill but are impaired in their whole-word recognition skills, and children with phonological dyslexia show the opposite reading profile. The first aim of this study was to examine the role of phonological decoding in orthographic learning with these two subtypes of dyslexia groups, using a novel paradigm that tracks orthographic learning of regular and irregular words. The second aim of the study was to explore the predictors of orthographic learning with a group of poor readers using the same paradigm. The findings of this study suggest that phonological decoding skill alone is not sufficient for successful orthographic learning, and that orthographic knowledge may also play an important role in the acquiring of orthographic representations.

Word count: 167

Keywords: developmental dyslexia, subtypes, orthographic learning, phonological decoding

Orthographic learning is defined as the transition from slowly sounding out an unfamiliar new word to rapid automatic recognition of the word, and is thought to be the pathway to fluent reading (Castles & Nation, 2006). Ehri and Wilce (1983) described this final stage in word recognition as automatised reading. Many studies and theories in reading development have proposed that phonological decoding is one of the important phases that leads to this final stage of automatic reading (for a review, see Ehri, 2005). For example, Share (1995) proposes that phonological decoding is crucial to the success of orthographic learning, and that this learning takes place at an item level. According to this view, the process of converting the letters of a novel word to their corresponding sounds, draws readers' attention to the order and the details of the letters of the word. With repeated exposure to the new word, an orthographic representation of the word is established, through which rapid and direct word recognition is possible.

If phonological decoding is in fact the key to acquiring orthographic representations, proficient phonological decoding processes should lead to success in orthographic learning, and impaired phonological decoding processes should lead to difficulties in orthographic learning. Indeed, abundant studies have supported the view that deficits in phonological processing skills may be the primary cause of reading difficulties (e.g., Rack, Snowling & Olson 1992; Stanovich & Siegel, 1994) as well as orthographic learning difficulties (Share & Shalve, 2004).

However, a large body of evidence on heterogeneity within the dyslexic population and on the existence of different subtypes of dyslexia suggests that the relationship between phonological decoding skills and orthographic learning might not be straightforward. Research on children with developmental dyslexia has suggested that impairments in phonological decoding and impairments in automatic whole-word recognition can occur selectively - one aspect of reading can be impaired without impairment to the other (Castles & Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang & Petersen, 1996; Stanovich,

Siegel & Gottardo, 1997; Valdois, Boose, Ans, Carbonnel, Zorman, David & Pellat, 2003). Children with *surface dyslexia* have difficulty in reading irregular words (like *yacht*) but are unimpaired at reading nonwords (like *grep*), indicating that their phonological decoding skills have been acquired normally but not their whole-word recognition skills. Conversely, children with *phonological dyslexia* show impairments in nonword reading but not irregular word reading, suggesting normal whole word recognition but difficulties with phonological decoding. In other words, despite the fact that children with phonological dyslexia have impaired phonological decoding processes, they appear to be able to build up orthographic lexical knowledge within the normal range; in contrast, children with surface dyslexia have normal phonological decoding processes, yet have difficulties in acquiring orthographic representations.

The existence of these subtypes suggests that there might be factors other than phonological decoding skill involved in orthographic learning, at least for readers with dyslexia. Indeed, it has been proposed that poor readers might rely on alternative learning strategies in order to compensate for poor phonological decoding skills (Castles, Datta, Gayan & Olson, 1999; Stanovich & Siegel, 1994; Siegel, Share & Geva, 1995). Specifically, some poor readers might focus on the details of the orthographic input more carefully than other readers to compensate for their inferior phonological decoding skills. As such, orthographic learning might actually be more effective for them, than for other children of the same reading level. In addition, it is possible that vocabulary knowledge or paired-associate learning skills are relied on more heavily during orthographic learning by children who have difficulties with phonological decoding. In support of this, previous studies have found that when decoding can only be partially successful, in the case of irregular novel words, contextual information and vocabulary knowledge play a role in orthographic learning (Duff & Hulme, 2012; Wang, Castles, Nickels & Nation, 2011, In preparation). Similarly, word meaning has also been found to assist the reading of irregular words (e.g.,

Bowey & Rutherford, 2007; Nation & Snowling, 1998; Ouellette, 2006; Ricketts, Nation & Bishop, 2007; Nation & Cocksey, 2009).

Studies on orthographic learning have found that children with dyslexia need more exposures to acquire novel word representations than normally-developing readers (Ehri & Saltmarsh, 1995; Manis, 1985). The most extreme evidence of this was reported by Reitsma (1983, Experiment 3). In that study, there was no sign of orthographic learning in a group of children with dyslexia, even after six exposures to the novel words. On the contrary, clear evidence of orthographic learning was found in a Grade 1 group with the same items.

To date, only two studies have explicitly contrasted differences in orthographic learning in children with phonological and surface dyslexia. As expected by their specific reading profiles, Castles and Holmes (1996) found a surface dyslexia group to be poorer at learning novel words (measured by an orthographic choice task in which the child had to choose the target item from its distracters) than the phonological dyslexia group. Castles and Holmes (1996) therefore suggested that the relationship between decoding skills and acquiring orthographic representations may not be straightforward. However, since the novel words were all irregular, it may be that the reason the surface dyslexia group learn less well is because their usual phonological decoding strategy is not effective for these stimuli.

Bailey, Manis, Pedersen, and Seidenberg (2004) built on Castles and Holmes (1996) and explored orthographic learning of both regular and irregular words in children with phonological and surface dyslexia. They found that both subtypes of dyslexia readers were more impaired in orthographic learning compared to the chronological age controls. In addition, they found that only the surface dyslexia, and not the phonological dyslexia group, showed an advantage in learning regular words as compared to the irregular words. Although Bailey and colleagues provided more insight into the orthographic learning in different subtypes of dyslexia, there were some limitations. First, orthographic learning was

measured with reading accuracy.⁷ In this case, the effect of regularity on the surface dyslexia group may have been a function of ‘decodability’ of the words. In other words, it is still unclear whether the surface dyslexia children read these words correctly via phonological decoding or via newly acquired orthographic representations. Conversely, the regularity effect within the phonological dyslexia group might have been reduced as a result of their impaired decoding ability. Second, as mentioned in their paper, the subgroups’ selection was based on a relatively lax criterion. Instead of selecting children that were only impaired on nonword reading and only impaired on irregular word reading whilst being within the average range of the other skill, Bailey and colleagues based their selection on a discrepancy score between nonword and irregular word reading. Hence, for example, a phonological dyslexic child in that study could be poor on both nonword and irregular word reading, with irregular word being relatively better than nonword reading.

The current study aimed to better understand orthographic learning in two groups of children with selective impairments in reading: a group of children with surface dyslexia and a group of children with phonological dyslexia. Building on the studies of Castles and Homes (1996) and Bailey et al. (2004), we used subgrouping criteria that selected subgroups that were impaired on one reading process but normal in the other. In addition, we developed a novel paradigm that tracks orthographic learning more dynamically than in the previous studies. This paradigm allowed us to explore whether the two subtypes of dyslexia differ in the success of orthographic learning, and whether orthographic learning improves over learning exposures. Moreover, with the manipulation of word regularity, we were able to investigate how the two types of poor readers were affected by differences in the ease with which the words could be decoded phonologically.

In this novel word-learning paradigm, regular and irregular words were presented in

⁷ Bailey et al. (2004) also used a spelling task to measure orthographic learning, however, due to the fact that accuracy of spelling was at floor, only reading accuracy results were discussed.

three cycles. In each cycle, we measured reading accuracy under two conditions: untimed and time-limited stimulus exposure duration. After all three cycles were completed, the more standardly-used spelling and orthographic choice tasks were also administered.

The untimed reading condition provided the opportunity for children to decode the novel words. In order to measure whether the orthographic learning had taken place, each untimed reading block was followed by a time-limited exposure duration (200 ms) that allowed examination of the extent to which the words were being recognised automatically. This time-limited reading was considered a measure of orthographic learning. It has been suggested that rapid recognition of words is only possible when orthographic representations have been acquired (Yap & van der Leij, 1993). Similarly it has been argued that when a word is read as a whole unit and not by decoding, the time that is required to read the word is reduced (e.g., Coltheart, 1983; Ehri, 2005).

The first part of the study explored the success of regular and irregular orthographic learning trials in the two groups of children with dyslexia. It was predicted that if phonological skills are essential for orthographic learning, the surface dyslexia group should be better at acquiring orthographic representations than the phonological dyslexia group. On the other hand, if orthographic learning can successfully take place without reliance on phonological decoding, perhaps by relying more heavily on other skills, the phonological dyslexia group might show an advantage in orthographic learning. In addition, since the surface dyslexia group relies heavily on phonological decoding, they were predicted to show a larger advantage in learning regular novel words compared to the irregular novel words than the phonological dyslexia group. This would also be expected based on the assumption that the phonological dyslexia group may rely more on whole word processing than the surface dyslexia group.

The second part of the study used regression analyses to explore in detail how well different reading subskills predicted orthographic learning of regular and irregular words

within a larger group of poor readers. For this purpose, we drew on an explicit model of the component processes involved in skilled reading, the dual route model, presented in Figure 1 (Coltheart, 1978; Coltheart, Curtis, Atkins & Haller, 1993; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). This model proposes a *lexical* route through which words are directly recognised as whole units and a *sublexical* route through which words are decoded phonologically.

As can be seen from Figure 1, each of these routes can be broken down into a number of processing components, some shared across the routes and some separate. When a reader sees a printed word, the letters will first be recognised in the *letter analysis* component. Then in the nonlexical route, the graphemes of the word are phonologically decoded by the *grapheme-to-phoneme conversion* component. In the lexical route, the orthography of known words is activated as a whole unit in the *orthographic lexicon*. Subsequently, in the *semantic system*, the meaning of the word is activated and then in the *phonological lexicon* the sound of the word is activated. The final component of the model is the *phonemic buffer* where phonemes are temporarily stored before they are spoken.

To our knowledge, no previous research has investigated the relationship between the functioning of the specific components of the dual-route model and orthographic learning. As noted earlier, phonological decoding is often assumed to be the key to orthographic learning (Share, 1995). However, when decoding is compromised, factors such as vocabulary knowledge or context may be important (McKay, Davis, Savage & Castles, 2008; Taylor, Plunkett & Nation, 2011; Duff & Hulme, 2012). Therefore, we predicted that skills reflecting lexical components to be more strongly related to orthographic learning of irregular words than regular words. In sum, we aimed to develop a more detailed picture of the reading subskills associated with skills orthographic learning by exploring the strengths of the relationships between the reflecting sublexical components to be more strongly related

to orthographic learning subcomponents of the dual route model and the outcome measures orthographic learning.

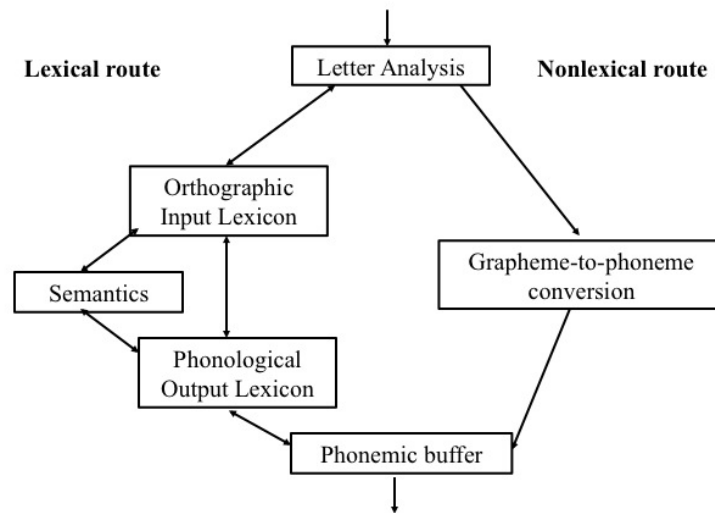


Figure 1. The dual route model and its six basic components.

Method

Participants

Sixty-one poor readers participated in the study. They were recruited from schools, clinics or via advertisements to participate in a reading training study at Macquarie University. They were selected on the basis of having reading accuracy one standard deviation below average for their age on either regular, irregular, or nonword reading on the Castles and Coltheart 2 test (CC2; Castles, Coltheart, Larsen, Jones, Saunders & McArthur, 2010). These poor readers were on average 9.3 years old (ranging from 7 to 12.3) and scored on average -1.58 ($SD = 0.67$) on regular word reading; -1.52 ($SD = 0.57$) on nonword reading; and -1.57 ($SD = 0.58$) on irregular word reading. In addition, all children scored within normal ranges on non-verbal IQ according to the Kaufman Brief Intelligence Test (K-*Bit*, Kaufman & Kaufman 1990).

Within this group there were eight poor readers with a surface dyslexia reading profile (mean age: 9.34, SD = 1.4) and nine with a phonological dyslexia reading profile (mean age: 9.42, SD = 1.51). The criteria for surface dyslexia was performance within the normal range (z -score > -1.00) on nonword reading accuracy and impaired performance on irregular word reading (z -score < -1.00), and that the difference between nonword and irregular word reading was a z -score of more than 0.5. The selected children with phonological dyslexia had the opposite reading profile (nonword z -score < -1.00 , irregular word > -1.00 , with a difference of more than 0.5).

In the first part of the Results section, we compared the two subgroups of dyslexia directly on their performance on the experimental orthographic learning task. In the second part, we conducted regression analyses across all 61 poor readers to explore which reading subskills best predict orthographic learning.

Materials and Procedure

This section consists of two subsections of material and procedures. The first part includes measures of reading sub-process of the dual-route model and the second part includes the orthographic learning task.

Measures of reading sub-processes. We assessed the poor readers on six basic components in the dual-route model (see Figure 1) as measures of predictors of orthographic learning. Each component was assessed with one test as described in the sections below.

Letter analysis. Letter analysis skill was measured with a cross-case matching task (McArthur et al., In preparation). This task consists of 14 letters, 7 in upper case and 7 in lower case. When the letter was in lower case, the child was asked to write down the upper case of the same letter (e.g., t – T), and vice versa for upper case letters.

Grapheme-phoneme conversion. The ability to convert graphemes to phonemes in the sublexical route was tested using a Letter Sound Test (LeST, Larsen, Kohnen, McArthur

& Nickels, 2011). Each child was asked to produce the appropriate sound of 51 single letter or multi-letter graphemes. The items were presented on individual flash cards. The graphemes that were selected had the same pronunciation in more than 75% of occurrences according to the CELEX database (Baayen, Piepenbrock & van Rijn, 1993), which formed the basis of correct answers for this test.

Orthographic lexicon. Word-specific orthographic knowledge was assessed with a DOOR/DOAR lexical decision test with pseudohomophone distractors (McArthur et al., In preparation). Thirty target words, ranging from three to 625 instances per million words, were selected from the Children's Printed Word Database (CPWD, Masterson, Stuart, Dixon & Lovejoy, 2003). All words had alternative, homophonic spellings with adjustments of the vowel (e.g., FLAME changed to FLAIM) or a consonant (e.g., CURL changed to KURL). Each item was presented in a list, paired with its alternative homophonic spelling (e.g., DOOR and DOAR). The child was asked to circle the correct spelling.

Semantics. Semantic knowledge was measured with the Peabody Picture Vocabulary Test 4 (PPVT-IV, Dunn & Dunn, 2007). The child was presented with four pictures in each item, and was asked to point to the picture that was named by the tester. The administration of the test was stopped when the child made more than eight errors in a set of 12 items. Scores were standard scores with a mean of 100 and a standard deviation of 15.

Phonological lexicon. The ability to access the phonological lexicon was measured with the Naming subtest of the ACE6–11 test (Adams, Cooke, Crutchley, Hesketh & Reeves, 2001). The child was asked to name 25 pictures. No stopping rule was applied.

Phonemic buffer. We tested the phonological output buffer and phonological output processes with a standardised nonword repetition task, a subtest of the NEuroPSYchology (NEPSY) test (Korkman, Kirk & Kemp, 1998). In this task, the child was asked to listen to and orally repeat digitally-recorded nonsense words (e.g., crumsee). Scores were standard scores with a mean of 10 and a standard deviation of 3.

Orthographic learning task. This task consisted of eight regular and eight irregular four-letter and five-letter nonwords (e.g., vack). The nonwords were similar to the items used in Wang et al. (2011). The regular items were pronounced according to a set of typical grapheme-phoneme correspondence rules (Rastle & Coltheart, 1999). “Typical” was defined on the basis that the pronunciation of the vowel occurred in more than 50% of words containing that vowel grapheme in both the CELEX database (Baayen et al., 1993) and the Children’s Printed Word Database (CPWD; Masterson, Stuart, Dixon & Lovejoy, 2003). The irregular nonwords had pronunciations that did not follow typical grapheme-phoneme conversion rules. The allocated pronunciation of the vowel in the target word occurred in fewer than 50% of words in the CELEX and the CPWD. All of the irregular pronunciations were still existing grapheme-phoneme correspondences in English. However, the pronunciations were infrequent and did not occur in the context of the final consonants (bodies) of the irregular nonwords that were used in this task.

The nonwords were introduced in two separate sessions in order to reduce the task demands for the poor readers. In each session, the child learned four regular items followed by four irregular items. For both regular and irregular words, the same procedure was used consisting of: an initial exposure phase, learning trials and two post tests (see Figure 2).

At the beginning of the experiment, the child was presented with a picture with elves and was told they were going to learn the names of some of these elves. Next, the tester introduced the spoken forms of the four target nonwords (‘elves names’) to the children (initial exposure). This was necessary in order to expose the children to the pronunciations of the irregular nonwords. The nonwords appeared on the screen one at a time, and the tester told the child: the name of this elf is _____. The children were not asked to read the novel words at this point and no accuracy was recorded. After all four nonwords were introduced to the child, the first cycle of the learning trials began and reading accuracy was recorded. The four nonwords would appear on the screen again, one at a time in a randomised order,

and the child was asked to read them aloud. This was the untimed exposure reading.

Feedback was provided regardless of whether the child read the target word correctly or not, to give an equal number of phonological exposures to each word.

In order to obtain an ongoing measure of orthographic learning after every orthographic exposure with a minimised extra learning/decoding opportunity, each round of the untimed reading block was followed by a block of time-limited exposure duration reading (200 ms presentation, with ##### as backward masks) of the target words. Again, all four target words were presented in random order. This step was introduced to the child as the ‘speed reading game’. The reading accuracy of time-limited exposure duration was considered a measure of orthographic learning. One block of untimed reading followed by one block of time-limited exposure duration reading was considered a cycle, and this cycle was repeated three times.

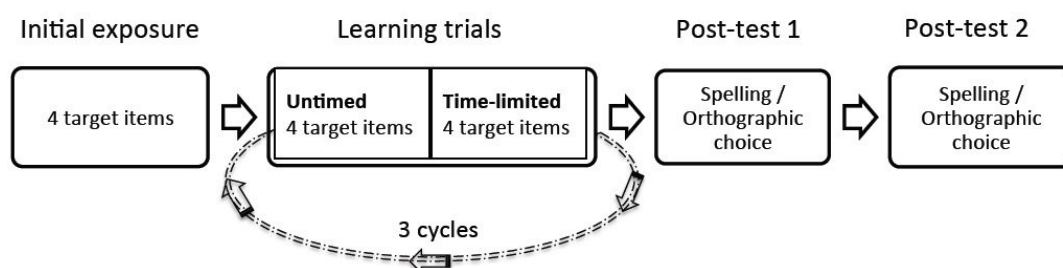


Figure 2. Procedure of the orthographic learning task

After the three cycles were completed, two post-tests were conducted to measure orthographic learning using both spelling and orthographic choice tasks. For the spelling task, the tester dictated all trained words in a random order. The children were asked write down the elves’ names exactly as they had learned them on the computer. For the orthographic choice task, each target item (e.g., *ferb*) was presented together with its homophonic foils (e.g., *furb*) and two visual distractors (e.g., *ferq*, *furq*) on one A4 page.

The children were asked to choose the correct spelling of the elves' names that they had learned from those four options. These two tasks were conducted once immediately after the learning trials, and once after an hour.

The exact procedure was repeated after eight weeks with the other half of the items (four regular and four irregular) in the second session. Thus, there were in total scores for eight regular target words and eight irregular target words.

Results

The results are presented in two sections: in the first section, we report orthographic learning in the two subtypes of dyslexia, and in the second section, we explore the predictors of orthographic learning for the entire sample of poor readers.

Orthographic Learning of the Two Subtypes of Dyslexia

Before analysing the performance of the two subgroups on the orthographic learning task, we first checked whether the subgroups were significantly different on the selection measures. In addition, we analysed their profiles on the measures of the reading subprocesses to further validate their specific reading deficit.

Subgroup validation. The performance of the two subgroups of poor readers on the selection measures and the other measures of reading subprocesses is presented in Table 1.

The two groups were significantly different on the selection measures: nonword and irregular word reading accuracy. In addition, and as would be predicted, the phonological dyslexia group was significantly worse on the letter-sound knowledge test and the surface dyslexia group was significantly worse on orthographic knowledge (Door/Doar), $t(1,15) = 7.88, p < .01$. The two groups did not differ on any other measure. The results of the

Table 1.

Characteristics and Dual Route Processing Abilities of the Phonological and Surface Dyslexia Groups.

<i>Measures</i>	<i>Phonological Dyslexia</i>		<i>Surface Dyslexia</i>		<i>Phon. vs. Surf.</i>	
	Mean	SD	Mean	SD	<i>t</i> (1,15)	<i>p</i>
<i>Characteristics</i>						
Age	9.34	1.42	9.42	1.51		ns
Nonverbal IQ (K-Bit, standardised score / 100)	109.5	10.93	98.57	19.16		ns
Nonword reading (CC2, z-score)	-1.69	0.41	-0.71	0.20	39.57	< .01
Irregular word reading (CC2, z-score)	-0.58	0.27	-1.62	0.36	44.67	< .01
<i>Reading Subprocesses</i>						
Letter analysis (Cross-case matching, raw score /14)	13.38	1.06	13.22	1.64		ns
Grapheme-phoneme conversion (Letter-sound knowledge, raw score /51)	34.50	5.61	41.44	4.64	7.81	< .01
Orthographic lexicon (DOOR/DOAR, raw score /30)	23.13	3.31	18.78	3.07	7.88	< .01
Semantics (PPVT, standardised score /100)	100.5	6.72	94.67	6.89		ns
Phonological Lexicon (ACE, raw score /25)	16.75	1.28	17.22	2.64		ns
Phonemic Buffer (NEPSY, standardised score /10)	9.63	2.83	10.11	1.17		ns

assessment of reading subprocesses therefore confirmed that the phonological dyslexia group was impaired in the sublexical process and the surface dyslexia group was impaired in the orthographic lexicon in the lexical process.

Orthographic learning. The main questions of interest for the orthographic learning task were 1) whether the two dyslexia groups showed any improvement in reading accuracy over the learning cycles; 2) whether the surface dyslexia group would perform better than the phonological dyslexia group as a result of their superior phonological decoding skill; 3) whether there would be a word regularity effect and if so, 4) whether the effect differed across these two groups.

Learning cycles. Table 2 summarises results of the orthographic learning trials for untimed and time-limited exposure duration reading.

We ran mixed model ANOVAs with cycles (cycle 1/2/3) and word regularity (regular items/ irregular items) as within-subject factors, and group (phonological / surface dyslexia) as a between subject factor. The same analysis was performed for reading accuracy of both untimed and time-limited measures.

For untimed exposure duration, reading accuracy improved significantly over cycles, $F(2, 14) = 19.48, p < .01, \eta_p^2 = .74$, with a linear trend, $F(1, 15) = 40.91, p < .01, \eta_p^2 = .73$. A main effect of word regularity showed that regular items were read more accurately than irregular items, $F(1, 15) = 61.12, p < .01, \eta_p^2 = .80$. The interaction between word regularity and group approached significance, $F(1, 15) = 4.16, \eta_p^2 = .22, p = .059$, reflecting the fact that the regularity effect tended to be larger for the surface dyslexia group compared to the phonological dyslexia group. There was no main effect of group, $F < 1$.

For time-limited exposure duration, reading accuracy also improved over cycles, $F(2, 14) = 12.49, p < .01, \eta_p^2 = .64$, with a linear trend, $F(1, 15) = 25.03, p < .01, \eta_p^2 = .63$. Regular items were also read more accurately than irregular items, $F(1, 15) = 13.55, p < .01$,

$\eta_p^2 = .48$. There was no effect of group, $F < 1$. However, unlike untimed exposure duration, there was no suggestion of an interaction between word regularity and group, $F < 1$.

Table 2.

Reading Accuracy Across Learning Cycles (with SDs in brackets).

Reading Accuracy	Regular		Irregular	
	<i>Phonological Dyslexia</i>	<i>Surface Dyslexia</i>	<i>Phonological Dyslexia</i>	<i>Surface Dyslexia</i>
Cycle 1 (raw score /8)				
Untimed	4.88 (2.23)	5.56 (1.59)	3.13 (1.73)	3.11 (1.27)
Time-limited	5.13 (1.64)	5.11 (1.83)	3.75 (2.25)	3.56 (1.67)
Cycle 2 (raw score /8)				
Untimed	5.38 (1.85)	7.00 (0.87)	4.00 (2.00)	4.11 (1.76)
Time-limited	5.88 (1.36)	6.44 (1.74)	5.00 (1.60)	5.11 (1.54)
Cycle 3 (raw score /8)				
Untimed	6.38 (1.41)	7.22 (0.67)	4.88 (1.64)	4.67 (1.58)
Time-limited	5.88 (1.36)	6.44 (1.74)	4.50 (1.85)	5.11 (1.45)
<i>Total</i> (raw score / 24)				
Untimed	16.75 (5.09)	20.00(2.55)	12.00 (4.50)	11.67 (3.94)
Time-limited	16.88 (3.87)	17.89 (5.26)	13.25 (5.45)	13.78 (4.15)

In summary, the results for the learning cycles showed that the performance of both dyslexia groups improved over the cycles in both untimed and time-limited exposure durations, with regular words read more correctly than irregular words. In addition, for the untimed reading accuracy, the surface dyslexia group also showed much better performance with regular items than irregular items, while for the phonological dyslexia group, the word regularity effect was smaller.

Post-test measures of orthographic learning. Orthographic learning was measured immediately after the learning cycles using spelling and orthographic choice tasks, and once again after an hour delay. Results are summarised in Table 3.

Mixed model ANOVAs with factors of word regularity and time (immediately after/ one- hour delay) as within-subject factors, and group as a between-subject factor, were conducted for both spelling and orthographic choice tasks.

For spelling, accuracy was higher when spelling was measured immediately after learning compared to an hour later, $F(1, 15) = 16.64, p < .01, \eta_p^2 = .53$. There was no effect of regularity, $F < 1$, group, $F < 1$, nor any significant interactions, $F < 1$.

For the orthographic choice task, similar results were found. Accuracy was higher when orthographic choice was measured immediately after learning, compared to the delayed test an hour later, $F(1, 15) = 7.64, p = .015, \eta_p^2 = .34$. There was no effect of regularity, $F < 1$, nor any significant interactions. However, in contrast to the spelling task, there was a main effect of group, $F(1, 15) = 7.08, p = .018, \eta_p^2 = .32$, indicating that the phonological dyslexia group performed better on this task than the surface dyslexia group.

In summary, the results from the spelling and orthographic decision tasks for both dyslexia groups showed that the performance was better when measured immediately after learning compared to the delayed test. There was no effect of word regularity in these two measures for either dyslexia group. Finally, orthographic learning measured from the orthographic choice task showed that the phonological dyslexia group outperformed the surface dyslexia group on orthographic learning of both regular and irregular items.

Summary and Interim Discussion: Orthographic Learning

The two dyslexia groups showed evidence of orthographic learning, with improvement over the learning cycles. Different from the prediction of the self-teaching hypothesis, the surface dyslexia group did not perform better on orthographic learning as a

result of their superior phonological skill, compared to the phonological dyslexia group. In fact, orthographic learning measured from the orthographic choice task suggested that the phonological dyslexia group was more successful in orthographic learning.

As predicted, there was a word regularity effect on both untimed and time-limited reading accuracy. In addition, the surface dyslexia group showed a larger regularity effect on the untimed reading accuracy. However, no effect of word regularity was found on the post-test measures.

The results from these two dyslexia groups suggest that there are different effects on orthographic learning depending on which processing route is impaired for reading aloud. For example, the larger regularity effect in untimed reading accuracy for novel words for the surface dyslexia group is likely to be the result of their reliance on the sublexical route. Regular novel words can be read correctly via the sublexical route while irregular novel words require lexical processing. Hence, as the surface dyslexia group was impaired in lexical but not sublexical processes, irregular novel word reading was more disadvantaged compared to the regular words. In addition, the inferior performance of the surface dyslexia group on the orthographic choice task compared to the phonological dyslexia group also supported the idea that the differences in impairment affected orthographic learning differently.

Table 3.

Mean Accuracy on Spelling and Orthographic Choice Tasks as a Function of Time, Word Regularity and Dyslexia Group (with SDs in brackets).

	Spelling (raw score / 8)		Orthographic choice (raw score / 8)	
	Regular	Irregular	Regular	Irregular
Immediately after				
<i>Phonological Dyslexia</i>	5.13 (3.04)	5.88 (2.64)	7.50 (1.07)	7.13 (1.46)
<i>Surface Dyslexia</i>	5.89 (1.83)	6.00 (1.73)	6.67 (1.32)	6.33 (1.23)
One hour delay				
<i>Phonological Dyslexia</i>	4.38 (3.46)	4.88 (2.17)	7.38 (1.06)	6.50 (1.31)
<i>Surface Dyslexia</i>	5.11 (1.96)	5.22 (2.22)	5.44 (1.88)	4.88 (2.32)

There was no significant effect of regularity for either spelling or orthographic decision tasks for both dyslexia groups. However, the regular novel words in the study were created in a way that each target word always had a homophone partner (e.g., *voar* can be spelled as *vore*). Hence, for accuracy in both spelling and orthographic choice, letter-sound knowledge alone was insufficient; orthographic knowledge was required for both the regular and irregular words. Therefore, this could account for the lack of an advantage for regular word spelling and orthographic choice in the surface dyslexia group despite such an advantage in reading.

Predictors of Orthographic Learning

In this section, we explore the relationships between orthographic learning of regular and irregular novel words and the lexical and sublexical processing components of the dual route model. Lexical processing components are predicted to be more strongly related to irregular novel word learning, and sublexical processing components more strongly related to regular word learning. The analyses in this section were conducted with all 61 poor readers.

Correlations between reading subprocesses and orthographic learning. Table 4 shows the results of a series of partial correlations controlling for age between the outcomes of the orthographic learning task (outcome measures: no. 1-8) and the components involved in lexical and sublexical processes (predictors: no. 9-14). All of the components showed significant associations, except semantic knowledge. Orthographic knowledge, measured by the Door/Doar test, was highly correlated with all outcomes of the orthographic learning task. In contrast, sublexical processing, measured by the letter-sound knowledge test, was not correlated with orthographic learning which was measured using orthographic choice task, for either regular or irregular items, and the correlation only approached significance for timed-limited reading and for spelling accuracy of the irregular items.

Table 4.

Partial Correlation of the Outcome Measures and the Predictors with Age and Nonverbal IQ Controlled.

		1	2	3	4	5	6	7	8	9	10	11	12	13
<i>Regular</i>	1. Untimed reading	1												
	2. Time-limited reading	0.9*	1											
	3. Spelling	0.56*	0.6*	1										
	4. Orthographic choice	0.39*	0.5*	0.63*	1									
<i>Irregular</i>	5. Untimed reading	0.54*	0.47*	0.38*	0.39*	1								
	6. Time-limited reading	0.59*	0.59*	0.5*	0.43*	0.85*	1							
	7. Spelling	0.51*	0.54*	0.62*	0.42*	0.66*	0.69*	1						
	8. Orthographic choice	0.39*	0.48*	0.53*	0.54*	0.59*	0.57*	0.79*	1					
<i>Predictors</i>	9. Letter Analysis	0.24	0.23	0.3*	0.29*	0.22	0.39*	0.35*	0.39*	1				
	10. Letter-sound Test	0.51*	0.39*	0.31*	0.19	0.32*	0.28	0.27	0.15	0.15	1			
	11. Orthog. Lexicon	0.38*	0.43*	0.59*	0.54*	0.46*	0.49*	0.58*	0.63*	0.28	0.11	1		
	12. Semantics	0.15	0.07	0.15	0.17	0.08	0.17	0.2	0.23	0.32*	0.18	0.3*	1	
	13. Phono. Lexicon	0.41*	0.29*	0.12	0.11	0.29*	0.39*	0.2	0.16	-0.13	0.29*	0.2	0.19	1
	14. Phonemic Buffer	0.52*	0.43*	0.35*	0.32*	0.31*	0.41*	0.29*	0.19	0.16	0.15	0.34*	0.31*	0.3*

* = $p < .05$

Regression analyses. A set of stepwise multiple regressions was conducted with the dual route processing components as predictors, and the various orthographic learning measures as the dependent variables. The results of the regression analyses are summarised in Table 5. For regular items, untimed exposure duration reading was predicted by letter-sound correspondence knowledge and phonemic buffer efficiency (measured using nonword repetition). For time-limited exposure duration reading accuracy, word-specific orthographic knowledge (measured by the Door/Doar test) was also a significant predictor, in addition to letter-sound knowledge and phonemic buffer efficiency. Spelling accuracy was predicted by letter-sound knowledge and orthographic knowledge, whereas accuracy of orthographic choice was only predicted by orthographic knowledge.

For irregular novel word learning, different predictors were found compared to regular novel word learning. Untimed exposure duration reading accuracy was predicted by both letter-sound knowledge and orthographic knowledge. For time-limited exposure duration reading, spelling and orthographic choice, only orthographic knowledge predicted the accuracy of those measures.

Summary and Interim Discussion: Predictors of Orthographic Learning

The aim of second part of this study was to explore in detail to what extent tasks tapping different subprocesses of the dual route model predicted orthographic learning for a group of poor readers. The results showed that orthographic learning of regular words is predicted by different subprocesses compared to orthographic learning of irregular words. In addition, different measures of orthographic learning had different predictors.

Table 5.

Summary of Regression Results Predicting Orthographic Learning of Regular and Irregular Words from Lexical and Sublexical Processing components.

			Age	Nonverbal IQ	Letter analysis	Letter- sound knowledge	Orthogr- aphic lexicon	Semantic knowledge	Phono- logical lexicon	Phono- logical buffer
Regular items	<i>Step</i>	<i>R</i> ²	<i>Beta</i>							
	1	0.22	0.34*	0.23						
Untimed-Reading	2	0.66	0.20	0.04	0.17	0.43*	0.18	-0.19	0.14	0.34*
	1	0.19	0.35*	2.57						
Time-limited Reading	2	0.54	0.24	0.04	0.11	0.34*	0.32*	-0.25	0.06	0.28*
	1	0.22	0.15	0.40*						
Spelling	2	0.57	-0.07	0.29*	0.05	0.27*	0.54*	-0.13	-0.10	0.17
	1	0.15	0.05	0.37*						
Orthographic Choice	2	0.43	-0.16	0.28*	0.01	0.15	0.52*	-0.06	-0.07	0.15
Irregular Items										
	1	0.13	0.30*	0.12						
Reading	2	0.46	0.15	0.00	0.21	0.29*	0.40*	-0.23	0.10	0.14
	1	0.17	0.33*	0.16						
Speed-Reading	2	0.51	0.15	0.02	0.11	0.18	0.37*	-0.12	0.20	0.21
	1	0.28	0.19	0.44*						
Spelling	2	0.57	-0.06	0.31*	0.10	0.20	0.50*	-0.04	0.00	0.07
	1	0.31	0.25	0.42*						
Orthographic Choice	2	0.59	-0.04	0.32*	0.09	0.08	0.56*	0.05	0.01	-0.05

Orthographic learning of regular novel words measured by spelling accuracy was predicted not only by letter-sound knowledge in the sublexical route, but also by orthographic knowledge. However, when orthographic learning was measured by the orthographic choice task, letter-sound knowledge was no longer a significant predictor. One possibility that may account for the differences in predictors across spelling and orthographic choice is that phonology was provided in the spelling task but not in the orthographic choice task. Therefore, in the spelling task, the children could use their sound-to-letter knowledge to perform the task for the regular words. In contrast to the findings for regular words, for irregular novel words, only orthographic knowledge (but not letter-sound knowledge) predicted orthographic learning measured by spelling and orthographic choice tasks.

For both regular and irregular novel word learning, untimed and time-limited exposure duration reading accuracy had different patterns of predictors. For regular words read under untimed exposure durations, letter-sound knowledge and phonemic buffer processing were significant predictors. Interestingly, for time-limited reading accuracy, orthographic knowledge was a significant predictor in addition to letter-sound knowledge and phonemic buffer processing. For irregular novel word learning, untimed reading accuracy was predicted by both letter-sound knowledge and orthographic knowledge whereas time-limited reading accuracy was only predicted by orthographic knowledge. This suggests that reading accuracy with untimed and timed-limited exposure durations reflect two different mechanisms. Time-limited exposure duration was designed to measure orthographic learning and this is supported by the fact that it shared predictors with spelling and the orthographic choice task but not with untimed reading.

General Discussion

This study comprised two parts. The first part compared orthographic learning of regular and irregular words in two subtypes of dyslexia. The results showed that the selective reading impairments of the two dyslexia groups were reflected in different patterns of orthographic learning. Children with phonological dyslexia were better at orthographic learning when learning was measured by an orthographic choice task, compared to children with surface dyslexia. This was despite the fact that the surface dyslexia group had better phonological decoding skill. However, it should be noted that when orthographic learning was measured by a spelling task, the two subtypes performed no different from each other. One possible explanation is that in a spelling task, phonology was provided and hence the surface dyslexia group could use their letter-to-sound knowledge to assist spelling. The results of the orthographic choice task are consistent with Castles and Holmes (1996) who also found that children with phonological dyslexia were better at orthographic learning than children with surface dyslexia. This suggests that orthographic learning can happen with little reliance on phonological decoding and this view is inconsistent with the self-teaching hypothesis (Share, 1995). In addition, the fact that both dyslexic groups' orthographic learning improved over learning cycles suggested that they were capable of learning novel orthographic representations. However, further research is required to explore whether dyslexic children are able to retain what they learn over a longer period of time.

Nevertheless, the word regularity effect found in reading accuracy with time-limited exposure duration for both groups suggests that phonological decoding plays a role in the process of orthographic learning, and this is not only true for the surface dyslexia group, but also the phonological dyslexia group. The regularity effect found for both dyslexia groups is inconsistent with Bailey et al. (2004) where only the surface dyslexia group showed a word regularity effect in orthographic learning. It is possible that differences in methodology

could account for this. We would suggest that the paradigm used in the study reported here is more dynamic and sensitive in measuring effects on orthographic learning.

It should be noted that the effect of word regularity was only found in untimed and time-limited reading accuracy but not in the spelling and orthographic choice tasks. Although we suggest that the time-limited reading task measures orthographic learning, it nevertheless involves reading aloud the novel words. In contrast, in the spelling and orthographic choice tasks, no production of the phonology was involved. Hence, it is possible that the regularity effect here was a result of interference from sublexical processing in reading aloud. This is in line with the literature on adult skilled readers, where word regularity effects are often found in tasks involving reading aloud but not in word recognition tasks, such as lexical decision (e.g., Coltheart, Besner, Jonassen & Davelaar, 1979; Seidenberg, Waters, Barnes & Tanenhaus, 1984; but see Parkin, 1982). In addition, as mentioned earlier, the lack of word regularity effect on spelling and orthographic choice tasks may also be due to the nature of the stimuli used in this study. Further research is required to explore the effects of word regularity with different measures of orthographic learning and different types of stimuli to disentangle this issue.

The second part of this study explored whether different reading subprocesses predicted orthographic learning of regular and irregular words with a group of poor readers. The results showed that, in general, orthographic learning of regular words was predicted not only by the letter-sound knowledge component of sublexical processing, but also the orthographic knowledge component of lexical processing. On the other hand, orthographic learning of irregular words was predicted only by orthographic knowledge. The findings are consistent with previous studies on orthographic learning with typically developing readers, in which not only phonological decoding, but also orthographic knowledge has been found to be important in orthographic learning (Cunningham, 2006; Connors, Loveal, Moore, Hume & Maddox, 2010).

Orthographic knowledge in this study could be seen as a measure of the childrens' historic ability to acquire orthographic representations. Hence, one possible explanation is that the relationship between orthographic knowledge and orthographic learning is simply a reflection of the children's ability to acquire lexical representations: the children who have better abilities to acquire orthographic representations will be better at both the task tapping the orthographic lexicon and at our orthographic learning task. Alternatively, it could be possible that existing orthographic representations contribute to the process of acquiring new representations and therefore children who have acquired more representations will find it easier to acquire future representations. This could perhaps occur by using analogies of known words or utilising familiarity of orthographic patterns. Future studies perhaps comparing orthographic learning between novel words embedded with familiar words ('more' in *smore*) and no embedded familiar words (*smoar*), or novel words with high or low orthographic neighbourhood size might allow us to better understand how orthographic knowledge assists orthographic learning.

Finally, as mentioned earlier, one might expect that for poor readers, the success of orthographic learning might be related to alternative factors, such as vocabulary knowledge as a compensation for their poor phonological decoding skill. This study did not find any evidence that pre-existing vocabulary knowledge (measured by PPVT-IV and ACE6-11) predicted orthographic learning. However, the orthographic learning paradigm in this study did not provide vocabulary knowledge for the novel words. Hence, it would be interesting for future studies to explore the relationship between vocabulary knowledge and orthographic learning with these poor readers using a paradigm that provides the opportunity for the use of vocabulary knowledge in learning the orthographic forms of novel words.

In short, the current study used a novel paradigm that allows us to explore the role of phonological decoding and track orthographic learning with two subtypes of dyslexia children that have contrasting reading impairments. Orthographic learning patterns across

the two subtypes of dyslexia suggested that phonological decoding skill alone is insufficient for acquiring orthographic representations. Examining predictors of orthographic learning with a larger group of poor readers determined that in addition to phonological decoding (letter-sound knowledge) word specific orthographic knowledge was found to determine the success of orthographic learning.

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Paper 5

Dissecting Components of Orthographic Learning: Evidence from Two Cases with Dyslexia

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Wang, H.-C., Nickels, L., Castles, A. (in preparation). Dissecting the components of orthographic learning: Evidence from two cases with dyslexia. *Cognitive Neuropsychology*.

Abstract

This study investigates orthographic learning in two 10 year-old children with developmental dyslexia, one, BM, with a reading profile of surface dyslexia and the other, PD, with a reading profile of phonological dyslexia. They participated in three experiments exploring three of the important components involved in orthographic learning: phonological decoding, paired-associate learning, and context. The results showed that first, despite BM having superior phonological decoding skill, his orthographic learning performance was not better than PD. Second, BM showed impaired paired-associate learning abilities while PD was not different from the controls. Lastly, PD's performance on orthographic learning measured from a spelling task benefited from contextual information while BM's performance was no different with or without context. Overall, the results indicated that sufficient phonological decoding skill does not directly transfer to the success of acquiring orthographic representations. However, all three components under investigation, phonological decoding, paired associate learning and context were associated with orthographic learning, and impairments in any of the three components might cause difficulties in orthographic learning.

Word count: 169

Keywords: orthography, developmental dyslexia, word recognition, orthographic learning

Research into how children learn to read novel words has found that phonological decoding skills play an important role, and that phonological decoding impairments are strongly implicated in reading impairments (e.g., Rack, Snowling & Olson 1992; Stanovich & Siegel, 1994). However, research with developmental dyslexia children suggests that these children not only have difficulties in phonological decoding, but also in learning new sight words (Reitsma, 1983; Manis, 1989; Ehri & Saltmarsh, 1995; Castles & Holmes, 1996; Share, 2004). The purpose of this study was to examine factors that affect sight word learning with two children who have selective reading impairments.

The dual route model of reading aloud (Coltheart, 1978; Coltheart, Curtis, Atkins & Haller, 1993; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001) comprises two routes for reading: the lexical and sublexical routes, which equate to a sight word mechanism and a phonological decoding mechanism (see Figure 1). In this model, therefore, reading impairments can be the result of selective impairment to the lexical route, sublexical route, or both routes (Castles & Coltheart, 1993). Children with ‘surface dyslexia’ have an impaired lexical route and read aloud via the sublexical route using rules to convert letters to sounds (graphemes to phonemes). As a result, these children can read nonwords (e.g., *bome*) and regular words (e.g., *home*) correctly but often struggle with irregular words (e.g., *come*). Children with phonological dyslexia have the opposite reading profile: they have difficulties with sublexical processing but not lexical processing. Hence, they have normal irregular word reading ability but have difficulty reading nonwords.

However, the dual route model is not a learning model and one still has to account for how orthographic representations are acquired and stored in the orthographic lexicon, that is, how orthographic learning occurs. Probably the most influential account of orthographic learning is Share's self-teaching hypothesis (Share, 1995). According to Share, children acquire orthographic representations via a self-teaching mechanism, the cornerstone of which is the phonological decoding of a novel word. This is proposed to draw the reader's

attention to the order and identity of the letters in the word, and also allow bonding to occur between the phonology and the orthography in the spirit of paired associate learning. This process is repeated on subsequent presentation of the word until it is learned.

The self-teaching hypothesis provides an excellent foundation on which to base examinations of orthographic learning. However, precise detail about how this mechanism might work is lacking. To provide a more explicit account, it is helpful to conceptualise and break down the process in the context of the dual route model (see Figure 1).

In this model, when an unfamiliar written word is encountered, there will be no corresponding representation in the orthographic lexicon, so the only pathway to successful pronunciation of the word will be via grapheme-phoneme conversion of the novel written word in the sublexical route (① in Figure 1). This conversion results in the activation of a series of phonemes in the phonemic buffer, which, if the novel word is already in the child's spoken vocabulary, will activate the corresponding phonological representation of this word in the phonological lexicon. The phonology of the novel word will then be linked with the orthography via paired-associate learning (② in Figure 1). This process is repeated until the orthographic representation of the novel word is firmly established in the orthographic lexicon. At this point, the word can be read via the lexical route, allowing rapid automated reading.

However, when grapheme-phoneme conversion can only generate partially correct decoding, such as in the case of irregular words, or when the sublexical route is not fully functioning, not all the correct phonemes will be activated in the phonemic buffer. For example, if the novel word STEAK is presented, the grapheme-conversion rules would result in the activation of "s" "t" "ee" and "k". In this case, "steak" will not be fully activated in the phonological lexicon. However, information from the context (e.g. "He ordered rump...") can (pre)activate the meaning of STEAK. This will in turn activate the phonological form in the phonological lexicon. When combined with the (partial) activation from the phonemic

buffer ("s", "t" & "k") this will result in sufficient activation of the phonological form for paired-associate learning with the orthography to occur. Hence, in these circumstances, 'contextual guessing' is particularly important in providing information that feeds into the semantic system and eventually leads to the correct phonology of the word (③ in Figure 1).

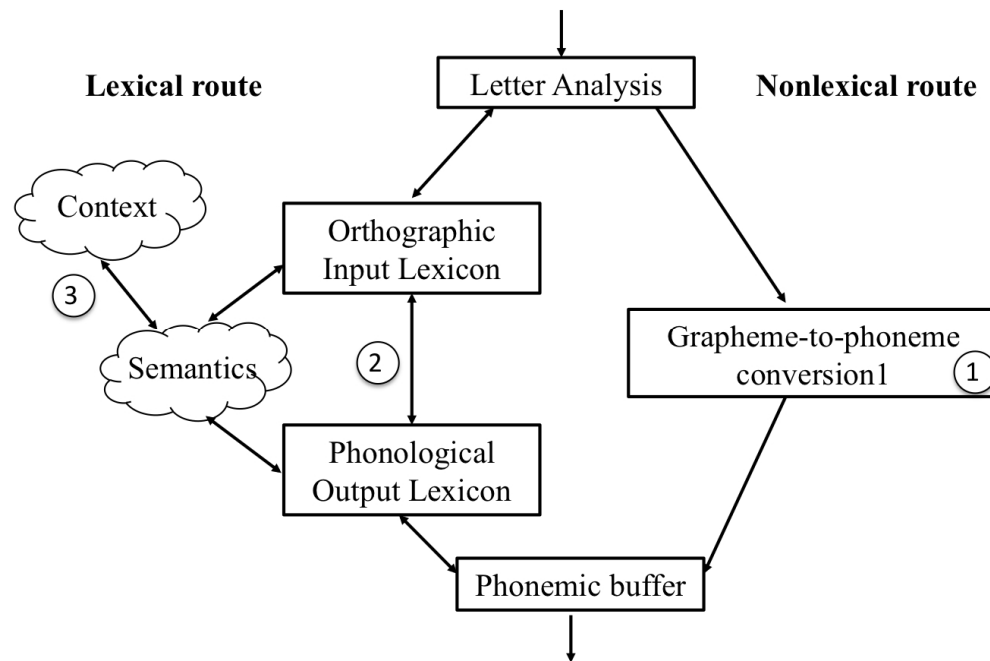


Figure 1. The dual route model of reading aloud. The numbers indicate the components of orthographic learning that are under investigation in this study.

Having defined more precisely the mechanisms potentially underlying orthographic learning within the dual route model, the aim of this study was to examine these mechanisms in more detail than that of previous research on orthographic learning, and to explore what the locus of the learning impairment might be in cases of developmental dyslexia. In particular, we investigated the role of three components: phonological decoding, paired-associate learning and context (as illustrated in Figure 1) in orthographic learning with two children with two different subtypes of dyslexia: surface dyslexia and phonological dyslexia.

The first component of orthographic learning is phonological decoding, which in the dual route model is accomplished by the sublexical route. If this component is indeed important for orthographic learning, intact sublexical route processes should lead to success in acquiring orthographic representations, and impaired sublexical processes should lead to difficulties in orthographic learning. This prediction is in line with the view that phonological processing deficits are the primary cause of difficulties in reading (e.g., Rack, Snowling & Olson 1992; Stanovich & Siegel, 1994) and learning to read (Share, 2004). In addition, it would be predicted that there should be an effect of word regularity on orthographic learning, as regular novel words can be accurately pronounced via letter-sound conversion and irregular novel words cannot (Wang, Castles & Nickels, In press).

The second proposed component of orthographic learning is the ability to learn the association between two forms, being phonology and orthography in the case of orthographic learning. This process of learning to associate a print form with its phonology is essentially a kind of visual-verbal paired-associate learning. Previous studies have found that paired-associate learning accounts for unique variance in word reading (Windfuhr & Snowling, 2001; Hulme, Goetz, Gooh, Adams & Snowling, 2007), and that dyslexic children have more difficulty learning associations, particularly when there is a verbal component (Gascon & Goodglass, 1970; Vellutino, Steger, Harding & Philips, 1975; Messbauer & de Jong, 2003). We predict that children with surface dyslexia might have an impaired paired-associate learning ability, while children with phonological dyslexia do not. The fact that children with surface dyslexia have normal phonological decoding ability, but an impaired orthographic lexicon, suggests that they may have succeeded in the first component of orthographic learning (to phonologically decode the word) but may have failed in the second component (to associate the phonology and the orthography of the word). On the contrary, children with phonological dyslexia may have failed in the first component of orthographic

learning but compensate by using the second or third components to establish their orthographic lexicon.

In addition, we explored the relationship between different types of paired-associate learning and orthographic learning in our two cases. Although evidence suggests that paired-associate learning may play an important role in reading development, it is less clear whether the paired-associate learning process involved in orthographic learning is specific to visual-verbal paired-associate learning, or a more general cross-modality process (see also discussion by Byrne, 2008). Therefore, we followed Hulme et al. (2007) in conducting three different kinds of paired-associate learning tasks: visual-verbal, visual-visual, and verbal-verbal.

Finally, the third component investigated in this study was the role of context in orthographic learning. Share (1995) suggests that when decoding can only be partial, contextual information is important. Partial decoding can be due to insufficient phonological decoding skill (as in the case of phonological dyslexia), or due to irregularity, where words are not pronounced as would be expected following grapheme-phoneme rules. Previous studies have found no effect of context on orthographic learning using regular words with normally developing readers (Nation, Angell & Castles, 2007; Cunningham, 2006). Landi, Perfetti, Bolger, Dunlap, and Foorman (2006) even suggest that context may be detrimental for long-term orthographic learning as it draws attention away from novel words during reading. They found that children learned novel words more effectively when they were presented in isolation, than in context, and that this was particularly true for less-skilled readers.⁸ Nevertheless, Wang, Castles, Nickels, and Nation (2011) found that for novel words with irregular grapheme-phoneme mappings, orthographic learning was better in context, than when the words were presented in isolation.

⁸ Landi et al. (2006) used WRAT word reading accuracy to divide the children into more-skilled and less-skilled readers. However, as WRAT word reading was highly correlated with nonword reading in that study, they also refer these less-skilled readers as poor decoders.

If contextual information is important only when decoding is partial, this predicts that children with poor sublexical skills should be more affected by context than other kinds of poor readers. In other words, the effect of context on orthographic learning should be larger for children with phonological dyslexia than those with surface dyslexia. However, if, as argued by Landi et al. (2006), learning novel words in context hinders orthographic learning, both phonological and surface dyslexic children should learn novel words better in isolation.

In order to investigate these three factors in orthographic learning, we conducted three experiments with the two single cases of surface and phonological dyslexia: two orthographic learning experiments and one paired-associate learning experiment. In the following sections, we first report the general characteristics of each child, including their reading and spelling accuracy, non-verbal IQ and other cognitive abilities. We then characterise the reading profile of each child in the context of the dual route model. Finally, we report the results of the three learning experiments.

Case Report

General Characteristics

Each case's general cognitive abilities, and overall reading and spelling ability were assessed using the same battery of tests. Nonverbal IQ was measured by the Kaufman Brief Intelligence Test (K-Bit, Kaufman & Kaufman 1990); short term and working memory were measured using the digit span (forward and backward) subtest from Wechsler Intelligence Scale for Children (WISC-IV, Wechsler, 2004); and visual memory was measured by the Benton Visual Retention test (Benton, 1974). Lexical reading processes were tested using irregular words, and sublexical reading processes using nonwords from the Castles and Coltheart test (CC2; Castles, Coltheart, Larsen, Jones, Saunders & McArthur, 2010). Lexical and sublexical spelling processes were assessed using the Diagnostic Spelling Test (DiSTi

(irregular words) and DiSTn (nonwords); Kohnen, Nickels & Castles, 2009; Kohnen, Nickels, Colenbrander & Castles, 2011). The results of these assessments are summarised in Table 1 and discussed for each case below.

Case 1: Surface dyslexia. BM is a boy who was aged 10 years and 4 months at the time of testing. His parents were both highly literate with professional occupations. BM had two siblings, neither of whom had reported reading difficulties. BM did not have any history of physical or spoken language developmental delay, nor neurological disorders. BM's parents were concerned about his reading ability and brought him to participate in a reading treatment study (McArthur et al., In preparation) when he was eight years old. His reading at age 8 displayed a profile of surface dyslexia in that his ability to read nonwords was within the normal range (CC2 z-score = -0.50) and his ability to read irregular words was impaired (CC2 z-score = -2.01). Two years later, at the time of testing for the current study, BM continued to show a reading profile of surface dyslexia (CC2 nonword reading, z-score = -0.62, CC2 irregular word reading, z-score = -2.01). BM's spelling accuracy showed a similar pattern, his nonword spelling was within the average range and his irregular word spelling was below average.

BM showed average performance on the tests of nonverbal intelligence, normal short-term and working memory, and normal visual retention.

Case 2: Phonological Dyslexia. PD was a girl aged 10 years and 1 month at the time of testing. PD was adopted from an orphanage in China and moved to Australia at the age of 3. She did not have any history of neurological disorders or any physical developmental delay. However, due to the limited communicative environment, PD had no reported communication (in Mandarin) before arrival in Australia at the age of three. However, she began communicating 6 months after arrival in Australia, and has no current reported speech or language difficulties. She is described as an average child academically at school.

However, PD's mother was concerned about her reading ability and her schoolteacher referred to her as a 'sight word' reader.

PD had a reading profile of phonological dyslexia, as her nonword reading was well below average and her irregular word reading was within the average range (CC2 nonword reading, z -score = -1.62, CC2 irregular word reading, z -score = -0.66). PD's spelling accuracy also showed a similar pattern with impaired nonword spelling and normal irregular spelling. PD performed within the normal range for visual retention⁹, short term and working memory. While her score for nonverbal IQ was below average, it was our observation that she had no problem in understanding instructions and in performing any of the tasks during the experiment.

Table 1.

Performance of BM and PD on Measures of General Ability, Reading and Spelling.

		BM (Surface dyslexia)	PD (Phonological dyslexia)
Chronological Age		10; 4	10; 3
Reading accuracy ¹			
Irregular words	z -score	-2.01*	-0.66
Nonwords	z -score	-0.50	-1.62*
Spelling Accuracy ²			
Irregular Words	z -score	-1.31*	-0.4
Nonwords	z -score	-0.24	-1.33*
Nonverbal IQ ³			
	std. score mean: 100	103	75*
Digit Span ⁴			
Digit span forward	std. score	8	10
Digit span backward	mean: 10	9	7
Visual retention ⁵			
	raw score/10	7	4

* Indicates scores below normal range (more than 1 standard deviation below 0).

¹ The Castles and Coltheart Test (CC2; Castles et al., 2010), ²Diagnostic Spelling Test (DiSTi & DiSTn; Kohnen et al., 2009; Kohnen et al., 2011), ³Kaufman Brief Intelligence Test (K-Bit, Kaufman & Kaufman, 1990), ⁴Wechsler Intelligence Scale for Children (WISC-IV, Wechsler, 2004), ⁵Benton Visual Retention test (Benton, 1974).

⁹ PD scored 4/10 on the visual retention test, which is relatively low compared to BM (7/10). However, according to the normative data, it is still within normal range.

Reading Profile

We assessed BM and PD's reading skills in greater detail in the context of the dual route model. According to this model, there are six basic components involved in reading aloud, as illustrated in Figure 1, each of which were assessed separately. The results are summarised in Table 2.

Letter analysis. Letter analysis skill was examined using a cross case matching task (McArthur et al., in preparation). In this task, there were 14 letters, half in upper case and half in lower case. When the letter was in lower case, the child was asked to write the upper case of the same letter (e.g., t – T), and vice versa for upper case letters. Normative data are not available for this test, but BM and PD both performed close to ceiling.

Grapheme-to-phoneme conversion. In the sublexical route, the ability to convert letters and groups of letters into their corresponding sounds was tested using a Letter-sound test (LeST; Larsen, Kohnen., McArthur & Nickels, 2011). For each of a list of single letter and multi-letter graphemes, the child was asked to produce the appropriate sound. The graphemes selected have the same pronunciation in more than 75% of occurrences according to the CELEX database (Baayen, Piepenbrock & van Rijn, 1993).

As would be predicted from their nonword reading, PD's performance was significantly worse than BM's on this test (McNemar's test, $p < .01$, one-tailed¹⁰). BM was relatively accurate, with errors mostly on vowel digraphs (e.g., *oi*, *au*). In contrast, PD performed poorly with errors on single letters (consonants and vowels) and digraphs.

Orthographic lexicon. The first component specific to the lexical route is the orthographic lexicon. In order to assess the children's word-specific orthographic knowledge, we used a lexical decision test with pseudohomophone distractors (McArthur et al., in preparation). Thirty target words were selected from the Children's Printed Word

¹⁰ One-tailed tests were used for the letter-sound knowledge test and the orthographic knowledge test as they measured the components where the two types of dyslexia are predicted to differ.

Database (CPWD). These words ranged in frequency from three to 625 instances per million words, and were words that had alternative, homophonic, spellings with adjustments to a vowel (e.g., FLAME changed to FLAIM) or consonant (e.g., CURL change to KURL). Each item was paired with its alternative homophonic spelling (e.g., DOOR and DOAR) and the child was asked to circle the correct spelling of the word. Norms are not available for this task.

PD performed close to ceiling, and better than BM. Despite ceiling effects, this difference was close to significance (McNemar's test exact, $p = .07$, one-tailed), suggesting that PD had somewhat superior word-specific orthographic knowledge than BM.

Semantics. Semantic knowledge was measured by the Peabody Picture Vocabulary Test 4 (PPVT-IV; Dunn & Dunn, 2007). In each item, the child was presented with four pictures, and was asked to point to the picture that was named by the tester. Scores were standard scores with a mean of 100 and an SD of 15.

BM scored within the normal range, but PD was impaired on this task. The difference between their raw scores was not significant (McNemar exact test, $p = .19$, two-tailed).

Phonological lexicon. The ability to access representations in the phonological lexicon was measured with the Naming subset of the ACE6–11 test (Adams et al., 2001). In this task, the child was shown 25 pictures and was asked to name each of them.

The errors that BM and PD made were mostly semantically related to the target. BM was within normal range, and PD scored just below the normal range on this task, however, the difference between their raw scores was not significant (McNemar's test exact, $p = .42$, two-tailed).

Phonological output. We tested the phonological output buffer and phonological output processes with a standardised nonword repetition task, a subtest of the NEuroPSYchology test (NEPSY; Korkman, Kirk & Kemp, 1998). In this task, the child was

asked to listen to digitally-recorded nonsense words (e.g., ‘crumsee’) and repeat what was heard. Scores were standard scores with a mean of 10 and a SD of 3. Both BM and PD were within the average range for this test.

Table 2.

Standardised and Raw Scores of the Dual Route Component Measures.

	BM	PD	BM <i>cf.</i> PD
Letter Analysis			
Cross Case Matching, raw score/14	13	14	n.s.
Grapheme-to-Phoneme Conversion			
LeST, raw score/51	43	15	$p < .01$
Orthographic Lexicon			
DOOR/DOAR, raw score/30	20	26	$p = .07$
Semantics			
PPVT, standard score, mean=100, SD=15	95	80*	$p = .02$
Phonological Lexicon			
ACE, standard score, mean=10, SD=3	7	6*	n.s.
Phonological Output			
NEPSY, standard score, mean=10, SD=3	11	9	n.s.

* Indicates the scores are below normal range (greater than one standard deviation below the average standard score); n.s. indicates $p > .1$ (one-tailed for the LeST and the DOOR/DOAR test; two-tailed for all other measures).

In summary, the tests of the components of reading showed that BM and PD had contrasting patterns of lexical and sublexical processing, and that the patterns shown were consistent with their irregular and nonword reading abilities. For the sublexical route, BM, the surface dyslexic case, was better at grapheme to phoneme conversion than PD, the phonological dyslexic case. In contrast, for the lexical route, PD had a strong tendency towards having better orthographic knowledge than BM. However, although PD’s average irregular word reading suggested that her lexical processing route is intact, her semantic knowledge and naming fell slightly below the average range, perhaps reflecting her relatively late exposure to English.

Experiments 1 - 3

Three experiments were conducted to explore the three components involved in orthographic learning: phonological decoding, paired-associate learning, and context.

These three experiments were carried out over four sessions, with each session being separated by about a week. Measures of orthographic and paired-associate learning were obtained immediately after and during learning sessions (PT1), and again about a week later (PT2) to see how well the children retained any learning.

The results of the tasks from the two cases were analysed in comparison with five age-matched controls (average age 10 years 2 months, ranging from 10 years 0 months to 10 years 6 months). The controls were average readers as determined by their z-scores on CC2 irregular word reading ($M = 0.53$, $SD = 0.46$) and nonword reading ($M = 0.55$, $SD = 0.56$).

Analyses comparing the controls and the dyslexic readers were performed using Singlims modified t-test from Crawford and Garthwaite (2002). Analyses comparing differences between two cases or within subject differences between conditions were performed using McNemar's test or Fisher Exact Test as appropriate. Moreover, when exploring whether the effect of conditions was larger or smaller for the controls than the dyslexia cases, we used the Revised Standardised Difference Test (RSDT, Crawford & Garthwaite, 2002).

Experiment 1: Orthographic Learning and Phonological Decoding

This experiment aimed to better understand the role of phonological decoding in orthographic learning with the two dyslexia cases, using a novel paradigm we have previously developed (Wang, Castles, Nickels & Marinus, In preparation). As previous studies have suggested that children with dyslexia require more exposures to acquire orthographic representations (Manis, 1989; Ehri & Saltmarsh, 1995), it is important to track

orthographic learning dynamically. This novel paradigm was designed to allow us to explore whether the two subtypes of dyslexia differ in the extent of orthographic learning after every learning trial, and how orthographic learning improves over learning trials. Moreover, with the manipulation of word regularity, we were able to investigate how the two types of poor readers are affected by differences in the ease with which the words can be decoded phonologically.

In this novel word learning paradigm, regular and irregular words are presented in three cycles. In each cycle, we measure reading accuracy under two conditions: untimed stimulus exposure and time-limited stimulus exposure duration. After all three cycles are completed, spelling and orthographic choice tasks are also administered as post-tests.

The untimed reading condition provides the opportunity for children to decode the novel words. Each untimed reading block is followed by a time-limited exposure duration (200 ms) that allows examination of the extent to which the words are being recognised automatically. It has been suggested that rapid recognition of words is only possible when orthographic representations have been acquired (Yap & van der Leij, 1993). Similarly it has been argued that when a word is read as a whole unit and not by decoding, the time that is required to read the word is reduced (Coltheart, 1983; Ehri, 2005). Hence, this time-limited reading condition is considered a measure of orthographic learning.

Wang et al. (In preparation) explored the role of phonological decoding in orthographic learning with two groups of children with surface and phonological dyslexia using this paradigm. The results of the study showed that when reading exposure duration was untimed, the surface dyslexia group had a larger word regularity effect and performed better than the phonological dyslexia group. For both dyslexia groups, the time-limited reading results showed improvement over learning cycles, with regular words read better than irregular words. However, this word regularity effect was absent when orthographic learning was measured with spelling or orthographic decision tasks. In addition, despite the

advantage in phonological decoding skills, the surface dyslexia group still had poorer orthographic learning compared to the phonological dyslexia group demonstrated by worse performance on an orthographic choice task at two posttests. Although this study provided interesting insights into how these subtypes of dyslexia are learning to read differently, the results were not compared to control data. In addition, the post-tests in the study were only measured up to one hour after the learning trials and thus, it was not clear whether orthographic learning was retained over a longer period of time. The present study aimed to build on Wang et al., (in preparation) and examine orthographic learning in more detail with the two single cases of surface and phonological dyslexia and compared their performance to age-matched controls. A post-test a week later was included to examine longer term retention of learning.

In summary, this experiment aims to explore orthographic learning and the role of phonological decoding in orthographic learning. As outlined previously, if phonological decoding skill is the key to orthographic learning, PD, the phonological dyslexia case, will be more impaired in orthographic learning compared to the controls and to BM, the surface dyslexia case. In addition, there should be a word regularity effect in orthographic learning, and this effect might be particularly large for the surface dyslexia case, BM, who relies more on phonological decoding skill for reading. Finally, we plan to see whether the two cases will require more exposures in orthographic learning compared to the controls as suggested in the literature, and whether the two cases can retain the orthographic learning as well as the controls after a week time.

Method. The experiment followed that of Wang et al., (In preparation), with two exceptions: in the present study, eight more items were added to increase statistical power (making 24 items in total); the second post-test was conducted after a week, rather than an hour delay.

Materials. The stimuli comprised 12 regular and 12 irregular four and five letter nonwords (e.g., vack). The regular items were pronounced according to a set of typical grapheme-phoneme correspondence rules (Rastle & Coltheart, 1999). ‘Typical’ refers to the fact that the allocated pronunciation of the vowel occurred in more than 50% of words containing that vowel grapheme in both the CELEX database (Baayen et al., 1993) and the Children’s Printed Word Database (CPWD; Masterson, Stuart, Dixon & Lovejoy, 2003). The irregular nonwords had pronunciations that did not follow typical grapheme-phoneme conversion rules. For these words, the allocated pronunciation of the vowel occurred in fewer than 50% of words in the CELEX database and the CPWD. All of the irregular pronunciations were nevertheless existing grapheme-phoneme correspondences in English. However, the pronunciations were infrequent and do not occur in the context of the final consonants (bodies) of the irregular nonwords that were used in this task.

Procedure. The nonwords were introduced in three separate sessions in order to reduce the task demands for the poor readers. In each session, the child learned four regular items followed by four irregular items. For all items the procedure consisted of: an initial exposure phase, learning trials and two post-tests (see Figure 2).

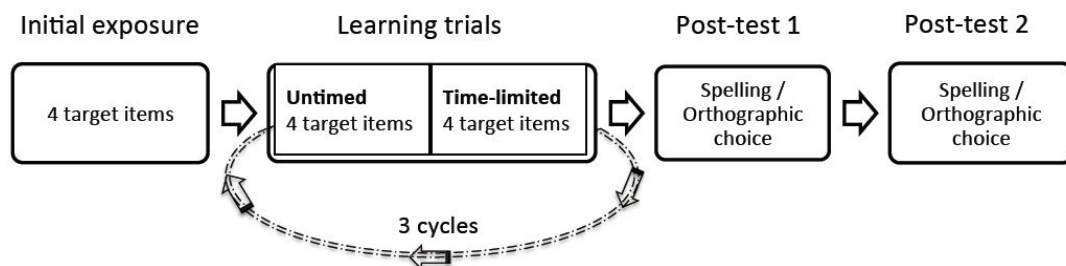


Figure 2. Procedure for the orthographic learning task

At the beginning of the experiment, the child was presented with a picture of some elves and told they were going to learn the names of some of these elves. Next, the nonwords

appeared on the screen one at a time and the tester told the child: the name of this elf is _____. (initial exposure). The children were not asked to read the novel words at this point and no accuracy was recorded. Then the first cycle of the learning trials began, the nonwords were presented again, one at a time in a randomised order, and the child was asked to read them aloud. This was the untimed exposure reading. Feedback was provided regardless of whether the child read the target word correctly or not to give an equal number of phonological exposures to each word. Each round of the untimed reading block was followed by a block where the target words were presented with limited exposure duration (200 ms presentation, with ##### as backward masks). One block of untimed reading followed by one block of time-limited exposure duration reading was considered a cycle, and this cycle was repeated three times.

After the three cycles were completed, two post-tests were conducted to measure orthographic learning using both spelling and orthographic choice tasks, once immediately after the learning trials (PT1), and once a week later (PT2). The exact procedure was repeated after a week with the second third of the items (four regular and four irregular) in the second session, and again after another week with the final eight items in a third session. Thus, there were in total 12 regular target words and 12 irregular target words.

For the spelling task, the tester dictated all trained words. The children were asked write down the elves' names exactly as they had learned them on the computer.

For the orthographic choice task each target item (e.g., *ferb*) was presented together with its homophonic foils (e.g., *furb*) and two visual distractors (e.g., *ferq*, *furq*) on one A4 paper. The children were asked to choose the correct spelling of the elves' names that they had learned from those four options.

Results. We report the data analysis in relation to the predictions and questions raised earlier: 1) We compared performance of the two cases with the controls; 2) We compared the two cases to see whether they performed differently from each other; 3) We

compared accuracy of regular and irregular items to see whether there was an effect of word regularity in reading and orthographic learning, and we compared the size of this effect between the two cases and the controls; 4) We compared the dyslexia cases to the controls to see whether the dyslexia cases were worse at retaining what was learned (whether there is a difference in the effect of time on orthographic learning).

A summary of analyses of accuracy comparing the two cases with the controls and comparing the two cases with each other can be found in Table 3. A summary of analyses exploring the effect of word regularity and time can be found in Table 4.

Untimed and time-limited reading accuracy. As can be seen in Table 3, results from untimed reading accuracy showed that both dyslexic readers were not significantly different from the controls when the target items had regular grapheme to phoneme correspondences. However, when the target items were irregular, both dyslexic readers were poorer than the controls in producing the correct pronunciation in response to the printed word (PD significantly poorer, and BM marginally significant).

Results from the time-limited exposure duration reading showed that both dyslexic cases were significantly poorer than the controls, regardless of target word regularity. There was no significant difference between BM and PD on any reading measure.

As shown in Table 4, the controls showed a word regularity effect for untimed reading accuracy, and time-limited exposure duration reading accuracy was close to significant. BM and PD showed a significant effect of regularity for both untimed and time-limited reading accuracy. Compared to the controls, the regularity effect was larger for both BM and PD for untimed reading, but not for time-limited exposure duration measure.

Spelling. As shown in Table 3, both BM and PD performed no differently to the controls in spelling of either regular or irregular words at PT1, when orthographic learning was measured immediately after exposure. However, when learning was measured again a week later (PT2), both BM and PD were poorer at spelling the novel words compared to the

controls (although, despite showing the same trend, BM's irregular word spelling at PT2 was not significantly different to the controls).

There was no significant difference between BM and PD's accuracy on any spelling measure.

The analyses exploring word regularity effects revealed that the effect of regularity on the controls was not significant on spelling at PT1 but approached significance at PT2. The effect of regularity was not significant for either BM or PD.

There was no significant difference in the size of the regularity effect between the controls and the two cases at PT1, but at PT2, the regularity effect on spelling accuracy was significantly smaller for both BM and PD than the controls.

The analyses exploring the effect of time overall revealed that for the controls, spelling accuracy was higher at PT1 compared to PT2 for both regular and irregular items. PD and BM showed the same pattern, although BM's accuracy at PT1 was only marginally better than at PT2.

Comparing the effect of time between the controls and the two cases (see Table 4), it was evident that for the regular items, both BM and PD showed a larger effect of time (i.e., they retained their learning less well). For irregular items, while the two cases also appeared to retain the words less well than the controls, the difference was not significant.

Orthographic choice task. This task was quite easy for the control children who performed close to ceiling (see Table 3), PD also performed well and not significantly differently from the controls. However BM seemed to have more difficulty with this task: his performance for the regular items was worse than the controls at both PT1 and PT2, and this was close to significance at PT2 for irregular items.

There was no significant difference between BM and PD on any orthographic learning measure.

The analyses exploring regularity showed no significant difference between regular and irregular words in the orthographic choice task for either the controls or the two cases.

There was also no difference in the size of the effect of regularity between the controls and the two cases.

The analyses exploring the effect of time showed that the controls' performance on the task was no different at PT1 compared to PT2, and this was also the case for PD.

However, BM was worse than the controls at retaining the irregular items.

There was no difference in the effect of time on orthographic choice performance between BM and the controls for either regular or irregular words. While PD showed a significant difference compared to the controls, this reflected the fact that the results of PD and the controls at PT1 and PT2 were in different directions. PD actually scored higher at PT2 than PT1.

Table 3.

Accuracy for Reading and Orthographic Learning Measures.

	Untimed (raw score /36)		Timed -limited (raw score /36)		Spelling (raw score / 12)				Orthographic Choice Task (raw score / 12)			
	Regular	Irregular	Regular	Irregular	Regular		Irregular		Regular		Irregular	
					PT1	PT2	PT1	PT2	PT1	PT2	PT1	PT2
Controls (n = 5)												
Mean	35	31	35.6	34	11.6	10	11.6	8	11.8	11	11.6	10
(SD)	(1.00)	(3.03)	(0.55)	(2.07)	(0.55)	(0.55)	(0.89)	(1.00)	(0.45)	(0.55)	(0.89)	(1.87)
BM	34	22+	32**	19**	11	6**	10	5*	10*	9*	11	5+
PD	35	19*	33*	19**	12	7**	12	6	11	12	10	8
BM cf. PD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

BM's and PD's performance is compared to control performance with Singlims (Crawford & Garthwaite, 2002) comparing each case to the controls. The bottom row compares BM and PD's accuracy, using Fisher Exact test, two tailed. PT1 = task measured immediately after learning exposure; PT2 = task measured with a week's delay.

** indicates $p < .01$; * indicates $p < .05$; + indicates $p < .1$; n.s. indicates $p > .1$, (all two-tailed).

Table 4.

Summary of Statistics Evaluating the Effects of Regularity and Time.

	Regularity effect (Regular <i>cf</i> Irregular)						Effect of time (PT1 <i>cf</i> PT2)			
	Untimed	Time-limited	Spelling		Orthographic choice		Spelling		Orthographic choice	
			PT1	PT2	PT1	PT2	Regular	Irregular	Regular	Irregular
Controls	**	+	n.s.	+	n.s.	n.s.	**	**	.n.s.	n.s.
BM	**	**	n.s.	n.s.	n.s.	n.s.	+	*	n.s.	*
PD	**	**	n.s.	n.s.	n.s.	n.s.	*	**	n.s.	n.s.
Controls <i>cf.</i> BM	*	n.s.	n.s.	**	<i>n.s.</i>	<i>n.s.</i>	**	n.s.	n.s.	n.s.
Controls <i>cf.</i> PD	**	n.s.	n.s.	**	<i>n.s.</i>	<i>n.s.</i>	**	+	*	n.s.

The comparisons of regularity and time were performed with t-tests for the controls, and Fisher Exact Tests for the cases BM and PD. Statistics in the bottom two rows compared whether the effects of regularity and time for BM or PD were different to the controls using the Revised Standardised Difference Test (RSDT), Crawford & Garthwaite (2002). PT1 = task measured immediately after learning exposure; PT2 = task measured with a week's delay.

** indicates $p < .01$; * indicates $p < .05$; + indicates $p < .1$; n.s. indicates $p > .1$ (all two-tailed).

Summary: Experiment 1. The results of the experiment showed that 1) Both dyslexic cases were impaired on several measures of orthographic learning compared to the controls. In particular, the poorer performance on the time-limited reading accuracy of the two cases suggested that they require more exposures to learn the nonwords; 2) Contrary to what was predicted, that good phonological skill results in superior orthographic learning, BM, the surface dyslexia case was not better at orthographic learning compared to PD, the phonological dyslexia case. Moreover, BM, in fact, was worse than controls on orthographic learning measured by the orthographic choice task, while PD performed no differently from the controls; 3) We predicted that there would be a word regularity effect in orthographic learning and that the effect would be stronger for BM as he may rely more on phonological decoding skill for reading. The results showed that for all participants, there was a word regularity effect on reading accuracy during the learning trials but the effect was not evident in post-tests of orthographic learning. In addition, when reading accuracy was untimed, not only BM, but also PD showed a larger regularity effect compared to the controls; 4) Both cases appeared to be worse at retaining the orthographic representation. Further discussion of the implications of these results is presented in the General Discussion.

Experiment 2: Paired-Associate Learning

As outlined earlier, paired-associate learning is assumed to be an important component of orthographic learning. Based on the fact that, by definition, children with surface dyslexia have normal phonological decoding ability but have failed to establish mappings between orthographic representations and their phonological forms, it seems possible that their paired-associate learning ability may be impaired. In contrast, for children with phonological dyslexia, it may be that the good mappings between orthography and phonology reflect their strong paired-associate learning ability. This may be able to

compensate for phonological dyslexic children's deficit in phonological decoding enabling them to learn orthographic representations.

Therefore, we predict that BM, the surface dyslexia case, will be impaired in this paired-associate learning task compared to the controls and PD, the phonological dyslexia case.

In addition, this experiment examined paired-associate learning across modalities to identify the scope of any impairment. Specifically, whether the ability to perform paired-associate learning is more impaired for the poor readers when there is a verbal component involved as suggested by previous research (e.g., Gascon & Goodglass, 1970; Hulme, 1981).

Method. Three types of paired-associate learning tasks were used in this experiment: visual – visual; visual – verbal; verbal – verbal (from Hulme et al, 2007; Experiment 2). Each task was carried out in one session, with each session being a week apart. The results of each trial were recorded during the learning task (PT1), and retention of paired-associate learning was tested in the next session, about a week later (PT2). The procedures of the three tasks are adapted from Hulme et al, (2007).

Visual – visual paired-associate learning. In this task, children were asked to learn which shapes went together. There were three sets of six-sided shapes, printed in black and each set had a different background color (Vanderplas & Garvin, 1959). First, one set of four cards with shapes was laid out in a row in front of the child, the experimenter held a second set of four cards with different shapes, and placed each one next to its pair in the first set of cards. When the two shapes were placed adjacent to each other, the experimenter said 'this shape goes with this shape'. The two cards remained adjacent for 5 seconds, and then the experimenter removed the card from the second set and placed the next card with the same procedure. After all four pairs were introduced, the experimenter shuffled the second set of cards and asked the child, one card at a time, 'which shape goes with this shape'. The child was asked to point to the correct match from the first set of cards to be scored as correct.

Feedback was given on responses. This procedure was repeated six times, making a total of 24 responses.

Visual – verbal paired-associate learning. In this task, the child was asked to learn which shape went with which nonsense word. First, the experimenter asked the child to repeat the four nonwords used in the task (huk, fot, jat, raz). The experimenter held a set of four cards (that were different from the shapes used in the visual-visual PAL), showed the child one card at a time and said the associations twice. For example, ‘this shape goes with huk, [2-s interval], this shape goes with huk’. After all four pairs were introduced, the experimenter held one card at a time and asked the child ‘which nonsense word goes with this shape?’ Feedback was given in each trial. This procedure was also repeated six times.

Verbal – verbal paired-associate learning. In this task, the child was asked to learn which nonsense words went together using two sets of four. First the child was asked to repeat the eight nonsense words (dof, teg, lum, mab; kel, gug, nid, bim). The experimenter then said the associations twice ‘e.g., dof goes with kel, [2-s interval], dof goes with kel’. After all pairs were introduced, the child was asked ‘which nonsense word goes with dof?’ Feedback was provided. The procedure was repeated eight times¹¹, making a total of 32 responses.

Results. In order to answer the research questions raised earlier, we conducted the following analyses: 1) We compared the results of paired-associate learning of the two cases with the controls; 2) We compared the differences between BM and PD; 3) We compared the pattern of results across the three paired-associate learning tasks and examined whether the two cases have more difficulties on the paired-associate learning tasks with verbal components compared to the controls.

¹¹ In Hulme et al. (2007)’s first experiment, there were 6 learning trials for the verbal-verbal PAL and they found that the average accuracy was close to floor. Hence, in their second experiment, the number of learning trials was increased to 8.

Results of the three paired-associate learning tasks during the training trials (PT1) and at retention measured a week later (PT2) are summarised in Table 5.

BM performed significantly more poorly than the controls during the learning (PT1) trials on all three paired-associate learning tasks. PD's performance on visual-visual PAL was not different from the controls, her visual-verbal PAL approached significance, and her verbal-verbal PAL seemed to be poor but the difference compared to controls did not reach significance. This was most probably due to the high variability in control performance, which ranged from 16 to 22 correct at PT1 for visual-verbal and from 15 to 30 for verbal-verbal.

Comparing BM and PD's performance on this task, they were not significantly different on the visual-visual PAL and visual-verbal, but BM was significantly worse than PD on the verbal-verbal PAL at PT1.

Comparing the effect of modality across three paired-associate learning tasks (PT1 only), both the controls and the two cases were significantly better at visual-visual PAL compared to verbal-verbal PAL. The difference between visual-verbal and verbal-verbal PAL was not significant for either controls or PD but was significant for BM. Although BM seemed to be particularly struggling with verbal-verbal PAL, the size of the differences across modalities of PAL was statistically equivalent for the controls and both BM and PD (see Table 6).

Summary: Experiment 2

The findings of this experiment are 1) BM, the surface dyslexia case, was poorer than the controls on all three paired-associate learning tasks, consistent with our predictions. The fact that BM was poorer on all three paired-associate learning tasks suggests that the impairment in learning associations is not specific to learning the visual-verbal mappings required in orthographic learning; PD, the phonological dyslexia case, on the other hand,

was not different from the controls in verbal-verbal and visual-visual paired-associate learning tasks, but marginally worse at visual-verbal paired-associate learning. 2) Comparing the two cases, PD was better than BM at verbal-verbal paired-associate learning, but there were no significant differences for visual-visual paired-associate learning or visual-verbal paired-associate learning; 3) The two children with dyslexia showed no greater a decrement than the controls for paired-associate learning with verbal components (relative to purely visual PAL), which was not as predicted.

The implications of these results will be discussed in more detail in the general discussion below.

Experiment 3: Orthographic learning and the effects of context

The third component of orthographic learning we explored was the effect of context on the success of learning. As discussed earlier, Share (1995) suggested that context may only play a role in orthographic learning when decoding can only be partial. Thus, according to Share, it is predicted that the effect of context will be evident with PD, the phonological dyslexia case, as her phonological decoding process is not fully functioning. However, if

Table 5.

Accuracy for the Paired-Associate Learning Tasks.

	Visual- visual (raw score / 24)		Visual- verbal (raw score / 24)		Verbal- verbal (raw score / 32)	
	PT1	PT2	PT1	PT2	PT1	PT2
Controls (n = 5)	23 (1.73)	2.8 (1.79)	19.8 (2.39)	1.8 (1.48)	21.8 (5.45)	1 (0.71)
BM	16*	4	10*	0	1*	1
PD	21	4	13 ⁺	1	11	0
BM cf. PD	n.s.	n.s.	n.s.	n.s.	**	n.s.

BM's and PD's performance is compared to control performance with Singlims (Crawford & Garthwaite, 2002) comparing each case to the controls. The bottom row compares BM and PD's accuracy, using the Fisher Exact test.

PT1= task measured immediately during learning; PT2 = task measured with a week delay.

* indicates $p < .05$; ** indicates $p < .01$; + indicates $p < .1$; n.s. indicates $p > .1$ (all 2-tailed).

Table 6.

Summary of Statistics Evaluating the Effect of Modalities Across Three paired-associate learning tasks at PT1.

	Modality Effect		
	visual- visual <i>cf</i>	visual- visual <i>cf</i>	visual- verbal <i>cf</i>
	visual-verbal	verbal-verbal	verbal-verbal
Controls	n.s.	*	+
BM	n.s.	**	**
PD	*	**	n.s.
Controls <i>cf.</i> BM	n.s.	n.s.	n.s.
Controls <i>cf.</i> PD	n.s.	n.s.	+

The analyses of comparison were done with t-test for the controls, and Fisher Exact for the cases BM and PD. Statistics in the bottom two rows compared whether the effect of modality for BM or PD is different to the controls (Revised Standardised Difference Test (RSDT), Crawford & Garthwaite, 2002).

** indicates $p < .01$; * indicates $p < .05$; + indicates $p < .1$; n.s. indicates $p > .1$ (all two-tailed).

Landi et al. (2006) are correct, both PD and BM may be distracted by context and their orthographic learning will be disadvantaged for novel words presented with context compared to without context.

We used a variation of Share's self-teaching paradigm developed by Byrne (2008) to examine the effect of context on orthographic learning. The main differences between Byrne's orthographic learning task and the self-teaching paradigm is that the first sentence in the story explicitly highlights to the child what the novel word is and feedback is provided by the tester if the child mispronounces the novel words. Feedback was provided to ensure that the children had the correct pronunciation, either self-generated or from the tester.

In order to explore the effect of context with the two dyslexic readers, we developed a version of the task in which novel words were also presented without context (No Context condition) rather than in stories (Context condition).

In summary, the specific issues of interest for this experiment are: 1) Whether the surface and phonological dyslexia cases show an impairment in orthographic learning in this paradigm, replicating Experiment 1; 2) Whether the two cases perform differently on orthographic learning; 3) Whether the effect of context effect is stronger for PD as she uses it to compensate for her insufficient phonological decoding skill, as suggested by Share (1995), or, alternatively, whether context will have a detrimental effect for both BM and PD, as suggested by Landi et al. (2006); 4) whether the dyslexia cases are worse at retaining what was learned than controls, replicating the results of Experiment 1.

Method. The design and procedure of this experiment is adapted from Byrne et al. (2008).

Materials. There were in total, 48 target items, 24 in each condition (see Appendix 1). All target items were based on those of Byrne et al. (2008) with 15 taken directly from that study.¹² The target items were 4-5 letter nonwords, and the items in the Context and No Context conditions were matched for bigram frequency from the CELEX database (Baayen, Piepenbrock & van Rijn, 1993).

Design and procedures. In the context condition, the 24 nonword items were each presented in a story, starting with “The new word is _____”, and then a story containing the novel word three times. Thus, each novel word was exposed four times. The child was asked to spell the nonword after every three stories, and then continue to read the next three stories, spell the three nonwords in those stories, until all 24 items were introduced and spelled by the child.

¹² We used Byrne et al.’s (2008) items in one condition and created the others by changing the consonants (e.g., we created *faip* from *laif*; *slaib* from *staip*). In this way, the items across the two conditions are similar in level of difficulty.

In the no context condition, the target items were also presented four times, once in a sentence and three times in lists of words presented in table format. Similar to the context condition, there was a sentence above the table stating what the nonword was (e.g., “The new word is *deve*). Each list contained the same number of words as the story in the context condition. The filler words in the no-context lists were the (non-target) words used in the context condition scrambled across all 24 stories. The items in this condition were printed individually on the page in a grid and the child read the individual words.

After the child had read all stories/words and finished the spelling task for the last three items, an orthographic decision task was conducted to measure orthographic learning. For each target item, one homophonic foil and two visual distractors were created (e.g., *deve*, *deev*, *dete*, *deet*). All target items, homophones of the target items, and visual distractors were randomised and presented one at a time on flash cards. The children were asked to look at each card carefully and say “Yes” if the word on the card was a word they had learned with the correct spelling, and “No” if it was not.

Results. In order to answer the questions outlined earlier, the results were analysed as follows: 1) We compared the results of orthographic learning between the dyslexia cases and the controls; 2) We compared the results between the two cases; 3) We compared the results between the context and no context conditions (context effect); 4) We compared orthographic learning across the two time points to see whether the dyslexia cases are worse at retaining what was learned.

The results are presented in two sections: reading accuracy during initial exposures to the words, and orthographic learning, as measured by the spelling and orthographic decision tasks.

Reading accuracy. During orthographic learning, participants were asked to read the novel words embedded in stories or tables. The accuracy of reading for all four exposures of the 24 nonword items in each condition is shown in Table 7.

Table 7.

Summary of Total and First Exposure Reading Accuracy for the Self-teaching Task.

	Total Reading accuracy		First Exposure Reading accuracy	
	(raw score / 96)		(raw score / 24)	
	Context	No Context	Context	No Context
Control Mean (SD) (n = 5)	94.2 (2.17)	93.4 (1.14)	22.6 (1.67)	21.6 (0.89)
BM	78**	84**	14**	18*
PD	87*	82**	15*	11**

BM's and PD's performance is compared to control performance using a modified t-test (Singlims; Crawford & Garthwaite, 2002).

** indicates $p < .01$; * indicates $p < .05$; + indicates $p < .1$ (all two-tailed).

Both BM and PD were significantly poorer overall in decoding of the novel words compared to controls. Therefore, the analysis of orthographic learning measures only included the items that were decoded correctly at the first exposure for both the two cases and the controls. In this way, any differences in orthographic learning could be attributed to context and not to differences in initial decoding.

Orthographic learning measures. Orthographic learning was measured with spelling and orthographic decision tasks at two time periods: immediately after orthographic exposure (PT1), and approximately a week later (PT2). Note that for the spelling task at PT1, the child was asked to spell the novel words after every three target items were exposed, whereas for the PT1 and PT2 orthographic decision tasks and the PT2 spelling tasks, the child was asked to do the task after all target items were exposed. Accuracy is reported only for the items that were read correctly at the first exposure for all participants.

Spelling. Results of the spelling task are summarised in Table 8, and the analyses for the effects of context and time are summarised in Table 9.

For BM, orthographic learning in context measured from the spelling task was significantly worse than the controls at PT1; his performance at PT2 appeared to remain

poorer than the controls but this did not reach significance. In the no context condition, BM's accuracy was also lower than the controls, but this did not reach significance. There was no significant effect of context on BM's spelling accuracy, and the size of any context effect was not significantly different from that of the controls. There was also no significant effect of time on BM's spelling, and the effect of time between BM and the controls was not significantly different.

For PD, when novel words were presented in context, her spelling accuracy at PT1 was not different to the controls; at PT2, PD's spelling performance dropped substantially to .33, and was approaching significance compared to the controls. The effect of time for PD was significantly larger compared to the controls. Like BM, in the no context condition, PD's accuracy was not significantly different to the controls.

As for the effect of context, in contrast to BM, PD spelled more novel words accurately in the context condition compared to the no context condition at PT1. In addition, this effect of context was larger for PD compared to the controls.

Orthographic decision. Accuracy for the items that were read aloud correctly at the first exposure is summarised in Table 10.

For BM, total accuracy on orthographic choice measured immediately after learning was poorer than the controls in the context condition, but not in the no context condition. When accuracy was measured after a week's delay, BM performed no differently from the controls in either condition. BM was less accurate at rejecting the foils, at both PT1 and PT2 in the context condition.

For PD, total accuracy was lower than the controls at PT1 in the context condition (but not in the no context condition), and this difference was due to low accuracy on rejecting the foils. At PT1, PD was worse in the context condition compared to the controls, but not in the no context condition. At PT2, there was no difference between PD and the

controls in either condition. Like BM, PD was also less accurate at rejecting the foils than controls.

It is important to note that this task was challenging to all readers, and this is particularly true for PD. It was the experimenter's observation that PD was unsure about the purpose of the task and responded 'Yes' to almost all items when she encountered the task for the first time (session 1, context condition). In contrast in the second session she seemed to have a better grasp on the task demands. Consequently, the poor performance of the task in the context condition, and the apparent difference across conditions may not be reflect her orthographic learning but rather task demands and practice effects.

Table 8.

Summary of Spelling Accuracy Results.

Spelling accuracy (proportion correct for words read correctly at the first exposure)				
	Context		No Context	
	PT1	PT2	PT1	PT2
Controls Mean (SD) (n = 5)	.89 (.11)	.77 (.17)	.84 (.13)	.72 (.14)
BM	.50*	.38	.61	.50
PD	.93	.33+	.64	.46
BM <i>cf.</i> PD	*	n.s.	n.s.	n.s.

BM's and PD's performance is compared to control performance with Singlims (Crawford & Garthwaite, 2002). The last column compares BM and PD's accuracy, using Fisher Exact test. PT1= task measured immediately during learning; PT2 = task measured in a week delay. * indicates $p < .05$; ** indicates $p < .01$; + indicates $p < .1$; n.s. indicates $p > .1$

Table 9.

Summaries of Statistics Evaluating the Effects of Context and Time.

	Context effect (Context <i>cf.</i> No Context)				Time effect (PT1 <i>cf.</i> PT2)			
	Spelling		Orthographic choice (total correct)		Spelling		Orthographic choice (total correct)	
	PT1	PT2	PT1	PT2	Context	No Context	Context	No Context
Controls	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.
BM	n.s.	n.s.	-	-	n.s.	n.s.	-	-
PD	*	n.s.	-	-	**	n.s.	-	-
Controls <i>cf.</i> BM	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Controls <i>cf.</i> PD	*	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.

The analyses of comparison were done with t-test for the controls, and Fisher Exact for the cases BM and PD for the spelling task. Statistics in the bottom two rows compared whether the effect of context and time of BM or PD is different to the controls (the Revised Standardised Difference Test (RSDT), Crawford & Garthwaite, 2002). For the orthographic decision task, the comparison between BM and PD was not possible due to the fact that Fisher Exact can only analyse exact numbers but not mean proportions.

** indicates $p < .01$; * indicates $p < .05$; + indicates $p < .1$ (two-tailed)

As shown in Table 9, there was no significant effect of context (at PT1 or PT2) or time on orthographic learning for either PD or BM or the controls. There was also no significant difference in the (lack of an) effect of context or time between controls and the two cases.

Summary: Experiment 3. The results in this experiment showed that: 1) When orthographic learning was measured using spelling accuracy immediately after reading exposure, BM, the surface dyslexia case, was worse than the controls at learning the novel words in context; PD, the phonological dyslexia case, on the other hand, performed no differently to the controls; 2) Similar to the results of Experiment 1, PD was better at orthographic learning than BM, albeit only as measured by spelling in the context condition. 3) As predicted by the self-teaching hypothesis, PD's orthographic learning measured by spelling benefited from contextual information whereas that of the controls and BM did not; 4) Although it appeared to be that both dyslexic readers were poorer at retaining orthographic learning compared to the controls, only PD's spelling accuracy in the context condition showed a larger time effect than the controls.

As mentioned earlier, the orthographic decision task appeared to be quite challenging for the two cases as well as the controls, who showed great variability in their performance. This variability also made it difficult to demonstrate effects of context and/or time. For these reasons, orthographic learning in this experiment will mainly be discussed based on the results of the spelling task.

Table 10.

Mean Accuracy for the orthographic decision task (with SDs in brackets).

Mean proportion of correct responses to items read correctly at first exposure										
	Context					No Context				
	Total correct	'yes' to targets (<i>noar</i>)	'no' to foil 1 (<i>nore</i>)	'no' to foil 2 (<i>noal</i>)	'no' to foil 3 (<i>nole</i>)	Total correct	'yes' to targets	'no' to foil 1	'no' to foil 2	'no' to foil 3
PT1										
Control	.84 (0.20)	.67 (.18)	.83 (.05)	.94 (.05)	.96 (.04)	.84 (0.15)	.49 (.16)	.94 (.06)	.96 (.05)	0.97 (.04)
<i>BM</i>	.70+	.43	.57**	.93	.86+	.85	.56	.94	.89	1
<i>PD</i>	.65**	.80	.53**	.60**	.67**	.80	.82	.82	.82	.73**
PT2										
Control	.84 (0.39)	.66 (.20)	.74 (.28)	.97 (.04)	1 0	.85 (0.16)	.51 (.12)	.91 (.06)	.98 (.04)	0.98 (0.04)
<i>BM</i>	.78	.57	.38	.75**	1	.83	.50	1	.90	.90
<i>PD</i>	.75	.40	.56	.78*	1	.81	.50	.75+	1	1

“Yes” responses from the two cases and the controls. Foil 1 refers to the homophonic pair of the target item; foil 2 refers to visual distractor of the target item; foil 3 refers to the visual distractor of the homophone (foil 1).

BM's and PD's performance is compared to control performance with Singlims (Crawford & Garthwaite, 2002). * indicates $p < .05$; ** indicates $p < .01$; + indicates $p < .1$

General Discussion

We have reported two single case studies of children with dyslexia, BM and PD. The two dyslexic cases showed selective impairment in reading and this is reflected in their performance on tests of the components of orthographic learning.

BM is a case of surface dyslexia with normal nonword reading and impaired irregular word reading. The cause of his surface dyslexia could be isolated to the orthographic lexicon: he performed in the normal range for semantic processing (PPVT) and spoken word retrieval (phonological lexicon; ACE picture naming) but poorly on a lexical decision task with phonological distractors (DOOR/DOAR),

PD, a case of phonological dyslexia, demonstrated the opposite reading and spelling profile to BM, her nonword reading was impaired but her irregular word reading was within average range. PD's poor sublexical processing was demonstrated in her difficulty with the grapheme-phoneme conversion task. However, PD was within the normal range on the test of the orthographic lexicon (DOOR/DOAR).

The aim of this study was to break down the processes of orthographic learning and investigate how children with selective reading impairments, that is, surface and phonological dyslexia, learn to read. We will discuss the results in relation to the three processing elements, which we hypothesised may be involved in orthographic learning: phonological decoding, paired-associate learning, and context (see Figure 1, earlier, ①-③).

Orthographic Learning and Phonological Decoding

We first explored the role of phonological decoding in orthographic learning by using an orthographic learning task that required both regular and irregular novel word learning. In addition, Experiment 1 was designed to track orthographic learning, by measuring performance after each learning opportunity.

In the self-teaching hypothesis phonological decoding is the key to orthographic learning. Therefore, this hypothesis predicts that BM, the surface dyslexia case, should have learned the novel regular words better than PD, the phonological dyslexia case. However, our results showed that BM and PD were no different in their orthographic learning. When comparing the performance of the two cases with controls, the phonological dyslexia case, PD, was no different from controls on orthographic learning measured by an orthographic choice task, whereas BM was significantly worse. This result suggested that better phonological decoding skill does not guarantee better orthographic learning ability.

In addition, the results from the time-limited exposure duration suggested that both dyslexia cases required more exposures to learn the novel words compared to the controls. This was consistent with previous research that more exposures are required for dyslexic readers to acquire novel orthographic representations (Ehri & Saltmarsh, 1995). The time-limited exposure duration aimed to measure orthographic learning under the assumption that rapid word recognition is only possible when the orthographic representation has been acquired. The poorer performance of the two dyslexia cases on this measure thus indicated that they were less able to acquire the orthographic representations compared to the controls. However, an alternative explanation of the results could be that the two dyslexia cases have acquired the novel word representations just as well as the controls, but have difficulties activating the representation within 200 ms. Whether the dyslexic readers require more time in word recognition compared to normal readers requires further research.

Another prediction from the self-teaching hypothesis is that regular novel words, which can be fully decoded, should be learned more effectively than irregular novel words. In terms of word regularity effects, the results from the controls were consistent with our predictions and previous findings (Laxon, Masterson & Coltheart, 1991; Manis, 1985; Rack, Hulme, Snowling & Wightman, 1994; Nilsen & Bourassa, 2008): regular words were read and learned more accurately than the irregular words. Both dyslexic cases showed a

regularity effect in both untimed and time-limited exposure duration reading. This result suggested that although the phonological dyslexia case was impaired in her ability to use the sublexical route, phonological decoding still played a role in the process of orthographic learning.

However, an effect of word regularity was absent in the post-test measures (spelling and orthographic choice) for both the cases and controls. As Wang et al. (In preparation) have pointed out, one possible account for this absence is that the regular novel words in the study were created in a way that each target word always had a homophone partner (e.g., *voar* can be spelled as *vore*). In other words, although they were regular for reading (the vowel had one frequent pronunciation), the vowels were inconsistent for spelling (there was more than one possible spelling for each vowel). Hence, even for regular words, accurate performance in both spelling and orthographic choice cannot be achieved using sound-letter knowledge alone. In order to correctly spell, or select the correct spelling in orthographic choice, there needs to be knowledge of the orthographic form. In other words, these tasks require orthographic learning for both regular and irregular words. Therefore, this could account for the lack of an advantage for regular words in spelling and orthographic choice despite such an advantage in reading across both controls and the children with dyslexia.

The effect of regularity found in the untimed and time-limited reading accuracy and the lack of regularity effect on spelling and orthographic choice tasks were also consistent with Wang et al. (In preparation). An alternative explanation put forward by Wang et al. rested on the fact that while the reading accuracy measures require phonological output, this is not the case for spelling and orthographic choice. Hence the regularity effect may be linked to the requirement to produce the phonological form. As Wang et al. note, further research is required to determine whether one or other or both of these accounts is correct.

Extending on the findings of Wang et al, the untimed reading accuracy of BM and PD showed a larger regularity effect compared to the controls. This suggested that phonological

decoding played an important role in the process of orthographic learning. The larger word regularity effect for the dyslexia cases might also reflect the fact that the controls were able to lexicalise the novel words quicker and were hence less affected by word regularity.

Overall, the results of this study suggest that phonological decoding played a role in the process of orthographic learning for both BM and PD. Inconsistent with the prediction from the self-teaching hypothesis, BM was not better at orthographic learning as a result of his superior phonological decoding skill compared to PD. This suggests that phonological decoding may be important, but is not sufficient, for the success of orthographic learning.

Paired-Associate Learning

The second element in the process of orthographic learning that was investigated in this study was paired-associate learning. Previous studies on paired-associate learning ability with poor readers have found that dyslexic readers have difficulties in such learning when verbal elements are involved, but they are, on average, within the normal range for paired-associate learning that does not involve verbal elements (for a review, see Hulme, 1981).

Consistent with our predictions, BM, the surface dyslexia case, was impaired in his paired-associate learning ability while PD, the case with phonological dyslexia, was not: BM was worse than the controls on paired-associate learning in all modalities, including visual-visual paired-associate learning. In contrast, PD performed no differently from the controls on visual-visual and verbal-verbal paired-associate learning, although her performance in visual-verbal paired-associate learning was close to being significantly lower than the controls. Messbauer and de Jong (2003) have also suggested that children with dyslexia may not be completely normal in learning non-verbal associations. They found that although the dyslexia group did not differ on the performance of learning non-verbal paired-associations, they were worse at retaining the associations compared to age-matched controls. Retention of learning was not analysed in the current study due to the small number of items and

subjects. Although in the present study the impaired performance was found during the learning trials rather than retention, it nevertheless challenges the claim that non-verbal learning is unimpaired in children with dyslexia (Vellutino et al., 1975; Vellutino et al., 1978; Vellutino & Scanlon, 1989; Vellutino et al., 1983; Vellutino et al., 1995). One possible explanation for the differences between the previous and the present findings is that there are individual differences within poor readers. While the present study looked at the details of single cases, previous studies have used groups of poor readers and therefore have reported on average patterns which may obscure variability within the group.

In addition, the results in this study challenge the view that the problems poor readers encounter in reading and visual-verbal paired-associate learning reflect phonological decoding deficits (Vellutino, Sacnlon & Spearing, 1995). If phonological decoding deficits are the cause of visual-verbal paired-associate learning difficulties, then the phonological dyslexia case should have been more impaired in this task than the surface dyslexia case. Hence, the results of this study argue against a causal relationship between phonological decoding and visual-verbal paired associate learning. Further research is required to investigate the underlying cause of impairments in learning paired-associations.

Our results support the view that orthographic learning is related to the ability to learn associations between visual and verbal components. As suggested in models of sight word acquisition, the ability to form connections between visual and phonological forms of words is the foundation to building up sight word vocabulary (Ehri, 1995; 1999; Harm & Seidenber, 1999). Moreover, the results of our study also supported the idea that orthographic learning may be linked with a more general learning ability that is not specific to visual-verbal associations (Byrne et al., 2008; Byrne, 2005).

Orthographic Learning and Context Effect

The last element of orthographic learning explored in the study was the effect of context. As predicted from the self-teaching hypothesis, context should be more important when decoding is partial (Share, 1995). Wang et al. (2011) confirmed this hypothesis when examining orthographic learning of irregular novel words. In the current study, we examined partial decoding due to impaired sublexical processes in (phonological) dyslexia. The results were consistent with the prediction that PD, the phonological case, benefited from the contextual information when learning novel words (measured by a spelling task), while BM's orthographic learning did not benefit from contextual information. The context effect on PD was also larger than that of controls. The effect of context found in PD's orthographic learning might suggest that in order to compensate for her impaired decoding skill, PD instead used assistance from contextual information when learning novel orthographic representations. However, there was no evidence of context effects in the orthographic decision task for either case. The reason for this may be that, as noted earlier, this orthographic decision task may have been too difficult for the poor readers.

Landi et al. (2006) suggest that context draws attention away from the orthography and thus orthographic learning is less effective when novel words are presented in context, and this is particularly the case for less-skilled readers. The results from PD and BM did not support this view. However, there are two differences between Landi et al. (2006) and the present study that might contribute to the differences in the findings. First, the no context condition in Landi et al. was presented with the novel words on flash cards. In the present study, the novel words were presented embedded in a list of words in order to control for similarity of visual presentation between context and no context conditions. It is possible that the poor readers may benefit more from the flash card presentation where there is a greater focus on the novel words. Second, the negative effect of context in Landi et al. was found in retaining the orthographic representations acquired. As PD and BM were both

worse than controls at retaining the novel words, any effect of context (positive or negative) might not be observable in the delayed tests.

PD's orthographic learning measured by spelling accuracy was better than BM's when novel words were learned in context. This is consistent with Experiment 1 and is again inconsistent with the prediction that the surface dyslexia case would be better at orthographic learning compared to the phonological dyslexia case.

Although PD seemed to be unimpaired in orthographic learning, her delayed test performance indicates that she may be unable to retain the words that were learned. When orthographic learning was measured in the delayed tests, PD's performance dropped dramatically and this effect of time was larger than that of the controls. Hence, it could be that PD did not learn the novel words via phonological decoding, but rather with some other means such as paired-associate learning or using the assistance from contextual information, which may result in more difficulty retaining the newly learned words. Further research on not just the process of orthographic learning, but also its relationship to retaining what was learned is required.

Conclusions

This study was the first to fractionate the process of orthographic learning and investigate the orthographic learning of children with selective reading impairments in detail. We explored three important components of orthographic learning: phonological decoding, paired-associate learning, and context, and found that all three components played a role. We provided clear evidence that there are more processing components necessary for the acquisition of orthographic representations than phonological decoding alone; and similarly, impairments in orthographic learning can be caused by factors other than a phonological deficit. Below we summarise the orthographic learning processes for each case based on the findings of this study.

BM, the surface dyslexia case, was able to proceed with the first component of orthographic learning, that is, phonological decoding. However, he may have been impaired in the second component, that is, using paired-associate learning to establish the link between phonology and the orthography of the word. In addition, BM did not seem to use assistance from contextual information when acquiring orthographic representations. This is consistent with previous findings on the lack of context effect in orthographic learning when decoding of the novel words is not compromised (Nation, Angell & Castles, 2007; Cunningham, 2006). In summary, BM's impairment in orthographic learning may have been caused by his impaired paired-associate learning ability. Therefore, despite his normal phonological decoding skill, he still encountered difficulties in acquiring orthographic representations.

PD, our phonological dyslexia case, on the other hand, despite her poor phonological decoding skills, performed no differently to the controls on most of the orthographic learning and paired-associate learning tasks. This suggested that although the first component of orthographic learning was not successful, she went on and used the second component – paired-associated learning to build up orthographic representations of the novel words. However, as evident from the word regularity effect on her performance, this is not to say that phonological decoding did not play a role in PD's orthographic learning. In addition, PD used contextual information to assist her in learning novel words. Nevertheless, PD's performance on retaining the orthographic learning was generally poorer than the controls. This indicated that orthographic representations might not be as solid when they are not supported via phonological decoding. In short, all three processing components appeared to play a role in PD's orthographic learning. Although she was able to learn the novel words relatively successfully, she seemed to have difficulty in retaining them, and this could be due to her compromised decoding skill.

In summary, the findings of this study challenge the view that phonological decoding alone is sufficient to acquire orthographic representations successfully. The phonological and surface dyslexia cases each appeared to acquire orthographic representations differently, according to their selective reading impairments. This also provided further evidence of the components that may be involved in orthographic learning and allow us to better understand the nature of how orthographic representations are typically acquired.

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General Discussion

The five papers presented in this thesis explored factors that affect orthographic learning with both typically developing and low progress readers. The overall aim of the thesis was to fill gaps in the current literature and establish a more complete picture of how orthographic learning takes place by examining the specific processes involved. To do this, I utilised the dual-route model of reading and the self-teaching hypothesis of orthographic learning to pinpoint the components that may be involved in orthographic learning. The components under investigation were: phonological decoding, paired-associate learning, vocabulary knowledge, context, and orthographic knowledge. I also developed two novel paradigms in order to explore the effect of these components on orthographic learning.

Overall, Paper 1 provided evidence supporting the effect of context on orthographic learning of irregular words using a variation of the self-teaching paradigm; Paper 2 demonstrated a word regularity effect on orthographic learning; Paper 3 revealed the predictors of orthographic learning; Paper 4 tracked orthographic learning in children with two subtypes of dyslexia using a second novel paradigm; Paper 5 provided evidence of how one child with surface dyslexia and one with phonological dyslexia utilise specific components during the process of orthographic learning.

In this chapter, I discuss the components of orthographic learning based on the findings of each paper, along with implications and future directions. The contributions and limitations of the thesis are addressed in the subsequent chapter.

Phonological Decoding Component

Summary of Findings

Phonological decoding is considered a crucial factor in orthographic learning (Share, 1995) and its role has been well established empirically (Share, 1999; Kyte & Johnson, 2006; Bowey & Miller 2007, Cunningham, et al., 2002; Cunningham, 2006). However, in English, there are many irregular words (e.g., *yacht*) that cannot be fully decoded. The

relationship between phonological decoding and orthographic learning of irregular words is thus unclear, with little research undertaken to examine this. Therefore, this thesis examined the role of phonological decoding using both regular and irregular novel words. In addition, the role of phonological decoding in orthographic learning was explored with dyslexic readers who have phonological decoding deficits (phonological dyslexia) and dyslexic readers with normal phonological decoding skill (surface dyslexia).

All five papers in this thesis made some contribution to specifying the role of phonological decoding in orthographic learning. Paper 1 was the first in the literature to demonstrate that when phonological decoding is compromised, in the case of irregular novel word learning, further assistance, such as from contextual information, becomes important. Paper 2 was the first to directly test a key prediction of the self-teaching hypothesis, that there should be a word regularity effect on orthographic learning. The results support the role of phonological decoding and demonstrated that when phonological decoding can only be partial, as in novel irregular words, orthographic learning is also less effective. Paper 3 examined the relationship between phonological decoding and orthographic learning with a group of 45 typically developing children. This study found that the level of pre-existing phonological decoding skill is generally associated with the level of orthographic learning of both regular and irregular words: those children with better phonological decoding tended to have better orthographic learning. However, further analysis at an item level revealed that correct reading of a novel word does not predict the successful orthographic learning of the same novel word. Therefore, it was suggested that while phonological decoding is important, the relationship between phonological decoding and orthographic learning is not straightforward. Paper 4 and Paper 5 examined the role of phonological decoding with two subtypes of dyslexic readers: phonological and surface dyslexia. The results suggested that phonological decoding plays a role in orthographic learning not only for readers with surface dyslexia (who rely heavily on phonological decoding skill) but also for readers with

phonological dyslexia (who have impaired phonological decoding skill). However, despite the fact that the surface dyslexic children had superior phonological decoding skill, they did not outperform the phonological dyslexia children on their orthographic learning results. Together, Papers 4 and 5 show that having normal phonological decoding skill does not guarantee success in orthographic learning, and having impaired phonological skill does not necessarily lead to a failure of orthographic learning.

In sum, papers 1 to 5 all provide support for the important role of phonological decoding in orthographic learning. However, the results of these studies also suggest that phonological decoding skill alone may be insufficient for acquiring orthographic representations.

Implications and Future Research

One valuable future direction for research would be to carry out a systematic cross-language study on the role of phonological decoding in orthographic learning. In a transparent writing system such as Hebrew, phonological decoding is always a reliable means of arriving at the correct pronunciation of words. In a less transparent writing system such as English, where many words have irregular letter-sound mappings, factors beyond phonological decoding may be important in the process of orthographic learning. Furthermore, it would be interesting to explore whether or how phonological decoding assists orthographic learning in a logographic writing system such as Mandarin, where phonological decoding within a Chinese word character itself is not applicable. Although there are studies exploring orthographic learning across different languages (e.g., Hebrew: e.g., Share, 1999, 2004; Dutch: e.g., de Jong & Share, 2007; de Jong, Bitter, van Setten & Marinus, 2009; English: e.g., Cunningham, Perry, Stanovich & Share, 2002; Cunningham, 2006; Bowey & Muller, 2005; Byrne et al., 2008; Nation, Angell & Castles, 2007), none have systematically investigated orthographic learning using the same paradigm in

languages that differ in the level of transparency of writing scripts. Nor has there been an investigation of whether this difference in writing scripts interacts with the role of phonological decoding and other components in orthographic learning. An overview of how orthographic learning takes place and how phonological decoding assists orthographic learning in different writing systems will provide a better model of orthographic learning and a better understanding of the nature of the processes required for successful orthographic learning.

Another issue that deserves more attention is how phonological decoding is defined and exactly how it operates in the process of orthographic learning. Paper 3's item level analysis replicated the results of Nation et al. (2007) in that correct reading of the novel word did not directly transfer to successful orthographic learning of the same word. Share (2009) argued against Nation et al. (2007)'s finding, maintaining that the self-teaching hypothesis proposes only that phonological decoding provides opportunity for orthographic learning but does not guarantee its success. In Share (1995, footnote 1, p. 125) he described phonological decoding as follows:

“the term phonological decoding does not imply any particular procedure but it is used as an umbrella term for the process of print to sound conversion by whatever means this is accomplished. This covers several possibilities including (but not necessarily limited to) explicit letter-by-letter application of grapheme-phoneme correspondence rules, an analogical activation-synthesis mechanism, an implicit statistical learning mechanism, or automatic activation of a distributed (connectionist) network of simple neuron-like units”

According to this definition, it seems that phonological decoding is not restricted to letter-sound knowledge, but could also be achieved partly via word-specific orthographic learning (e.g., analogy). However, the theory also proposes that “exhaustive phonological decoding” is the basis of orthographic learning as it draws the reader's attention to the order and

identity of each grapheme and letter of the word. According to this view, it is possible that using analogy to ‘decode’ a novel word may result in less effective orthographic learning. Therefore, it would be interesting to explore whether phonological decoding using letter-sound knowledge would be more effective than that of using analogy as decoding draws the reader’s attention to every letter or grapheme of the word.

Finally, although the findings of this thesis suggested that phonological decoding is important but insufficient for successful orthographic learning, when orthographic learning was achieved via means other than phonological decoding, the effect of learning appeared to be compromised. The results of the case study from Paper 5 provided initial evidence that PD, a phonological dyslexia reader, may have used contextual information to assist orthographic learning as a compensation for her insufficient phonological decoding skill. Although her orthographic learning measured immediately after learning was not different from controls, she was not able to retain the words she learned after a week delay. One possible explanation for this was that, because PD did not acquire the representations via phonological decoding, the acquired representations were not as strong. This result implies that while phonological decoding may be insufficient, it may still be crucial in the process of learning to read and thus deserves more detailed investigation.

Contextual and Vocabulary Knowledge Components

Summary of Findings

As suggested in the self-teaching hypothesis, contextual guessing may be important in orthographic learning when decoding is partial. Partial decoding can result either when a word has irregular letter-sound mapping, or when the reader has insufficient phonological decoding skills. Paper 1 was dedicated to exploring this hypothesis.

The role of vocabulary knowledge is not explicitly addressed in the self-teaching hypothesis; however, it is reasonable to assume that vocabulary is essential for contextual

information to be utilised. For example, if the novel word STEAK is presented, phonological decoding using letter-sound rules would result in the activation of "s" "t" "ee" and "k". In this case, "steak" will not be fully activated in the phonological lexicon. However, information from the context (e.g., "He ordered rump...") can (pre)activate the meaning of STEAK. Thus, contextual information provides assistance to deriving the correct phonology of the word. For contextual information to be of assistance however, prior (vocabulary) knowledge of the meaning and the phonology of the word is required, in order that the context can pre-activate this information. For this reason, the effects of context and vocabulary knowledge are discussed together in this section.¹³

Together, Papers 1, 3 and 5 provided evidence for the role of context and vocabulary knowledge in orthographic learning. Contrary to previous studies (which found no effect of context when using a standard self-teaching paradigm with regular words and no vocabulary knowledge provided) (Nation, Angell & Castles, 2007; Cunningham, 2006), Paper 1 was the first to demonstrate the assistance of contextual information (or contextual guessing) in orthographic learning by using irregular words. Since vocabulary knowledge is important for context to be effective, the effect of context was explored with the provision of vocabulary knowledge prior to orthographic learning. This adaptation of previous paradigms of self-teaching is the first that considers vocabulary knowledge and test orthographic learning in a manner more similar to the way in which children typically encounter new written words. Paper 3 found that vocabulary knowledge is indeed associated with orthographic learning of irregular novel words, and that this was also true at an item level. Papers 2 and 3 together demonstrated that contextual and vocabulary knowledge are important in orthographic learning when decoding can only be partial as in the case of irregular novel words. In line with this finding, Paper 5 found contextual information (with no pre-existing vocabulary

¹³ Vocabulary knowledge is important for 'contextual guessing' to be effective. However, in a standard self-teaching paradigm, no vocabulary knowledge is provided. Hence, contextual assistance in a self-teaching paradigm is the assistance of word meaning extracted from context. In other words, this contextual assistance in a standard self-teaching paradigm is different from what Share meant by assistance of contextual guessing.

knowledge provided) to be helpful in learning regular novel words with a phonological dyslexic reader, where partial decoding resulted from inadequate phonological decoding skill.

These three studies provide clear support for the assistance of contextual information and vocabulary knowledge in orthographic learning when phonological decoding is compromised.

Implications and Future Research

As suggested by previous studies of word reading with children, vocabulary knowledge is associated with irregular word reading (e.g., Bowey & Rutherford, 2007; Nation & Snowling, 1998; Ouellette, 2006; Ricketts, Nation & Bishop, 2007; Nation & Cocksey, 2009). The results from this thesis extend the evidence for the importance of vocabulary knowledge to the actual acquisition of orthographic representations.

The most important implication of this finding is that contextual information and vocabulary knowledge may be able to assist poor readers with impairments in phonological decoding skills when they are learning to read. Clearly, improving decoding itself should be the primary aim of intervention for such poor readers. Nevertheless, until decoding skills improve, these readers should be encouraged to combine their partial decoding attempts with the information they have gleaned from context and vocabulary knowledge in order to better make sense of what they read (just as this thesis found assistance for typically developing readers with irregular words). Further studies on the effect of contextual or vocabulary knowledge in reading intervention would provide a test of this hypothesis.

Finally, the results of the case study from Paper 5 provided initial evidence for the assistance of contextual information on orthographic learning with PD, a phonological dyslexia reader. However, PD did not retain the words she learned after a week delay. One possible explanation is that the experiment in Paper 5 did not provide vocabulary knowledge

for the novel words to be learned and this limitation may also have produced the resulting retention problem. Therefore, the meanings of the novel words were only extracted from the context during story reading, and this may not be enough to support orthographic learning in the longer term. Further studies, providing vocabulary knowledge prior to novel word learning in children with phonological dyslexia, are required for clarification purposes.

Paired-Associate Learning

Summary of Findings

Ehri's phase theory of sight word learning (Ehri, 1995; 1999) suggests that the ability to form connections between visual and phonological forms of words is the foundation for building up a consolidated sight word vocabulary. It has been shown that the ability to learn visual-verbal association accounts for unique variance in reading ability (Windfuhr & Snowling, 2001). Results from Paper 5 provided further evidence supporting this relationship with two dyslexic children, each of whom had a specific reading impairment.

In Paper 5, paired-associate learning ability was explored across three pairings of two modalities: visual-visual, visual-verbal, and verbal-verbal, with one phonological and one surface dyslexia case. The results showed that the surface dyslexia case was impaired in all three paired-associate learning tasks compared to controls while the phonological dyslexia case did not appear to have the same impairment. This deficit in paired-associate learning may explain why, despite the fact that the surface dyslexia case had normal phonological decoding ability, orthographic learning was still impaired. Hence, this study supports the view that paired-associate learning is one of the critical foundations for learning to read. However, since it was not just visual-verbal paired associate learning that was impaired, this suggests that, for this case at least, the impaired orthographic learning was not due to a specific problem learning visual-verbal associations but a more general learning ability. This

is consistent with Byrne's suggestion that a general learning mechanism may be associated with reading acquisition (Byrne et al., 2008; Byrne, 2005).

Implications and Future Research

It would be interesting for future research to explore whether paired-associate learning ability is also more associated with orthographic learning of irregular words than regular words. This is motivated by Papers 3 and Paper 4, which show that the effect of context and vocabulary knowledge is more important for orthographic learning of irregular words than regular words. Hulme et al. (2007) explored different types of paired-associate learning with reading accuracy for different types of words. They found that visual-verbal paired-associate learning was associated with regular and irregular word reading, whereas nonword reading ability was not associated with any kind of paired-associate learning abilities. Although Hulme et al. provided evidence of the associations between reading accuracy and paired-associate learning abilities, the author notes that it is possible this association reflects a consequence of, rather than a cause of differences in reading skills. That is, those children who have better word reading, may also have acquired more visual-verbal associations and as a consequence have improved their ability to do these tasks. Thus, further exploration of the relationship between paired-associate learning ability and orthographic learning of both regular and irregular words, rather than reading, will provide a better understanding of the relationship between word learning and the ability to learn paired-associations.

This study also found that the surface dyslexia case, who had normal phonological decoding skills, was impaired in paired-associate learning. Hence, it challenges the view that the problems poor readers encounter in reading and visual-verbal paired-associate learning always reflect phonological decoding deficits (Vellutino, Scanlon & Spearing, 1995). Further research is required to investigate the underlying cause of impairments in learning

paired-associations. It would also be valuable to investigate the effect of intervention on paired-associate learning and its relationship to reading acquisition.

Orthographic Knowledge

Summary of Findings

Many studies have found that orthographic knowledge is associated with orthographic learning (Cunningham et al., 2002; Cunningham 2006; Connors, Loveal, Moore, Hume & Maddox, 2010), even after phonological decoding is accounted for (Cunningham et al., 2002). As outlined earlier, it was predicted, yet untested, that orthographic knowledge may be more important in acquiring irregular novel words than regular novel words.

Taken together, Paper 3 and Paper 4 provided strong evidence of the importance of orthographic knowledge in orthographic learning. Paper 3 found that both pre-existing phonological decoding skills and pre-existing orthographic knowledge is highly associated with the success of orthographic learning of both regular and irregular words. Paper 4 revealed that orthographic knowledge, as for typically developing readers, predicted orthographic learning of both regular and irregular words for a group of dyslexic readers.

Implications and Future Research

Since the relationship between orthographic knowledge and orthographic learning has been well-established, in both previous research and this thesis, the next question of interest may be what the nature of this association is, and whether it is a causal one.

One possible explanation for the importance of orthographic knowledge is that existing orthographic representations could contribute to the process of acquiring new representations. In other words, children who have a larger orthographic lexicon or better orthographic knowledge will benefit from this knowledge when acquiring novel

representations. For example, these children would have a larger base of known words with which they could use analogies or familiar orthographic patterns. Future studies comparing orthographic learning between novel words embedded with familiar words ('more' in *smore*) and no embedded familiar words (*smoar*), or novel words with high or low orthographic neighbourhood size might allow us to better understand how orthographic knowledge assists orthographic learning.

The finding that orthographic knowledge contributes to orthographic learning in this thesis is correlational, hence could also be explained by a potential confound. Orthographic knowledge in Paper 3 and Paper 4 was measured using children's pre-existing orthographic knowledge, however, this could be seen as a measure of the children's historic ability to acquire orthographic representations rather than the orthographic knowledge of the novel words to be learned. That is, the relationship between orthographic knowledge and orthographic learning may simply be a reflection of the children's ability to acquire lexical representations. In this case, children who have better ability to acquire orthographic representations will both be better at the task tapping the orthographic lexicon and at our orthographic learning task. One possible way of exploring this question would be to investigate the relationship between orthographic knowledge and orthographic learning at an item level: measure the orthographic knowledge associated with a novel word and investigate its relation to the success of orthographic learning of the same novel word. For instance, in relation to the previous example, we could examine whether having the word-specific knowledge of 'more' assists orthographic learning of 'smore'.

In sum, although the findings in this thesis provided support to the importance of orthographic knowledge in orthographic learning, and further extended the findings to orthographic learning of irregular novel words, the underlying mechanism remains unclear. Thus, an investigation of exactly how and why orthographic knowledge assists orthographic learning still requires further research.

Contributions and Limitations

In this section, the broader contribution of this thesis to the field is discussed, along with limitations and future directions.

The Process of Orthographic Learning

A major aim of this thesis was to investigate the process of orthographic learning that occurs when children encounter new written words with both regular and irregular pronunciations. This thesis was the first to provide an explicit conceptualisation of orthographic learning within the influential dual route model and the self-teaching hypothesis of orthographic learning. The components involved in this process have been outlined above. This section will discuss the findings of papers 1 to 5 in the context of the proposed model introduced in Chapter 1 (Figure 1).

In this model, orthographic learning was hypothesised to proceed as follows: When a reader sees a novel word in print, this word will first be phonologically decoded via the sublexical route (① in Figure 1, findings from Paper 1-5), and as a result the phonology of the word will be produced (② in Figure 1). Subsequently, the connection between the phonology of the word and the orthography will be established via paired-associate learning (③ in Figure 1, findings from Paper 5). This process will be repeated until the orthographic representation is established in the orthographic lexicon, and the rapid automatic recognition of the word via the lexical route is accessible. However, if the novel word has irregular letter-sound mapping, the phonology of the word will not be correctly derived via phonological decoding. In this case, information from context may (pre)activate the meaning

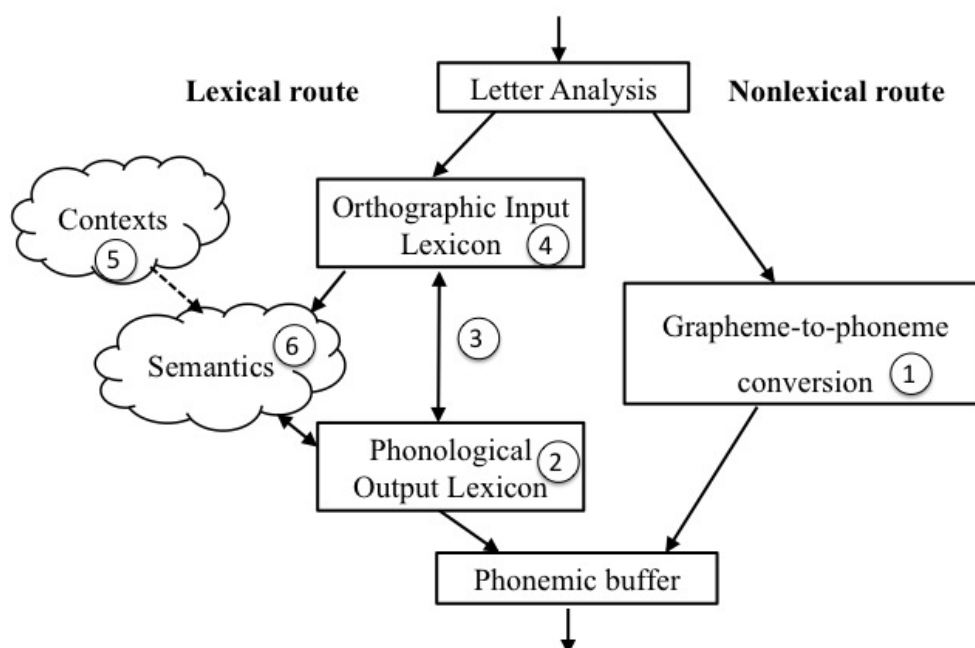


Figure 1. The dual route model of reading aloud. The numbers indicate the components of orthographic learning that this thesis investigates.

of the novel word (⑤ in Figure 1, findings from Paper 1). This will in turn activate vocabulary knowledge in the semantic system (⑥ in Figure 1) and the phonological lexicon (② in Figure 1) (findings from Paper 3). When combined with the partial activation from the phonemic buffer, this will result in sufficient activation of the phonological form and subsequently for the paired-associate learning with the orthography to occur (③ in Figure 1, findings from Paper 5).

This thesis has provided evidence that orthographic knowledge (④ in Figure 1, findings from Paper 3 & 4) may also play a role in the process of orthographic learning, and this can occur in two possible ways. As previously mentioned, Share's self-teaching hypothesis proposes that phonological decoding can be achieved by 'whatever means'. Hence, one way for orthographic knowledge to assist orthographic learning may be that it facilitates the process of phonological decoding using analogy with known words. Note that this is different to the traditional conception of phonological decoding via grapheme-phoneme conversion that the dual-route model proposes. Alternatively, orthographic

knowledge may contribute at a later stage when learning the paired-associations between phonology and orthography. Here, the familiarity of orthographic patterns or knowledge of similar words could consolidate or speed up the process of learning the associations.

In short, this thesis conceptualised the process of orthographic learning in dissected components. The results from the five papers provided evidence of the importance of each component, and the findings will provide a basis for future research.

Two Novel Paradigms

In this thesis, two novel paradigms were developed to explore specific research questions of orthographic learning. One was a variation of the self-teaching paradigm that aimed to explore orthographic learning of regular and irregular novel words (Paper 2 and Paper 3), as well as the effect of context on orthographic learning with the provision of pre-existing vocabulary knowledge (Paper 1). The second paradigm was developed to track orthographic learning of both regular and irregular novel words in a more sensitive and dynamic way than has been possible with previous paradigms (Paper 4 and Paper 5). The designs of the paradigms and the findings from using these two paradigms are briefly discussed below.

The first paradigm involved three phases. The first (*preexposure*) phase was designed to provide oral vocabulary knowledge of the novel words. The vocabulary knowledge of the novel words was introduced to the children as “new inventions” from a factory and were presented with drawings depicting the inventions and descriptions of their function (See Appendix 1). During the second (*orthographic learning*) phase, the participants were exposed to the written forms of the new words for the first time. During the final (*orthographic test*) phase, spelling, orthographic choice and lexical decision tasks were used to assess the success of orthographic learning.

This first paradigm has two features that are different to, and arguably improve upon, the traditional self-teaching paradigm. First, the exposure to the meaning and phonology of the novel words prior to orthographic learning allowed us to subsequently make the novel words ‘irregular’ without explicit instruction to the child. Second, having knowledge of the sound and meaning of a word before seeing it in print provided a more natural learning environment that is closer to children’s real-life experience when encountering new words. In addition, the provision of vocabulary knowledge also allowed us to directly explore the relationship between retention of vocabulary knowledge of a word and learning the orthographic representation of the same word successfully. The results from this paradigm provided further evidence of the role of phonological decoding in orthographic learning by demonstrating the effect of word regularity on orthographic learning (Paper 2); the importance of context in learning irregular words with the provision of vocabulary knowledge (Paper 1), and revealed the predictors of orthographic learning of regular and irregular words as well as the role that vocabulary knowledge plays in acquiring irregular orthographic representations (Paper 3).

The second paradigm was designed to track orthographic learning of regular and irregular words after every learning trial in order to explore how orthographic learning improves over successive learning trials. In this paradigm, regular and irregular words were presented in three cycles. In each cycle, reading accuracy was measured under two conditions: untimed and time-limited stimulus exposure duration. The untimed reading condition provided the opportunity for children to decode the novel words. This was followed by a time-limited exposure duration (200 ms) block to measure rapid recognition of the word as an indication of whether orthographic learning had taken place. After all three cycles were completed, spelling and orthographic choice tasks were administered as post-tests.

The second paradigm introduced time-limited exposure duration as a more sensitive measure that tracks orthographic learning. This time-limited exposure duration measured orthographic learning after each untimed learning trial. Therefore, it allowed us to explore individual differences in a child's learning rate, and it also provided information about the improvement in orthographic acquisition over learning cycles. In addition, the word regularity manipulation, it allowed tracking of orthographic learning for both regular and irregular words. The results from this paradigm revealed a regularity effect in both untimed and timed reading for children with surface and phonological dyslexia, suggesting that phonological decoding plays a role in the process of orthographic learning for not only the dyslexia group with normal phonological decoding skill (the surface dyslexia group), but also the one with impaired phonological decoding skills (the phonological dyslexia group). In addition, orthographic learning measured from the time-limited exposure duration provided evidence that orthographic learning of the two dyslexia groups improved across learning cycles (Papers 4 & 5).

Limitations and Future Directions

One recurring issue throughout this thesis is finding discrepancies between the results using different measures which were thought to be tapping the same process, and also difficulties in finding the appropriate measure of orthographic learning. Studies of reading acquisition adopt a number of different outcome measures of orthographic learning, with some using speed of reading aloud (e.g., de Jong, et al., 2009; Share, 1999), some reading accuracy (e.g., Landi et al., 2006; Bailey et al., 2004), and most using spelling (e.g., Ouellette & Fraser, 2009; Ouellette, 2010) and orthographic choice tasks (e.g., Cunningham, 2006; Share, 1999; 2004). This broad range of measures has made it difficult to compare research findings across different studies. In addition, certain measures may be confounded by other factors and, depending on the research question, may be problematic to use.

One such problem discussed in Paper 2, was the use of naming accuracy and naming speed as measures of orthographic learning in previous studies, which may have been influenced by phonological decoding skills. This is evident in studies with children that have demonstrated a word regularity effect in word learning tasks using measures of reading aloud (Manis, 1985; Rack, Hulme, Snowling & Wightman, 1994; Nilsen & Bourassa, 2008). The problem here is that if a child is more accurate in reading aloud a regular word than an irregular word, this may not be a result of having a more precise or accurate orthographic representation of the regular word than the irregular word. Rather, the advantage may be due to the fact that the regular word can be read aloud accurately purely by phonological decoding, even if the child has no word-specific orthographic representation at all, whereas the irregular word cannot.

In relation to this issue, a discrepancy in results of word regularity effect was found between measures of orthographic learning used in Paper 4 and Paper 5. These two studies used the second paradigm that was developed to track orthographic learning of regular and irregular words, and measured orthographic learning with a time-limited exposure duration presentation. The results showed that the effect of word regularity was only found in untimed and time-limited reading accuracy but not in the spelling and orthographic choice tasks. One possible explanation may be due to differences between task demands in the measures. Although we suggested that the time-limited exposure duration (200 ms) reading task should measure orthographic learning with minimal decoding opportunity, it still involved the production of spoken output. In contrast, the spelling and orthographic choice tasks do not require production of phonology. Hence, it is possible that the regularity effect found was a result of interference from other components involved in the sublexical reading aloud of a word.

Another discrepant result for different measures of orthographic learning was found in Paper 1. In this paper, an effect of context was found with an orthographic decision task

but not with spelling and orthographic choice tasks. It was argued that correct spelling is possible only with a complete and fully specified orthographic representation (Frith, 1980, 1985). In orthographic choice and orthographic decision tasks however, a relatively weak representation of the word might be sufficient to perform the task correctly. Across the two orthographic recognition tasks used in this study, the effect of context on irregular word learning was found only in the orthographic decision task and not in the orthographic choice task. The orthographic decision task allowed the children to make independent judgments on all targets and their foils rather than being restricted to only one option as in the orthographic choice task. Hence, the orthographic decision task might be a measure that is more sensitive to weaker representations of the novel word form and less susceptible to the effects of children's strategies on their decisions. An alternative explanation for the discrepancy between results from the orthographic choice and the orthographic decision task could be the difference between the role of phonology plays in these two tasks. In the orthographic choice task, target items and the phonological foils are presented adjacent to each other, hence, a child would know that using the phonological knowledge of the word is not sufficient to choose the correct answer. On the other hand, in the orthographic decision task, as the target items and the foils were presented individually, phonological knowledge may contribute to the decision more.

However, perhaps for the same reason outlined above, the orthographic decision task appeared to be too difficult for the dyslexic readers in Paper 5. Here, the effect of context was clear in the spelling task, but not in the orthographic decision task due to a floor effect. Hence, the benefits of the orthographic decision task may not be applicable in all situations or with all readers. In addition, spelling tasks are often quite challenging for younger children and consequently may induce a floor effect, whereas orthographic choice tasks may be too easy and lead to ceiling effects.

In sum, two novel measures were created in order to measure orthographic learning: orthographic decision and time-limited exposure duration presentation. These two measures provided interesting findings such as word regularity and context effects in orthographic learning that traditional measures have not been able to reveal. However, further research on discrepancies between the measures of orthographic learning is required. Indeed, discrepancies in results for different measures of orthographic learning have often been found in other studies (e.g., Nation et al., 2007; Ouellette & Fraser, 2009). It appears, therefore, that a better way of measuring orthographic learning is required to solve this problem. By definition, orthographic learning is referred to as having acquired an orthographic representation that is sufficient for the automatic and rapid recognition of the word. Hence, ideally, orthographic learning should be measured in a similar fashion.

One promising approach may be to draw on the prime lexicality effect in masked priming. Studies of masked priming suggest that a word prime, compared to a nonword prime, has a different effect on the target word that follows it, and that this priming effect takes place subliminally (Davis & Lupker, 2006; Forster & Veres, 1998). Hence, if a novel word has been acquired and stored in the orthographic lexicon, this same difference between a real word and a nonword prime may also present between a learned novel word and a nonword. If the novel word that was learned previously showed the same priming effect as a familiar word, it would provide strong evidence that the orthographic representation had been acquired. In addition, data from event related potentials shows differences in processing real words and nonwords, that is, a lexicality effect (Sereno, Rayner & Posner, 1998), and this may also be used as a possible measure of orthographic learning.

Concluding Remarks

Orthographic learning is one of the most important skills in reading development as it is utilised when new words are encountered and is the precursor to efficient word reading.

The majority of previous studies have been focused on the role of phonological decoding in orthographic learning. The studies in this thesis explored factors beyond phonological decoding and suggested that orthographic learning involves a number of processing components that assist and interact with each other. A breakdown of any component might cause difficulties in acquiring the orthographic representations or in retaining them. The findings of this thesis have allowed us to further understand the process of how children learn to read, how failures in learning to read may occur, and provided important implications for educational and intervention purposes.

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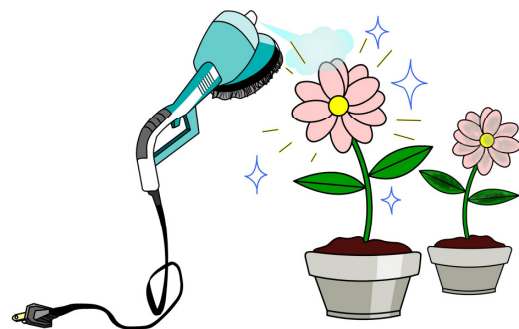
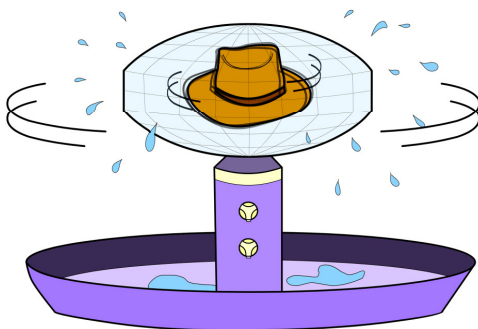
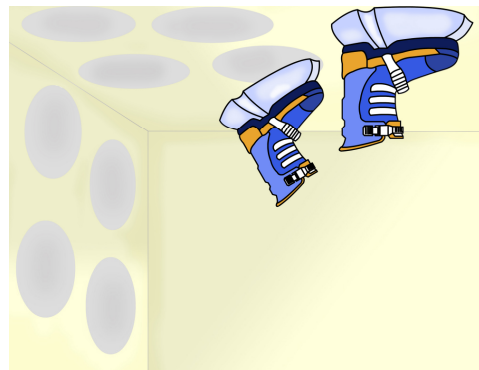
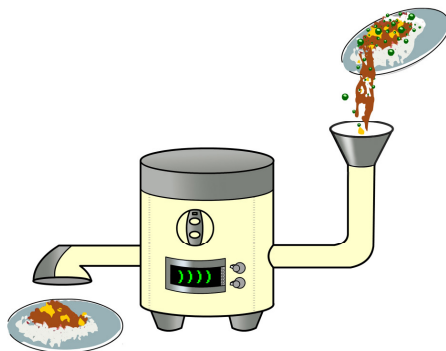
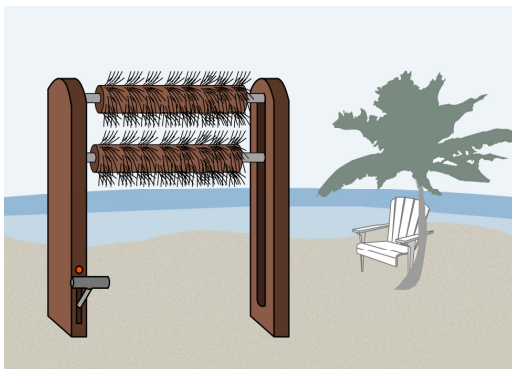
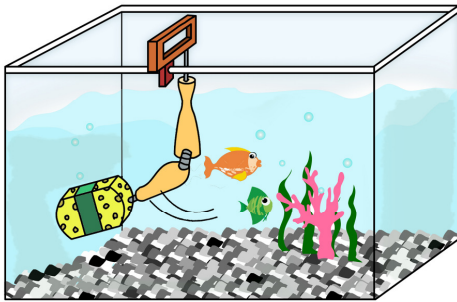
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Appendix 1

Pictures used in the vocabulary training phase.



12 September 2007

Dr Anne Castles
Macquarie Centre for Cognitive Science
Division of Linguistics and Psychology

Reference: HE24AUG2007-R05406

Dear Dr Castles

FINAL APPROVAL

Title of project: *Exploring the bases of reading problems in children: beyond phonological deficits*

Thank you for your recent correspondence. Your responses have satisfactorily addressed the outstanding issue raised by the Committee. You may now proceed with your research.

Please note the following standard requirements of approval:

1. Approval will be for a period of twelve months. At the end of this period, if the project has been completed, abandoned, discontinued or not commenced for any reason, you are required to submit a Final Report on the project. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. The Final Report is available at <http://www.ro.mq.edu.au/ethics/human/forms>
2. However, at the end of the 12 month period if the project is still current you should instead submit an application for renewal of the approval if the project has run for less than five (5) years. This form is available at <http://www.ro.mq.edu.au/ethics/human/forms>. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report (see Point 1 above) and submit a new application for the project. (The five year limit on renewal of approvals allows the Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).
3. Please remember the Committee must be notified of any alteration to the project.
4. You must notify the Committee immediately in the event of any adverse effects on participants or of any unforeseen events that might affect continued ethical acceptability of the project.
5. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University (<http://www.ro.mq.edu.au/ethics/human>).

If you will be applying for or have applied for internal or external funding for the above project it is **your responsibility** to provide Macquarie University's Research Grants Officer with a copy of this letter as soon as possible. The Research Grants Officer will not inform external funding agencies that you have final approval for your project and funds will not be released until the Research Grants Officer has received a copy of this final approval letter.

Yours sincerely



Dr Margaret Stuart
Director of Research Ethics
Chair, Ethics Review Committee [Human Research]