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The case for frequency sensitivity in orthographic learning

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This paper positions the importance of frequency sensitivity in the development of orthographic knowledge throughout childhood and promotes learning to spell as a vehicle which may be used effectively to develop this sensitivity. It is suggested that orthographic knowledge is advanced via a process of 'frequency sensitivity' to 'patterns and sequences' and 'rules and regularities' particular to English orthography and that the process of sensitivity to these coarse grain orthographic patterns is influenced by consistency in sound and by morphological knowledge (knowledge of morphemes; words or word parts that form the smallest unit of meaning in language). A model highlighting the increasing importance of orthography and morphology as reading and spelling development progresses is presented. Discussion of the importance of considering phonology, orthography and morphology throughout literacy development and the relative importance of each is discussed. Distinctions are drawn between the processes involved in children who are good readers and good spellers, children who are good readers and poor spellers, and children who are poor readers and poor spellers. This paper outlines how considering these interrelated and developmentally sensitive contributors to literacy development can contribute to the practice of educational professionals in promoting the development of literacy skills throughout childhood.

What is orthographic knowledge?

Orthographic knowledge refers to the spelling or writing system of any language. It is 'knowledge particular to print' (Corcos and Willows, 1993, p. 163). It is highly language specific because letters occur in patterns that are particular to a given orthography. English is a deep orthography (with many sounds representing one grapheme and vice versa), whilst Italian, Spanish and Finnish are shallow orthographies (one letter corresponds to one sound only, making it much easier to apply a phoneme decoding and encoding strategy in these languages). Orthographic knowledge, therefore, is found in the spelling patterns of written language and provides the reader with information about the likelihood of certain letter sequences occurring in print and about positional constraints. Orthography is the grouping of letters at levels greater than phoneme level (Table 1). Corcos and Willows (1993) contend that orthographic knowledge is central to the automatic recall of words from the mental lexicon and is regarded by Shahar-Yames and Share (2008, p. 22) to be 'one of the cornerstones of literacy'.

Although the outcome of successful orthographic learning is clear, as Castles and Nation (2008) point out, much less is known about how orthographic learning takes place. Indeed Shahar-Yames and Share (2008) point out that the elements in the spelling process that contribute most to orthographic learning have yet to be identified.

When considering orthographic knowledge, it is important to consider the relationship between orthography and phonology (sounds). Four levels of sound and orthographic knowledge can be clearly identified. The smallest units of sound (level 1) are phonemes which are represented by graphemes, and this is most commonly known as alphabetic knowledge. The other three levels of sound are represented by combinations of graphemes which represent combinations of phonemes and can be described as orthographic knowledge. Orthographic knowledge, therefore, consists of onset and rime, syllables and whole words. These levels of sound and orthography can be more closely examined in Table 1.

It should be noted that using the term 'level' in this table does not refer to a sequence in development but rather to the size of the unit of sound. Anthony et al. (2003) maintain that phonological sensitivity is a single ability developing from sensitivity to words to sensitivity to phonemes in a quasi-parallel progression rather than a discrete sequential progression. Furthermore, in research conducted by Anthony and Lonigan (2004), it was found that phonological sensitivity at all levels is important, and they advise against placing greater importance on any one level.

Table 1: Levels of sound and orthographic knowledge

Sounds: that is, What we hear	Visual: that is, what we see	Form of knowledge	Level of sound	Essential for
Phonemes	Represented by one letter (grapheme) for example, 'b' and 'a' or in the case of digraphs 2 letters for example,'sh' and 'oa'	**Alphabetic**	**Level 1** This level consists of fine-grain sounds (Ziegler and Goswami, 2005)	Decoding and encoding in the beginning stages of reading and spelling and decoding and partial encoding at the stage of multiple mappings.
Onsets	Onsets include individual phonemes (e.g., p, t, b), blends (e.g., cr, bl) and initial consonant clusters (e.g., str, spl)	**Onsets consist of alphabetic knowledge** (individual phonemes) and **orthographic knowledge** (blends and clusters) Onsets are also referred to as intra-syllabic units. Onsets are the first part of the syllable up to the vowel sound. St/amp St = onset	Onsets include fine and coarse grain sounds **Level 1 –** Fine grain (individual phonemes) **Level 2 –** coarse grain (consonant blends and clusters)	Exchange of sounds (phonemes) Level 2: More efficient storage in long-term memory and to reduce the demands in working memory (consonant blends and clusters)
Rhymes ('rimes')	Final letter clusters in one syllable words which include the vowel immediately preceding the final consonant(s) for example, 'an', imp, ight	**Orthographic** Intra-syllabic unit (syllables are broken into two with the division coming after the initial consonant(s) and before the vowel sound for example, stamp St/amp amp = rhyme	**Level 2** Coarse grain (Level 1: There are a few fine grain rhymes e.g., 'ay' as in play)	Essential to reduce storage demands in long-term memory and to reduce the demands in working memory. Rimes are also essential for stabilising vowel digraphs, which have multiple mappings, but become stable within particular rimes (Adams, 1990, p. 320) which in turn allows efficient storage in memory (Adams, 1990, p. 321).
Syllables	Unified unit (cluster of letters) without a break in the sound	**Orthographic** 'Interesting' has 4 syllables In/ ter/est/ing	**Level 3** Coarse grain	It is essential that children can recognise syllables for more efficient decoding and encoding of multi-syllable words.
Whole word	House, yacht, the, begin, complicated etc.	**Orthographic**	**Level 4** Coarse grain	Whole word or automatic sight word recognition is essential for reading fluency.

Phonological knowledge

Table 1 presented four levels of phonological knowledge which are essential for normal literacy development; phonemes, onset and rimes, syllables and whole words. The acquisition of phonological knowledge at all four levels cannot be considered without consideration of the implications for memory. Each level of sound places differing demands on memory both in terms of long-term storage and retrieval and also processing within working memory. To obtain reading fluency, children need to develop the ability to process larger units from letters and spelling patterns into whole words using working memory and connect these to phonological and semantic codes in long-term memory (Breznitz, 2006). Learning individual phonemes is important, however, some children with literacy difficulties find learning individual phonemes, in advance of reading

text and in the absence of some basic sight words, extremely difficult due to the de-contextualised nature of the activity. Research has demonstrated that an appropriate semantic context facilitates efficient retrieval from memory (Muter, 2006; Tulving and Thompson, 1973; Tweedy, Lapinski and Schvaneveldt, 1977). Therefore, without such a context, the sole use and retrieval of phonemes, which in themselves carry no meaning, can be extremely difficult. Also, children with limited working memory capacity find it difficult to blend more than two sounds together (Baddeley, 1979; Gathercole and Baddeley, 1993). By the time they get to the last sound in sequences of three or more, the memory trace for the first sound(s) has faded away making blending an impossible task (Gathercole and Alloway, 2008). Teachers will recognise children who have this difficulty. These children know the individual sounds but just cannot blend them together to make words. Chunking words into component units or finding smaller words in larger ones are therefore essential strategies for this group, and have been used effectively with struggling early years readers (Juel and Minden-Cupp, 2000). There has, in recent years, been a growing emphasis on intervention at phoneme level (Duff, Hayiou-Thomas and Hulme, 2012; Lonigan et al., 2013; Slavin et al., 2011). This is not problematic except in cases where phoneme level intervention is seen as an alternative to, or in opposition with, coarse grain level sounds, that is, patterns and sequences at the intra-syllabic (onset and rime) level. This 'onset and rime' level is important because long-term memory is dependent upon it for efficient storage. The mental lexicon is limited in capacity, therefore, reasoning by analogy is essential to prevent memory overload. The mental lexicon stores the pattern from which many words can be generated simply by changing the initial sound. Working memory is also dependent on onset and rime to reduce the demands of short-term temporary storage in complex processing tasks such as decoding and encoding. The demands of 'taking each sound in turn' in, for example, a five-phoneme word, is reduced to two units when onset and rime is used. Consider the word stamp ('st' = onset, 'amp' = rime).

It is important that once phoneme knowledge is established, and not necessarily all phonemes absolutely, that children develop quickly their ability to progress to larger sound groupings such as initial consonant blends and end rhymes. This level is important because failure to identify the 'onset and the rime' within a syllable results in greater workload on the working memory system in order to cope with the demands of utilising a decoding or encoding strategy. It is important that children recognise that if they can spell one word they can spell many more by changing the initial sound. Goswami (2008, p. 71) states:

> *'Of course children need to develop efficient grapheme–phoneme recoding strategies, but they also need to develop "rhyme analogy" strategies to take advantage of spelling sound consistency at the larger "grain size" of the rhyme.'*

In further support of the importance of the intra-syllabic unit Turner and Bodien (2007, p. 41) draw on evidence from the case study of a 7-year-old who failed to progress despite considerable phonics teaching.

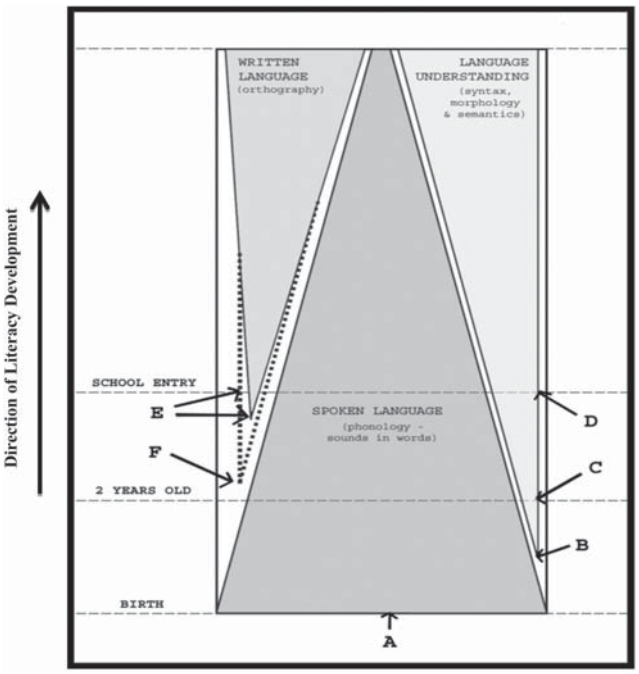
> *'She was not segmenting words into their ONSET AND RIME. Consequently, each word appeared as a new item to her that she laboriously decoded phoneme by phoneme rather than decoding by ANALOGY for lists such as "cat, fat, mat, sat, and hat" where just the first phoneme needed to be changed.'*

This point is supported by Thomson (2009, p. 88) who noted that children with dyslexia 'cannot remember individual phonemes blended together' and require an analytic approach to sounds as well as a synthetic approach.

Compatibility theory

It is proposed that if phonological knowledge at the level of the phoneme advances without wider phonological knowledge (fine and coarse grain) and ahead of the other sources of knowledge (orthographic and morphological), then orthographic representations of sounds in spoken words will develop at incompatible levels (see Figure 1). Brown and Ellis (1994) identified this difficulty, pointing out that although a child may have representations of phonological 'rime' units (intra-syllabic units-coarse grain level) from spoken input, they may have no visual (orthographic) representations of 'rime' letter cluster units stored

Figure 1: The importance of phonology, orthography and morphology as reading and spelling development progresses
The top of the diagram represents the fluent reader and competent speller.



in the lexicon that correspond to the spoken input. This is due to lack of experience of written forms at that level. It should be clear to the reader that these different levels of sound are not at odds with each other; to the contrary, they are complementary interdependent knowledge bases which must interact for effective learning. They are all part of a highly complex and interdependent system, as noted by Goswami (2008, p. 71)

> *'Recommendations concerning direct instruction of phonics need to recognise that English phonology is complex, that English orthography is complex (with varying levels of consistency) and hence teaching might also have to be complex.'*

The findings of Nunes, Bryant and Barros (2012) further support the use of additional approaches to reading and spelling, to compliment the teaching of decoding strategies and further develop literacy skills. The authors found that children's use of larger graphophonic units and of morphemes in reading and spelling made independent contributions to their performance in reading comprehension and fluency. On the basis of their findings, Nunes et al. (2012) also noted that teaching which promotes the development of these different ways of reading and spelling should be included in policy and practice. Furthermore, researchers such as Berninger et al. (2013) and McMurray (2006) found that intervention which includes orthographic strategies and consideration of working memory performance were beneficial in helping students with dyslexia to spell and read in English.

How does orthographic learning take place?

Research evidence has established that phonological awareness is a powerful causal determinant of progress in reading and spelling (Bradley and Bryant, 1983; Goswami and Bryant, 1990). However, tests of preschool phonological sensitivity cannot detect potential later problems in orthographic processing (orthographic processing being defined as amalgamating phonology and orthography at 'coarse grain' level). It is proposed that difficulties in orthographic processing cannot be detected at preschool level because children have insufficient experience of written language (orthography) for orthographic processing difficulties to be identified. If we acknowledge that children require extensive experience of spoken language preschool in order to become sensitive to sounds within the words they hear, then it seems reasonable to suggest that likewise they need significant experience of orthography to become sensitive to (and able to detect) patterns and sequences, and rules and regularities in print. This suggestion is supported by the findings of Booth et al. (2004), which compared neuroimaging data in adults and children. Booth et al. (2004) found evidence of greater activation of the supramarginal/angular gyrus, which the authors note has been attributed to the extraction of statistical rules between orthography and phonology.

From birth to school entry

From birth to school entry, the experience of spoken language is extensive in comparison to preschool experience of orthography (Figure 1). From birth (A) the developing infant responds to words he/she hears. Their rapidly expanding world is full of oral language. However, the child must also develop his/her *understanding* of language which emerges sometime between birth and 2 years of age for the majority of children (B). Vocabulary understanding (the development of morphemic knowledge; words or word parts that form the smallest units of meaning in language) develops from the child's first word (between B and C) and as grammatical understanding develops implicitly, without conscious thought, so one word utterances progress until children, on school entry, are speaking in more complex and grammatically correct sentences (D). Figure 1 illustrates how extensive the experience of the spoken word is compared to the written word (orthography). The dotted line between point E and F in the sections entitled orthography represent exceptional cases of advanced word reading found in children of very high ability but also too in cases of children with exceptionally low ability (IQ less than 50) who are 'hyperlexic' and some children with Down syndrome who can be taught to read from the age of 2 because of their strong visual (orthographic) processing ability (Buckley and Bird, 1993).

Figure 1 is intended to show that on school entry, oral language is the child's most significant knowledge base, and the child is familiar with the sounds of words (implicitly or explicitly). Therefore, phonics-based strategy/strategies (at phoneme/grapheme level) are important and predominant at this stage. Children who have limited sensitivity to sounds will obviously experience difficulties establishing sound–symbol relationships. The development of phonemic awareness must, however, be in judicious balance with word meanings (morphemic knowledge), the structure of language (grammar) and orthographic knowledge (i.e., visual patterns and whole words that allow for automatic retrieval of words when reading and spelling). Figure 1 shows how the importance of these strategies changes as the child develops with age and literacy experience.

Support for the model comes from developmental research which found that multiple interrelated factors are important in reading and spelling development, including oral or spoken language factors (Bowey, 1994; Bowey and Patel, 1988; Dickinson et al., 2003; Speece et al., 1999), orthographic knowledge (Boets et al., 2008; Bowey and Patel, 1988; Chaney, 1998; Devonshire, Morris and Fluck, 2013) and metalinguistic awareness of language structures (Bowey and Patel, 1988; Chaney, 1992, 1994, 1998; Deacon, 2012; Devonshire et al., 2013). In addition, in line with Figure 1, research evidence suggests that the influence of such factors may change with development (Deacon, 2012; Speece et al., 1999; Storch and Whitehurst, 2002; Whitehurst and Lonigan, 1998). What is unclear at present, however, is the precise nature of relationships between

language skills in addition to possible change in the nature of these relationships throughout development. Thus, Figure 1 illustrates the importance of considering phonology, orthography and morphology throughout development, and how relationships between phonology, orthography and morphology change with development.

What can we learn from good and poor spellers?

In a review of comparative research into the spelling performance of good and poor spellers, the findings of Lennox and Siegel (1994) support the view that phonological skills are of primary importance in the development of spelling.

While acknowledging the fundamental importance of phonological skills, it has been further proposed that there is a shift in development from a phonological stage in spelling towards the use of additional skills in literacy development (Ehri, 1986; Frith, 1985; Gentry, 1981, 1982). This shift is recognised by a number of researchers who variously refer to it as a 'transitional stage' (Gentry, 1981, 1982) or 'an orthographic stage' (Frith, 1985) or a 'morphemic stage' (Ehri, 1986) where adults and older children rely on visual patterns and reasoning by analogy.

Lennox and Siegel (1994) investigated this proposed shift in development. It was found that children with normal spelling abilities (i.e., good readers and good spellers) develop visual skills and the use of analogy from exposure to print 'in tandem' with phonological skills. They noted that, however, it is not until spelling development is more advanced that the use of analogy is common. However, those children who were poor spellers but good readers were able to use phonological skills in their spelling but had more difficulty than good readers and spellers in choosing the correct orthographic representation of a word from the phonologically accurate alternatives. This was due to deficits in visual memory and lack of awareness of orthographic patterns. On the other hand, the group of children who were poor readers and poor spellers were found to rely on visual memory skills because they had difficulty using phonological skills.

It is not possible to detect an 'orthographic deficit' (that is the inability to detect patterns in printed words and store them in memory) preschool due to lack of experience of the written word. Indeed Pammer and Vidyasagar (2007, p. 110) recognise that it may be the case that the 'weighting of visual and auditory deficits in pre-readers predicts the relative acquisition of orthographic and phonological skills'.

Children identified as presenting with spelling problems, who rely heavily on spelling by sound, have weak orthographic processing as do children who read in a laboured and pedantic way with heavy emphasis on decoding skills.

Good readers, good spellers

It is proposed that once children begin to read through their increasing experience of the reading process, those children who have strong information processing in all modalities begin to abstract orthographic patterns and rules and regularities from print and internalise these representations in memory. It is argued that the reading process provides 'frequency sensitivity' for this group of '**good readers, good spellers**'. Considerable implicit learning takes place once reading begins, and drawing on these implicit learning abilities they compensate for elements not being explicitly taught. These children will recognise that the vowel sound in 'g**o**', 'sn**ow**', 'n**ote**', 'g**oa**t' and 'th**ough**' is not spelled the same way even though the vowel sound is the same.

Likewise, they will recognise that 'light', 'bright' and 'fright' share the same spelling pattern and that 'write' does not. They can use a 'reasoning by analogy' strategy effectively. This ability to detect patterns in print (orthography) and group these patterns (which are also consistent in the sound they make) in orthographic memory (mental lexicon) ensures that children can recognise whether a spelling 'looks right'. This substantially reduces the load on memory. If you can spell 'man' then you can spell 'ran' by simply changing the initial sound.

Good readers, poor spellers

Good readers and unexpectedly poor spellers, however, have limited ability to detect orthographic patterns in written language. The reason for these unexpected spelling difficulties is that when reading, words encountered in a meaningful context may only be partially processed (Holmes and Carruthers, cited in Shahar-Yames and Share, 2008). Beech and Mayall (2007) provide evidence that the outer features of a word have greater influence on word recognition than the inner features. Good readers, poor spellers may respond to phoneme/grapheme interventions because they need only apply them for the beginning and ends of words when they draw on a 'context facilitation strategy' (Muter, 2006). This improves their reading ability but not their spelling. When task demands dictate the need to process each individual phoneme in a word, this can occur without processing the larger orthographic representation for the whole word or coarse grain clusters of letters within the word. This is because this group has difficulty in the unitisation of sounds. Unitisation (Breznitz, 2006; Ehri, 2005; Ehri and Wilce, 1983; LaBerge and Samuels, 1974) is the ability to process incrementally larger orthographic units (i.e., letters, spelling patterns and whole words) and connect them to semantic and phonological codes in memory.

Poor readers, poor spellers

The final group for consideration are poor readers. Poor readers are also poor spellers, and they experience the greatest difficulty in the acquisition of literacy skills. However, some poor readers, if they have been taught a phonemic strategy, can spell simple consonant-vowel-consonant (CVC) words such as cat or man that they cannot read (Bryant and Bradley, 1980). Words are encoded sound-by-sound (for spelling) or decoded sound-by-sound (for

reading). Consequently, although there may appear to be a promise in these attempts, once spelling and reading leaves this simple CVC stage, the orthographic irregularities of the English language arrest progress. These children are unable to develop their orthographic and phonological processing capabilities because they have very limited experience of print as a consequence of these difficulties. In addition to this when they deem it necessary to process each individual phoneme, one at a time, like the group of 'good readers, poor spellers', this can occur without processing the larger orthographic representation for the whole word or coarse grain clusters of letters within the word. These children, because they have difficulty processing orthographic and phonological knowledge, continue to be poor at spelling often into adult life.

Some poor readers and poor spellers experience extensive difficulties with a synthetic phonic-based approach to reading because they have other compounding difficulties; for example, speech and language difficulties (either specific or general) and/or difficulties in working memory.

Some children with dyslexic-type difficulties also experience difficulty in selecting the correct graphemes from a range of plausible alternatives when spelling (Treiman, 1998), and their spelling difficulties continue long after their reading difficulties are remediated.

The case for frequency sensitivity acquired via learning to spell in aiding the development of orthographic knowledge

The ability to acquire orthographic knowledge is important for automatic word recognition when reading (Baron, 1979; Coltheart et al., 1993, 2001; Forster and Chambers, 1973; Frith, 1986; Morton, 1989) and is of critical importance for spelling development, especially in the later stages (Sprenger-Charolles et al., 2003). This is because fluent reading involves recognition of the word via an orthographic route (Coltheart, 2005), whereas spelling requires full retrieval. Once past the initial stage in development, phonological knowledge alone cannot be relied upon to spell words accurately (Frith, 1985; McMurray, 2004; McMurray, 2006; Treiman and Cassar, 1997). This is due to the high proportion of words in English that are not phonemically regular and sounds that have multiple mappings (Frost, 2012). For many children, identifying and remembering spelling patterns and sequences is easy. The brain can organise and classify words on the basis of sound similarity and orthographic consistency and retrieve them with ease. However, for some children, auditory (sound) and orthographic (visual) processes fail to do this effectively; the brain cannot link effectively the sounds they hear and the orthographic representations they see (Breznitz, 2006; Hasko et al., 2012). Booth et al. (2004) have demonstrated a developmental increase in the activation of the neural region responsible for extraction of statistical regularities between orthography and phonology.

This paper proposes that it is not until the brain has experience of a significant number of visual patterns and sequences consistent in sound and spelling that it can begin to make sense of the common elements in the specific formula (pattern) that make up, for example, rhyme patterns and sequences in general. Each rhyme pattern is different; for example, man, can/got, lot, hot, but rhyme patterns, consistent in sound and spelling, have common elements – that is, same end pattern with changes only in the initial sound. What may be sufficient experience for one child, to abstract these statistical relationships between phonology and orthography, may be insufficient experience for another. Repeated attempts to spell the same rhyme pattern for weeks on end can be unproductive for some children. This may be because repeating the same rhyme pattern over and over again does not supply the brain with sufficient information regarding common elements relating to rhyme patterns in general. The 'formula' remains undiscovered, and without the formula, the appropriate calculations cannot be made to generate the correct spelling (McMurray, 2004). This is further complicated by the need to ensure that semantics (word meanings) mediate output. Word meanings are essential for retrieval from memory – consider the case of homophones their/there, made/maid. Given the working memory difficulties experienced by some children, it is also important that orthographic demands increase incrementally to prevent cognitive overload in the developing reader and speller. This suggestion is in line with recommendations made by Gathercole, Lamont and Alloway (2006) for children with working memory difficulties.

The process of spelling requires attention to letter identity and order and, according to Shahar-Yames and Share (2008, p. 23), 'sub-lexical print to sound relationships in a comprehensive manner'. They contend, therefore, that the process of spelling demands 'the integration of multiple sources of information from several modalities including visual-perceptual, motor-kinesthetic and linguistic information'. Shahar-Yames and Share (2008) point out that the next step for research is to pinpoint the elements in the spelling process that contributes most to orthographic learning. They contend that the process of 'phonological recoding' does not solely comprise of a decoding process through sounding out letter by letter and blending, and instead they suggest that multi-letter sequences may be processed as integral units, either overtly or covertly. Castles and Nation (2008) also draw attention to the need for greater knowledge of what facilitates the transition from slow, effortful alphabetic decoding in words to their rapid and automatic orthographic recognition. Ehri (2005) proposes that orthographic learning is a process involving the memorisation of spelling patterns in words so that words can be retrieved automatically without decoding.

Peters (1992) implicates stochastic memory in spelling development contending that stochastic memory operates at an abstract level in that the probabilities of letters occurring in certain sequences are remembered as the subject becomes

sensitised to these patterns. Aaron, Wilcynski and Keetay (1998) propose that word-specific memory is likely to be memory for intra-word segments within words. They suggest that this type of stochastic memory, although limited, is sufficient to override most of the potential spelling errors caused by inconsistencies between pronunciation and spelling.

> *'Word specific memory is memory for intraword letter patterns conditioned by the frequency of their occurrence in print.'* (Aaron et al., 1998, p. 417)

However, Peters' theoretical perspective is different from the frequency sensitivity proposed here, as Peters' believed this process did not integrate sound. The argument presented in this paper is that orthographic learning is best facilitated when visual patterns are linked to sound regularity at both fine and coarse grain level and meaning is embedded. This is best achieved through the process of learning to spell because these relationships can be explicitly taught. Neuroscientific findings, which have indicated activation of neural pathways responsible for both visual and phonological processing during spelling (Booth et al., 2004; Norton, Kovelman and Petitto, 2007), support this suggestion. It is suggested that if the learning process is structured to ensure interaction between these modalities, effective storage and retrieval from memory can be achieved, thus allowing orthographic learning to take place. Without effective storage, that is representations in the mental lexicon, children do not recognise whether a spelling looks right and phonemically based spelling errors ensue. It is contended that children who are poor at processing orthographic knowledge can be identified by their difficulties in spelling accuracy. This suggestion is supported by the findings of Burt (2006) and McMurray (2006). They have indicated that orthographic coding is an important contributor to spelling accuracy.

Language development linked to frequency sensitivity to patterns and sequences consistent in sound and spelling and irregular high-frequency words taught via a systematic spelling programme is proposed as a key component of orthographic learning. Language development is important, not only for children who have difficulties abstracting rules and regularities from print implicitly but also for children who need to develop their language understanding at word and sentence level. It is contended that the link between usage, meaning, the orthographic features and phonological representation of patterns and sequences and irregular words allows associations between these various sources of knowledge to develop simultaneously, thus ensuring their associations in memory which will ultimately strengthen retrieval. Without this, performance in independent writing will not improve. Many high-frequency words, which do not conform to regular phoneme/grapheme correspondences, are required by children in their earliest attempts at independent writing. For this reason, it is necessary to develop orthographic knowledge for irregular words in the early stages of spelling, even though the predominant strategy is phonetic. It is argued here that orthographic and phonological processes (at all levels) interact throughout development. Therefore, it is not desirable to promote dependence on one strategy to the exclusion of another at any stage in spelling development, as the variation in task demands necessitates the ability to draw on a range of strategies and sources of knowledge, in line with Siegler's (2005) overlapping waves model.

With regard to the challenge of developing effective phonic skills, in addition to the development of frequency sensitivity to sounds and their orthographic representations, patterns and sequences also provide an important vehicle for learning vowel sounds. Vowel sounds present the greatest challenge to young children, particularly vowel digraphs, which Adams (1990) points out, are quite stable within particular rimes. Indeed, Adams (1990) argues that strategies utilise rimes for the translation of vowel sounds. Furthermore, it is the ability to recognise 'rimes' and separate them from the initial 'onset' of a word that facilitates a 'reasoning by analogy' strategy. This reduces the load on working memory (in complex tasks) and the mental lexicon (by reducing number of units requiring storage) and involves interaction between phoneme knowledge and word specific memory (orthography and morphology). Key to our understanding of orthographic learning is the recognition that English orthography is complex and cannot be separated from phonology. Throughout development, orthography and phonology must interact at compatible levels, also taking into account other factors such as limitations in working memory. This suggestion contrasts with stage models of literacy development (Frith, 1985; Larkin and Snowling, 2008), which suggest that children's ability to use strategies are dependent on their discrete stage of development. Critically, this has implications for educators, as it is recommended that connections to language understanding and usage are embedded early in order to promote high-literacy standards for all children. It is also contended that, for children who have difficulties in acquiring orthographic knowledge, it is essential that coarse grain sound–symbol relationships (Ziegler and Goswami, 2005) are explicitly taught. The teaching of spelling provides the opportunity to develop the relationship between sounds, orthography and word meanings (morphemic knowledge), strengthening recall and enhancing application in independent writing. The development of vocabulary understanding also enhances reading for meaning because of wider vocabulary knowledge. Reading fluency may improve because of increased automatic word recognition facilitated by the process of learning to spell.

Conclusion

Education professionals must recognise that the various levels of sounds and orthography discussed here contribute to literacy development in fundamentally different ways and that they are all essential for normal literacy development. However, these various levels of sounds and orthography should not be taught in isolation of the development

of other sources of knowledge such as morphemic knowledge. It is the integration of these various sources of knowledge at the point of learning that promotes the development of literacy skills. Learning to spell facilitates the integration of phonological, orthographic and morphological knowledge. Alphabetic knowledge (knowledge of phoneme–grapheme correspondences) is essential for decoding when reading but is insufficient for spelling and for the development of orthographic knowledge. The development of orthographic knowledge, for children who are poor at detecting orthographic knowledge from reading, can be achieved via learning to spell. Morphemic knowledge aids the development of orthographic knowledge and the selection of the correct graphemes; for example, the spelling rule for adding the morpheme 'ed' to make the past tense of regular verbs. This morphemic rule avoids phonemic spelling errors such as 'landid' for 'landed'. It is important that children have experience of a programme of intervention that enables the interaction of all cognitive processes to facilitate the development and use of all sources of knowledge at compatible levels.

What does this mean for educators: implications for teaching and learning

1. The development of phoneme/grapheme knowledge is essential knowledge for decoding unknown words when reading but is insufficient for the development of orthographic knowledge and spelling.
2. Words spelled with plausible but incorrect graphemes (e.g., sed for said; stue for stew) should be viewed as a warning signal that the child is not storing and applying orthographic knowledge and requires explicit teaching.
3. Phonemic, orthographic and morphemic knowledge should be taught from the very beginning with orthographic and morphemic knowledge gaining in importance and overriding the use of an exclusively phonemic strategy for spelling. This should follow a clear and developmentally appropriate progression which is structured, sequential and cumulative.
4. To enhance the development of orthographic knowledge via frequency sensitivity teaching should provide experience of visual spelling patterns consistent in sound and spelling (e.g., night, fright, bright but **not** stove, glove, prove). This learning will reduce the demands on working memory that many children experience.
5. A new visual spelling pattern should be learned every week so that children become sensitive to common elements in rhyme patterns that are consistent in sound and spelling – that is, same end pattern with changes only in the initial sound. Each rhyme pattern is different; for example, man, can, fan/got, lot, hot, but rhyme patterns, consistent in sound and spelling, have common elements – that is, same end pattern with changes only in the initial sound. Sensitivity to this 'formula' facilitates the development and efficient storage of orthographic knowledge.
6. Associated development of morphemic knowledge supports orthographic learning and effective retrieval. It is well recognised that retrieval from memory is dependent on meaningful associations.
7. Spelling is an excellent vehicle for developing and extending vocabulary understanding and usage.
8. High-frequency irregular words should also be included in teaching and learning. These should be within meaningful combinations that facilitate their immediate application in independent writing.

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References

Aaron, P. G., Wilcynski, S. & Keetay, V. (1998) 'The anatomy of word-specific memory.' In C. Hulme & R. M. Joshi (eds), *Reading and Spelling Development and Disorder*, pp. 405–19. New Jersey, NJ: Lawrence Erlbaum Associates.

Adams, M. J. (ed.) (1990) *Beginning to Read: Thinking and Learning about Print*. Cambridge, Massachusetts: The MIT Press.

Anthony, J. L. & Lonigan, C. J. (2004) 'The nature of phonological awareness: converging evidence from four studies of preschool and early grade school children.' *Journal of Educational Psychology*, 96 (1), pp. 43–55.

Anthony, J. L., Lonigan, C. J., Driscoll, K., Phillips, B. M. & Burgess, S. R. (2003) 'Phonological sensitivity: a Quasi-parallel progression of word structure units and cognitive operations.' *Reading Research Quarterly*, 38 (40), pp. 470–87.

Baddeley, A. D. (1979) 'Working memory and reading.' In P. A. Kolers, M. E. Wrolstad & H. Bouma. (eds), *Processing of Visible Language*. pp. 355–70. New York: Plenum Press.

Baron, J. (1979) 'Orthographic and word specific mechanisms in children's reading of words.' *Child Development*, 50, pp. 587–94.

Beech, J. R. & Mayall, K. A. (2007) 'The word shape hypothesis re-examined: evidence for an external feature advantage in visual word recognition.' In L. Cornelissen & C. Singleton (eds), *Visual Factors in Reading*, pp. 302–19. Oxford: Blackwell Publishing.

Berninger, V. W., Lee, Y., Abbott, R. D. & Breznitz, Z. (2013) 'Teaching children with dyslexia to spell in a

reading-writers' workshop.' *Annals of Dyslexia*, 63 (1), pp. 1–24.

Boets, B., Wouters, J., van Wieringen, A., De Smedt, B. & Ghesquière, P. (2008) 'Modelling relations between sensory processing, speech perception, orthographic and phonological ability, and literacy achievement.' *Brain and Language*, 106 (1), pp. 29–40.

Booth, J. R., Burman, D. D., Meyer, J. R., Gitelman, D. R., Parrish, T. B. & Mesulam, M. M. (2004) 'Development of brain mechanisms for processing orthographic and phonologic representations.' *Journal of Cognitive Neuroscience*, 16 (7), pp. 1234–49.

Bowey, J. A. (1994) 'Phonological sensitivity in novice readers and nonreaders.' *Journal of Experimental Child Psychology*, 58, pp. 134–59.

Bowey, J. A. & Patel, R. K. (1988) 'Metalinguistic ability and early reading achievement.' *Applied Psycholinguistics*, 9, pp. 367–84.

Bradley, L. L. & Bryant, P. E. (1983) 'Categorising sounds and learning to read: a causal connection.' *Nature*, 301, pp. 419–21.

Breznitz, Z. (2006) *Fluency in Reading: Synchronization of Processes*. Mahwah, NJ: Lawrence Erlbaum Associates.

Brown, G. D. A. & Ellis, N. C. (1994) 'Issues in spelling research an overview.' In G. D. A. Brown & N. C. Ellis (eds), *Handbook of Spelling: Theory, Process and Intervention*. pp. 3–25. Chichester: John Wiley and Sons Ltd.

Bryant, P. E. & Bradley, L. (1980) 'Why children sometimes write words which they do not read.' In U. Frith (ed.), *Cognitive Processes in Spelling*. pp. 355–70. London: Academic Press.

Buckley, S. J. & Bird, G. (1993) 'Teaching children with Down syndrome to read.' *Down Syndrome Research and Practice*, 1 (1), pp. 34–9.

Burt, J. S. (2006) 'Spelling in adults: the combined influences of language skills and reading experience.' *Journal of Psycholinguistic Research*, 35 (5), pp. 447–70.

Castles, A. & Nation, K. (2008) 'Learning to be a good orthographic reader.' *Journal of Research in Reading*, 31 (1), pp. 1–7.

Chaney, C. (1992) 'Language development, metalinguistic skills, and print knowledge in 3-year-old children.' *Applied Psycholinguistics*, 13, pp. 485–514.

Chaney, C. (1994) 'Language development, metalinguistic awareness, and emergent literacy skills of 3-year-old children in relation to social class.' *Applied Psycholinguistics*, 15, pp. 371–94.

Chaney, C. (1998) 'Preschool language and metalinguistic skills are links to reading success.' *Applied Psycholinguistics*, 19, pp. 433–46.

Coltheart, M. (2005) 'Modeling reading: the dual-route approach.' In M. J. Snowling & C. Hulme (eds), *The Science of Reading: A Handbook*. pp. 6–23. Oxford: Blackwell.

Coltheart, M., Curtis, B., Atkins, P. & Haller, M. (1993) 'Models of reading aloud: dual-route and parallel-distributed-processing approaches.' *Psychological Review*, 100 (4), pp. 589–608.

Coltheart, M., Rastle, K., Perry, C., Langdon, R. & Ziegler, J. (2001) 'DRC: a dual route cascaded model of visual word recognition and reading aloud.' *Psychological Review*, 108 (1), pp. 204–56.

Corcos, E. & Willows, D. M. (1993) 'The processing of orthographic information.' In D. M. Willows, R. S. Kruk & E. Corcos (eds), *Visual Processes in Reading and Reading Disabilities*. pp. 163–90. Hillsdale, NJ: Lawrence Erlbaum Associates.

Deacon, S. H. (2012) 'Sounds, letters and meanings: the independent influences of phonological, morphological and orthographic skills on early word reading accuracy.' *Journal of Research in Reading*, 35 (4), pp. 456–75. doi: 10.1111/j.1467-9817.2011.01496.x; Early view article.

Devonshire, V., Morris, P. & Fluck, M. (2013) 'Spelling and reading development: the effect of teaching children multiple levels of representation in their orthography.' *Learning and Instruction*, 25, pp. 85–94.

Dickinson, D. K., McCabe, A., Anastasopoulos, L., Peisner-Feinberg, E. S. & Poe, M. D. (2003) 'The comprehensive language approach to early literacy: the interrelationships among vocabulary, phonological sensitivity, and print knowledge among preschool-aged children.' *Journal of Educational Psychology*, 95 (3), pp. 465–81.

Duff, F. J., Hayiou-Thomas, M. E. & Hulme, C. (2012) 'Evaluating the effectiveness of a phonologically based reading intervention for struggling readers with varying language profiles.' *Reading and Writing*, 25 (3), pp. 621–40.

Ehri, L. (1986) 'Sources of difficulty in learning to spell and read.' In M. Wolraich & D. K. Routh (eds), *Advances in Behavioral Paediatrics*. pp. 121–95. London, CT: JAI Press Inc.

Ehri, L. (2005) 'Development of sight word reading: phases and findings.' In M. J. Snowling & C. Hulme (eds), *The Science of Reading: A Handbook*. pp. 135–54. Oxford: Blackwell.

Ehri, L. C. & Wilce, L. S. (1983) 'Development of word identification speed in skilled and less skilled beginning readers.' *Journal of Educational Psychology*, 75, pp. 3–18.

Forster, K. I. & Chambers, S. M. (1973) 'Lexical access and naming time.' *Journal of Verbal Learning and Verbal Behavior*, 12, pp. 627–35.

Frith, U. (1985) 'Beneath the surface of dyslexia.' In K. E. Patterson, J. C. Marshall & M. Colheart (eds), *Surface Dyslexia: Neuropsychological and Cognitive Studies of Phonological Reading*. pp. 301–30. Hillsdale, NJ: Lawrence Erlbaum.

Frith, U. (1986) 'A developmental framework for developmental dyslexia.' *Annals of Dyslexia*, 36, pp. 69–81.

Frost, R. (2012) 'Towards a universal model of reading.' *The Behavioral and Brain Sciences*, 35 (5), pp. 263–329.

Gathercole, S. E. & Alloway, T. P. (2008) *Working Memory and Learning A Practical Guide for Teachers*. London: Sage.

Gathercole, S. E. & Baddeley, A. D. (1993) *Working Memory and Language*. Hove: LEA.

Gathercole, S. E., Lamont, E. & Alloway, T. P. (2006) 'Working memory in the classroom.' In G. D. Phye & S. J. Pickering (eds), *Working Memory and Education*. pp. 220–38. London: Academic Press.

Gentry, J. R. (1981) 'Learning to spell developmentally.' *Reading Teacher*, 34 (4), pp. 378–81.

Gentry, J. R. (1982) 'An analysis of developmental spelling in GNYS AT WORK.' *Reading Teacher*, 36, pp. 192–200.

Goswami, U. (2008) 'Reading, complexity and the brain.' *Literacy*, 42, pp. 67–74.

Goswami, U. & Bryant, P. (eds) (1990) *Phonological Skills and Learning to Read*. Hove: Lawrence Erlbaum.

Hasko, S., Bruder, J., Bartling, J. & Schulte-Körne, G. (2012) 'N300 indexes deficient integration of orthographic and phonological representations in children with dyslexia.' *Neuropsychologia*, 50 (5), pp. 640–54.

Juel, C. & Minden-Cupp, C. (2000) 'One down and 80,000 to go: word recognition instruction in the primary grades.' *The Reading Teacher*, 53, pp. 332–5.

LaBerge, D. & Samuels, S. J. (1974) 'Towards a theory of automatic information processing in reading.' *Cognitive Psychologist*, 6, pp. 293–323.

Larkin, R. F. & Snowling, M. J. (2008) 'Comparing phonological skills and spelling abilities in children with reading and language impairments.' *International Journal of Language & Communication Disorders*, 43 (1), pp. 111–24.

Lennox, C. & Siegel, L. S. (1994) 'The role of phonological and orthographic process in learning to spell.' In G. D. A. Brown & N. C. Ellis (eds), *Handbook of Spelling: Theory, Process and Intervention*. pp. 93–109. Chichester: John Wiley & Sons Ltd.

Lonigan, C. J., Purpura, D. J., Wilson, S. B., Walker, P. M. & Clancy-Menchetti, J. (2013) 'Evaluating the components of an emergent literacy intervention for preschool children at risk for reading difficulties.' *Journal of Experimental Child Psychology*, 114 (1), pp. 111–30.

McMurray, S. (2004) Learning to Spell, unpublished Ph.D. thesis, Queens University, Belfast.

McMurray, S. (2006) 'Learning to spell: raising standards in spelling and independent writing.' *Support for Learning*, 21 (2), pp. 100–7. Wiley Blackwell.

Morton, J. (1989) 'An information-processing account of reading acquisition.' In A. M. Galaburda (ed.), *From Reading to Neurons*. pp. 43–66. Cambridge, MA: MIT Press.

Muter, V. (2006) 'The prediction and screening of children's reading difficulties.' In M. Snowling & J. Stackhouse (eds), *Dyslexia: Speech and Language*. pp. 54–73. London: Whurr Publishers.

Norton, E. S., Kovelman, I. & Petitto, L. (2007) 'Are there separate neural systems for spelling? New insights into the role of rules and memory in spelling from functional magnetic resonance imaging.' *Mind, Brain, and Education*, 1 (1), pp. 48–59.

Nunes, T., Bryant, P. & Barros, R. (2012) 'The development of word recognition and its significance for comprehension and fluency.' *Journal of Educational Psychology*, 104 (4), pp. 959–73.

Pammer, K. & Vidyasagar, T. R. (2007) 'Integration of visual and auditory networks in dyslexia: a theoretical perspective.' In L. Cornelissen & C. Singleton (eds), *Visual Factors in Reading*, pp. 105–16. Oxford: Blackwell Publishing.

Peters, M. L. (1992) 'Towards spelling autonomy.' In C. M. Sterling & C. Robson (eds), *Psychology, Spelling and Education*, pp. 220–3. London: Multilingual Matters Ltd.

Shahar-Yames, D. & Share, D. L. (2008) 'Spelling as a self-teaching mechanism in orthographic learning.' *Journal of Research in Reading*, 31 (1), pp. 22–39.

Siegler, R. S. (2005) 'Children's learning.' *The American Psychologist*, 60 (8), pp. 769–78.

Slavin, R. E., Lake, C., Davis, S. & Madden, N. A. (2011) 'Effective programs for struggling readers: a best-evidence synthesis.' *Educational Research Review*, 6 (1), pp. 1–26.

Speece, D. L., Roth, F. P., Cooper, D. H. & De La Paz, S. (1999) 'The relevance of oral language skills to early literacy: a multivariate analysis.' *Applied Psycholinguistics*, 20 (02), pp. 167–90.

Sprenger-Charolles, L., Siegel, L. S., Béchennec, D. & Serniclaes, W. (2003) 'Development of phonological and orthographic processing in reading aloud, in silent reading, and in spelling: a four-year longitudinal study.' *Journal of Experimental Child Psychology*, 84 (3), pp. 194–217.

Storch, S. A. & Whitehurst, G. J. (2002) 'Oral language and code-related precursors to reading: evidence from a longitudinal structural model.' *Developmental Psychology*, 38 (6), pp. 934–47.

Thomson, M. (ed.) (2009) *The Psychology of Dyslexia: A Handbook for Teachers*. Oxford: Wiley Blackwell.

Treiman, R. (1998) 'Beginning to spell in English.' In C. Hulme & R. M. Joshi (eds), *Reading and Spelling: Development and Disorders*, pp. 371–94. Hillsdale, NJ: Lawrence Erlbaum Associates.

Treiman, R. & Cassar, M. (1997) 'The beginnings of orthographic knowledge: Children's knowledge of

double letters in words.' *Journal of Educational Psychology*, 89 (4), pp. 631–44.
Tulving, E. & Thompson, D. M. (1973) 'Encoding specificity and retrieval processes in episodic memory.' *Psychological Review*, 80, pp. 352–73.
Turner, M. & Bodien, P. (eds) (2007) *Dyslexia Guidance: Helping Pupils with Specific Learning Difficulties in Reading and Writing*. London: nfer Nelson.
Tweedy, J. R., Lapinski, R. H. & Schvaneveldt, R. W. (1977) 'Semantic-context effects on word recognition: influence of varying the proportion of items presented in an appropriate context.' *Memory and Cognition*, 5 (1), pp. 84–9.
Whitehurst, G. J. & Lonigan, C. J. (1998) 'Child development and emergent literacy.' *Child Development*, 69 (3), pp. 848–72.
Ziegler, J. C. & Goswami, U. (2005) 'Reading acquisition, developmental dyslexia, and skilled reading across languages: a psycholinguistic grain size theory.' *Psychological Bulletin*, 131 (1), pp. 3–29.