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Elbro, C.; de Jong, P.F.

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The role of spelling pronunciations

Carsten Elbro and Peter F. de Jong
University of Copenhagen / University of Amsterdam

Looking depends on what we know about the things we look at. The novice botanist may look at a broken twig, while the zoologist sees an insect "walking stick". Similarly, looking at letters in a foreign alphabet is looking at squiggles, whereas looking at familiar letters is *looking at sounds*, because that is what the letters stand for. Learning to decode written words is learning to see *through* the written letters and activate the sounds and words that they represent. In this chapter we explore what this way of looking can tell one about reading words and learning to read words. We simply consider learning to read as a kind of verbal learning, i.e. *learning new phonological material*, and we explore how this new material is used to access existing words in the reader's mental lexicon. This section presents a brief overview of the chapter.

For beginning readers, deciphering written words is a slow and effortful process as they lack the orthographic knowledge to identify words immediately from their written form (as "sight words"). As a result, beginning readers depend on phonological re-coding (Figure 1). That is, beginning readers have to associate the individual letters with their standard sounds in a serial manner and somehow attempt to connect the resulting string of sounds to an existing spoken word (phonological representation) in their vocabulary (Marinus & de Jong, 2010; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003; Zoccolotti et al., 2005).

In the example in Figure 1, the beginning reader sees the printed word *was* and associates the letters *w*, *a* and *s* with the sound sequence "w", "æ" (as in *cat*), "s" formed of the standard sounds of each letter. This leaves the beginner with the "spelling pronunciation" "wæs", which is not a word. And the beginner may get stuck there. With the help of others, the sentence context, or guessing, the beginner may be able to activate the standard pronunciation "woz" and thus recognise the word *was*. The re-coded form of a word, its *spelling pronunciation*, may not be identical to its standard spoken form, although often close enough to find the correct pronunciation (Elbro, de Jong, Houter, & Nielsen, 2012).

This re-coding to identify written words requires various kinds of verbal learning. Firstly, the beginner has to learn the standard letter sounds (Byrne, 1998). That is no trivial matter because the sounds do not mean anything. The sounds are – at best – single segments of spoken language which are of little practical use to children before they learn to read. That is why it is helpful for pre-readers to become aware of these segments of

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speech, i.e. to acquire some degree of phoneme awareness (Section 2). The learning of letter sounds and (gradually) the sounds of frequent letter patterns (such as *re*, al, and *-ing*) is a core aspect of verbal learning in reading development (Section 3). Letter sounds have to be learned so well that they can be produced (recalled) when the reader looks at the corresponding letters. It is not enough that the letter sounds can be recognised. This demand for production-quality letter sound learning is one that is taxing for some children and that may continue to put constraints on their reading development (Section 4).

The decoding of words becomes easier as their spelling pronunciations are learned. Learning to recognise spelling pronunciations is a much less commonly considered kind of verbal learning in reading (Section 5), though it is well documented that learning written words influences the reader's phonological representation of them. Spelling pronunciations are either learned on an individual word basis – or as a "dialect", i.e., a systematic alternative to standard word pronunciations. In our view spelling pronunciations are an intermediate step between the written form of a word and its standard pronunciation. Fluent, automatized word decoding is possible when whole written words activate the stored pronunciation(s) in the reader's lexicon (Figure 2). We suggest that the formation of spelling pronunciations is an intermediate developmental step between letter-sound decoding and 'sight word' reading which is an accurate way of looking at what is usually called "orthographic" whole word learning (Section 6).

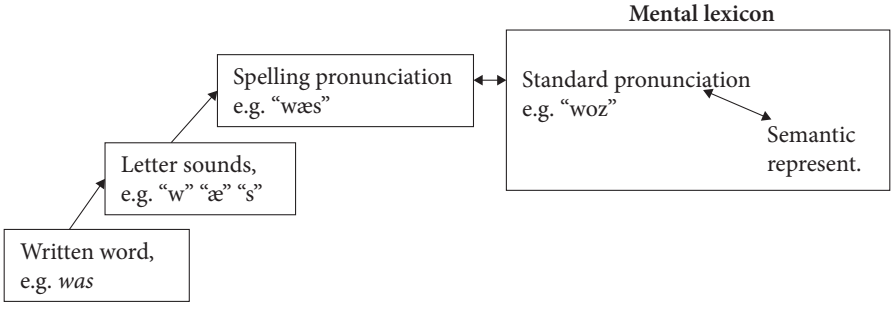

Figure 1. Verbal learning in initial reading development comprises letter sounds and spelling pronunciations of words.

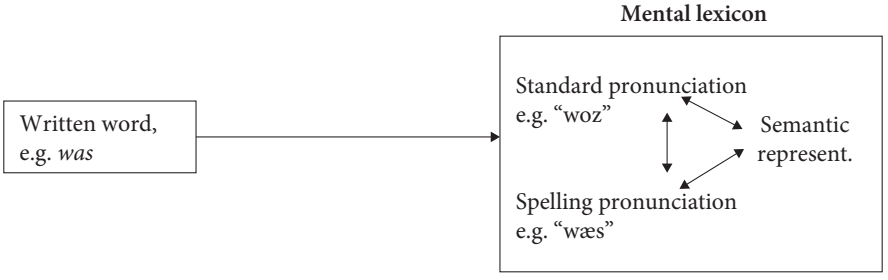

Figure 2. Automatised word recognition based on parallel activation of phonological representations of the corresponding word in the mental lexicon.

Learning the segments of speech

Writing systems represent spoken language in various ways. Alphabetic writing systems use letters to represent sound segments of phoneme size. Other systems represent syllables or morphemes by units of writing (see e.g., Nag, this volume, and McBride, this volume). In order for children to come to grips with the particular units of writing, it is a great advantage if they have some level of awareness of the corresponding units of spoken language. Thus, for learning to read a morphemic writing system, some awareness of the morphemes of the spoken language is helpful (e.g., McBride-Chang et al., 2011). Similarly, for learning to read in an alphabetic language, it is helpful to be aware of the sound segments of phoneme size of the spoken language, i.e., to have some degree of phonemic awareness (e.g., Liberman, Shankweiler, Fisher, & Carter, 1974). For example, the awareness of the three sound segments in "bus" makes it a lot easier to understand why the written word has three letters.

Phonemic awareness is typically assessed by tasks such as phoneme identification ("which of these words has the sound "m" as in *milk*? Show pictures of cat, mouse, cereal." Expected choice: *mouse*), phoneme deletion ("try to say *mall* without the "m". Expected answer: "all"), or phoneme reversal or spoonerism ("try to swap the first sounds of these words "mill bee"". Expected answer: "Bill me"). Such tasks require that the participant can detach from the word meaning and turn their attention towards the sound segments of the word. Most pre-school children can spot a mispronunciation, some can identify words that contain certain speech sounds, but few can manipulate individual speech sounds.

Obviously, learning to read provides a great opportunity to become aware of speech sounds. More importantly, the relationship between phonological awareness and reading is one of reciprocal causation. There is abundant evidence that phonological awareness is, indeed, a foundational ability for learning to read in alphabetic languages (e.g., Byrne, 1998; Ehri, 2005; National Early Literacy Panel, 2008). Numerous studies have now established that phonological awareness has a causal effect on beginning reading development (de Jong & van de Leij, 1999; Lervåg, Bråten, & Hulme, 2009; Wagner et al., 1997). Phonological awareness at pre-school is a strong predictor of reading problems later (e.g., Elbro & Scarborough, 2004a; van Bergen, de Jong, Plakas, Maassen, & van der Leij, 2012). Phonological awareness is generally impaired in both children and adults with reading problems (e.g., Elbro, Nielsen & Petersen, 1994; Moll, Loff, & Snowling, 2013), and fostering phonological awareness can indeed help to alleviate these problems (e.g., Elbro & Petersen, 2004; Elbro & Scarborough, 2004b; Snowling & Hulme, 2012).

The foundations of phonological awareness are much less studied than its development and consequences. When children have difficulties with phoneme awareness, one possible cause is that their mental representations of the words are somehow weakened or difficult to access (Elbro, 1996; Metsala & Walley, 1998). It is, of course, hard to analyse spoken words that are not very clear in the mind. There is evidence that children's initial difficulties in reading can be partly predicted by how well specified the children's representations are of phonologically complex words such as *crocodile*,

library, and *chocolate* (Elbro, Borstrøm, & Petersen, 1998; Snowling, 2000). When naming such words, children at-risk are more likely than not-at-risk children to omit syllables and consonants from consonant clusters. Similarly, children with reading difficulties are less able than others to detect and correct slight errors of pronunciation (Fowler & Swainson, 2004). The quality of phonological representations also tends to affect a wider range of phonological abilities that have been found to be related to reading acquisition (Elbro & Jensen, 2005; Snowling, 2000).

However, the prediction value is higher in known at-risk groups, such as children of dyslexic parents (Elbro et al., 1998) and children with speech language impairments (Anthony et al., 2011), than in unselected groups. This means that low quality phonological representations are usually not enough to place children at serious risk for reading disabilities. It is more likely that the quality of phonological representations reflect other aspects of phonological processing that are closer related to reading acquisition. One such aspect is verbal learning, i.e., the acquisition of phonological representations (e.g. Ramus & Szenkovits, 2008).

Letter-sound learning

Letter-sound knowledge is evidently of vital importance for being able to read an alphabetic orthography because letters (graphemes) represent the sound segments (phonemes) of words. Not surprisingly, pre-literate children's knowledge of letter names and letter sounds is the single strongest predictor of their future reading development (Elbro & Scarborough, 2004a). The strong predictive relationship has been found in many alphabetic orthographies (Caravolas, Lervåg, Defior, Málková, & Hulme, 2013; de Jong & van der Leij, 1999; Lervåg et al., 2009; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004). Conversely, impairments in the development of letter knowledge have been reported many times in children that turned out to become dyslexic (de Jong & van der Leij, 2003; Elbro et al., 1998; van Bergen, de Jong, Maassen, & van der Leij, 2014; Torppa, Lyytinen, Erskine, Eklund, & Lyytinen, 2010). The sources of these important individual differences in letter knowledge are much less well known. This section provides an overview and a hypothesis.

Learning the names and sounds of letters has traditionally been regarded as a form of visual-verbal paired associate learning (PAL) in which a visual symbol has to be paired with a spoken form. In line with dyslexic children's problems in the acquisition of letter knowledge, there is a wealth of studies showing visual-verbal PAL deficits in dyslexic readers when visual stimuli have to be associated with novel phonological forms such as nonwords (e.g., Elbro & Jensen, 2005; Litt & Nation, 2014; Messbauer & de Jong, 2003; Vellutino, Steger, & Pruzek, 1973; Windfuhr & Snowling, 2001).

However, a particular characteristic of letters is that they have both a name and a sound that are often learned in a specific order. For example, in North America children usually acquire letter name knowledge before learning the sounds of the letters. Consequently, letter name learning can be regarded as visual-verbal learning but letter

sound acquisition seems more dependent on verbal-verbal learning. More generally, the first label (name or sound) is probably learned by visual-verbal learning and the second, at least to some extent, by *verbal-verbal* learning (see Ellefson, Treiman, & Kessler, 2009). Measures of letter knowledge often ask for both letter sound and letter name knowledge (but see McBride-Chang, 1999), therefore they usually reflect a mixture of visual-verbal and verbal-verbal learning.

The role of verbal-verbal learning in letter sound acquisition has been demonstrated in a number of studies testing the hypothesis that letter-name knowledge facilitates letter-sound learning (Share, 2004; Treiman, Tincoff, Rodriguez, Mouzaki, & Francis, 1998). Children are expected to learn letter sounds faster if they know the letter names. The hypothesis rests on the observation that many letter names contain the sound of the letter, such as "bee" for *b* and "es" for *s*, though a few letter names, *h* and *y*, do not. Accordingly, children's knowledge of letter sounds that are embedded in the letter name is stronger than their knowledge of letter sounds that are unrelated to their letter name (Huang, Tortorelli, & Invernizzi, 2014; Kim, Petscher, Foorman, & Zhou, 2010; Treiman et al., 1998). Further support for the hypothesis comes from a number of experimental studies (Cardoso-Martins, Mesquita, & Ehri, 2011; Levin, Shatil-Carmon, & Asif-Rave, 2006; Piasta & Wagner, 2010; Share, 2004). For example, in Share's (2004) study children's letter-sound learning in the experimental condition was preceded by learning to associate letter names with letter-like visual symbols. In the control condition the visual symbols were paired first to meaningful words that did not contain the letter-sounds to be learned next. The results showed that children in the experimental condition learned more letter-sounds but only when the sounds were embedded in the previously learned letter names. Later studies have reported similar results.

In several countries letter name learning does not precede letter-sound learning. For example in the Netherlands and the UK, knowledge of letter names is relatively low before the start of reading instruction, which starts with the learning of the letter sounds. One might think that in this situation letter-sound acquisition requires the rote learning of letter-sound associations. However, this is far from always the case. Teacher experience has led to instructional methods in which a letter's sound is learned in conjunction with a known word that contains the sound. For example, the letter sound "b" is associated with the first sound in *bear*. De Jong (2007) showed that kindergartners use this phonological similarity in the paired associate learning of letters and sounds. In his study, children were taught the associations between unknown letter-like symbols and familiar words before they had to learn the sounds that were paired to these symbols. In one condition, the first sound of a word corresponded to the letter sound that had to be associated to the symbol. In the other condition the sound was not in the word. The results were clear: Letter sound acquisition was facilitated when the letter sound was embedded in the familiar word.

Learning written sounds well enough to recall them

The previous section demonstrated that letter sound learning poses demands on both visual-verbal and verbal-verbal learning. This raises the question about which type of learning is more strongly related to reading development. This section reviews the evidence and suggests an explanation.

Hulme and colleagues (Hulme, Goetz, Gooch, Adams, & Snowling, 2007; Warmington & Hulme, 2012) suggested that the crossmodal aspect, i.e., the establishment of visual-verbal associations, is responsible for the relationship between letter sound learning and learning to read. In their view, visual-verbal paired associate learning (visual-verbal PAL) may tap a unique crossmodal learning mechanism. The same mechanism is presumed to be involved in 'learning to map letter strings onto pronunciations' (Warmington & Hulme, 2012, p. 58). In support of their view, they showed that visual-verbal PAL, i.e., learning to pair novel words to visual symbols, was a unique predictor of reading whereas the unimodal verbal-verbal and visual-visual PAL was not (Hulme at al., 2007). These results suggest that it is the crossmodal aspect and not the verbal learning aspect that may be the more important aspect of letter sound learning for its relationship with reading.

However, more recently Litt and colleagues (Litt, de Jong, van Bergen, & Nation, 2013; Litt & Nation, 2014) have provided evidence that casts doubt on the crossmodal account of the PAL-reading relationship. Hulme et al. (2007) only used visual-verbal PAL to tap crossmodal learning. Litt et al. (2013) reasoned that if the ability to establish crossmodal associations is the common factor of PAL and reading, then verbal-visual PAL should also be related to reading. In a study including all four PAL mapping conditions, this was not found. Neither verbal-visual PAL nor visual-visual PAL were related to children's reading ability. In both of these conditions, the children were asked to *draw* letter-like shapes in response to what they heard or saw. In contrast, the relationships of visual-verbal and verbal-verbal PAL with reading were substantial. In both of these conditions, the children were asked to *say* the (new, monosyllabic) names corresponding to what they saw or heard. Moreover, Litt et al. (2013) did not find an advantage of visual-verbal PAL over verbal-verbal PAL in the prediction of reading. These results suggest that it is the acquisition of *novel phonological representations*, as revealed by the verbal output demand, that counts in the relationship between PAL and reading.

Further support for the verbal learning explanation – rather than the crossmodal hypothesis – was reported by Litt and Nation (2014) in a study with children with dyslexia. Clear PAL deficits were found when PAL tasks required a verbal output, but not when the output was visual. To further pinpoint the locus of the children's deficit in PAL tasks with a verbal output, Litt and Nation separated the verbal learning and associative learning part of the task. In a verbal pre-exposure phase, novel words were practiced by rehearsal and repetition. During this phase several free recall trials were given to measure the knowledge of the novel words. In the next phase, the novel words had to be associated with visual stimuli. As expected, the children with dyslexia acquired the

novel words more slowly than did the control children. More importantly, the lower performance of the children with dyslexia in the subsequent visual-verbal PAL task could be fully accounted for by their preceding verbal learning performance – confirming a deficit in phonological form learning (Litt & Nation, 2014).

On closer inspection, even the verbal-visual learning task (draw the character that represents the spoken sound) requires verbal learning to some degree. The child has to *recognise* the spoken word in order to be able to produce (draw) the correct letter-like shape. This recognition contrasts with the need for *recall* of the spoken sound in the verbal learning conditions (visual-verbal and verbal-verbal). Hence, the difference between the verbal and the visual learning PAL-tasks may reside with *the strength* of the new verbal representation in the mental lexicon. What is important for learning to read is the acquisition of novel verbal representations which are *so strongly represented* that they will allow for recall and active production. This makes immediate sense as far as letter sounds are concerned: children need to be able to produce the sounds of letters and letter sequences as they encounter them in print. However, there is a further need for verbal learning in reading. That is a topic of the next section.

Learning spelling pronunciations

Beginning word recognition via spelling pronunciations

Anyone who has listened to a beginning reader will have noticed that the beginner sometimes sounds out a word but fails to recognise it. This can easily happen with irregularly spelled words when each letter is given a standard pronunciation. The beginner may spell out "l" "i" "s" "t" "e" "n" and get stuck with the syllables "list" and "en" or "lis" and "ten" or with the full form "lis*t*en" with an audible "t". Problems may be caused not only by silent letters as in *lis**t**en*, *t**w**o*, *is**l**and*, *han**d**some* etc., but also by unusual letter sounds, as in *ha**v**e*, *o**n**e*, and *pi**n**t*. In addition, complex graphemes, such as *ng* (e.g., *sing*), *ou* (*house*), *sch* (*school*) etc., are a challenge to beginning readers because they have more than one letter per speech sound, even though some complex graphemes may be perfectly regular (Elbro, 2005).

Beginners can even get stuck when reading regularly spelled words. A beginner may read "hh" "oo" "dd" and blend the letter sounds correctly into "hhoodd", but still fail to recognise *hood* immediately. This is because the sum of the letter sounds is not the same as the whole word. When speech sounds are strung together, they are co-articulated to allow for a smooth and rapid pronunciation. This means that some features of sounds spill over into the following sounds, and the following sounds are anticipated in the pronunciations of those that come before. For example in *hood*, the "oo"-sound is pronounced with rounded lips. Because of co-articulation, the initial "h" is also rounded. In contrast, *hid* is pronounced with an unrounded "ee"-vowel, so by co-articulation, the "h" in *hid* is unrounded. Indeed, the "h" sound is produced in rather different ways in the two words. Similar effects apply to other speech sounds: they are pronounced differently

and sound different in different sound contexts. Segments of speech sounds are not constant (Liberman, 1992). Consequently, blending sounds together is not possible just by articulating them rapidly one after another (Venezky, 1972).

Difficulties with "blending" letter sounds into a recognisable phonological whole raise the question how beginners recognise words from *spelling pronunciations* – that is, from an assembled pronunciation based on standard sounds for each letter. One possibility is that the spelling pronunciation somehow activates the correct existing phonological representation (see Figure 1).

A spelling pronunciation may be viewed as a stepping stone between the orthographic representation of a word and its standard pronunciation. Once the basic orthographic code has been learned, it is by definition a straightforward matter to arrive at the spelling pronunciation of any written word. Similarly, in spelling, it is a straightforward matter to spell words correctly once their spelling pronunciations have been retrieved from memory. What remains to be explained is how readers connect spelling pronunciations to standard lexical pronunciations. Beginning readers have to associate the novel sound pattern, the spelling pronunciation, with an existing pronunciation in the phonological lexicon. This association requires some degree of phonological flexibility.

There is now some evidence that recognition of spelling pronunciations is a unique correlate of beginning reading. In one study, Dutch children in grade 1 were presented with spoken spelling pronunciations and asked to say the words correctly (Elbro et al., 2012, study 1). Individual variation in the children's ability to recognise the words predicted significant variance in their word reading accuracy. Importantly, this prediction was still substantial and significant even after controlling for other precursors: vocabulary, phonological awareness, and rapid automatized naming (RAN). This study does not solve the question of causal direction: indeed, it is likely that success in beginning to read is a source of learning spelling pronunciations. However, in a longitudinal study, Danish pre-school children's recognition of slightly mispronounced words was found to be a unique predictor of the children's initial success in learning to read words (Elbro et al., 2012, study 2).

In both studies spoken word recognition despite slight mispronunciations predicted reading of *both* regular *and* irregular words. So it is *not* the case that initial reading of only irregularly spelled words require phonological flexibility (or 'set for variability', Tunmer & Chapman, 2012). Regularly spelled words may also require phonological flexibility because of the fundamental difficulty (or impossibility) of letter sound "blending" described above.

It is beyond the scope of this chapter to present a detailed account of how spelling pronunciations are recognised as already known words. One possibility is that the association is done by means of a kind of attractor network (as proposed by Harm and Seidenberg, 1999, and Harm, McCandliss, & Seidenberg, 2003). In such a network, existing phonological representations (the sounds of known words) work like individual magnets on incoming spoken words. Hence, incoming words will be attracted to (and activate) the word in the mental lexicon that has the closest resemblance – no matter

whether words are heard or generated by print. In any case, hearing and recognising words in different accents and dialects is an everyday occurrence – nothing special to reading.

Spelling pronunciations in the mental lexicon

In the section above we presented evidence for the importance of verbal learning (rather than cross-modal association) for learning letter sounds. In this section, we suggest that learning to recognise written words is also a form of verbal learning. The important parts to be learned are spelling pronunciations, not the visual word forms. The spelling pronunciations are what the reader should see through the written word forms.

We suggest that readers *learn* spelling pronunciations as alternative (variant) phonological representations in addition to the familiar spoken ones that are already stored in their mental lexicon. So, for example, a reader who comes across the printed word *answer* may form a phonological representation "ans*w*er" that contains a "w" sound in addition to the already familiar representation "arnser". Similarly *Egypt* may be stored as "eg-yipt" in addition to the familiar "eedjipt" (Oakhill, 1960).

This suggestion may sound unnecessarily cumbersome at first. One might ask why beginning readers would take the trouble to learn additional phonological representations rather than just remembering the way words look. Apart from the general answer that the quality of looking depends on the knowledge of the object (a spoken word form), a more specific answer comes in three parts. First, there is sheer necessity: not only does learning spelling pronunciations greatly simplify learning the orthography with all its irregularities, it also makes letter sound "blending" possible at all. In addition, knowing a spelling pronunciation greatly supports spelling. The second part of the answer is that learning variant pronunciations of words is very common and not as cumbersome as it may sound. After all, various variants of one's spoken language – different dialects, sociolects, accents, age-related variants etc. – are usually comprehensible after a few exposures. Human beings have a facility for learning spoken languages (e.g., Pinker, 1994), and that facility can be utilised for learning the "dialect" of spelling pronunciations. The third part of the answer is that there is evidence that readers do learn spelling pronunciations as they see how words are written. This evidence is presented next.

Proficient *spellers* consciously rely on spelling pronunciations when they spell at least some irregular words. They recall the sound of a word as if it were spelled regularly (e.g., "ans*w*er", "sa*l*mon", "*i*sland") and then just spell the word by ear. Such a strategy can be taught with positive effects on spelling accuracy. An early study by Drake and Ehri (1984) found an advantage for practising spelling pronunciations (called "careful pronunciations") over standard pronunciation in 10-year-olds as a means of learning to spell words correctly. Similar positive effects of learning spelling pronunciations on spelling irregular words have been reported more recently by Hilte, Bor, and Reitsma (2005), Hilte and Reitsma (2006), and Thaler, Landerl, and Reitsma (2008).

It is not only a few idiosyncratic or trained words that have stored spelling pronunciations. Research on phonological representations suggest that orthography has a profound impact on how adults represent words in the mental lexicon. A number of experiments by Ranbom and Connine (2011) provided evidence that adult readers store spelling pronunciations as lexical phonological representations even though they have not been trained. The authors demonstrated that spoken words that are spelled with "silent letters" (e.g. the *t* in *castle*) have additional lexical phonological representations that contain the sounds of the silent letters, so-called "orthographically supported mispronunciations." For example, in a same/different judgement task, good readers made many errors (23%) with spoken word pairs like "casle" – "cas*t*le" (*castle*), i.e., when the deviant pronunciation ("castle") was supported by a silent letter (a spelling pronunciation) with an audible "t"-sound. By comparison, the good readers made a lot fewer errors (6%) with similar word pairs that were not supported by a spelling pronunciation (e.g. "hasle" and "hastle") (*hassle*) – and just as few errors when the words with silent letters were turned into nonwords by stripping off the initial consonant ("asle" – "astle"). Similarly, a priming experiment with lexical decision indicated that priming with a spoken spelling pronunciation like "cas*t*le" provided *as strong* a priming effect as priming with the standard pronunciation ("casle") for the ensuing lexical judgement of the written word, *castle*. In contrast, the priming effect of hearing "hastle" on the written word *hassle* was significantly lower. Ranbom and Connine (2011) argued that the spelling pronunciation is an *additional* phonological representation that is learned as a by-product during literacy development when students spell out words.

Lexical representations of spelling pronunciations are not limited to words that have written forms with additional segments (such as "silent" letters) but can also represent features not present in standard spoken forms but supported by the written form. One example is the "t"-sound in words that usually have a word-medial flap in American English (e.g., *pretty*). Such sounds are much more likely to be represented than would be expected from the frequency of the spoken form (Connine, 2004). Similarly, the weak schwa vowel may be lexically represented in the phonological lexicon even in words in which it is usually reduced, such as "accidently" for *accidentally* (Connine, Ranbom & Patterson, 2008).

In order for spelling pronunciations to be helpful in beginning word recognition, they should be easily and automatically learned. There is empirical evidence to support just that. As little as one exposure to a written word may be enough to add a variant pronunciation. For example, Bürki, Spinelli, and Gaskell (2012) taught French students to associate spoken non-words like "*plour*" with corresponding pictures. Then participants were shown a written variant of the novel word (either *plour* or *pelour*) and to copy it in writing. Both written forms were possible. After just one such exposure to the written *pelour*, about 5 % of the participants' pronunciations had the added schwa (for the written *e*), as compared to only 1 % when they had seen *plour*. Orthography also influenced recognition of spoken words. When students had seen *pelour* with an *e* they

were significantly more likely to accept an erroneous pronunciation of the word (with "e") as the previously learned (correct one) than if they had seen the short form *plour*.

In sum, we propose that one way or the other (through decoding, partial decoding or completely in parallel) readers make letter strings convey a sound pattern. This pattern is novel in the sense that it is not available in the readers' phonological lexicon, although it might be close to an existing representation. There are at least two reasons why the pattern is not identical to existing words in the lexicon: First, a string of letter sounds is not the same as a co-articulated string of phonemes. Blending does not lead to the right pronunciation. Second, there are thousands of more-or-less predictable deviations from basic grapheme-phoneme relationships. Only a single exposure to the written form of a word may be enough for the reader to set up a corresponding variant pronunciation of the word in the phonological lexicon. This form, here called *a spelling pronunciation*, has a simple relationship to the written form in which the segment sounds are the standard letter sounds or their close approximations.

Learning the dialect of spelling pronunciations

Learning to recognise words via their spelling pronunciations may be similar to learning a dialect of a familiar language. *On first encounter*, some of the words of the dialect sound rather foreign. In order to associate them with one's familiar variant of the language, context may be important. In addition, the syntax is familiar, and so the grammatical function and the part of speech may be known. A degree of phonetic (variants of the same phoneme are associated) and phonological (variants are associated across phoneme boundaries) flexibility may also be of great help.

Subsequent encounters with the variant pronunciations will be a lot easier than the first encounter. Some words will be directly recognised because they have been memorised as alternative representations, while other words will be recognised because they follow the systematic differences between the new and the known version of the words.

There is an extensive literature on the processing of phonological variants in speech perception and on the question about whether each variant is stored or derived from a standard representation. Fortunately, in the case of spelling pronunciations, the situation is easier because the relation between spelling pronunciations and standard pronunciations is well known and easily described: they are basically the conventions of the writing system (Carney, 1994). Clearly, some spelling pronunciations have to be stored, and some have to be derived as explained in the following.

At least some spelling pronunciations must be stored and kept in memory. This is so because the spelling of some words follows no pattern that can be learned from other words, e.g., *have*, *pint*, *yacht*. Consequently, the advanced reader and speller may have to retain the spelling pronunciations of such words because the spelling pronunciation is the simplest mnemonic. Over the years, these spelling pronunciations may become very familiar. Spellers may also develop their spelling pronunciations over the years and, for example, change the stress pattern to highlight the part of the word that has

a difficult-to-remember pronunciation, e.g. from *OCtopus* to *ocTOpus*. Any proficient speller knows how to say difficult-to-spell words to themselves in order to spell them correctly.

Whilst some spelling pronunciations are stored, most can be *derived*. As mentioned earlier, it may take only one exposure to a printed word to set up a spelling pronunciation of the word. However, many written words appear so infrequently that they either do not have a spelling pronunciation or the spelling pronunciation once learned is forgotten. That is when learning the regularities of the new "dialect" becomes necessary. This learning – or "tuning in" to the new system – capitalises on the regularities of the relationship between spelling pronunciations and standard pronunciations. It corresponds to learning the advanced orthographic rules (the extended code) but takes place *within* the phonological system of the reader and makes use of the same language learning mechanisms as those that support learning variants of a known language. For example, a native American English speaker may have difficulties understanding a standard British pronunciation of *water* with a "t" sound because the American version of the word is pronounced with a flap of the tongue "wa"-flap-"er". Once the connection between the unfamiliar and the familiar pronunciation is made, it may begin to generalise to other words with similar differences, such as *butter*, *centre*, and *twenty*. Similarly, an encounter with the non-standard British English pronunciation "wa'er" (*water*) with a glottal stop for the "t" sound may pose problems for the American speaker at first, but once solved, the pronunciation of "bu'er" for *butter* will be slightly less surprising.

It is an important point that even new words in a familiar dialect can be recognised *immediately* once the listener is tuned in to the dialect. We suggest that this ability carries over to the "dialect" of spelling pronunciation. As the "dialect" of spelling pronunciations is becoming familiar, printed words will be recognised immediately, that is, their pronunciations in the mental lexicon will be activated effortlessly just as words in a familiar dialect are understood effortlessly (Figure 2). Indeed, even words that the reader is *not* very familiar with *in print* can be recognised immediately as long as their standard *spoken form* is familiar to the reader.

Problems in learning spelling pronunciations

Difficulties in learning new phonological material (verbal learning) is a proximal cause of dyslexia (e.g., Litt & Nation, 2014; Ramus & Szenkovits, 2008;). Consequently, it is not surprising that individuals with dyslexia appear to have difficulties learning spelling pronunciations and distinct variants of known words (e.g., Bosman, van Hell, & Verhoeven, 2006; Elbro & Jensen, 2005; Heltbech & Nemholt, 2007) and, as a consequence, find it harder to learn to read and spell words correctly.

However, it may be important to distinguish between *production-strength* and *recognition-strength* representations. As mentioned earlier, measures of verbal learning typically require the active *production* (recall) of verbal material. This is the case

for both verbal-verbal and visual-verbal paired-associate-learning tasks. These tasks are precisely the PAL tasks on which children with dyslexia do poorly (Litt & Nation, 2014). They do not have similar difficulties with verbal-visual tasks because these tasks only require verbal *recognition*. This difference between verbal production and recognition may explain why individuals with dyslexia have particularly long-lasting problems with spelling (e.g., Lyon, Shaywitz, & Shaywitz, 2003): spelling requires the active production (recall) of spelling pronunciations without the aid of letter sounds (as in reading). The strength of the mental representations of spelling pronunciations need to be higher for spelling than for reading.

Direct evidence for the link between spelling difficulties and problems with maintaining spelling pronunciations in the mental lexicon was provided by Bosman et al. (2006). In the first experiment they found evidence that reading irregularly spelled words out loud using spelling pronunciations was more beneficial for subsequent spelling of the words than reading the words using standard pronunciations. This positive effect on spelling was found after reading aloud each word only three times, and the effect was found in both 3rd graders and older spelling-level-matched students with learning disabilities. However, a week after the training, the spelling performance of the poor spellers had dropped to their initial level, while the typically developing younger spellers had retained their level after training. A second experiment indicated that the poor spellers needed more practice of the spelling pronunciations, and that they profited significantly from practicing the *production* of spelling pronunciations when given the standard pronunciation of the words – even when this practice took less than a minute for all 16 words in the experiment.

Spelling pronunciations and sight word reading

So far, we have described spelling pronunciations as the outcome of phonological recoding – and as an intermediate step en route from letter sounds to known standard pronunciations of words. In this section we briefly discuss the possible role of spelling pronunciations as words are recognised as wholes, as "sight words." A couple of preliminaries are necessary.

Firstly, it should be brought to mind that "sight word" reading involves a tight and unique association between orthographic and phonological representations of words in the mental lexicon (Ehri, 2005) (see Figure 2 above). With experience, the written word and the phonological representation of it become strongly associated, and the written form immediately activates the phonological representation in the mental lexicon. Contrary to introspection and common belief, immediate recognition of written words is *not* based on a direct association between orthographic and semantic representations. If it were, slight semantic misreadings (e.g., *house* > "villa", *car* > "Ford") would be much more common. Instead, common misreadings almost always resemble the correct sound (e.g. house > "horse", *car* > "can"). See Ehri (1992) for a more detailed discussion.

Secondly, whilst *beginning* readers recode words letter by letter, *skilled* readers may *also* be able to recode several letters in parallel. This has been suggested in connectionist models of decoding (e.g., Harm & Seidenberg, 1999, 2004), but sparsely researched in human readers. Recently, de Jong and colleagues (de Jong, 2011; van den Boer & de Jong, 2015; van den Boer, Georgiou, & de Jong, 2016) showed that in skilled readers the reading speed of high frequency words is highly related to the speed of the rapid naming of alphanumeric symbols (e.g., *3*, *7*) – if the stimuli in both tasks are presented in an isolated (discrete) format. De Jong and colleagues reasoned that the naming of isolated alphanumeric symbols is a pure measure for the retrieval of a pronunciation from memory. If such a measure is highly related to isolated word reading, then the pronunciation of these words is most likely also retrieved from memory. In contrast, the relationship of *serial* naming with *isolated* word reading was much weaker in skilled readers. Surprisingly, van den Boer and de Jong (2015) found the same relationships with isolated nonword reading: isolated rapid naming was more strongly related to nonword reading than was serial rapid naming. Evidently, the pronunciation of a nonword is not available in memory. Instead, van den Boer and de Jong (2015) suggested that the ability to generate (or activate) phonology in parallel from print should be separated from the availability of orthographic knowledge.

In sum, skilled readers may be able to activate a string of phonemes simultaneously when presented with a written word (a string of letters). In order to recognise a word as a whole, all that is needed is that this string of phonemes activate an existing phonological representation in the mental lexicon (Figure 2). However, this is also the point where we have to turn to speculation rather than point to evidence.

There are at least two ways to skip the stepping stones of spelling pronunciations. Either they can be jumped over, or they can become part of the firm ground (the mental lexicon). That is, with growing reading experience, spelling pronunciations may either become superfluous because phonological recoding is tuned to provide the standard pronunciation, or spelling pronunciations become so well integrated into the mental lexicon that activating them is lexical activation (i.e., word recognition). Both options are possible in Figure 2. Let us briefly consider these two options.

The first option is the more standard one that *orthographic code learning* closes the gap between spelling pronunciations and the standard pronunciation of words. With growing reading experience, the outcome of the simultaneous recoding – the spelling pronunciations – may gradually approach existing phonological representations (see Perfetti, 1992, for a similar proposal). This can happen for specific words, but readers will also gradually learn *conditional* letter pronunciations, that is, pronunciations that depend on the neighbouring letters. For example, frequently occurring letter combinations – such as complex graphemes *oo*, *ng*, *ea*, *sh*, etc., and very frequent morphemes *-ing*, *-ed*, *in-*, etc.) – are treated as orthographic units (e.g., Elbro, 2005; McGuinness, 1998). Such letter patterns can be considered an extension of the alphabet, and their pronunciation follows the extended code. As the "window" into orthographic patterns is gradually widened from single letters to whole words, the accuracy of recoding will increase and ultimately reach perfection. In other words, the recoded phonological

output – the spelling pronunciations generated by parallel recoding – will gradually approach standard pronunciations. However, long before the extended code is mastered, frequently seen words will be recognised as wholes. This simply means that their unique letter sequence is associated with the unique sound sequences that are represented in the mental lexicon. This view fits with the learning part of connectionist models of reading (e.g., Harm & Seidenberg, 1999) and with the end state of localist models assuming a connection between an orthographic and a phonological lexicon (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001).

The second option – which does not exclude the first – is that *learning spelling pronunciations* closes the gap between spelling pronunciations and standard pronunciations. This option was already explained as a kind of language learning earlier. Learning spelling pronunciations was compared to learning a second variant (e.g., a dialect) of one's own language. This learning is likely to build on a combination of rote learning and rule learning. Once a dialect is learned, the listener immediately and effortlessly recognises the spoken words without taking notice of the "deviant" sound structure. The knowledge of spelling pronunciations may become so entrenched in the mental lexicon that the activation of a spelling pronunciation is just as efficient as (or even more efficient than) activation of a standard phonological representation. Word recognition of the new variant pronunciation becomes automatic with no need for conscious awareness.

At least two predictions follow from this second option – that spelling pronunciations are learned as spoken variants of known words. First, learning spelling pronunciations greatly reduces the need for learning the advanced orthographic code as a set of conditional orthography to phonology connections (or rules). This would explain why even good readers have great difficulties explaining the advanced orthographic rules that they appear to follow when reading. Second, if learning spelling pronunciations is an important aspect of orthographic learning, we would expect that spelling pronunciations may sometimes take over from standard pronunciations in words that are common in print. Indeed, there are many examples in support of this prediction. Several words have changed pronunciation (or resisted changes) over the years under the influence of orthography: *humour* and *hotel* were originally pronounced without the initial "h" (as in French) from the 14th century till the beginning of the 20th century when the spelling pronunciation with the "h" took over. *Blush* was originally pronounced "bloosh" until the spelling pronunciation took over. *Template* used to be "templit" (see Bloomfield, 1984, § 27.6 for additional examples).

Conclusion and future directions

In this chapter, we have detailed how learning to read words can be seen as a special case of verbal learning. Evidently, the standard sounds of the letters have to be learned. It is an important recent finding that the visual-verbal learning of letter sounds is related to reading development because of the verbal learning component (Litt et al.,

2013). What matters is that children are able to learn the letter sounds sufficiently well to allow for active production (recall). Mere recognition is not sufficient.

By sounding out the letters, beginning readers may be able to produce a spelling pronunciation which they can then often recognise as a real word. The main part of the chapter has described the nature and the recognition of such spelling pronunciations of words already in lexicon. Spelling pronunciations are mostly overlooked in the literature on reading even though anyone who listens to a beginning reader can easily observe them.

For beginning readers, spelling pronunciations are "stepping stones" in the process of word recognition. The recognition of words from their spelling pronunciations is no simple task though. It requires a (sometimes high) degree of phonological flexibility – especially in the case of irregularly spelled words.

There is strong evidence that orthographic learning influences phonological representations of the words in the reader's mental lexicon (e.g., Morais & Kolinsky, 2005; Nation & Hulme, 2011; Ranbom & Connine, 2011). Accordingly, we suggest that spelling pronunciations are learned just like any other variant of a spoken language – both on an item basis and by means of rules, that is, patterns that emerge from the relationships between spelling pronunciations and standard pronunciations. This learning is also a kind of verbal learning because the reader has to be able to both produce and recognise the spelling pronunciation.

The gap between spelling pronunciations and standard pronunciations are narrowed as the reader becomes familiar with more advanced orthographic conventions (the extended code) and can take into account several letters at once when their sounds are activated. The gap may completely disappear when specific links are formed between the unique letter sequences of words and their unique pronunciations (in "sight words"). Alternatively, the gap may diminish as spelling pronunciations are learned as variants (a "dialect") of standard pronunciations.

In both cases, once established spelling pronunciations will cease to be consciously activated in fluent reading. However, even proficient readers and spellers may activate (recall) spelling pronunciations in order to spell irregularly spelled words. As a result, spelling pronunciations for some words are rehearsed and thus fully retained in the mental lexicon.

Although there is ample evidence that both beginning readers and advanced spellers have access to spelling pronunciations, a number of central issues remain unknown:

To what extent are beginning readers supported by prior knowledge of spelling pronunciations? To our knowledge, no relevant teaching experiment has been reported.

How well does knowledge of patterns of spelling pronunciations ("orthographic conventions") generalise across words that share the pattern?

Are spelling pronunciations stored and activated separately or as variants of already known pronunciations? Functional brain imagery might shed light over this and related questions.

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