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Orthographic Mapping in the Acquisition of Sight Word Reading, Spelling Memory, and Vocabulary Learning

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Orthographic mapping (OM) involves the formation of letter-sound connections to bond the spellings, pronunciations, and meanings of specific words in memory. It explains how children learn to read words by sight, to spell words from memory, and to acquire vocabulary words from print. This development is portrayed by Ehri (2005a) as a sequence of overlapping phases, each characterized by the predominant type of connection linking spellings of words to their pronunciations in memory. During development, the connections improve in quality and word-learning value, from visual nonalphabetic, to partial alphabetic, to full grapho-phonemic, to consolidated grapho-syllabic and grapho-morphemic. OM is enabled by phonemic awareness and grapheme-phoneme knowledge. Recent findings indicate that OM to support sight word reading is facilitated when beginners are taught about articulatory features of phonemes and when grapheme-phoneme relations are taught with letter-embedded picture mnemonics. Vocabulary learning is facilitated when spellings accompany pronunciations and meanings of new words to activate OM. Teaching students the strategy of pronouncing novel words aloud as they read text silently activates OM and helps them build their vocabularies. Because spelling-sound connections are retained in memory, they impact the processing of phonological constituents and phonological memory for words.

A major hurdle for beginning readers is learning to read words from memory accurately and automatically in or out of text. Sight of the word activates its pronunciation and meaning immediately in memory and allows readers to focus their attention on comprehension rather than word recognition. Other ways of reading words serve as tools that transform unfamiliar words into familiar sight words. For example, decoding letters into blended sounds helps readers figure out words they have not read before. Rereading them a few times moves the words into memory so they can be read by sight. People used to regard sight words as limited to high-frequency or irregularly spelled words, but it turns out that all words when practiced become read from memory by sight.

The focus of this article is to review how sight words are retained in memory as children learn to read, to clarify the central role played by letter-sound connections and orthographic mapping, and to consider recent findings that extend our understanding of these processes. Orthographic mapping occurs when, in the course of reading specific words, readers form connections between written units, either single graphemes or larger spelling patterns, and spoken units, either phonemes, syllables or morphemes. These connections are retained in memory along

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with meanings and enable readers to recognize the words by sight. An important consequence of orthographic mapping is that the spellings of words enter memory and influence vocabulary learning, the processing of phonological constituents in words, and phonological memory.

WORD READING STRATEGIES AND ORTHOGRAPHIC MAPPING

Children are taught to read words in multiple ways, by applying strategies to read words that are unfamiliar in print, and by retrieving from memory words that have been read before and stored in memory. Several strategies might be used to read unfamiliar words. Readers might use their knowledge of the writing system to apply a *decoding strategy.* The writing system consists of graphemes that are single letters or digraphs that represent the smallest sounds or phonemes in words, for example, B represents /b/, PH represents /f/. It also includes larger grapho-syllabic and morphemic spelling-sound units (e.g., *-ump, -tion, -ed, -ing*; Moats, 2000). Decoding involves transforming graphemes into a blend of phonemes, or transforming spelling patterns into a blend of syllabic units and then searching the mental lexicon (word memory) for a familiar spoken word that matches the blend and fits the context. In languages with regular grapheme-phoneme relations, such as Spanish, decoding is straightforward. However, the English writing system includes multiple ways to pronounce letters and to spell sounds in words as well as spelling irregularities, so readers must be flexible and expect variability when they blend letters to form recognizable words. For example, if they decode *stomach* as "stow – match," they must try other pronunciations to figure out the real word (Tunmer & Chapman, 2012). This is helped by a meaningful context.

Another strategy for reading unfamiliar words is by *analogy.* This involves finding in memory the parallel spelling of a known word and adjusting its pronunciation to match letters in the unknown word (e.g., reading *thump* by analogy to *jump*). As beginners accumulate a larger store of written words in memory, this strategy becomes more useful.

The third strategy for reading unfamiliar words is by *prediction.* Readers use initial letters plus context cues in the sentence, the passage, or pictures to anticipate what the word might be. Once a word is predicted, then its pronunciation is matched to the spelling on the page to verify that the sounds fit the letters.

Whereas unfamiliar words are read by the application of print strategies, words that have been read before are read from memory. Ehri (1992, 1998, 2005a, 2005b) referred to these as *sight words* because sight of the word immediately activates its pronunciation and meaning in memory. To build sight words in memory, orthographic mapping is required. Readers must form connections between the spellings and pronunciations of specific words by applying knowledge of the general writing system. When readers see a new word and say or hear its pronunciation, its spelling becomes mapped onto its pronunciation and meaning. These mapping connections serve to "glue" spellings to their pronunciation in memory. For example, if a reader knows that the graphemes T and OW commonly symbolize the phonemes /t/ and /o/, respectively, then when the word TOW is seen and pronounced, two connections are formed linking T and OW to their phonemes, and the spelling is bonded to its pronunciation in memory. If a reader knows grapho-syllabic spellings as letter-sound units, then when a word such as *excellent* is seen, three connections are formed between the spelling units, *ex*, *cell*, *ent*, and their sounds to retain the word in memory. Processing the meanings of words bonds semantic connections to the word units as well. This enables readers to read words immediately from memory, thus precluding the need to apply word reading strategies to figure out the words.

To form connections and retain words in memory, readers need some requisite abilities. They must possess *phonemic awareness* (i.e., the ability to focus on and manipulate phonemes in speech), particularly segmentation and blending. They must know the major grapheme-phoneme correspondences of the writing system. At a more advanced level, they need to know grapho-syllabic spelling-sound patterns. Then they need to be able to read unfamiliar words on their own, by applying a decoding, analogy, or prediction strategy. Application of these strategies activates orthographic mappings to retain the words' spellings, pronunciations, and meanings in memory. Share (2004b, 2008) referred to this as a self-teaching mechanism. With repeated readings that activate orthographic mapping, written words are retained in memory to support reading and spelling.

When readers can read words from memory rather than by decoding, analogy, or prediction, text reading is greatly facilitated. Readers are able to read and comprehend more rapidly and to focus their attention on meanings while word recognition happens automatically. Although word reading strategies are no longer needed to identify words once they can be read from memory, decoding and prediction may still be activated as backup to confirm that the words identified fit the spelling and the context or to signal a mismatch needing repair (Perfetti, 1985).

Readers differ in the connections that are activated to bond the identities of words in memory. Perfetti (2007) proposed the concept of *lexical quality* to capture variation in the representations of words that are formed in memory to support reading and spelling. Words that are high in lexical quality (LQ) consist of complete spellings that are fully connected to their pronunciations at grapho-phonemic or syllabic levels in memory. High LQ also includes knowing the meanings of words in various contexts as well as pragmatic uses of the words. Possession of high LQ representations of words facilitates not only accurate word recognition but also reading comprehension.

PHASES IN THE DEVELOPMENT OF WORD READING SKILLS

Pinpointing when children begin reading words depends on what is counted as word reading. Very young children can read their own names and words in environmental print but they cannot decode novel words. During development the strategies children possess for reading unfamiliar words expand as well as the types of connections to read and spell words from memory. These developmental paths are captured in Ehri's (2005a) phase theory, which is centered on the acquisition of sight word reading but also portrays the emergence of skills and strategies that support sight word reading. Characteristics of the phases are summarized in Table 1.

According to Ehri (2005a), the storage of written words in memory for reading and spelling develops in phases which are labeled to reflect the *predominant types of connections* that are formed to remember how to read words, with the types transitioning from nonalphabetic to partial letter names or letter sounds to full grapho-phonemic to grapho-syllabic.

During the *prealphabetic phase*, children lack knowledge of the writing system, so they rely mainly on salient visual or contextual features to read words, features such as logos accompanying signs in the environment or semantic cues such as the two eyes in *look*. They may pretend to

TABLE 1
Summary of Word Reading and Spelling Abilities That Characterize Ehri's (2005) Four Phases of Development

Prealphabetic	*Partial Alphabetic*	*Full Alphabetic*	*Consolidated Alphabetic*
May or may not know letters	Most letter shapes and names known; incom- plete knowledge of GPs	Major GPs of writing system known	Grapho-syllabic spelling units known
Lack of phoneme awareness	Limited phonemic awareness; benefit of articulatory awareness instruction.	Full phonemic awareness: segmentation and blending	
No GP connections between spellings and pronunciations	Partial GP connections formed	Complete GP connections formed	Grapho-syllabic connections predominate
Sight words learned by remembering salient visual or context cues	Sight words learned by remembering partial GP connections	Sight words learned by remembering complete GP connections	Sight words learned primarily by grapho-syllabic connections
Sight word memory: unreliable, semantic errors, reading the environment	Sight word memory: Confusion of similarly spelled words	Sight word memory: accurate, automatic, unitized, growing, limited mainly to shorter words	Sight word memory: accurate, automatic, unitized, expanding rapidly; multisyllabic words easier to learn
No non-word decoding ability	Little or no non-word decoding ability	Growing ability to decode unfamiliar words and nonwords	Can decode unfamiliar words and nonwords proficiently
Cannot analogize	Analogizing precluded by partial memory for word spellings	Some use of analogizing but limited by smaller sight vocabulary	Greater use of analogizing as sight words accumulate
Unfamiliar words predicted from context	Unfamiliar words predicted using initial letters and context	Unfamiliar words in context read by decoding; context used to confirm or disconfirm words read	Unfamiliar words in context read by decoding or analogy; context used to confirm or disconfirm words read
Words spelled nonphonetically	Partial phonetic spellings invented; weak memory for correct spellings	Phonetically accurate GP spellings invented; growing memory for correct spellings	Grapho-syllabic and GP units to invent spellings; proficient memory for correct spellings

Note. Grapho-syllabic spelling units include subsyllabic units such as rime spellings, spellings of syllables, and spellings of morphemes including root words and affixes. GP = grapheme-phoneme connections.

read stories they have heard before, but they cannot point to the written words they are saying, indicating that they are relying on memory rather than print cues. They may recognize their own name written down and name its letters. They may spell words using scribbles, familiar letters, or numbers. However, because their word reading and writing do not involve the use of letter-sound connections, they are prealphabetic.

Children advance to the *partial alphabetic phase* when they learn letter names or sounds and can use them to remember how to read words by forming partial connections linking the more salient letters to sounds in pronunciations, for example, first and final letter-sounds. Partial phase readers might remember how to read *jail* by connecting the letters J and L to their names heard in the word's pronunciation (e.g., /je/ and /ɛl/; Ehri & Wilce, 1985). However, the connections formed are incomplete as a result of limited phonemic awareness and grapheme-phoneme knowledge, particularly vowels. One result of having partial representations of words is that similarly spelled words may be confused. Partial phase readers have little or no use of decoding or analogy strategies. To read unfamiliar words, they rely mainly on predicting words from initial letters and context cues. When they spell words, they write some of the letters accurately to represent sounds but they have difficulty remembering and writing words completely and correctly.

Children advance to the *full alphabetic phase* when they can form complete connections between graphemes and phonemes to read words from memory. Acquisition of a decoding strategy facilitates this process. Beginners acquire knowledge of the major grapheme-phoneme correspondences and the ability to segment pronunciations into phonemes. This enables them to map the spellings of words onto their pronunciations and retain these connections in memory along with meanings. Readers become able to recognize words automatically without attention or effort needed to transform letters into sounds. Sight of the word activates its pronunciation and meaning in memory immediately. The word is read as a single unit rather than sounded out letter by letter (Ehri & Wilce, 1983). Completely connected sight words are initially short monosyllabic words, but they grow to include longer words.

Full alphabetic phase readers can learn to read words by analogy, but they are limited by the size of their memory for sight words, which are needed as the base for analogizing. They can write phonetically complete spellings of unfamiliar words by segmenting pronunciations into phonemes and writing letters for each. They can remember correct spellings of words much better than partial alphabetic phase readers because they can connect spellings fully to pronunciations in memory.

As fully connected words and word parts accumulate in memory and can be read as single units, children move closer to the *consolidated alphabetic phase.* Connections linking spellings to pronunciations are formed out of grapheme-phoneme blends that have become consolidated into larger spelling-sound units (Bhattacharya & Ehri, 2004; Treiman, Goswami, & Bruck, 1990). These units include spelling patterns that recur in multiple words (e.g., *-ump* in *jump, pump, bump, dump*), sight words that form parts of longer words (e.g., *in – pin, at – bat, and – sand, up – cup*), and recurring syllabic and morphemic spelling units (e.g., root words and affixes). It is easier to remember how to read multisyllabic words during this phase than during the full phase because fewer connections need be formed, for example, only two grapho-syllabic versus seven grapho-phonemic connections to store the word *comfort* in memory. As readers' print lexicons of words grow, the analogy strategy becomes more useful for reading words. As they acquire more knowledge about spelling patterns, their ability to remember how to spell words fitting these patterns grows.

Phase theory has been questioned by some researchers who suggest that the development of sight word reading is continuous rather than divisible into discrete phases (Cunningham, Nathan, & Raher, 2011). However, continuity is not disputed by phase theory. Sight words are viewed as accumulating continuously in memory. It is the predominant type of orthographic connection that is distinct and that changes with development, from nonalphabetic to partial to full and then to consolidated. The succession of phases resemble overlapping waves (Siegler, 1996) rather than discrete stages. As proposed by Siegler, children acquire multiple ways of processing information during development, and these ways change gradually in the frequency of their use as more advanced ways emerge and predominate. To illustrate overlapping waves that characterize phases, children in the partial phase become able to form full grapho-phonemic connections to read and spell shorter words but still use partial cues for longer words. Children in the full phase learn some consolidated units such as *-ing* early during this phase. These larger units accumulate gradually during the full phase. Instruction in larger syllabic and morphemic units can facilitate this accumulation and hence movement into the next phase when they predominate. Likewise decoding instruction during the partial phase facilitates movement to the full phase.

FACILITATING SIGHT WORD LEARNING IN BEGINNERS

Several earlier studies have provided evidence for the development of sight word learning in phases (see Ehri, 1987, 1992, 1998, 2005a, 2005b, for reviews). Some recent studies have focused on the partial alphabetic phase and have clarified how training in phonemic awareness and letter knowledge can improve children's ability to read words from memory.

Phonemic Awareness

Many studies have shown that teaching children phonemic awareness enhances their word reading and spelling (Ehri et al., 2001). The type of phonemic awareness that is thought to underlie the process of connecting graphemes to phonemes is the ability to segment pronunciations into phonemes. Which property of phonemes forms these connections has remained unclear. It is common for teachers to direct students' attention to the *sounds* that are heard in words. However, there is reason to believe that sounds processed by the ear are less central than *articulatory gestures* produced by mouth movements in saying words. According to the motor theory of speech perception (Liberman, 1999), articulatory gestures rather than acoustic features represent phonemes in the brain. Also, ease of processing favors gestures. Whereas sounds are ephemeral and disappear as soon as they are heard, mouth positions are tangible and can be felt, viewed in a mirror, and analyzed by learners.

We conducted two phonemic awareness experiments to determine whether teaching children to analyze articulatory gestures in words would better secure spellings to pronunciations in memory and hence improve their sight word learning (Boyer & Ehri, 2011; Castiglioni-Spalten & Ehri, 2003). We reasoned that if articulation is central to the phonemic representation of words in memory, then enhancing children's sensitivity to the articulatory properties of phonemes should strengthen the grapheme-phoneme connections that are formed to remember how to read words. In the Boyer and Ehri study, 4- and 5-year-old preschoolers who knew letter names but were in the prealphabetic phase were randomly assigned to three groups. Children in the letters only condition were taught associations between 15 graphemes and phonemes and how to use them to segment and spell the phonemes in CV (consonant, vowel), VC, and CVC words and non-words. Phonetic spellings, with one grapheme for each phoneme, rather than correct spellings were taught (e.g., MO rather than MOW). Children in the letters plus articulation group received the same instruction with letters, but in addition they learned associations between 15 phonemes and eight mouth pictures depicting articulatory positions of the phonemes, for example, a picture of a mouth with closed lips to depict /b/, /p/, and /m/; a picture of a mouth with teeth touching the lower lip to depict /f/ and /v/; or a mouth open with lips pulled together and rounded to depict /o/. Then they were taught to segment CV, VC, and CVC pronunciations with these mouth pictures, for example, selecting the picture of closed lips and then the picture of open rounded lips to depict /*mo*/. A third control group received no instruction. Once children in the treatment groups learned the association and segmentation skills to criterion, they were given a sight word learning task to see whether articulatory training improved the letters plus articulation group's ability to learn to read the words more than the other two groups.

In the sight word learning task, children received several practice trials with feedback to learn to read six words spelled phonetically with the trained letters: BO (*bow*), SA (*say*), TE (*tea*), BEK (*beak*), SOP (*soap*), TAL (*tail*). As evident in Figure 1, the articulation group learned to read the words more easily than both of the other groups. It took the letters plus articulation group four trials on average to read most of the words, whereas it took the letters only group eight trials. The no-treatment control group read fewer than two words by the eighth trial. Moreover, 1 week later, the articulation group showed the same advantage in learning a second set of words. These findings paralleled those in an earlier study (Castiglioni-Spalten & Ehri, 2003). Our interpretation is that articulation training improved children's access to the motoric gestures configuring the phonemic representations of words in memory. As a result, during the sight word learning trials, letters in the words became more securely attached to these motoric phonemic constituents to support word reading. Other studies have also shown that place of articulation influences children's sight word learning (Laing & Hulme, 1999; Rack, Hulme, Snowling & Wightman, 1994). These findings suggest the value of teaching phoneme segmentation with mouth pictures.

These results bear on Ehri's (2005a) phase theory. When children began this study, they were in the prealphabetic phase. They knew some letters but had little ability to read or spell words. During the study, two of the groups were taught the requisite alphabetic knowledge—phonemic awareness and grapheme-phoneme relations. On word reading and spelling tests given at the end of training, children receiving this instruction far outperformed the no-treatment control group, indicating that these skills moved children from the prealphabetic to the partial alphabetic phase of development.

Letter Knowledge

Grapheme-phoneme knowledge is critical for enabling students to build a reliable vocabulary of sight words. One source for learning grapheme-phoneme relations comes from letter names. In English most letter names contain phonemes commonly symbolized by those letters in words (e.g., *bee* /b/, *eff* /f/, *jay* /j/). Studies have shown that beginners who know letter shapes and names can use this knowledge to learn sounds in the names (Cardoso-Martins, Mesquita, & Ehri, 2011; Share, 2004a) and to remember how to read words they have seen better than children who do not know names (Ehri & Wilce, 1985; Roberts, 2003).

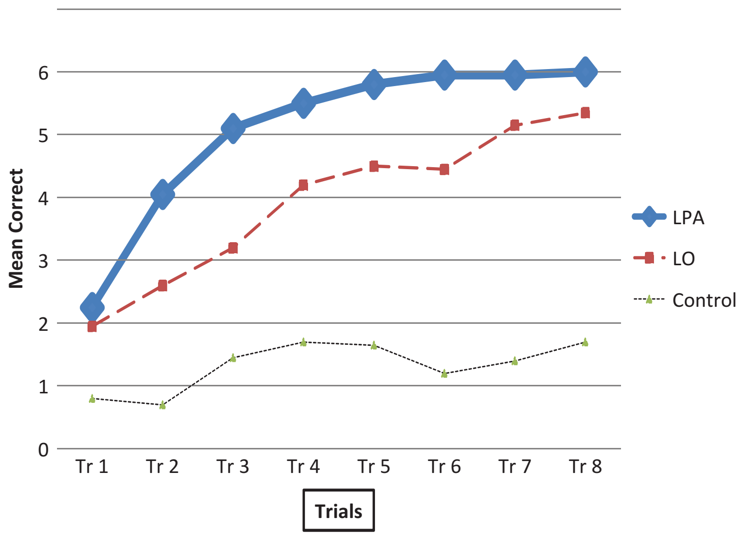

FIGURE 1 Mean number of words read correctly (six maximum) by 4-year-olds on each trial during the sight word learning posttest for the groups trained with letters and articulation pictures (LPA) and with letters only (LO) and by the no-treatment control group. From "Contribution of Phonemic Segmentation Instruction With Letters and Articulation Pictures to Word Reading and Spelling in Beginners" by N. Boyer and L. Ehri, 2011, *Scientific Studies of Reading, 15,* p. 459. Copyright 2011 by the Society for the Scientific Study of Reading. Reprinted with permission. (Color figure available online.)

If children do not know letter names, then teaching them all of the arbitrary, meaningless shapes, names, and sounds takes time. An approach that eases the task is to use embedded picture mnemonics. These are not just any letter–picture pairs, but ones that bear a special relationship to each other. The basic principle for constructing embedded picture mnemonics is to identify an object (e.g., snake) whose name begins with the sound of the letter to be taught (/s/) and whose shape can be drawn to resemble the shape of the letter (S). Other examples are M drawn as mountains, T drawn as a table. To the extent that learners can look at the letter, be reminded of the object because of the shared shapes, say the object's name, and segment its initial sound to produce the sound of the letter, the mnemonic is effective in linking the letter shape to its phoneme in memory. With practice, letter shapes are learned and associations between letters and sounds are established in memory. Ehri, Deffner, and Wilce (1984) showed that embedded picture mnemonics were more effective in teaching children grapheme-phoneme correspondences than were the same objects drawn in a different shape from the letter (e.g., snake coiled or stretched out, called disassociated mnemonics) and more effective than practice associating letters, objects and sounds without any pictures.

More recently we conducted an experiment applying this principle to teach Hebrew letter-sounds to children who spoke English but no Hebrew (Shmidman & Ehri, 2010). In our study, embedded picture mnemonics were created to teach 5-year-old children Hebrew

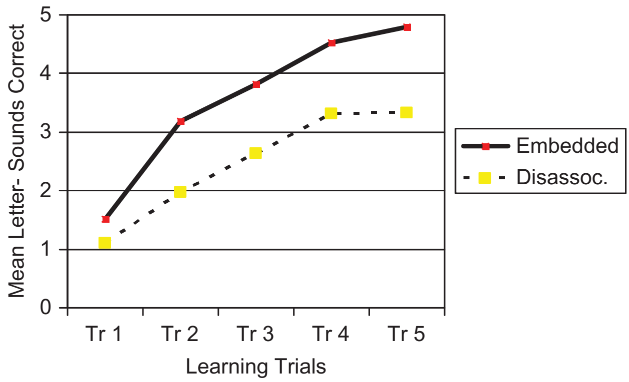

FIGURE 2 Mean number of letter-sound correspondences recalled (five maximum) over the first five learning trials by 5-year-olds in the embedded mnemonics and disassociated mnemonics conditions. From "Embedded Picture Mnemonics to Learn Letters" by A. Shmidman & L. Ehri, 2010, *Scientific Studies of Reading, 14,* p. 173. Copyright 2010 by the Society for the Scientific Study of Reading. Reprinted with permission. (Color figure available online.)

grapheme-phoneme correspondences using English object names as the mnemonics. For example, ה was drawn as a house symbolizing /h/, ש was drawn as a ship with sails symbolizing /sh/, and ק was drawn as a key symbolizing /k/. Students were taught grapheme-phoneme relations with these embedded picture mnemonics in one condition. In the control condition, students were taught with disassociated mnemonics having the same object names and meanings but drawn differently from the shapes of the letters. Children in both conditions were taught to segment and pronounce the initial phonemes in the object names. Then they completed as many practice trials as was necessary to be able to recall all of the sounds perfectly when they were shown the bare letters. Results revealed that children took fewer trials to master letter-sounds taught with embedded mnemonics than with disassociated mnemonics. Learning during the first five trials is shown in Figure 2. Compared to disassociated letters, embedded letters were less frequently mixed up during learning and were remembered better on posttests 1 week later.

The children were in the prealphabetic phase when they began this study. They had no knowledge of Hebrew, and they had little ability to read English primer words. We examined whether they would be able to use their newly acquired letter-sound knowledge to function at the partial alphabetic phase in reading and spelling English words written with Hebrew letter-sounds. After children had learned the letter-sound correspondences, they practiced reading simplified spellings of 10 English CVC words written phonetically with Hebrew consonants (e.g., שק read as *shake*). Also children were given Hebrew letter blocks to spell the consonant sounds in English CVC words. Results showed that performance of the embedded mnemonics group was significantly better in both the sight word learning and spelling tasks than performance of the disassociated mnemonics group.

These findings carry implications for instruction. Embedded picture mnemonics offer an effective way to teach grapheme-phoneme relations to beginners, especially children having letter learning difficulties. Embedded mnemonics can be used to teach harder-to-learn correspondences such as the short vowels sounds of A, E, I, O, and U; the consonants W, Y, and H; and the hard sounds for C /k/, and G /g/, all letters whose names do not contain their sounds. Also embedded mnemonics can be devised to teach letter-sound correspondences to students learning a foreign language as was done in this study.

ORTHOGRAPHIC MAPPING TO FACILITATE VOCABULARY LEARNING

We have also conducted studies to examine the connection forming process in more advanced readers, those functioning at the full and consolidated alphabetic phases in their word reading. Of interest here are studies examining the contribution of orthographic mapping for building the pronunciations and meanings of new vocabulary words in memory.

Students learn new vocabulary words not only by hearing them but also by reading them in print. Based on our work showing that spellings become bonded to pronunciations in memory, we wondered whether showing students the written forms of novel words would enhance vocabulary learning. Traditionally, spellings have not been considered an important contributor. The prevailing view has been that when an unknown word is encountered in print, students pronounce it and then store the pronunciation with its meaning in memory. The spelling is left out on the page. However, as just discussed, this is not so.

In our study, students were taught the spoken forms and meanings of several unfamiliar, low-frequency words (Ehri, 2005b; Rosenthal & Ehri, 2008). Second graders participated in one experiment, fifth graders in another. The same designs were used, but the words were harder in the latter study. Fifth graders were taught 10 words, for example, *vibrissa* (the whiskers on a cat) and *tamarack* (a big tree), whereas second graders were taught 6 words, for example, *sod* (wet, grassy ground) and *pap* (soft mushy food for babies). In each experiment, the words were pronounced, defined, embedded in sentences, and depicted in drawings on flash cards. Children were given several practice trials to learn the pronunciations and meanings of the words. On each trial they were prompted to recall either the pronunciation or the meaning of each word. In one condition, spellings appeared on the cards during study and feedback periods but not when children recalled the words. In the control condition, the same procedures were followed except that students were not shown spellings. To compensate, they pronounced the words extra times. Results were clear in showing the benefit of spellings at both grade levels.

In the fifth-grade experiment, students were grouped by reading/spelling ability into higher and lower levels. Figure 3 shows how well they recalled pronunciations of the words across learning trials when spellings had been seen and when they had not. It is evident that both ability groups remembered pronunciations much better when they had been exposed to their spellings, especially the higher readers. Note that spellings were not present when students recalled pronunciations so the benefit had to come from memory. This was evident in the comments of students who had seen spellings. In trying to recall *hicatee* (a kind of turtle), one student said, “I know there are two ‘*ees*’ at the end.” Two other students named some of the letters before recalling the words. Exposure to spellings also enhanced students’ recall of word meanings compared to not seeing spellings. Results were similar in the experiment with second graders, revealing that spellings facilitate vocabulary learning in younger as well as older readers. It took longer to learn

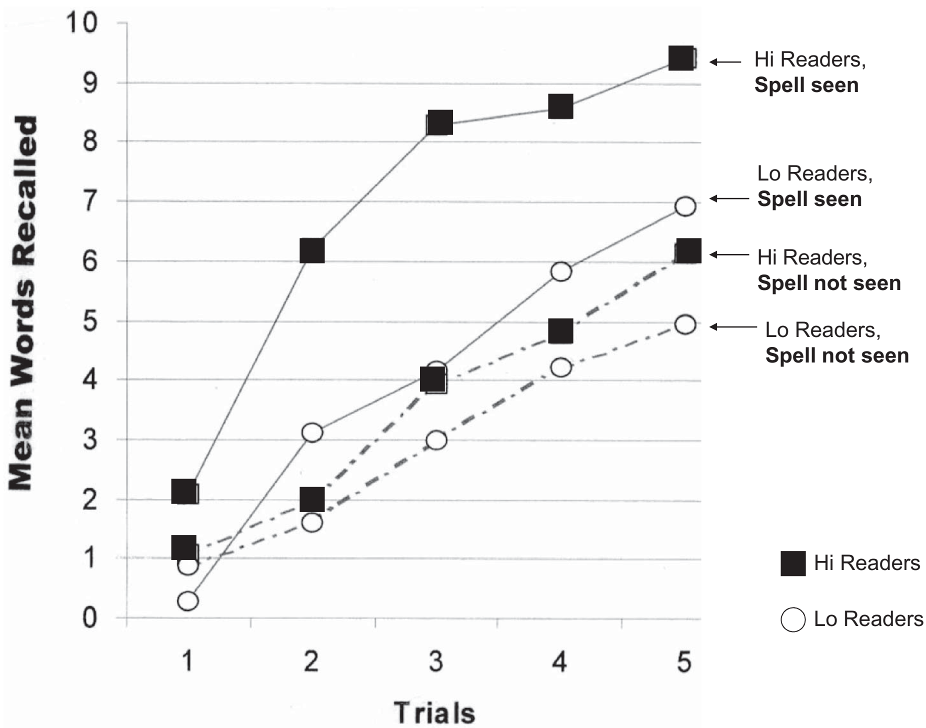

FIGURE 3 Mean number of pronunciations (10 maximum) recalled over five learning trials by higher and lower ability fifth-grade readers in the spelling seen and spelling not seen conditions. From "The Mnemonic Value of Orthography for Vocabulary Learning" by J. Rosenthal & L. Ehri, 2008, *Journal of Educational Psychology*, *100*, p. 184. Copyright 2008 by the American Psychological Association. Reprinted with permission.

the pronunciations than the meanings of the words, indicating that exposure to spellings was important in facilitating the harder part of vocabulary learning.

Gathercole (2006) suggested that superior phonological working memory for novel words explains why good readers are better at building their vocabularies than poor readers. However, our findings suggest that orthographic knowledge is more important than phonological memory. Comparison of the performance of students higher and lower in reading ability in Figure 3 (see the broken lines) reveals that the higher readers outperformed the lower readers by very little in remembering pronunciations of the novel words when they had only practiced hearing and saying the words during learning. This indicates only a small difference in phonological memory. However, higher readers were far superior to lower readers in remembering pronunciations when spellings were seen during learning (compare the solid lines). This suggests that once students become literate, superior ability to connect spellings to pronunciations in memory explains why good readers build larger vocabularies than poor readers, not phonological working memory.

Our explanation of the facilitative effects of spellings on vocabulary learning is that when students were shown spellings as they heard and pronounced the words, connections were formed. Spellings became bonded to pronunciations, clarified their phonemic constituents, and strengthened their phonological representations in memory. Meanings became better connected as well. From previous research, we know that letters in spellings of new words are remembered easily. Share (2004b) found that third graders remembered letters in novel words after only one exposure, and they remembered them as long as 1 month later. This suggests that, in our study, spellings served to establish in memory a word base that was more substantial and formed earlier during learning than that formed by the pronunciation-meaning bond without spellings. Others have replicated the effects of exposure to spellings on vocabulary learning (Ricketts, Bishop, & Nation, 2009).

In an earlier study, we found that not only seeing spellings but also directing second graders to *imagine* the spellings of novel CVC words improved their memory for their pronunciations compared to students who only practiced saying the words extra times (Experiment 4, Ehri & Wilce, 1979). Knowledge of grapho-phonemic connections prescribed by the writing system provides readers with clear expectations about how pronounced words might be spelled (Stuart & Coltheart, 1988) and spellings are visual forms so it is not surprising that students can generate images of written words in their heads.

Extension to Text Reading

Beyond the early years, children's vocabularies grow substantially from reading text (Nagy & Scott, 2000). However, when students read text silently on their own, they may not bother to pronounce unfamiliar words but rather may skip over them and just infer their meanings. As a result, connections are not formed to secure the new words in memory. Skipping unknown words may be especially characteristic of students with weaker decoding skills and may retard their vocabulary growth compared to good readers. This may contribute to Matthew Effects (i.e., the rich getting richer in vocabulary knowledge) observed to distinguish good from poor readers over time (Cain & Oakhill, 2011).

We undertook a study to examine students' learning of new vocabulary words as they read text silently (Rosenthal & Ehri, 2011). Fifth graders were randomly assigned to one of two target word reading conditions, a read-aloud condition and a silent condition. Higher and lower ability readers were distinguished. They read silently eight passages, each about 100 words. Each passage elaborated the meaning of a low-frequency target word that appeared three times, was underlined, defined, discussed, and depicted with a drawing. Students in one condition were directed to read the texts silently but when they came to the underlined (target) words, they were to pronounce them aloud. In the control condition, students also read the texts silently. When they came to underlined words, they were told to pencil a check next to the words if they had seen them before, but nothing was said about reading the words aloud. The purpose of the check was to make sure that controls at least stopped and looked at the target words. Students in both conditions adhered to the instructions.

Results showed that the oral word reading strategy enhanced vocabulary learning significantly in both better and weaker readers compared to the silent condition. After reading the text, students orally recalled the story they had read. Figure 4 shows these results. The two bars on the left

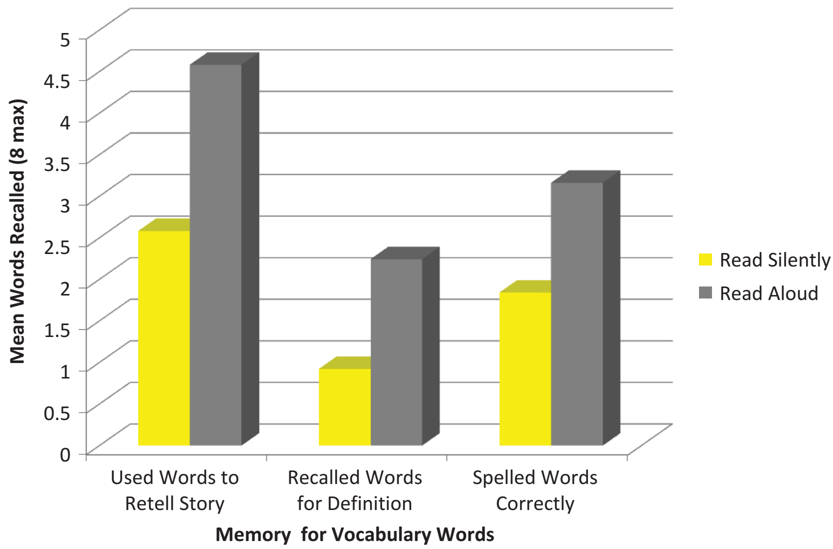

FIGURE 4 Mean vocabulary words produced, recalled and spelled correctly (eight maximum) after fifth graders silently read a passage and either pronounced the underlined vocabulary words aloud or read them silently. Data for this figure extracted from Rosenthal and Ehri (2011). (Color figure available online.)

show that those in the aloud condition included the vocabulary words more frequently in their oral retellings than students in the silent condition. The latter students used synonyms more often. The middle bars show that students who spoke the words learned the meaning–pronunciation associations better than those who did not. The third pair of bars shows that speaking the words enhanced students' memory for their spellings. Note that students never wrote the words so memory for spellings was improved simply by pronouncing the written words aloud.

We examined whether poorer readers might show bigger effects than better readers. Because poorer readers have more trouble decoding novel words, they might skip over them during silent reading, so their word learning might be especially depressed compared to the aloud condition. This is what we found. Effect sizes were moderate to large favoring the aloud over the silent treatment in both reader groups across the three measures in Figure 4. However, effect sizes were substantially larger for poorer readers. On two measures, effect sizes were about twice as great: recalling pronunciations, $d = 1.58$ (poor readers) vs. 0.71 (good readers); recalling spellings, $d = 1.07$ (poor readers) vs. 0.61 (good readers). This shows that forcing the poorer readers to say the words aloud was especially beneficial. They had some ability to decode the words but they were less inclined to do so when they read them silently.

Findings of these vocabulary learning studies are explained by orthographic mapping. They support two conclusions and implications for practice. The first is that exposing students to the spellings of spoken vocabulary words helps them learn the words compared to only hearing and saying the words. This suggests that teachers should display spellings as part of vocabulary instruction to enhance learning. The second conclusion is that students should be directed to pronounce new vocabulary words aloud when encountering them in text. By transforming letters into sounds, this strategy helps to form connections and retain the words' spellings, pronunciations, and meanings in memory.

IMPACT OF ORTHOGRAPHIC MAPPING ON PHONOLOGICAL REPRESENTATIONS

According to our theory and evidence, spellings of words are retained in memory when their letters become bonded to phonemes and syllables in their pronunciations. If so, then spellings should influence how people perceive and process the sounds in words. In the Rosenthal and Ehri (2008) study just described, we showed in Figure 3 that orthographic mapping better explained the acquisition of new vocabulary words including their pronunciations than phonological working memory. Other research has provided supportive evidence as well (Ehri, 1984).

Grapho-phonemic mapping has been shown to influence how people segment words into phonetic constituents, particularly when there is ambiguity. For example, the endings of *pitch* and *rich* are pronounced identically yet *pitch* contains an extra letter T potentially drawing attention to an extra sound which can be detected in articulating *pitch* (i.e., tongue touching the roof of the mouth). To determine whether readers would segment *pitch* into more sounds than *rich*, fourth graders were given a segmentation task in which they had to pronounce the separate sounds in words and move tokens for each. No spellings were present. As expected, most found four sounds in *p-i-t-ch* but only three in *r-i-ch*. Spelling-based segmentation of ambiguous sounds were replicated for other pairs of words as well (i.e., /t/ in *catch* vs. *much*, /d/ in *badge* vs. *page*; Ehri & Wilce, 1980). In another study, spellings influenced syllable segmentation. Students who knew how to spell a word such as *interesting* segmented it into the four syllables represented in the spelling (*in-ter-est-ing*), whereas those who misspelled the word tended to find three segments (*in-tres-ting*) reflecting the way they pronounced the word (Ehri, 1987). In a study by Seidenberg and Tanenhaus (1979), spellings influenced rhyme judgments. Students listened to two *orally presented* words. Their speed to decide "Yes" or "No" whether the two words rhymed was measured. They took longer to say "Yes" to rhyming words when the spellings differed (e.g., *tomb – room*) than when spellings were similar (e.g., *boom – room*). They took longer to say "No" to nonrhyming words when spellings were similar (e.g., *tomb – comb*) than when they were different (e.g., *tomb – come*). These are just a few of the studies showing that when children learn to read, written words bond to spoken words in memory and change the way people conceptualize their phonological constituents including phonemes, syllables, and rhymes.

CONCLUDING COMMENTS

Learning to read words is central to children's success in attaining reading skill. Several abilities and skills become integrated as acquisition proceeds. Phonemic awareness and knowledge of the writing system are applied to read unfamiliar words and to build a vocabulary of high-quality sight words with spellings fully connected to pronunciations and meanings in memory. The accumulation of written words in memory is continuous. However, the predominant connections that are used to remember the words change developmentally, from nonalphabetic visual features, to partial alphabetic connections between some letters and sounds, to full grapho-phonemic connections, to consolidated grapho-syllabic connections. These orthographic mapping processes underlie the emergence of students' skill in reading words accurately and automatically from memory.

Use of alphabetic knowledge to connect spellings to pronunciations and retain sight words in memory is an internal process that is activated spontaneously when words are seen and their pronunciations are produced or heard. The spontaneous nature of activation was evident in our vocabulary learning study described earlier (Rosenthal & Ehri, 2008). Second and fifth graders were exposed to spellings, but no attention was drawn to them. Students did not actively decode them. Rather the experimenter pronounced the words as soon as they were seen and students repeated them orally. Nevertheless, connections were formed and spellings were retained in memory as evidenced by their facilitative effect on vocabulary learning. The immediate formation and durable nature of the resulting connections were evident in Share's (2004b) self-teaching study in which third graders read novel words independently in text and showed greater-than-chance level memory for their letters a month later after reading them only once.

What sort of instruction teaches students spontaneous orthographic mapping? First, it entails teaching students the knowledge and skills that *enable* connections to be activated when words are seen and read. This includes teaching the writing system beginning with grapheme-phoneme relations, teaching phonemic segmentation, and teaching a decoding strategy for reading novel words (Share, 2004b). Second, it entails having students practice using these skills to read and spell words. Practice may involve having students decode and pronounce unfamiliar words aloud during independent reading of text (Rosenthal & Ehri, 2011). Practice may involve having students explicitly identify the connections to be formed for specific words by segmenting pronunciations into phonemes and matching them to graphemes seen in spellings (Gaskins, Ehri, Cress, O'Hara, & Donnelly, 1996). Practice may involve recalling these connections to produce correct spellings of words. Practice may involve reading sequences of similarly spelled, single syllable words whose letters change across successive words (e.g., *sock, sack, sick, sing, song, sang*; Ehri & Wilce, 1987; McCandliss, Sandak, Beck, & Perfetti, 2003). Practice may involve repeatedly reading sets of multisyllabic words by segmenting them into their grapho-syllabic units (Bhattacharya & Ehri, 2004).

Knowledge of the writing system is a key ingredient in learning to read words, and the relationship is reciprocal. Beginners are taught grapheme-phoneme relations and these are used to read words. As written words accumulate in memory, additional knowledge about the writing system is formed, and this in turn facilitates word reading ability. According to phase theory, grapho-phonemic and grapho-syllabic units are major contributors. However, students learn other types of orthographic regularities as well. They learn about the statistical properties of spellings involving the co-occurrence of letters (Treiman & Kessler, 2006). They learn about grapho-tactic features involving legitimate and illegitimate letter combinations. Venezky's (1999) analyses revealed more than 200 regularities that characterize the English spelling system. Many of these are learned implicitly as readers' mental lexicons grow and patterns that recur in different words are detected (Tunmer & Nicholson, 2011). As knowledge about the writing system accumulates, it constrains and refines readers' expectations about the spellings of words so that when unfamiliar words are seen on the page and read, they are easier to remember.

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I regret that space limitations preclude citation of many studies contributing relevant findings. Additional references can be found in the studies that are cited.

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