LSHSS

Tutorial

Statistical Learning and Spelling

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Purpose: The purpose of this article is to provide a tutorial on statistical learning and its role in learning to spell and to discuss the implications of the research for educators.
Method: The tutorial begins with a discussion of statistical learning and its characteristics. It then discusses research on how statistical learning plays out in learning to spell, how spelling should be taught, and similarities and differences among learners. The focus is on the learning of English, although studies of other alphabetic writing systems are also considered. Research shows that, from an early age, children use their statistical learning skills to learn about the visual characteristics of written words. Children also use their statistical learning skills to help learn about the relations between visual units and units of language, supplementing what they are explicitly taught in school.
Conclusion: Statistical learning plays an important role in learning to spell, and this can help to explain why some aspects of spelling are more difficult to learn than others. If children are to learn to spell effectively and efficiently, structured instruction is also important.

The goal of this tutorial is to review what we know about the role of statistical learning in the acquisition of spelling. I begin by discussing the characteristics of statistical learning and then review research on how children use their statistical learning skills when learning about spelling. The statistical learning perspective helps us to understand certain aspects of spelling development that are not well explained by other theoretical perspectives. It also sheds light on how spelling should be taught and on similarities and differences across children. This tutorial focuses on learners of English, but many of the points also apply to learners of other alphabetic writing systems.

What Is Statistical Learning and How Might Children Use It in Learning About Spelling?

We learn many things through direct instruction. A teacher identifies a problem, tells us how to solve it, corrects any errors we make, and praises us when we get the right answer. However, we also learn many things through exposure. We pick up patterns in the world even when they are not explicitly pointed out to us, even when they are probabilistic rather than all or none, and even when we receive no direct teaching, reinforcement, or feedback. We may lack conscious intention to learn, and we may be unaware of the products of learning, but learning has nevertheless occurred. The term *statistical learning* has been used to describe such learning. Information that is learned in this manner is vital for survival. It allows us to learn about patterns in the world, helping us to predict future events and to behave appropriately in new situations.

Statistical learning was most famously documented in a study of 8-month-old infants (Saffran, Aslin, & Newport, 1996). The infants were exposed to a string of spoken syllables that were presented in a monotone and with no pauses between them. Some of the syllables always occurred in succession, whereas others did not. For example, the syllable /pa/ might always be followed by /do/. The infants' performance on a subsequent listening preference test suggested that they had learned that the occurrence of /pa/ predicted the occurrence of /do/ and that /pado/ was a common unit. That is, the infants seem to have become sensitive to the statistics of the speech stream. This outcome is impressive given the young age of the learners and given their small amount of exposure to the string of syllables—only 2 min. Infants could potentially use the statistical learning skills documented in this study to help segment the speech that they hear into potential words. For example, they could learn that /be/ is often followed by /bi/ and that /bebi/ (*baby*) could be a unit that is attached to a meaning.

Subsequent studies showed that the statistical learning abilities documented by Saffran et al. (1996) are not limited to infants and not limited to auditory or linguistic materials (see Aslin, 2017, for a review). These studies

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also revealed some important characteristics of statistical learning. One is that people learn more when they devote their full attention to the to-be-learned material than when they simultaneously attend to something else (Toro, Sinnett, & Soto-Faraco, 2005; Turk-Browne, Jungé, & Scholl, 2005). Thus, statistical learning operates for items and events that are important to the learner, not for every stimulus that reaches the senses. Moreover, ease of learning varies with the materials and the statistics to be learned. Patterns involving unfamiliar elements tend to be difficult (Gebhart, Newport, & Aslin, 2009), and so are patterns that depend on context, such as that /b/ may occur at the beginning but not the end of a syllable if the syllable contains /i/ but that the opposite is true if the syllable contains /a/ (Chambers, Onishi, & Fisher, 2011). Patterns that involve nonadjacent elements are particularly difficult to learn (Gebhart et al., 2009). Consideration of these factors helps to explain why the infants in the Saffran et al. study learned the patterns in the string of syllables that they heard. Human speech is familiar and important to infants; there was little else in the experimental environment to draw the infants' attention, and the patterns to be learned were fairly simple.

The results of Saffran et al. (1996) suggest that infants may use their statistical learning skills to begin learning about spoken language. At this age, there are few other options: Infants cannot be taught explicitly about the words or rules of language. Could statistical learning also play a role in the learning of written language? The situation here seems rather different because children are explicitly taught how to spell and read when they are old enough to learn from formal instruction. According to a statistical learning perspective, however, children begin to learn about the properties of written words before formal literacy instruction begins on the basis of their exposure to written words on boxes of food, toys, books, and so on. Children also use their statistical learning skills to supplement what they are taught once literacy instruction is underway. In the section that follows, I present evidence in support of these claims (see Treiman & Kessler, 2014, for more extensive discussion).

Evidence About the Role of Statistical Learning in the Acquisition of Spelling

Writing has two sides. A written word is an object in itself: a string of visual elements that are arranged along a line. Writing is also a representation of something else: language. Learning to spell involves learning both about the visual appearance of written words and about how written words symbolize words' linguistic forms. Studies show that statistical learning plays a role in learning about both aspects of spelling.

Learning About the Appearance of Written Words

Words in alphabetic writing systems are made up of letters, and some letters and combinations of letters are more common than others. Just as a spoken language has phonotactic patterns—patterns involving the arrangement of phonemes—a writing system has graphotactic patterns involving the arrangement of letters. For example, the digram (pair of adjacent letters) ‹ng› and the digram ‹ff› do not occur at the beginnings of English words but do occur in the middles and at the ends. (Angled quotes, ‹ ›, are used for content that is cited as characters of writing.) Some graphotactic patterns reflect the fact that spellings represent the sounds of speech. For example, the letter group ‹ng› does not appear at the beginnings of written English words because the phoneme that it represents, /ŋ/, does not occur at the beginnings of spoken English words. Other graphotactic patterns, including the lack of word-initial ‹ff› in English, are not directly motivated by pronunciation. Many English words begin with /f/, but no words are spelled with ‹ff› at the beginning. Although these two types of patterns occur for different reasons, children could use their visual statistical learning skills to learn about both.

Indeed, there is evidence that children begin to learn about some of the simpler graphotactic patterns of their writing system before they understand how the spellings of words relate to the words' linguistic forms. Consider prephonological spellers: children who use letters when asked to write words but who do not use phonologically plausible letters more often than would be expected by chance. For example, one U.S. 4-year-old in the study of Zhang and Treiman (2015) wrote *bear* as ‹ioah› and *mosquito* as ‹b›. These spellings do not make phonological sense, and the child's spelling of the three-syllable word *mosquito* does not even contain more letters than the spelling of the one-syllable word *bear*. Despite prephonological spellers' weaknesses in the area of phonology, these children seem to have learned about some of the graphotactic features of the writing in their environment. When asked to write, they try to reproduce these features within the limits of their ability. One piece of evidence for this claim is that the frequency with which these children use particular letters is related to the frequency with which the letters appear in written materials of the language (Kessler, Pollo, Treiman, & Cardoso-Martins, 2013; Pollo, Kessler, & Treiman, 2009; Treiman, Kessler, Boland, Clocksin, & Chen, 2018). According to these same studies, prephonological spellers' use of digrams is also related to the frequency with which the digrams occur in written materials. For example, U.S. prephonological spellers are more likely to produce a letter string that contains ‹bi›, a fairly common digram, than a letter string that contains ‹bn›, an uncommon digram.

Preschool children are not explicitly taught that ‹b› is more likely to be followed by ‹i› than ‹n› in the words of English. They must have picked up this information on their own. Statistical learning is a likely mechanism. Support for this idea comes from the finding that older prephonological spellers, who have had on average more exposure to writing than younger prephonological spellers, show more knowledge of its graphotactic patterns. In the study of Treiman et al. (2018), adults were asked to rate the degree to which children's spelling attempts looked like real English words. The productions of older prephonological spellers received higher ratings, on average, than the productions of

younger prephonological spellers. Further supporting the importance of statistical learning, prephonological spellers who are exposed to different languages produce spellings that differ in some respects, reflecting the different statistics of the writing in their environments. The proportion of letters in words that are vowels, for instance, is higher in Portuguese than in English. Correspondingly, prephonological spellers who are exposed to Portuguese produce a higher proportion of vowel letters in their own attempts to write words than do prephonological spellers who are exposed to English (Pollo et al., 2009). Such findings show the importance of input from the child's environment, and they demonstrate that children learn about statistical patterns in the particular writing system to which they are exposed.

Statistical learning, as mentioned earlier, does not operate over every stimulus that we encounter (Turk-Browne et al., 2005). Rather, it operates on those that are important and that draw the learner's attention. Writing is normally of little importance to young children. When an adult reads a book to a preschool child, for example, it is the adult's spoken language and the pictures in the book that mostly attract the child's attention. Of the time that 4-year-olds spend looking at the pages of a storybook while being read to, only around 5% is devoted to the written words. The rest of the children's time is spent looking at the pictures (Evans & Saint-Aubin, 2005; Justice, Pullen, & Pence, 2008). This failure of writing to draw children' attention is not surprising. Writing is not particularly attractive, and humans did not evolve to pay attention to it, as they did to speech. These things help explain why statistical learning about the graphotactic patterns of written words begins later and takes longer than statistical learning about the phonotactic patterns of spoken words.

Although writing does not usually attract children's attention, it can do so in some situations. Children usually pay more attention to their own written name than to other words, not because the name is intrinsically more attractive but because it is personally important. Moreover, adults draw attention to children's names by pointing to them when they occur in the environment, by talking about them, and by showing them to children in isolation. These things help to explain why the name plays a leading role in literacy development and why young children often include letters from their names when trying to write other words (e.g., Bloodgood, 1999; Pollo et al., 2009). If adults talk about the characteristics of written words while reading aloud to children, or if they point to words as they read, children pay more attention to written words than they otherwise would (Justice et al., 2008). Even when adults do these things, however, young children's gaze is most often directed at the pictures in storybooks or electronic books (Skibbe, Thompson, & Plavnick, 2017) rather than at the words.

As children get older, they learn that written words are not just visual patterns but that they symbolize language. Children who receive phonics instruction are explicitly taught how specific letters and letter groups represent specific sounds. However, children do not usually receive explicit teaching about graphotactic patterns. For example, it would be unlikely for a teacher or parent to point out that ‹ff› rarely occurs after sequences of more than one vowel letter in English (e.g., ‹meaff› would be very unlikely to be an English word) but that ‹ff› sometimes occurs after single vowel letters (e.g., ‹meff› could be an English word). If U.S. children avoid producing spellings, such as ‹meaff›, as they tend to do as early as second grade (Hayes, Treiman, & Kessler, 2006), this must result from implicit learning rather than explicit instruction.

Children have some knowledge of simple graphotactic patterns even before formal literacy instruction begins, as already discussed, and they continue to learn about the graphotactic patterns of their writing system during the school years. Complex graphotactic patterns take more time to learn than simpler ones. For example, French third graders show some knowledge that a double consonant may follow a vowel (as in *messe* "mass") but not another consonant (‹melsse› is not acceptable), but they are less knowledgeable about this context-dependent pattern than about simpler patterns, such as that ‹ss› is more common than ‹jj› (Pacton, Sobaco, Fayol, & Treiman, 2013).

The discussion so far has focused on one side of writing: its visual appearance. Starting from an early age, research shows, children use their visual statistical learning skills to learn about such characteristics of writing as which letters tend to follow one another and which letters are less likely to do so. These aspects of writing may be learned starting at an early age because their learning does not require children to link elements in one sensory modality (letters) to elements in another modality (speech sounds). Indeed, learning of graphotactic patterns does not require children to know that writing symbolizes speech or that spoken words can be analyzed into phonemes, knowledge that takes time to develop. Learning about graphotactic patterns is valuable, but it is not enough. I now turn to how children learn about the other side of writing: how it symbolizes language.

Learning How Writing Represents Language

Learners of alphabetic writing systems must learn that letters symbolize phonemes and how they do so. Many children receive some explicit teaching about the links between phonemes and letters, learning in phonics instruction, for example, that /b/ is generally represented with ‹b›. However, the research to which I now turn shows that children use their statistical learning skills to supplement what they learn through formal instruction.

Caravolas, Kessler, Hulme, and Snowling (2005) studied British 5- and 6-year-olds who had received explicit teaching about the links between vowel letters and their "short" sounds, such as the link between ‹e› and /ɛ/. These children had not learned a letter or letter group that is associated with certain other vowel phonemes, including /aʊ/. When asked to spell words that contained various vowel phonemes, the children performed better on the

taught vowel correspondences than the untaught ones. The important finding for present purposes is that children's performance on sound-to-letter correspondences was also influenced by the amount of statistical evidence for a correspondence in the words that appeared in their reading materials. The evidence for the /ɛ/–‹e› correspondence is rather strong. For example, the large majority of English words that contain /ɛ/ spell it with ‹e›, although not all do (e.g., *head*). The evidence for certain other correspondences is less strong, and children tended to perform less well on these latter correspondences. The results of this study point to the importance of implicit learning through exposure to print, showing that it exerts an influence beyond explicit teaching.

Phonics instruction stresses the most common spelling of each sound. For example, the most common spelling of /ɛ/ in English is ‹e›, as in *hen,* and this is the spelling that is taught in phonics instruction. However, some words have other spellings of /ɛ/, including ‹ea› as in *head*. The words that contain the ‹ea› spelling are not a random subset of the words with /ɛ/. Rather, ‹ea› tends to occur in certain contexts, including when /ɛ/ is followed by /d/. For example, *head, bread,* and *instead* all have ‹ea›. In this and other cases, consideration of context could potentially help a child determine which spelling to use. The U.S. 8- to 10-year-olds in the study of Treiman and Kessler (2006) used ‹ea› to spell /ɛ/ in made-up words like /glɛd/ more often than in made-up words like /glɛp/, suggesting an implicit knowledge of this contextually driven pattern. In the case of /ɛ/, as in many other cases, children are not usually taught about how the choice among spellings varies with context. It is likely that children pick up the patterns on their own, using their statistical learning skills. Although the 8- to 10-year-olds in the study of Treiman and Kessler varied their spellings of the vowels examined in the study as a function of the following consonants, the 6- and 7-year-olds did not. A similar result was found for the 5- and 6-year-old British children in the study of Caravolas et al. (2005). This outcome probably reflects the fact that patterns that require consideration of context are more difficult to learn than those that do not. Moreover, context affects spelling in different ways for different phonemes, and the number of words with each context may be small.

English includes many cases in which the spelling of a vowel is systematically influenced by the consonant that follows it, as in the preceding example. It also includes some cases in which the preceding consonant is influential (Kessler & Treiman, 2001). One of these cases involves the vowel /ɑ/. This vowel is often spelled as ‹o›, as in *pond* and *lot,* and the ‹o› spelling of /ɑ/ is taught in phonics instruction. However, /ɑ/ is often spelled as ‹a› when it follows /w/, as in *wand* and *squat*. The children tested by Treiman and Kessler (2006) were more likely to use ‹a› when spelling nonwords like /kwɑp/ than when spelling nonwords like /blɑp/, suggesting that they had picked up this pattern. Knowledge of this context-dependent pattern, like knowledge of context-dependent patterns involving following consonants, increases with spelling experience.

The examples of context use discussed so far involve vowels in English. In English and some other writing systems, there are also cases in which the spellings of consonants are systematically influenced by context. Children become sensitive to these patterns over the school years. For example, Juul (2005) showed that Danish-speaking 11- and 12-year-olds use context to help select among alternative spellings of certain consonant and vowel phonemes.

Children who are explicitly taught the most common sound-to-spelling mappings of their writing system can use their statistical learning skills to supplement this instruction, learning about the less common mappings and about the contexts in which they occur. Statistical learning has more work to do in children who receive little or no direct instruction about the links between sounds and letters. This is the case for children in New Zealand, who, since the 1960s, have generally been taught using a whole-language approach. This approach eschews direct teaching of correspondences between letters and phonemes, although children are taught letters' names. Such an approach works less well than one that includes explicit instruction about the links between sounds and spellings (e.g., Butyniec-Thomas & Woloshyn, 1997). However, children who receive whole-language instruction seem to use their statistical learning skills to compensate to some extent. For example, children in New Zealand use their knowledge that ‹v› is named /vi/ to infer that the letter ‹v› may be used to spell /v/, the first phoneme of its name (Thompson, Fletcher-Flinn, & Cottrell, 1999).

So far, the discussion of context use has concentrated on how consideration of phonological context can help in selecting among possible spellings of phonemes. In some writing systems, including English and French, consideration of morphology can also help. For example, the phoneme sequence /ɛt/ has a number of possible spellings in French, including ‹aite›, ‹ette›, ‹ête›, and ‹ète›. To choose among the spelling options, it is helpful to consider the morphological status of /ɛt/. When /ɛt/ is a diminutive suffix, as in *fillette* "young girl" and *cigarette* "small cigar," it is always spelled as ‹ette›. The ‹ette› spelling is sometimes used when /ɛt/ is a not diminutive suffix, as in *gazette* "newspaper," but other spellings are more likely in this case. Similarly, /o/ is virtually always spelled as ‹eau› when it is a diminutive, as it is in many words for young animals, including *lapineau* "young rabbit." When /o/ is not a diminutive, it may be spelled as ‹eau› or in other ways. Around second grade, according to the findings of Pacton, Fayol, and Perruchet (2005), French children begin to produce more ‹ette› spellings when nonwords ending with /ɛt/ are presented as diminutives (e.g., when they are told that a /soʁivɛt/ is a little /soʁiv/ and asked to write /soʁivɛt/) than when such nonwords are not presented as diminutives. This phenomenon emerges about a year later in the case of /o/. The lag between /o/ and /ɛt/ probably reflects the fact that the proportion of nondiminutives that have the ‹eau› spelling of /o/ is larger than the proportion of nondiminutives that have the ‹ette› spelling of /ɛt/. That is, the statistical relationship between the special spelling—‹ette› or ‹eau›—and diminutive

status is weaker in the case of ‹eau› than in the case of ‹ette›. Importantly, French children are not explicitly taught that /ɛt/ and /o/ have predictable spellings when they are diminutives. They seem to learn this using their implicit statistical learning skills.

To summarize the findings reviewed in this section, children use their statistical learning skills when learning about links between units of language and units of writing. In this way, they can pick up associations that are not explicitly taught. Some statistical patterns that relate linguistic forms to spellings are more complex than others, and the evidence for the patterns varies in strength. These things help to explain why children master some aspects of spelling later or with more difficulty than others.

Other Perspectives on Spelling Development

The statistical learning perspective on spelling development laid out here contrasts in some important ways with other theoretical perspectives on spelling development (Pollo, Treiman, & Kessler, 2008). One influential alternative, phase theory (Ehri, 2000), describes the development of spelling skill in terms of children's increasing ability to map sounds to letters. During the prealphabetic phase, children do not yet use letters for their sound values. When asked to write words, these children scribble or produce random strings of letters. As children get older, typically as they enter school, they become able to map some of the sounds in words to letters. During this partial alphabetic phase, children produce spellings that symbolize some of the sounds in a word and omit others, as when they spell *lady* as ‹lde›. Later, during the full alphabetic phase, children become able to represent all of the phonemes in a word when spelling it. The fourth and final phase of spelling development, according to phase theory, is the consolidated alphabetic phase. Children now begin to treat common letter sequences as chunks and to follow the graphotactic patterns of their writing system.

Phase theory captures some important aspects of spelling development, for example, that learning to spell involves more than rote visual memorization of letter sequences. The theory draws attention to the phonological knowledge that children acquire and their use of this knowledge to select letters. However, phase theory gives short shrift to nonphonological knowledge, including knowledge of morphology and graphotactics. It also gives short shrift to context-sensitive phonological patterns. Research within the statistical learning perspective shows that these types of knowledge play important roles in spelling development. Learning about the graphotactic patterns of the writing system begins early, for example, even before children can map sounds to letters. It is not restricted to the most advanced phase of spelling development, as phase theory maintains.

Implications for Educators

Having presented and defended a statistical learning perspective on spelling development, I now consider how this perspective can be applied in the classroom and the clinic. I begin this section by describing different methods of teaching spelling.

One approach to the teaching of spelling is not to teach it. According to this natural learning perspective, what is important is that children read a lot. They will learn about the graphotactic patterns in written words and about links between spellings and linguistic units through exposure to words as they read (Krashen, 1989). The whole-language approach to literacy instruction that was mentioned earlier is founded on these assumptions. The research reviewed in this tutorial shows that children use their statistical learning skills to learn a number of things about spelling and that exposure to written words is important. However, research also shows that children learn to spell more efficiently and effectively when they receive systematic instruction about spelling than when they do not (Graham & Santangelo, 2014). That is, educators should not rely on statistical learning to do all the work.

If explicit teaching of spelling is beneficial, what teaching method should be used? One approach is to encourage children to memorize the spellings of words as wholes. This approach is common in the case of English, motivated in part by the idea that the spelling rules of this language have too many exceptions to be very useful. Children who are taught by this approach may receive a list of words to learn each week in preparation for an end-of-the-week spelling test. The words may be chosen because of their relationship to a theme, such as an upcoming holiday, or because they are common in the books that children are reading in the classroom. Often, the words are not chosen because of any similarity in their spelling patterns or linguistic forms.

Phonics is another approach to the teaching of spelling and reading. As has been discussed, phonics instruction generally covers the most common links between sounds and spellings in a language, such as the link between ‹o› and /ɑ/ that occurs in the English words *pot, stop,* and others. These links are taught as rules that should always hold. Phonics instruction also covers a small number of context-dependent rules that are based on phonology. For example, some phonics programs teach a rule that consonant letters should double in two-syllable words when the first vowel is short and stressed. This rule accounts for the doubling that occurs in words such as *muffin* and *hammer*. Phonics instruction places more emphasis on translation from spellings to sounds, the kind of decoding that occurs in reading, than on translation from sounds to spellings. Because it covers only the simpler patterns of the writing system, phonics instruction is limited to the first year or two of school. It does not cover graphotactics, and it does not cover many of the cases in which the spelling of a sound varies as a function of the surrounding phonemes or letters or as a function of morphological status. Thus, children are not taught that /ɑ/ is often spelled ‹a› rather than ‹o› in words like *squat* and *wand* where /w/ precedes the vowel. They are not taught that consonant letters do not usually double before ‹ic›, as in *panic* and *comic*. Words that deviate from phonics rules are typically taught as sight words. It is assumed that, because

these words disobey the rules, they do not follow any other patterns and must be individually memorized. For English, a large number of words fall into this category.

The research discussed in this tutorial shows that children learn about contextually driven patterns, influences of morphology, and graphotactics even when these are not explicitly taught. However, instruction could speed the process. It makes sense to begin with patterns that apply to a large number of words and patterns that apply to words that are used most frequently. However, instruction need not stop there. It can cover other patterns as well, such as how /ɑ/ is often spelled as ‹a› rather than ‹o› when it is preceded by /w/ (e.g., *wand, squat*), how consonants rarely double after more than one vowel letter (e.g., ‹beall› and ‹beallage› would be very unlikely words in English), and how consonant doubling is more common before some letter sequences (e.g., word-final ‹er›) than others (e.g., word-final ‹ic›). Instruction about these patterns could help children to avoid such spelling errors as ‹wond› for *wand,* ‹deaff› for *deaf,* and ‹pannic› for *panic*. It could encourage children to look for additional patterns in the words that they encounter.

If spelling instruction is to cover more material than it currently does, it must take up more time in the school day or must continue for more years. The latter is a better approach. Spending a small amount of time each school day on spelling takes advantage of the fact that people learn and remember better when instruction is spaced than when it is massed (Seabrook, Brown, & Solity, 2005). Moreover, spelling instruction need not take place in isolation. It can be combined with instruction in vocabulary. For example, older students can learn about the root *bene-,* which maintains its spelling in *benefit, benevolent,* and *beneficial* and which conveys a meaning as well.

The natural learning approach assumes that children will pay attention to the spellings of the words that they see, both words in books that are read to them and words in books that they read themselves. However, this is not necessarily true. Statistical learning and learning from explicit instruction both work better when learners attend to the material to be learned, and children need encouragement to attend to words' spellings. Expecting young children to learn very much about spelling by being read to from storybooks or by looking at electronic books is not realistic because children pay more attention to the story and the pictures than to the written words, even when adults do such things as run their fingers under the words as they read them (Evans & Saint-Aubin, 2005; Justice et al., 2008). Similarly, older children and adults pay more attention to the ideas being conveyed than to the details of spelling when they read, limiting the amount that they can learn about spelling by reading. Learning about spelling is further limited by the fact that readers can often understand a word without fully processing all of the letters in it. To understand the word *crocodile* in a story, for example, a reader does not have to notice that the second vowel letter is ‹o› rather than ‹u›. Presenting written words in isolation and discussing the words' spellings draws children's attention to details of spelling, as does encouraging children to remember those details and later testing their memory.

Providing children with structured opportunities to discover patterns in written words can not only teach them about the patterns but also increase their interest in why words are spelled as they are. For example, children could be led to discover that, although *have* is an exception to the generalization that /æ/ is generally spelled as ‹a› with no final ‹e›, it is one of a number of words (e.g., *give, live, glove*) that has an otherwise unexpected final ‹e› to protect it from ending with ‹v›, which is rare at the ends of English words. Children could be led to discover that commercial products may be given names that end with ‹v› in order to draw purchasers' attention. If spelling is treated as an object of inquiry, children can be expected to find it more interesting, pay more attention to it, and learn more about it. Learning about words can become as interesting as learning about rockets or weather patterns.

To provide good instruction, educators need to know a good deal about spelling and spelling development. Although teachers are likely to be excellent spellers and readers themselves, their knowledge about some of the patterns in their writing system, such as the graphotactic constraint against word-final ‹v›, may be implicit rather than explicit. Awareness of this and other patterns can help educators plan instruction, use commercially available spelling programs in a thoughtful rather than a rote manner, and offer helpful feedback when students misspell words. Opportunities to learn about writing systems and spelling development are lacking in many professional preparation programs, and more such opportunities are needed (Moats, 2014).

Similarities and Differences Across Learners

The statistical learning perspective draws attention to differences among words and spelling patterns. For example, as mentioned earlier, most French children learn about the link between diminutive status and ‹ette› earlier than they learn about the link between diminutive status and ‹eau› because the statistical link between diminutive status and the special spelling in the input to which the children are typically exposed is stronger in the former case (Pacton et al., 2005). If a particular child learns the patterns in the opposite order, the statistical learning perspective encourages us to seek an explanation in the properties of the input to that child. For example, such a child may have read unusually many books with words like *lapineau* "young rabbit" and *éléphanteau* "young elephant."

In the development of spelling, as in the development of other skills, there are differences not only across items but also across learners. Children with dyslexia and children with specific language impairment (SLI), for example, learn to spell more slowly than typically developing children. However, these children show patterns of performance across types of words that are quite similar to those observed in younger children who are learning to spell at an average pace. The kinds of spelling errors made by older

children with dyslexia and SLI are also very similar to the kinds of errors made by typically developing younger children (Cassar, Treiman, Moats, Pollo, & Kessler, 2005; Cordewener, Bosman, & Verhoeven, 2012; Protopapas, Fakou, Drakopoulou, Skaloumbakas, & Mouzaki, 2013). These similarities support the view that all children possess the same statistical learning mechanisms and the same mechanisms for learning from explicit instruction. These mechanisms operate more rapidly and efficiently in some children than in others, but they may not operate in a qualitatively different manner.

Many researchers have sought to document differences across people in the speed and efficiency of statistical learning, asking whether these differences are associated with performance in spelling, reading, and other linguistic and nonlinguistic tasks. Studies have found that children with disorders, including dyslexia and SLI, perform more poorly than typically developing children in a variety of tasks assessing statistical learning of visual and auditory patterns (Gabay, Thiessen, & Holt, 2015; Lammertink, Boersma, Wijnen, & Rispens, 2017; Obeid, Brooks, Powers, Gillespie-Lynch, & Lum, 2016). However, findings such as these do not show that difficulties in statistical learning are a cause of these children's problems with spelling, reading, and other tasks. They may simply be a correlate. The best way to draw conclusions about cause and effect would be to show that children can be taught to improve their statistical learning skills and that this improves their performance in spelling or another task of interest. In one of the few such training studies that has been conducted to date, Smith, Conway, Bauernschmidt, and Pisoni (2015) developed a task that was designed to improve people's ability to notice regularities in the order with which circles lit up on a computer screen. Practice with this task did not improve adults' ability to use the context of a sentence to perceive spoken words under poor listening conditions. This result is not encouraging for the view that training in statistical learning benefits language processing. Interestingly, broadly similar results have been found when researchers have attempted to train another general ability, working memory. Although such training improves the memory skills that were taught, it does not transfer to more distant skills such as reading (Melby-Lervåg, Redick, & Hulme, 2016).

The best way to improve children's performance on a skill, spelling in the present case, is to focus on that skill directly. Trying to improve children's general learning ability and trusting that this improvement will transfer to spelling is, as suggested by the studies mentioned above, a riskier proposition. As McArthur and Castles (2017, p. 3) stated when discussing interventions for poor readers, "the 'closer' the intervention is to an impaired reading behaviour, the more likely it is to be effective." The same is likely to be true for spelling. That is, interventions that focus directly on spelling are more likely to benefit spelling than are interventions that focus on other skills.

The suggestions about spelling instruction that are offered in this tutorial are based on what we know about statistical learning and other forms of learning, and they target the specific spelling skills that we wish children to learn. These methods are likely to be effective for a wide range of children, including both faster and slower learners. The pace of instruction must be adjusted across children, but the basic principles of instruction are the same.

Conclusions

Learning to spell words correctly is an important skill, and it facilitates reading and writing (Ouellette, Martin-Chang, & Rossi, 2017). Good spellers produce correct spellings easily and without much effort, allowing them to concentrate while they are writing on the ideas that they wish to express. Their readers can grasp those ideas without being distracted by misspellings. Thus, even though learning to spell can be difficult, it is worth learning. Children use their statistical learning skills to help in learning to spell and learning to read (see Arciuli, 2018), but structured instruction is also needed.

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