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Tracking the evolution of orthographic expectancies over building visual experience

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Abstract

Literate children can generate expectations about the spellings of newly learned words they have not yet seen in print (Wegener et al., 2018). These initial spelling expectations, or *orthographic skeletons*, have previously been observed at the first orthographic exposure to known spoken words. Here, we asked what happens to the orthographic skeleton over repeated visual exposures. Grade 4 children (N=38) were taught the pronunciations and meanings of one set of 16 novel words while another set were untrained. Spellings of half the items were predictable from their phonology (e.g. *nesh*) while the other half were less predictable (e.g. *koyb*). Trained and untrained items were subsequently shown in print, embedded in sentences, and eye movements were monitored as children silently read all items over three exposures. A larger effect of spelling predictability for orally trained compared to untrained items was observed at the first and second orthographic exposure, consistent with the notion that oral vocabulary knowledge had facilitated the formation of spelling expectations. By the third orthographic exposure this interaction was no longer significant, suggesting that visual experience had begun to update children's spelling expectations. Delayed follow-up testing revealed that, when visual exposure was equated, oral training provided a strong persisting benefit to children's written word recognition. Findings suggest that visual exposure can alter children's developing orthographic representations and that this process can be captured dynamically as children read novel words over repeated visual exposures.

Word count: 234

Highlights

- Children form expectations about the spellings of orally known words
- Eye movements during reading of novel written words reveal these expectancies
- Spelling expectancies are evident the first and second time a novel word is read
- By the third reading, spelling expectancies show evidence of updating
- Oral vocabulary knowledge benefits longer term retention of written words

It is well known that children's spoken language skills and their emerging literacy skills are closely intertwined, with oral vocabulary knowledge likely playing a causal role in children's reading development (Duff et al., 2015; Duff & Hulme, 2012; Lee, 2011; McKague et al., 2001). Since virtually all children begin formal schooling in possession of knowledge about a substantial number of spoken words they cannot yet read (Chall, 1987), there may be potential to support reading acquisition through the implementation of oral vocabulary interventions. Understanding the nature of the mechanism or mechanisms that support the link between oral vocabulary and reading is an important but relatively overlooked prerequisite to this endeavour. One such mechanism has been recently proposed: children may utilise their knowledge of the mappings between phonemes and graphemes to form expectations about the spellings of known spoken words they have not yet seen in writing (Wegener et al., 2018). These initial spelling expectations, or *orthographic skeletons*, were observed to influence reading behaviour the first time words were seen in print. Here, we address the question of what happens to children's initial spelling expectancies over subsequent visual exposures and ask: does accumulating visual experience prompt the commencement of an updating process which might serve to bring orthographic skeletons closer to the correct written form, and if so, when does this occur?

Orthographic learning refers to the gradual acquisition of written word representations (Castles & Nation, 2006; Nation & Castles, 2017) and oral vocabulary is generally viewed as providing assistance with this process. Mechanistic accounts typically focus on how spoken word knowledge might assist children to make mappings between orthographic forms and their pronunciations. In so doing, they make the explicit prediction that oral vocabulary knowledge exerts an effect on word reading that begins upon exposure to a novel written word. A prominent example is the self-teaching hypothesis (Share, 1995, 2008), which positions phonological decoding as central to the process of orthographic learning. On this view, oral vocabulary knowledge is thought to provide top-down support during phonological decoding by assisting children to correct partial decoding attempts. Partial decodings might occur for a number of reasons. A child might have incomplete knowledge of the mappings between letters and sounds; they might make a decoding error for a mapping that they do know; or they might encounter a word with an irregular print-to-pronunciation mapping. Using the latter possibility as an example, if a child attempts to phonologically decode the written word *break*, they should produce an unfamiliar pronunciation rhyming with *peak*. If the child knows the spoken word 'break' and recognises that their phonological decoding attempt sufficiently resembles it, this may prompt the child to review their decoding attempt, thereby potentially aligning the two pronunciations. This idea resonates with related theories suggesting that the ability to match discrepant pronunciations of spoken words may contribute to reading development (Dyson et al., 2017; Elbro et al., 2012; Kearns et al., 2016; Savage et al., 2018; Tunmer & Chapman, 2012).

An alternative possibility is that oral vocabulary knowledge may also exert an effect on word reading that begins prior to visual exposure, via children's ability to translate from pronunciation to print. Data from skilled readers suggests that the existence of such an alternative causal mechanism is plausible. For example, adults automatically activate orthographic knowledge when processing spoken words (Chéreau et al., 2007; Pattamadilok et al., 2007, 2009; Taft, 2011; Taft et al., 2008; Ziegler & Ferrand, 1998). Notably, a similar effect has also been observed when adults received training on the pronunciation and meaning of novel words prior to encountering them in print for the first time (McKague et al., 2008), suggesting that oral vocabulary knowledge may have resulted in the formation of early orthographic representations.

The orthographic skeleton hypothesis (Wegener et al., 2018) provides an account of how one's spoken word knowledge might support reading acquisition prior to visual exposure. Specifically, when children know a spoken word and when they possess knowledge about phoneme-to-grapheme mappings, they could be in a position to generate expectations about the spellings of words they have not yet seen in writing. This possibility was tested for the first time with developing readers in the context of a novel word training study. Children were taught the pronunciations and meanings of a set of novel words prior to reading sentences containing the trained items and another set of items they had not heard before. Children's eye movements revealed that, compared with untrained items, those that had received oral training and were shown in print with predictable spellings (e.g. the spoken word '*nesh*' written as *nesh*) were associated with shorter fixation durations. However, when orally trained items were presented with unpredictable spellings (e.g. the spoken word '*coib*' written as *koyb*) there was no benefit of training. These findings show that children's online processing is facilitated when orthographic expectancy matches the actual orthographic form; in contrast, there is a processing cost when there is a mismatch between expectancy and form.

The original investigation of the orthographic skeleton hypothesis addressed children's online processing at the first visual exposure to orally trained and untrained items on the assumption that the initial encounter should be particularly informative. This is because, if children do indeed form spelling expectations for orally known words, it should be most apparent at the earliest point in learning when phonology-to-orthography influences are likely to be strongest (see also McKague et al., 2008). Of course, in natural reading, written words are often encountered on more than one occasion. An important outstanding issue therefore concerns what happens to children's spelling expectations when the corresponding written form is experienced on subsequent occasions.

The frequency with which a spelling occurs in writing is associated with the speed with which it is processed – frequently occurring written words require shorter processing times than less common written words (for a review see Brysbaert, Mandera, & Keuleers, 2018). Indeed, models of skilled reading all offer an account of the word frequency effect (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Norris, 2006; Plaut, Seidenberg, McClelland, & Patterson, 1986), and while the specifics of the explanations differ, the effect is usually interpreted as reflecting the outcome of learning that has occurred during repeated visual exposures. Similarly, theories of orthographic learning all recognise a role for visual experience that extends beyond the initial visual exposure. The self-teaching hypothesis (Share, 1995, 1999, 2004), for example, proposes that each phonological decoding of a novel printed word provides an opportunity to learn its spelling, with the probability of subsequent word recognition depending at least in part on the frequency with which it has been seen. In a similar vein, the lexical quality hypothesis (Perfetti, 1992, 2007; Perfetti & Hart, 2002) proposes that knowledge about individual words is accrued gradually, with orthographic representations becoming increasingly robust and specific as visual experience builds.

Evidence for a direct role of repeated visual experience in reading acquisition is derived from learning paradigms that manipulate exposure frequency. Notwithstanding substantial methodological differences between paradigms, evidence converges on the view that written word learning improves with increasing visual experience (but see Share, 2004). For example, naming accuracy improves (Duff & Hulme, 2012) while naming speed reduces (Bowey & Muller, 2005; Reitsma, 1983a, 1983b, 1989) as children encounter words over repeated exposures. More recent investigations favour orthographic choice as a more sensitive means of interrogating orthographic learning, with several studies showing that as trials increase so does children’s ability to discriminate between learned and novel written forms that overlap with respect to pronunciation but differ in terms of their spellings (Bowey & Muller, 2005; Nation, Angell, & Castles, 2007). Further, eye movement work with both children (Joseph & Nation, 2018) and adults (Elgort, Brysbaert, Stevens, & Van Assche, 2018; Joseph, Wonnacott, Forbes, & Nation, 2014) shows that as novel written words become increasingly familiar during the course of accrued visual experience, they are read more efficiently.

Since orthographic representations are thought to develop over time, how might this occur? According to the lexical quality hypothesis (Perfetti, 1992, 2007; Perfetti & Hart, 2001), the end-point of lexical knowledge acquisition is a *precisely* specified orthographic form that encodes an exact spelling. Before this time, developing orthographic representations are imprecise; this imprecision may arise either because the encoded spelling is incomplete, or because it contains one or more temporarily incorrect letters. The key consequence of imprecision, whether it arises from a partial or erroneous encoded spelling, is a representation that is unstable and subject to change (Perfetti, 1992). Since orthographic representations are conceived of as “evolving towards completeness” (Perfetti, 1992, p. 159), visual exposure during the initial stages of learning may provide an opportunity for developing orthographic representations to change, or be updated, in light of experience.

Extending this reasoning to the orthographic skeleton, two possible outcomes of an initial encounter with a known spoken word might be anticipated. In some instances, the child’s spelling expectancy might match the orthographic form they experience in print. The effect of this encounter would be the provision of support for the orthographic skeleton, with the presumed effect that the initial orthographic representation is enhanced. In other cases, the orthographic skeleton will be misaligned in some way with the orthographic form. The consequence of such an encounter should be that one or more aspects of the orthographic skeleton is contradicted, presumably providing a prompt to alter the initial orthographic representation. In either event, the visual experience provides an opportunity for the reader to incrementally update their initial spelling expectancy, gradually bringing their initial spelling expectancy into alignment with the form they experienced in print. Eye movement monitoring during successive visual exposures has previously been shown to be sensitive to building visual experience with words (Elgort et al., 2018; Joseph & Nation, 2018; Joseph et al., 2014), suggesting that this approach may be a useful means of indexing the evolution of the orthographic skeleton across visual exposures.

The current experiment

We investigated the relationship between oral vocabulary knowledge and children's online processing over successive visual exposures to familiar and unfamiliar spoken words. Three issues were of particular interest. First, we sought to determine whether oral vocabulary knowledge permits children to form expectations of the spellings of known spoken words at the first visual exposure, a finding that if observed, would replicate that of Wegener and colleagues (2018). Second, if the effect was observed at the first visual exposure, we sought to determine whether it would remain as children read the words for a second and third time. Third, we were interested in the longer term influence of these learning events on children's delayed visual word recognition.

Two groups of Year 4 children were taught the pronunciations and meanings of a set of novel words (e.g., 'nesh', 'coib') while a second set of items were untrained. All items, both trained and untrained, were embedded in sentences which were presented to children over a series of three blocked exposure trials. The children's eye movements were monitored as they silently read the sentences. The spelling predictability of the novel words was manipulated such that half of the items in each set had spellings that were highly predictable from phonology and therefore consistent with children's likely orthographic expectations (e.g., *nesh*), while the remaining items had spellings that were unpredictable from phonology and therefore inconsistent with children's likely expectations (e.g., *koyb*). In line with Wegener and colleagues (2018), if children do form spelling expectations for orally known words, this should be evident in looking times at target words during sentence reading. Specifically, when words are orally familiar, there should be a larger difference in looking time if words have unpredictable vs. predictble spelling, relative to words that are not orally familiar. This interaction between training and spelling predictability repesents key evidence for the formation of orthographic expectancies and should be observed across each of the looking time measures of interest (first fixation duration, gaze duration, total reading time). Extending previous work and drawing on the lexical quality hypothesis, we anticipated that written exposure to known spoken words should provide an opportunity for children to update their initial spelling expectations, gradually aligning them with the written form experienced during reading. We elected to provide three orthographic exposures per target in view of prior work (e.g., Share, 1999, 2004) demonstrating that orthographic representations can be acquired over just a few visual exposures (ranging from 1 to 4 when assessed using orthographic choice). The notion that orthographic representations undergo a process of updating would be supported by diminishing evidence of the interaction between training and spelling predictability. Additionally, in line with prior work (Chaffin et al., 2001; Wegener et al., 2018), we anticipated that oral familiarity would be associated with a reduced probability of rereading.

Based on prior work suggesting that oral vocabulary supports orthographic learning, it was anticipated that children's delayed visual word recognition would be superior when an item had been trained in spoken form compared to when it had not. Less clear, however, were predictions relating to the influence of the spelling predictability manipulation. One possibility is that when orthographic expectancy matches the orthographic form experienced in print, this correspondence might convey a particular benefit to orthographic learning because the requirement to alter the initial spelling expectation is greatly reduced. Alternatively, if there is a mismatch between expectancy and experience, this incongruence might provide a strong cue to update the early orthographic representation, which may in turn drive a boost in performance for these items.

Method

Participants

Forty children in Year 4 were recruited from a primary school in New South Wales, Australia. All children who returned a consent form were considered eligible. One child withdrew consent while another was unable to be adequately calibrated, so data are reported for the remaining 38 participants (17 males). The mean age of children was 10 years and 0 months (range: 9y;4m -10y;10m). The sample size was informed by previous investigations of orthographic learning (Share, 2004; Wang et al., 2011), and particularly by the first experiment reporting the orthographic skeleton effect (Wegener et al., 2018). Because the current experiment employed the same methods and stimuli as Wegener and colleagues (2018), we sought to recruit an equal or larger number of children.

Standardized tests

Standardized measures of spoken vocabulary knowledge, reading and spelling were administered to characterize the sample. Vocabulary was assessed using the naming subtest from the Assessment of Comprehension and Expression 6-11 (ACE 6-11; Adams, Coke, Crutchley, Hesketh, & Reeves, 2001). Reading of regular, irregular and nonwords was assessed using the Castles & Coltheart 2 (CC2; Castles et al., 2009). Spelling ability was assessed with the Diagnostic Spelling Test – irregular words (DiSTi; Kohnen, Colenbrander, Krajenbrink, & Nickels, 2015) and the Diagnostic Spelling Test – nonwords (DiSTn; Kohnen et al., 2015). Summary data are presented in Table 1 and show that mean performance was broadly within the average range across all measures.

Table 1

Children's performance on standardized tests of spoken vocabulary, reading and spelling

	M	SD	Min	Max
Spoken vocabulary knowledge (ACE)[a]	8.71	2.73	3.00	16.00
Reading aloud (CC2)				
Regular [b]	-0.36	1.36	-2.37	2.99
Irregular [b]	-0.56	0.88	-2.29	1.67
Nonwords [b]	-0.43	1.09	-2.29	1.72
Spelling				
DiSTn [b]	-0.12	0.93	-1.71	1.75
DiSTi [b]	-0.05	0.93	-1.69	1.93

Note: ACE, Assessment of Comprehension and Expression 6-11; CC2, *Castles & Coltheart 2;* DiST*, Diagnostic Spelling Test – nonwords;* DiSTi*, Diagnostic Spelling Test irregular words.*[a] *Age scaled score (M = 10, SD = 3);* [b] *Grade-based z-scores (M = 0, SD = 1)*

Experimental materials

Items were taken from Wegener et al. (2018) and consisted of two sets of 16 three-phoneme, monosyllabic nonwords matched for consonant/vowel structure. All items were regular for reading: they employed the most common grapheme-to-phoneme correspondence (type frequency *M* = 94.23%, *SD* = 10.78%). Half of the items in each set were assigned spellings that were highly predictable from phonology because they contained frequent phoneme-to-grapheme mappings (e.g., 'f' for /f/). The other items were assigned spellings that were unpredictable from phonology because they contained less frequent phoneme-to-grapheme mappings (e.g., 'ph' for /f/). For details of the pilot testing that confirmed this manipulation, see Wegener and colleagues (2018). Of note, predictable and unpredictable items could not be matched for number of letters or bigram frequency, but these features were matched across training sets and all items were matched on number of phonemes. Item sets appear in Table 2.

Table 2.

Experimental target words.

	Set 1		Set 2	
	Phonology	Orthography	Phonology	Orthography
Predictable Items	/dʒev/	jev	/tem/	tem
	/jæg/	yag	/nId/	nid
	/vIb/	vib	/dʒIt/	jit
	/tʌp/	tup	/jæb/	yab
	/neʃ/	nesh	/vIʃ/	vish
	/tʃɒb/	chob	/ʃep/	shep
	/ʃʌg/	shug	/θɒg/	thog
	/θʌb/	thub	/tʃIg/	chig
Unpredictable Items	/viːm/	veme	/juːn/	yune
	/baɪp/	bype	/kaɪv/	kyve
	/jɜːp/	yirp	/bɜːv/	birv
	/kɔɪb/	koyb	/dʒaɪf/	jayf
	/dʒiːb/	jeabb	/miːf/	meaph
	/fɜːf/	phirf	/gʌz/	ghuzz
	/gæk/	ghakk	/feg/	phegg
	/mɜːb/	mirbe	/veɪp/	vaype

Procedure

Oral vocabulary training. Using the same procedure as Wegener et al. (2018), children were taught one set of 16 novel spoken words at a class level, while the other set were untrained. Item sets were counterbalanced across classes. Children were introduced to the novel spoken words in sessions over a period of four days. Each session was of approximately 20-minutes duration. In the first session, eight items were introduced (four from each spelling predictability condition) while the remaining eight were introduced in the second session. All 16 items were rehearsed in the third and fourth training sessions. If a child was absent for any training session, a catch-up session was provided at the earliest opportunity. Children were told that they would be learning about ‘Professor Parsnip’s Inventions’ (Wang et al., 2011, 2013). Spoken invention names were paired with a picture referent (see Figure 1); information about the function of the invention and two perceptual features was also provided. For example, children learned that a ‘nesh’ is ‘used to shuffle cards’ and ‘is made of metal and has two hands’. Children were asked to learn both the novel words and the function of each invention.

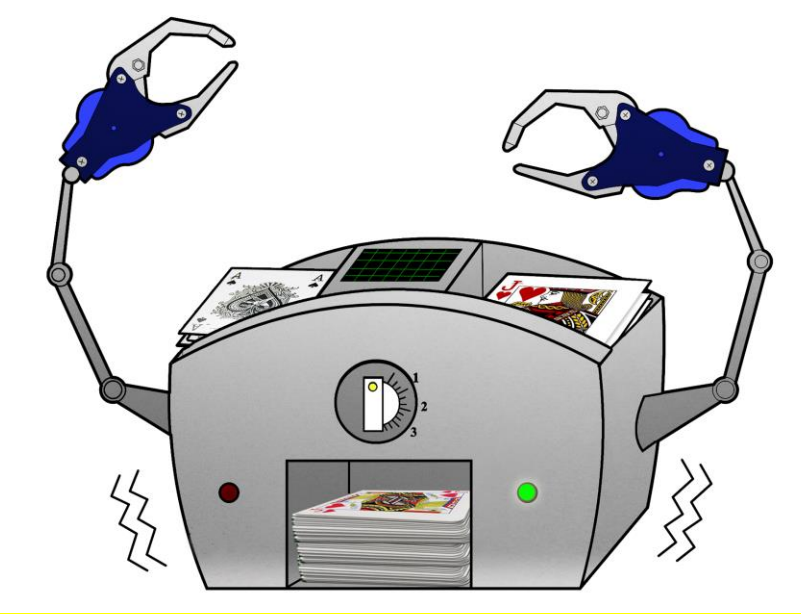

Figure 1. Sample picture: A ‘nesh’ is used to shuffle cards.

Learning check. Following the completion of training but prior to the initial orthographic exposure, the children’s oral vocabulary learning was assessed individually in a picture-naming task. Individual children were shown pictures of the inventions, one at a time, and were asked to provide both the name of the invention and its function. To control the number of phonological exposures, feedback was provided regardless of accuracy.

Orthographic Exposure. The children encountered the written form of the orally trained words for the first time between 1 and 7 days following their final oral vocabulary training session (*M* = 2.58, *SD* = 1.45). Invention names were embedded in contextually meaningful sentences. Sentences referring to the trained and untrained inventions were mixed and presented to children for silent reading over three blocked orthographic exposures. The first orthographic exposure took the same form and employed the same sentences as Wegener and colleagues (2018): children read sentences containing the 16 inventions they had learned; 16 sentences contained inventions they had not learned about; and eight filler sentences which contained novel words not learned by any group. On the second and third orthographic exposure, children read different sentences containing the target words. No filler sentences were presented during these exposures in order to limit the length of the testing session. Children read a total of 104 experimental sentences. An example is provided in sentences *a*, *b* and *c* (target words were not italicized during the experiment).

a. Nick put the deck of playing cards into the *nesh* to shuffle them.

b. He watched the playing cards as the *nesh* mixed them up.

c. After the cards had been well shuffled the *nesh* turned itself off.

An Eyelink 1000 eye tracker (SR Research; Mississauga, Canada) in head stabilized mode and with a sampling rate of 1000Hz recorded children's eye movements as they read the sentences on a computer screen. The viewing distance was 104cm and each character subtended approximately 0.25 degrees of horizontal visual angle. Sentences appeared in black Courier New font on a white background. Participants read binocularly but only the movements of the right eye were recorded. Following an initial calibration, children read three practice sentences before progressing to the experimental sentences. Maximum calibration error was set at 0.5º. The start of each trial was triggered by the experimenter when the children fixated a drift correct target, and recalibration was performed when necessary. The end of each trial was triggered when children directed their gaze towards a rectangle. Children were required to answer a (yes/no) question after each trial as a means of promoting attention to task.

Eye movement dependent variables were: first fixation duration (the duration of the initial fixation on the target word); gaze duration (the sum of all fixations made on the target word before the eyes move past the target to a subsequent word within the sentence); total reading time (the sum of all fixations on the target word, including any regressions back to it); and regressions in (the probability of making a regression back to the target word from a later portion in the sentence).

Delayed post-exposure testing: Go/no-go lexical decision. At a delay of between two and six days (*M* = 4.08; *SD* = 0.91) following the eye-tracking task, a go/no-go lexical decision task was administered in order to investigate the influence of the orthographic skeleton on children's longer-term retention. The 16 trained items, the 16 untrained items, and a set of 32 novel words that children had never seen or heard before, were presented on a laptop using DMDX software (Forster & Forster, 2003). All items, both trained and untrained, were presented to each participant in a random order. Before commencing the task, children were reminded that they had read a number of novel words in the context of the eye-tracking task, some of which they had been taught orally while others they had never heard before. Children were told that they were going to see some words one at a time on a computer screen, and that they were to press a button as quickly as possible if they recognized a word as being familiar to them from the eye-tracking task. It was emphasized that they should respond to these words if they had seen them before, even if they had not learned the word in spoken form. Children were instructed that they would also see other words that were not present in the eye-tracking task – these words would therefore be totally new to them, having never been seen or heard before. Children were instructed that when they did not recognise a word as being familiar to them from the eye-tracking task, they should do nothing and simply wait for it to disappear on its own. If a response button was not pressed, the words were displayed for a maximum duration of 4000ms.

Results

Learning check: Picture naming

Participants correctly recalled a mean of 10.47 of the 16 orally trained invention names (*SD* = 4.14). The difference in recall between participants who learned set 1 (*M* = 10.11, *SD* = 4.27) and set 2 (*M* = 10.84, *SD* = 4.10) was not significant (*t*(36) = -0.54, *p* = 0.591), nor was the difference in recall for items with predictable (*M* = 5.24, *SD* = 2.24) and unpredictable spellings (*M* = 5.24 *SD* = 2.09; *t*(36) = 0.00, *p* = 1.000).

Eye movements

Data were analysed in the R computing environment (R Core Development Team, 2019). Linear mixed effects models were constructed using the lme4 package (Bates, Maechler, Bolker, & Walker, 2019). Consistent with other eye movement work (Wegener et al., 2018; Joseph & Nation, 2018; Taylor & Perfetti, 2016), reading time data were log transformed. Models were run for each of the dependent variables of interest: first fixation duration, gaze duration, total reading time and regressions in. For the purpose of analysis, the area of interest was the invention name, or target word. Fixations shorter than 80 milliseconds and within one character space of the previous or next fixation were merged, and any remaining fixations shorter than 80 milliseconds or longer than 1200 milliseconds were deleted. Trials were removed if a blink or track loss occurred on the target word, or if any of the three prespecified interest areas – target word, pre-target text, post-target text – were skipped during first pass reading. Following these cleaning steps, 89.52% of the experimental data remained.

Because exposure was ordered (first to third), contrast coding was implemented for all fixed effects using the successive differences function from the *MASS* package (Ripley et al., 2019). Training (untrained vs. trained), spelling (unpredictable vs. predictable), exposure (2 vs. 1, 3 vs. 2) and their interaction were entered as fixed effects while participants and items were entered as random effects. Fitting the full random effects structure with random intercepts and slopes for subjects and items resulted in issues with singularity and nonconvergence, suggesting that the models were over parameterized (Baayen et al., 2008).

For this reason, models were built from the simplest to the most complex random effects structure and the highest nonsingular converging model is reported (the structure of each final model appears in the Supplementary Material). Our primary aim was to determine whether the two-way interaction was present at each visual exposure to the target words. To this end, we ran an overall model. Whenever the two-way interaction between training and spelling predictability was significant in the omnibus model, interaction contrasts were computed to determine whether the interaction was present at each visual exposure to the target words. Interaction contrasts were implemented using the *phia* package (Rosario-Martinez, 2015). Three-way interactions from the overall model indicated whether the magnitude of the two-way interaction between training and spelling predictability differed significantly across exposures. For ease of interpretation, arithmetic means and standard errors for each of the dependent variables appear in Figure 2.

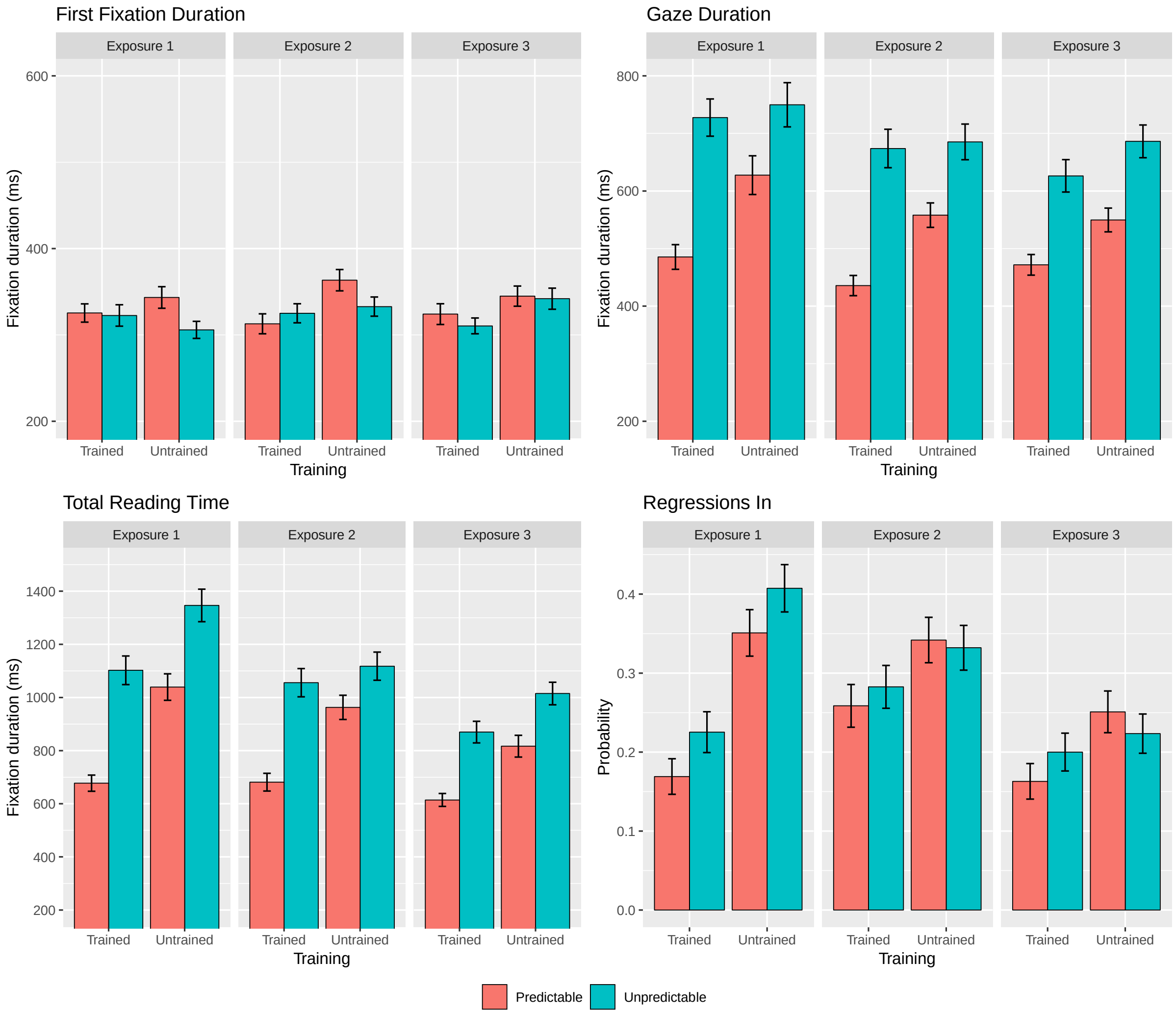

Figure 2. Arithmetic (untransformed) means and standard errors of target word fixation durations and probability of rereading. First fixation duration, gaze duration and total reading time are expressed in milliseconds while regressions in reflects likelihood of occurrence.

Results of the model for *first fixation duration* are presented in Table 3. There were no fixed effects of spelling predictability or exposure. However, there was a significant fixed effect of training such that orally trained items were associated with shorter fixation durations than untrained items. There was also an incidental and unexpected finding observed at first fixation: the effect of training varied across exposures. Interaction contrasts showed that the effect of training was not significant at the first visual exposure (χ^2 = 0.001, *p* =.975) but it was significant at the second (χ^2 = 8.623, *p* = .009) while it was marginal at the third (χ^2 = 4.49, *p* = .068). No other two-way or three-way interactions were significant.

Table 3.

Results of the linear mixed effects model for first fixation duration.

		Training	Spelling	Exposure 2 vs. 1	Exposure 3 vs. 2	
Fixed effects	*b*	0.05	-0.03	0.03	-0.00	
	SE	0.02	0.02	0.02	0.02	
	t	2.55	-1.31	1.45	-0.22	
	p	< .015*	.200	.148	.823	
		Training x Spelling	Training x Exposure 2 vs. 1	Training x Exposure 3 vs. 2	Spelling x Exposure 2 vs. 1	Spelling x Exposure 3 vs. 2
Two-way Interactions	*b*	-0.06	0.08	-0.02	0.05	-0.00
	SE	0.03	0.03	0.04	0.04	0.04
	t	-1.93	2.26	-0.64	1.19	-0.09
	p	.054*	.024*	.553	.236	.929
		Training x Spelling x Trial 2 vs. 1	Training x Spelling x Trial 3 vs. 2			
Three-way Interactions	*b*	-0.08	0.12			
	SE	0.08	0.08			
	t	-1.03	1.56			
	p	.302	.118			

Note. * denotes statistical significance

Results of the model for *gaze duration* are presented in Table 4. There was no significant fixed effect of exposure. However, there was an effect of training such that trained items were fixated for shorter durations than untrained items. There was also a significant effect of spelling, such that items with predictable spellings were fixated for a shorter duration than items with unpredictable spellings. Training and spelling predictability interacted, with the effect of spelling predictability being larger for orally trained compared to untrained items. Contrasts showed that the interaction between training and spelling predictability was only present in the first (χ^2 = 5.15, *p* = .046) and second exposure (χ^2 = 7.94, *p* = .014) but not in the third (χ^2 = 0.77, *p* = .379). No other two-way or three-way interactions were significant.

Table 4.

Results of the linear mixed effects model for gaze duration.

		Training	Spelling	Exposure 2 vs. 1	Exposure 3 vs. 2	
Fixed effects	*b*	0.12	0.26	-0.05	0.02	
	SE	0.03	0.04	0.05	0.03	
	t	4.09	6.41	-1.13	0.73	
	p	< .001*	< .001*	.269	.472	
		Training x Spelling	Training x Exposure 2 vs. 1	Training x Exposure 3 vs. 2	Spelling x Exposure 2 vs. 1	Spelling x Exposure 3 vs. 2
Two-way Interactions	*b*	-0.15,	0.06,	-0.03,	0.00,	-0.06,
	SE	0.05,	0.05,	0.05,	0.09,	0.06,
	t	-2.95,	1.24,	-0.67,	0.08,	-0.92,
	p	.007*	.216	.502	.932	.366
		Training x Spelling x Trial 2 vs. 1	Training x Spelling x Trial 3 vs. 2			
Three-way Interactions	*b*	-0.04,	0.15,			
	SE	0.10,	0.10,			
	t	-0.41,	1.53,			
	p	.679	.126			

Note. * denotes statistical significance

Results of the model for *total reading time* are presented in Table 5. A fixed effect of exposure was observed such that fixation durations reduced from the first to the second exposure and from the second to the third exposure. An effect of training was again observed such that trained items were fixated for shorter durations than untrained items. The effect of spelling predictability was also significant such that items with predictable spellings were fixated for a shorter duration than items with unpredictable spellings. Training and spelling predictability interacted, with the effect of spelling predictability being larger for orally trained compared to untrained items. Contrasts showed that the interaction between training and spelling predictability was only present in the first (χ^2 = 6.99, p = .016) and second exposure (χ^2 = 15.35, p < .001) but not in the third (χ^2 = 0.80, p = .372). A three-way interaction was also observed, which suggested that the interaction between training and spelling predictability was significantly smaller at the third exposure compared to the second exposure. No other interactions were significant.

Table 5.

Results of the linear mixed effects model for total reading time.

		Training	Spelling	Exposure 2 vs. 1	Exposure 3 vs. 2	
Fixed effects	*b*	0.23	0.31	-0.05	-0.12	
	SE	0.04	0.04	0.06	0.04	
	t	6.42	7.23	-0.78	-3.10	
	p	< .001*	< .001*	.439	.004*	
		Training x Spelling	Training x Exposure 2 vs. 1	Training x Exposure 3 vs. 2	Spelling x Exposure 2 vs. 1	Spelling x Exposure 3 vs. 2
Two-way Interactions	*b*	-0.19	-0.06	-0.03	-0.07	0.00
	SE	0.06	0.05	0.05	0.09	0.06
	t	-3.40	-1.25	-0.70	-0.73	0.01
	p	.002*	.213	.484	.472	.996
		Training x Spelling x Trial 2 vs. 1	Training x Spelling x Trial 3 vs. 2			
Three-way Interactions	*b*	-0.10	0.23			
	SE	0.09	0.09			
	t	-1.06	2.57			
	p	.291	.010*			

Note. * denotes statistical significance

Results of the model reflecting the *probability of regressions* back to the target word are presented in Table 6. There was no significant effect of spelling predictability. There was no significant difference in the probability of rereading between the first and second visual exposures, but the probability of rereading did reduce significantly between the second and third exposures. An effect of training was observed such that trained items were less likely to be reread than untrained items; this training effect reduced from the first to the second exposure, but not from the second to third exposure. No other interactions were significant.

Table 6.

Results of the linear mixed effects model for regressions in.

		Training	Spelling	Exposure 2 vs. 1	Exposure 3 vs. 2	
Fixed effects	*b*	0.55	0.15	0.11	-0.55	
	SE	0.10	0.11	0.10	0.10	
	t	5.52	1.35	1.12	-5.34	
	p	< .001*	.176	.264	< .001*	
		Training x Spelling	Training x Exposure 2 vs. 1	Training x Exposure 3 vs. 2	Spelling x Exposure 2 vs. 1	Spelling x Exposure 3 vs. 2
Two-way Interactions	*b*	-0.25	-0.65	0.02	-0.27	0.00
	SE	0.19	0.20	0.21	0.20	0.21
	t	-1.34	-3.27	0.09	-1.34	0.02
	p	.182	.001*	.925	.179	.984
		Training x Spelling x Trial 2 vs. 1	Training x Spelling x Trial 3 vs. 2			
Three-way Interactions	*b*	-0.08	-0.24			
	SE	0.40	0.41			
	t	-0.21	-0.58			
	p	.835	.560			

Note. * denotes statistical significance

Longer-term retention

Models reflecting accuracy and latency were run for the delayed go/no-go lexical decision task. Fixed effects were training, spelling predictability and their interaction. The same process of model construction and selection as described above was applied to the analysis of the follow-up task data.

On average, participants correctly inhibited responding to 81.9% of the distractor items. These data were removed prior to analysis and do not appear in Figure 3, which depicts the means and standard errors of lexical decision accuracy for orally trained and untrained items. A logistic linear mixed effects model with lexical decision accuracy as the dependent variable showed a fixed effect of training (β = -4.71, *SE* = 0.56, *z* = -8.38, *p* < .001) such that children recognized trained words with greater accuracy than untrained words. There was no effect of spelling predictability (β = 0.04, *SE* = 0.29, *z* = 0.15, *p* = .880) and no interaction between training and spelling predictability (β = 0.27, *SE* = 0.50, *z* = 0.54, *p* = .591).

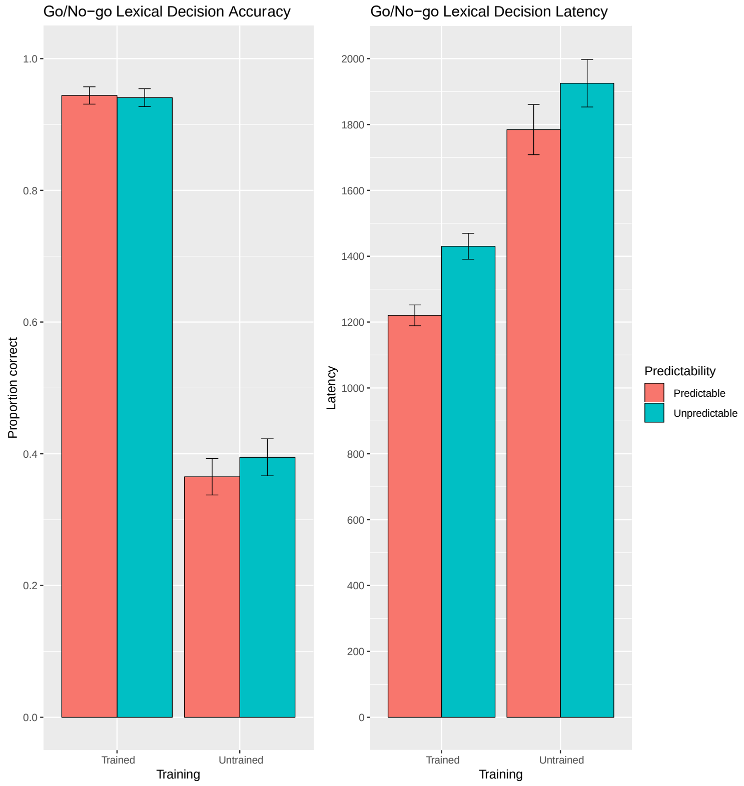

Figure 3. Means and standard errors of go/no-go lexical decision accuracy and latency. Accuracy is depicted as proportion correct while latency is expressed in milliseconds.

Latencies to correct ‘yes’ responses were analysed following log transformation. Means and standard errors of lexical decision latency are presented in Figure 3. The model showed a fixed effect of training ($\beta = 0.39$, *SE* = 0.04, *t* = 9.61, *p* < .001) such that children initiated a reading response to trained words more quickly than to untrained words. Predictable spellings were associated with a smaller response latency than unpredictable spellings ($\beta = 0.11$, *SE* = 0.04, *t* = 3.10, *p* = .005). The interaction between training and spelling predictability was not significant ($\beta = -0.08$, *SE* = 0.06, *t* = -1.31, *p* = .198).

Discussion

The present research aimed to replicate the orthographic skeleton effect at the first visual exposure to orally known words; to determine whether and when these spelling expectations might be observed to undergo an updating process with increasing visual experience; and evaluated the influence of these learning events on children's subsequent visual word recognition. On the basis that children do likely form orthographic expectancies, we anticapted a larger effect of spelling predictability for orally trained compared to untrained items. At the first visual exposure, this pattern was observed on the eye movement measures of gaze duration and total reading time, but not first fixation duration (discussed later), replicating Wegener and colleagues (2018). These findings provide additional support for the existence of causal processes that contribute to orthographic learning prior to visual exposure by permitting a flow of information from phonology to orthography. As such, existing theories of orthographic learning (Perfetti, 1992; Perfetti & Hart, 2002; Share, 1995, 2008) could reasonably be extended to accommodate this complementary causal mechanism through which oral vocabulary might support reading acquisition.

Having observed orthographic expectancies at the first visual exposure, we asked whether the effect remained evident subsequently. Data from the second visual exposure were consistent with the first orthographic exposure; there was persisting evidence of the orthographic skeleton effect on the looking time measures of gaze duration and total reading time. It has previously been argued that influences on orthographic processing measures arising from phonological expectancy are likely to be strongest at the first visual exposure (McKague et al., 2008; Wegener et al., 2018). Exposures to novel written words are thought to provide an opportunity for children to make mappings between orthography and phonology (Perfetti, 1992, 2007; Perfetti & Hart, 2002; Share, 1995, 1999, 2008). As such, one might anticipate that the accumulation of visual experience should result in diminishing influences on orthographic processing arising from spelling expectancies, in conjunction with increasing influences arising from the acquisition of orthography to phonology mappings. The persistence of the orthographic skeleton effect at the second visual exposure therefore likely reflects the influence of both processes; whereas the absence of the orthographic skeleton effect at the third visual exposure indicates that the growing influence of orthography to phonology connections were sufficient to update the orthographic skeleton at this point in learning.

Findings from the third orthographic exposure support the view, as espoused in theories of orthographic learning (Perfetti, 1992, 2007; Perfetti & Hart, 2002; Share, 1995, 1999, 2008), that children build orthographic representations rapidly from experience with orthographic forms. At this point in learning, the orthographic skeleton effect was not observed on any looking time measure. At total reading time, there was evidence that the orthographic skeleton effect diminished between the second and third orthographic exposures, suggesting that when children are provided with opportunities to build orthography-phonology mappings, their initial spelling expectancies undergo an updating process in light of this visual experience. The onset of this process is captured in measures of online moment-to-moment processing as visual exposures unfold over time, with clear evidence of updating occurring between the second and third encounters.

As already alluded to, the pattern of results obtained on the eye movement measure of first fixation duration differed from that observed on both other measures of looking time. At the initial visual exposure there was no significant effect of our experimental manipulations on the children’s first fixations. By the second exposure, a benefit of training emerged which reduced by the third exposure. However, at no point was an interaction between training and spelling predictability observed. The lack of an orthographic skeleton effect at first fixation differs from the pattern observed in Wegener and colleagues (2018) as well as the other looking time dependent measures in this experiment. Exactly why this might be is not yet clear. In Wegener and colleagues (2018), the orthographic skeleton effect is present at first fixation and is observed to build across looking time measures that take into account subsequent first pass fixations (gaze durations) and refixations (total reading times). In the current experiment, we similarly find that the orthographic skeleton effect is present when all first pass fixations are included and builds with the addition of refixations. Data from future experiments should clarify whether the orthographic skeleton effect is usually, or only sometimes observed at first fixation. In either event, it is clear that orthographic expectancies can be observed on first pass reading measures, consistent with the notion that they influence early word recognition processes.

As anticipated, an advantage for trained words was apparent in a measure reflecting the probability of regressions, demonstrating that children were less likely to reread orally familiar than unfamiliar words. This is consistent with the finding that novel words are more likely to be refixated than familiar words (Chaffin et al., 2001). It also aligns with prior work suggesting that oral familiarity is a more important determinant of rereading behaviour than the predictability of target word spellings (Wegener et al., 2018). Two other aspects of the current findings are of interest, both of which suggest that rereading behaviour is modified by visual experience. First, the training benefit was strongest at the first visual exposure to the novel target words, implying that for the probability of rereading, there may be a diminishing role of oral familiarity with building visual experience. Future work might test this possibility more directly by providing further visual exposures and asking at what point oral familiarity ceases to influence rereading behaviour; doing so will expand our understanding of how online processing evolves with building visual experience. Second, the overall probability of rereading reduced between the second and third visual exposures, regardless of whether the items had been trained. This latter finding resonates with others showing that that as reading experience accrues, participants engage in less rereading of new word forms (Joseph & Nation, 2018).

Follow-up testing addressed the question of the longer term influence of the orthographic skeleton on children's visual word recognition. We predicted that orally trained items would be more likely to be correctly recognized as visually familiar and would be responded to more quickly than items that were orally unfamiliar. However, it was not entirely clear what role spelling predictability might play. Based on the idea that children's orthographic expectancies were likely to match the written form of trained items with predictable spellings, the need to update the initial orthographic expectancy for these items should be substantially reduced or removed, potentially placing them at an advantage in the delayed word recognition task. In the event of misalignment of the child's orthographic expectancy and the orthographic form, the incongruence could either confer a smaller subsequent visual word recognition advantage because there is a greater requirement for adjustment; or, the incongruence might drive learning by providing a strong cue for updating the early orthographic representation. Results with respect to recognition accuracy revealed a very large effect of training only, with performance being essentially at ceiling for all trained items. Latency data similarly showed a strong effect of training and an additional effect of spelling predictability, but no interaction between them. The finding of a strong effect of training is consistent with our predictions and with the growing experimental literature demonstrating that spoken word knowledge conveys an advantage within the process of written word learning (Duff & Hulme, 2012; McKague et al., 2001; Nation & Cocksey, 2009). Our current findings build on this work by showing that the benefit of oral familiarity persists over time, extending over a period of at least several days regardless of the spelling predictability of the written form. We are unable us to draw firm conclusions about the processes underlying this training advantage. It may be that a single process underlies the training effect, or it may be the case that trained items with predictable and unpredictable spellings benefited from training in different ways. The general advantage for orally trained items on follow-up testing suggests that some updating, particularly of incongruent orthographic representations, occurred during the learning trials that was sufficient to support children's visual word recognition at the delayed test. By this, we do not wish to imply that the updating process was complete. Perfetti refers to lexical representations that are stable and spelling patterns that are precisely encoded (1992, 2007; Perfetti & Hart, 2002); we did not test children's spelling, so data from the current experiment cannot speak to this issue.

Findings from the eye movement monitoring task in the current experiment suggest that orthographic knowledge can be brought to bear on the task of reading even prior to an initial visual encounter with an orally known word. Further, the eye movement data point to the initiation of an updating process observable on moment-to-moment processing measures during the repeated reading of novel words, a finding consistent with Perfetti's notion that building visual experience allows orthographic representations to "evolve towards completeness" (Perfetti, 1992, p. 159). The observation that prior oral vocabulary knowledge supports the delayed recognition of previously encountered written word forms also supports the lexical quality hypothesis, insofar as it predicts that reading behaviours should be influenced by variations in the types (form and meaning) of available lexical information (Taylor & Perfetti, 2016). This experiment, together with that reported by Wegener and colleagues (2018) are, to the best of our knowledge, the first to use eye movements to evaluate the influence of prior phonological and semantic knowledge on children's eye movements during the reading of novel words. Both experiments observed long fixation durations compared with studies of children reading words with familiar written forms (Blythe et al., 2015; Joseph et al., 2013), suggesting that novelty influences looking times.

Before concluding, we outline a limitation of our experiment and offer ideas for future work. The manipulation of spelling predictability employed in the original investigation of the orthographic skeleton hypothesis (Wegener et al., 2018) was constructed with a view to providing maximal control over the likely correspondence between children's orthographic expectancies and the orthographic form they saw in print. A limitation of this strong manipulation was that predictable and less predictable spellings could not be matched on selected stimulus properties (i.e. number of letters and bigram frequency), a fact that was reflected in baseline processing time differences for these common and unusual spellings in the original experiment. In spite of this, the same stimuli were employed in the current experiment because processing time differences for common and unusual spellings could not account for any observed interaction with oral familiarity. When considered alongside the benefits of retaining close links between experiments, we concluded that retaining the spelling predictability manipulation was justified. Nevertheless, future work might seek to replicate these findings with more closely matched stimuli.

Future work should also seek to build on our current understanding of the orthographic skeleton and the conditions that support it. For example, investigations have so far been limited to questions surrounding children's ability to form spelling expectations for monosyllabic, monomorphemic words. Of future interest will be whether children might also be able to form spelling expectations for polysyllabic or polymorphemic words. Another important question concerns the issue of whether orthographic skeletons are generated automatically upon hearing a spoken word, or strategically as a form of mnemonic aid to assist children to encode the novel oral vocabulary.

Conclusions

This experiment provides evidence consistent with the view that spoken word knowledge, in combination with knowledge about mappings between phonemes and graphemes, permits children to form expectations about the likely spellings of words that have not been encountered in print. These spelling expectancies were observed at the first visual exposure, consistent with prior work. Persisting evidence of spelling expectancies was observed at the second but not at the third visual exposure, suggesting that experience with the written form serves to update orthographic representations and that this is observable in online processing. Children's performance on delayed follow-up testing suggested a substantial ongoing advantage for all orally trained items. This implies that when the initial orthographic expectancy is misaligned with the actual orthographic form experienced in writing, it is sufficiently updated by that experience. In turn, this drives orthographic learning and supports visual word recognition, as captured by lexical decision several days later.

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