

The effects of spacing and massing on children's orthographic learning

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Abstract

Despite substantial evidence that spacing study opportunities over time improves the retention of learned verbal material compared to study trials that occur consecutively, the influence of temporal spacing on children's learning of written words has not been investigated. This experiment examined whether temporal spacing influenced Grade 3 and 4 children's (N=37; mean age 8 years, 7 months) learning of novel written words during independent reading, compared to massing. Children read sixteen sentences containing a novel word under either spaced (sentences appeared once in each of four blocks) or massed (four consecutive trials) conditions. After a delay, orthographic learning was assessed using recognition (orthographic choice) and recall (spelling to dictation) measures. Words experienced in the spaced condition were better recognised than those in the massed condition, but there was no effect on recall. These findings suggest that temporal spacing influences the acquisition of new written word forms, extending the potential utility of the spacing principle to reading acquisition.

Word count: 157

The *spacing effect* refers to the finding that learning is improved when study trials are distributed (or spaced) over time compared to when study trials occur consecutively (massed). The spacing effect is among the most robust in cognitive psychology, having been demonstrated throughout the lifespan (Carpenter et al., 2009; Toppino, 1991; Toppino & DeMesquita, 1984) and across a wide array of tasks (for reviews see Carpenter et al., 2012; Cepeda et al., 2006; Wiseheart et al., 2019). Yet to date, remarkably, there have been no investigations of the effect of spacing on children's orthographic learning via reading, defined here as learning the written form of new words. If temporal spacing does influence orthographic learning during independent reading, this might have important practical implications for literacy instruction. In the present experiment, Grade 3 and 4 children independently read sentences containing novel words under spaced and massed conditions prior to completing final memory tests probing their recognition and recall of the learned orthography.

Much of the vast body of work evaluating the effect of temporal spacing has been within the broad domain of verbal learning (Wiseheart et al., 2019). Typically, the same information (word lists, unfamiliar word meanings or facts) is presented several times, with half of the items being spread out in time and half occurring consecutively. In the latter case, when there is no gap between presentations, learning is said to be *massed*. Whenever the gap between presentations exceeds zero, then learning is said to be *spaced* over time. Intervals between spaced presentations can vary from a few seconds to several weeks, but there is never a gap between massed presentations (Cepeda et al., 2006). Notwithstanding substantial methodological differences between paradigms, meta-analytic evidence converges on the view that spacing practice trials over time benefits verbal learning outcomes to a greater degree than massing practice over consecutive trials, with effect sizes in this domain estimated to be large ($d = 0.85$ estimated by Wiseheart et al., 2019 based on data reported in

Cepeda et al., 2006; Moss, 1996).

Although substantial efforts have been made to develop and evaluate theoretical accounts of the spacing effect in the broader memory literature, the specific mechanism or mechanisms that underlie the spacing advantage remain unclear. A range of factors have been identified as potentially playing a role in the phenomenon. For instance, spaced repetitions are thought to attract greater attentional resources than massed repetitions (e.g. Challis, 1993; Cuddy & Jacoby, 1982); spaced repetitions are thought to be more likely than massed repetitions to require the learner to retrieve their previous experiences (e.g. Thios & D'Agostino, 1976); and spaced repetitions are thought to be associated with greater variability at the point of encoding, thereby providing more retrieval routes than massed practice (e.g. Estes, 1955; Glenberg, 1979).

Evidence for spacing effects in verbal learning is persuasive, leading to widespread recognition that temporal distribution may hold great potential for boosting learning outcomes in educationally relevant settings (Carpenter et al., 2012). Accordingly, studies evaluating the influence of temporal distribution on the acquisition of academic knowledge have proliferated, particularly in the areas of history (Carpenter et al., 2009), science (Vlach & Sandhofer, 2012) and mathematics (Barzagar Nazari & Ebersbach, 2019; Rohrer & Taylor, 2006, 2007). These also frequently support the superiority of temporal spacing over massing. Reading research however, has been mostly absent from these endeavours, leading Nation and Castles (2017) to conclude that the field has not consistently been informed by progress in memory research.

Some studies have investigated whether temporal spacing influences the learning of word meaning via reading. Typically in these experiments, participants read sentences that contain novel words and their ability to recognise or recall the meaning of the embedded words is then evaluated at test. For instance, Koval (2019) provided an English translation

(e.g., *building*) of novel multisyllabic Finnish words (e.g., *rakennus*) before English-speaking participants silently read sentences containing the novel word. Following this exposure, there was a clear effect of temporal spacing on semantic learning, as assessed by a form-meaning matching task. Nakata and Elgort (2020) embedded English pseudowords into Japanese sentences and required their Japanese participants to read the sentences and make meaning inferences about the target words prior to receiving feedback. They observed a temporal spacing advantage on form-meaning matching and semantic recall tasks. Pagán and Nation (2019) embedded rare English words into sentences, allowing meaning to build incidentally via silent reading. They found no effect of temporal spacing on a two-alternative forced-choice meaning recognition task with adults, although performance was essentially at ceiling across both conditions.

Turning to orthographic learning, Pagán and Nation (2019) analysed their eye movement data to see whether spacing influenced fixation patterns on newly learned words. While some differences in lexical processing were observed at post-test, the spacing manipulation was not pure: because participants encountered the target words in a pre-exposure phase, a learning phase and a retrieval cue phase, the massed items were not always experienced consecutively. For this reason, the higher-order interaction that emerged in Pagán and Nation's (2019) experiment is difficult to interpret with reference to spacing. To the best of our knowledge, just two studies have evaluated the effects of spacing on learning new written forms during reading specifically. In the context of second language learning, Koval (2019) additionally evaluated the ability of adult participants to differentiate the target words they had previously read from a series of distractors, and found a clear benefit of spacing over massing. Of note, however, the target and each distractor had different pronunciations, meaning that this task was not a pure measure of written word form recognition, but rather tested the ability to recognise the decoded phonology of the learned

items. The second study relevant to orthographic learning evaluated the influence of different degrees of temporal spacing between short learning sessions in which 5-year-old children were taught foundational reading skills (Seabrook et al., 2005, Experiment 3). Because this experiment did not compare spacing with no spacing (massing), it tested the related but distinct *lag effect*, which refers to the phenomenon that longer intervals between learning episodes are associated with improved learning outcomes compared to shorter intervals (Cepeda et al., 2006). Seabrook and colleagues (2005) taught children in Grade 1 grapheme-phoneme correspondences (single letter graphemes such as *d* and digraphs such as *ch*) and how to read some high frequency regular words (e.g., *sit*, *bend*, *flip*). Instruction consisted of either one six-minute session per day (clustered practice sessions) or three two-minute sessions per day (distributed practice sessions). After two weeks of instruction, children who were taught in three two-minute sessions demonstrated greater improvement from pre- to post- testing than children taught in one six-minute session (8.3 versus 1.3 points of improvement), supporting the notion that longer spacing intervals can benefit learning outcomes among children acquiring early reading knowledge.

The effect of spacing on children's orthographic learning during reading has not been investigated directly. This is a surprising and critical gap in the literature, certainly compared with the focus on spacing and semantic learning. Since semantic and orthographic learning are predicted by distinct skills (vocabulary and decoding respectively; Ricketts et al., 2011), the question of whether the spacing effect is present in children's orthographic learning seems pressing. Orthographic learning refers to the process of forming representations of new written words that support rapid and fluent recognition (Castles & Nation, 2006) and is considered central to the transition from novice to skilled reader (Castles, Rastle & Nation, 2018). The self-teaching hypothesis (Share, 1995) states that when a novel word is encountered during reading, children attempt to deduce its pronunciation and this operates as

a self-teaching mechanism that provides an opportunity to learn its orthographic form, i.e., its spelling. Two common assessments of orthographic learning evaluate the ability to *recognise* and *recall* written word forms. Orthographic choice is a recognition task in which a learned spelling (e.g., *yait*) must be distinguished from a homophonic spelling (e.g. *yate*) and other distractors, while spelling to dictation is a cued recall task requiring the participant to remember the precise identity and order of letters. It is clear from the orthographic learning literature that encountering novel written words while reading sentences allows children to acquire item-specific knowledge of the novel words that is discernible on both recognition and recall tasks (Share, 1999, 2004; for review, see Castles & Nation, 2006; Nation & Castles, 2017).

Features of the exposure conditions influence orthographic learning, most notably frequency and the length of interval between exposure and test (e.g., Bowey & Muller, 2005; Nation et al., 2007). Potentially, spacing might influence these classic effects. Temporal spacing certainly exists out of the lab in a child's natural reading experience where some words are repeated or clustered within the same book whereas others might be encountered in a more distributed fashion. To date, however, there have been no systematic investigations of the effects of spacing versus massing on children's acquisition of novel orthographic forms via independent reading. This leaves teachers and education policymakers unsure about the kind of temporal distribution of exposures that should be presented in the classroom to foster optimal learning of new written words. Our experiment was designed to provide an initial test of this effect, with the aim of linking research on reading acquisition to existing work on temporal spacing in the domains of verbal and academic learning. To this end, children read aloud sixteen sentences in which a novel word was embedded. Each sentence was read a total of four times. Half of the items were temporally distributed (sentences appeared once in each of four blocks) while the other half were massed (presented consecutively). After a delay, the

acquisition of word-specific orthographic knowledge was assessed using orthographic choice and spelling. In line with the verbal learning literature, a benefit of spacing over massing was predicted on both outcome measures. This hypothesis was preregistered (<https://aspredicted.org/blind.php?x=mk69z8>), along with the experimental design and analysis plan.

Method

Participants

Thirty-seven children in Grades 3 and 4 (17 females) were recruited in New South Wales, Australia via two sources: a vacation care provider and *Neuronauts* (<https://www.cogsci.mq.edu.au/apps/neuronauts/>), a child participant register administered by Macquarie University. The children's mean age was 8 years and 7 months (range: 7y;8m - 9y;11m). Children of this age were selected because they are typically acquiring orthographic representations rapidly through instruction and independent reading. The sample size was informed by previous investigations of orthographic learning (Share, 2004; Wang et al., 2011). A power analysis supported this decision: using a conservative effect size estimate of $d = 0.6$ (cf. $d = 0.85$: Wiseheart et al., 2019) we found that for the design to be powered at 80%, a sample size of 29.2 participants was required.

Standardized tests

Two standardized measures were administered to characterize the sample. Spoken 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 was assessed using the Castles & Coltheart 2 (CC2; Castles et al., 2009). Summary data are presented in Table 1 and show performance within the average range across all tasks.

Table 1.

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

	M	SD	Min	Max
Naming (ACE) ^a	9.27	2.42	5	14
Reading aloud (CC2)				
Regular ^b	0.57	1.09	-2.07	3.65
Irregular ^b	0.49	0.82	-1.66	2.26
Nonwords ^b	0.47	1.27	-2.42	2.91

Note: ACE, *Assessment of Comprehension and Expression 6-11*); CC2, *Castles & Coltheart 2*; ^a Age scaled score ($M = 10$, $SD = 3$); ^b Age based z-scores ($M = 0$, $SD = 1$)

Materials

Novel words. Two sets of 16 homophonic pairs (e.g., *prabe/pruib*) of pronounceable monosyllabic novel words were constructed (see Appendix A). Novel words were 4 to 5 letters in length and had regular pronunciations according to grapheme-phoneme rules (Rastle & Coltheart, 1999). To control for any preference for a given spelling, each manipulated grapheme was present in two novel words within each list and these were spelled differently. The manipulated grapheme was often in the vowel position (75% of items, e.g. *prabe/pruib*) and sometimes in a consonant position (25% of items, e.g. *sleff/sleph*). The experimental lists were counterbalanced such that half of the participants learned one spelling of the novel words (e.g., *prabe* and *glain*) while the other half learned the alternative spelling (e.g., *pruib* and *glane*). Each item set was divided into two subsets such that that each subset contained one written form of each manipulated grapheme; with counterbalanced allocation of subsets to the spaced and massed conditions (e.g., in one list *prabe* was in the massed condition while *glain* was in the spaced condition). In all, there were four versions of the experiment. Participants were randomly allocated to each version.

Experimental sentences. The novel words were nouns embedded in single line sentences (see Appendix B). Each sentence referred to a fictional invention (the novel word)

created by Professor Parsnip (Wang et al., 2011). Each sentence contained a single presentation of one novel word.

Procedure

The experimental design was one factor with two within-child levels (massed vs. spaced). The orthographic learning and testing tasks were administered individually using an online experiment platform (Anwyl-Irvine et al., 2020) and supervised by the experimenter via Zoom (<https://zoom.us>). The CC2 (Castles et al., 2009) was administered online (<https://www.motif.org.au/>) using screen sharing within Zoom, while the ACE (Adams et al., 2001) naming test was administered using the stimulus book over Zoom.

Orthographic learning task. Children were told that they would be reading aloud some sentences referring to Professor Parsnip's latest inventions. Further, children were instructed that they would read the same sentences several times, and that they should try to remember what they read. Each trial began with a fixation cross, presented for 500ms. A single line sentence then appeared, centred on the screen. After children read aloud each sentence, they pressed a button to terminate the trial. Reading aloud responses were recorded but not analysed, and no feedback was provided regarding word reading accuracy. Half of the items were presented in the spaced condition (the four sentences referring to an invention appeared once in each of four blocks); half of the items appeared in the massed condition (the four sentences referring to an invention were presented on consecutive trials). There were four blocks of 16 trials, with block order being randomised. Items from both the massing and spacing conditions were interleaved within each block. To maintain the time lag between sentences in the spaced condition, trial order was fixed within blocks. The blocks were separated by two-and-a-half minute breaks in which the children watched nonverbal cartoons. The learning phase was followed by a seven-minute delay during which a nonverbal cartoon was shown. Figure 1 depicts the order of administration of experimental tasks.

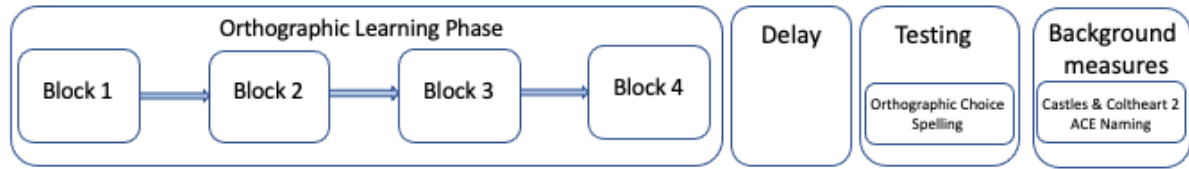


Figure 1. *Order of administration of experimental tasks*

Testing: Orthographic choice. To control for the number of exposures, this test was always administered first. Participants were shown four written words arranged horizontally on a computer screen and were asked to click on the spelling they read about during the orthographic learning phase. The four written words included the target spelling (e.g., *prabe*), the homophonic spelling from the untrained list (e.g., *praib*) and two homophonic visual distractors (e.g., *prate* and *prait*). Visual distractors appear in Appendix A. The target appeared in each screen location an equal number of times. Trial order was randomised for each participant. The dependent variable was target recognition accuracy.

Testing: Spelling to dictation. Participants listened to recordings of spoken target words one at a time. Items were randomised for each participant. Children spelled the target words by typing into a text box, and pressed “Enter” to submit their response. The dependent variable was spelling accuracy.

Results

Data were analysed in the R computing environment (R Core Team, 2021). Separate models were run for orthographic choice and spelling accuracy. Generalised linear mixed effects models were constructed using the *lme4* package (Bates et al., 2020) and *p* values were obtained using the *lmerTest* package (Kuznetsova et al., 2017). The fixed effect of exposure condition (massed vs. spaced) was treatment coded (0, 1). As described in the preregistration, a data driven approach to model selection was employed. The simplest model included the fixed effect of exposure condition and random intercepts for participants and items. No participant ever saw all versions of the target words during training, so random

slopes were not entered for items. In both models, the addition of random slopes by participant resulted in singularity so the random intercepts models are reported.

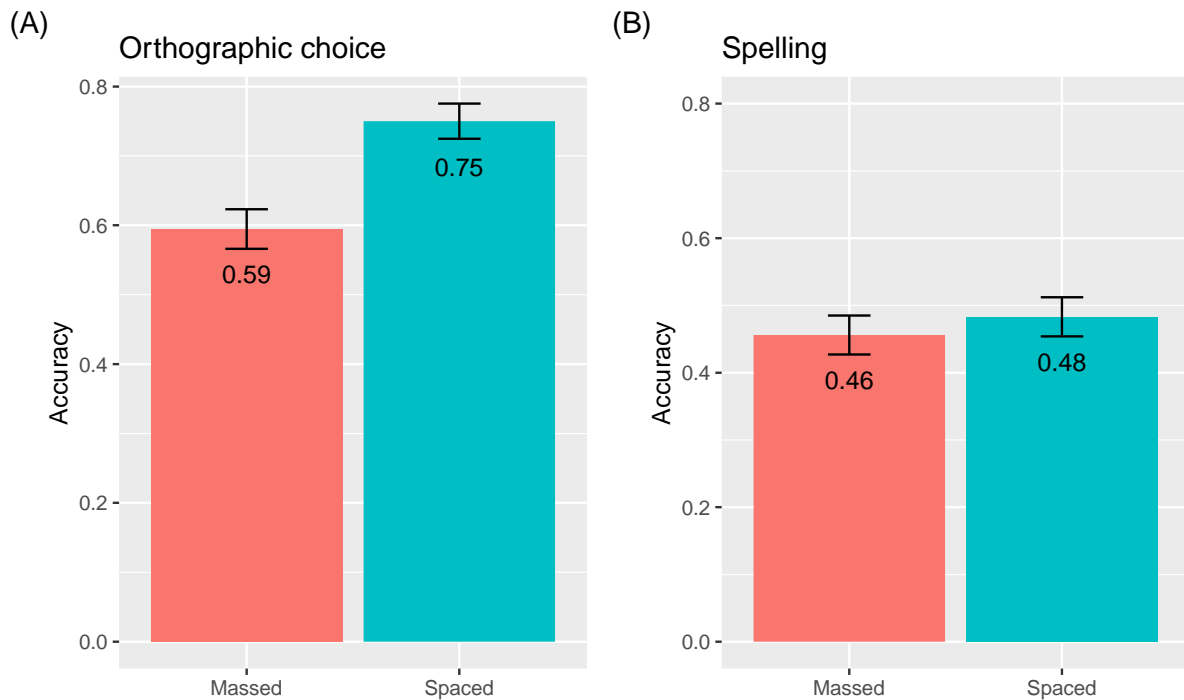


Figure 2. *Mean and standard error of the proportion correct on the orthographic choice and spelling tasks.*

Means and standard errors for the orthographic choice (Panel A) and spelling tests (Panel B) appear in Figure 2. The orthographic choice test model showed an effect of condition such that items learned with temporal spacing were recognised better than items learned in consecutive sentences ($b = 0.83$; $SE = 0.19$; $z = 4.29$; $p < .001$). In contrast, the spelling model showed no significant difference in participants' spelling accuracy for items learned with temporal spacing compared to items learned in consecutive sentences ($b = 0.17$; $SE = 0.20$; $z = 0.84$; $p = .402$). Some supplementary exploratory analyses that were requested during the review process can be found on the Open Science Framework (<https://osf.io/fvgy5/>).

Discussion

The current study examined the influence of spaced versus massed practice on primary school children's novel written word form learning during independent reading. Grade 3 and 4 children read sentences containing novel written words on four occasions, with half presented in a spaced condition (experienced once in each of four blocks) and half presented in a massed condition (consecutive presentations). Extrapolating from the verbal learning literature, we anticipated that spaced encounters with novel words would boost children's ability to recognise and recall their spellings. This proved to be the case when children's recognition memory was assessed: children were better able to distinguish the written word forms they had read earlier from homophonic spellings when the items had been spread out over time (mean accuracy 75%) compared to when they were read consecutively (mean accuracy 59%) during learning. This finding provides clear initial evidence of a spacing effect on children's written word form recognition following independent reading, thereby linking orthographic learning research with the broader memory and learning literature.

Contrary to predictions, however, children's cued recall performance as assessed via spelling to dictation did not differ as a function of whether the words were experienced under spaced (48%) or massed conditions (46%). This finding suggests that, at least under these specific experimental conditions, temporal spacing does not confer an advantage over massing on this more difficult cued recall task. The failure to find a spacing effect on cued recall is at odds with children's recognition of the same words just moments before. It is worth noting that other orthographic learning studies have also observed inconsistent patterns in learning outcomes as a function of task (e.g., Ouellette & Fraser, 2009) with spelling tending to be less sensitive to partial learning than other measures (Nation & Castles, 2017). Recall is typically more difficult than recognition; indeed, spelling frequently produces lower

estimates of learning than orthographic choice when both measures are taken within the same study (Kyte & Johnson, 2006; Mimeau et al., 2018; Wang et al., 2011). Spelling is difficult because it demands a high quality orthographic representation (Perfetti, 1992) to perfectly recall the identity and order of letters. In contrast, a relatively weaker representation may be sufficient to support recognition, as indexed by orthographic choice (Wang et al., 2011). Further, it is possible that when children are presented with a difficult spelling task, the phonological form of the cue word itself might cause them to rely on their sound-to-letter knowledge when producing a spelling, thereby potentially dampening the effect of the experimental manipulation.

An additional factor may have rendered spelling particularly challenging in this experiment. It is common for orthographic learning studies to include one manipulation of a given sound-to-print relationship per list, which serves to make each item distinct. In the present experiment, however, a large number of items were required which necessitated the inclusion of two alternative spellings for the same sound-to-print relationship (e.g., *prabe* and *glain*) within each list. Recent experience with a sound-spelling pattern does influence how young children choose to spell a novel word (Nation & Hulme, 1996) and therefore this feature of the stimuli may have served to render them less distinct and more easily confusable during recall. Whether greater item distinctiveness within lists might reveal an effect of temporal spacing on spelling remains to be determined in future work. A further possibility is that the absence of a spacing effect on the spelling task could potentially reflect an effect of test order, perhaps because the first test contaminated the purity of the second. To determine whether test order is an important factor, future work might investigate this directly by manipulating test order between-participants. Using this design, three key questions can be asked: is there a spacing effect when orthographic choice is administered first; is there a

spacing effect when spelling to dictation is administered first; and does the magnitude of the spacing effect differ when the task is administered first compared to second?

The aim of the current experiment was to determine whether spacing – an effect that is ubiquitous in the domain of verbal learning – influences children’s written word form learning during independent reading. We did not seek to investigate the potential mechanism or mechanisms that might contribute to the effect of spacing within orthographic learning, if we observed it. As discussed earlier, much effort (e.g. Challis, 1993; Cuddy & Jacoby, 1982; Estes, 1955; Glenberg, 1979; Thios & D’Agostino, 1976) has already been directed towards understanding the theoretical basis of the spacing effect within the broader memory literature, and this will undoubtedly provide a solid foundation from which to explore how these mechanistic accounts might apply to the learning of form and meaning during reading.

Experiments comparing the effects of spacing and massing typically present the same novel information on multiple occasions. Our decision to repeat the same sentences at each exposure was made with a view to maintaining tight links with this temporal spacing literature, since our experiment reports an initial test of the effect of spacing in written word form learning. An additional benefit of this approach is that any potential effects of sentence context are held constant. Repeated sentence reading is a different approach to that taken in experiments in the orthographic learning tradition (Share, 1999, 2004), which embed novel words in different sentence contexts that together form a coherent short story. Variations in sentence context more closely resembles children’s natural reading experiences than the repeated reading approach adopted in the current experiment. Relatedly, diversity in contextual experience shapes learning such that words experienced in more varied semantic contexts are recognised by children more easily than less diverse words (Hsiao et al., 2020; Hsiao & Nation, 2018). Therefore, in order to draw conclusions about the effect of spacing under more realistic reading conditions, it will be important for future work to determine

whether the spacing effect observed here on children's recognition of the trained orthography extends to situations in which the sentence context surrounding the target word varies from one exposure to the next. If the spacing effect is robust to changes in sentence context, this would provide a strong case for the spacing principle to be considered within reading instruction programs. Existing evidence suggests that varying spoken (Dellarosa & Bourne, 1985) and written (Koval, 2019; Nakata & Elgort, 2020) sentence contexts is associated with an effect of spacing on vocabulary outcomes, but this work needs to be extended to evaluate effects on written word form learning.

Having established that spacing influences children's learning of written word forms, future work should investigate both form and meaning aspects of word learning in the same experiment. A few studies have examined spacing effects on semantic learning during reading, but more work is required to understand the conditions under which spacing benefits meaning acquisition, and how this interacts with form learning. For example, what is the role of intentional versus incidental learning on word learning under spaced and massed conditions? This is important in view of evidence suggesting that from middle childhood onwards, much of children's learning occurs incidentally during independent reading (Nagy et al., 1985). Of further interest will be comparisons between the learning of orthographic form and meaning during reading. There may be conditions under which spacing is beneficial to one type of learning, whereas massing is more beneficial for the other. For instance, when the reader is required to infer the meanings of newly encountered words, spacing out encounters over time may make it more difficult for the reader to make links between their experiences of a novel item (Nakata & Elgort, 2020), which could potentially limit the effect of spacing. Since written word forms are fixed, it is possible that temporal spacing could support orthographic learning more than incidental semantic learning. Finally, to determine

whether the current findings generalise beyond English, it will be important to extend this work to other writing systems (Share, 2008).

In summary, this experiment provided initial evidence that temporal spacing promotes children's recognition of novel written word forms acquired during their independent reading, compared to temporally massed experiences. As such, it is the first to link the orthographic learning literature to the extensive temporal spacing literature in the domains of verbal and academic learning. The findings of this experiment suggest that the effect of temporal spacing within orthographic learning will likely be a fruitful area for future enquiry, in terms of elaborating both the boundary conditions on the learning of form and meaning, and the cognitive mechanisms that underpin it. For now, we would suggest that teachers and education policy makers bear in mind that spreading out exposures to new written words may be more effective in promoting learning than consecutive practice. More detailed guidance will become available as the evidence base in this area grows.

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Appendices

Appendix A

Experimental novel word stimuli and distractors

Subset	List 1	List 2	Visual Distractor 1	Visual Distractor 2
a	smope	smoap	smode	smoad
a	zeme	zeem	zene	zeen
a	murd	mird	murl	mirl
a	hule	hewl	hute	hewt
a	prabe	praib	prate	prait
a	thid	thyd	thib	thyb
a	draph	draff	druph	druff
a	wrog	rhog	wrig	rhig
b	broat	brote	broam	brome
b	peem	peme	peeg	peag
b	terg	turg	terp	turp
b	fewt	fute	fewb	fube
b	glain	glane	glaim	glame
b	chyb	chib	chyd	chid
b	sleff	sleph	sliff	sliph
b	rhup	wrup	rhep	wrep

Appendix B.

Experimental sentences

Number	Sentence
1.	You should shuffle the cards with the zeme/zeem before every game.
2.	If sand sticks to your skin at the beach, use the rhup/wrup to remove it.
3.	When the fish tank is dirty, use the prabe/praib to clean it.
4.	Put tennis balls into the hule/hewl before playing fetch with your dog.
5.	You can climb the wall like Spiderman with the chyb/chib on your feet.
6.	If you can't remember who someone is, the terg/turg will tell you.
7.	If you have cold feet, the broat/brote will warm them up.
8.	Put your meal into the sleff/sleph to take out the food you don't like.
9.	Birds will fly over and start singing when the thid/thyd is turned on.
10.	Put the dirty socks into the draph/draff to clean them.
11.	If you get caught in the rain, we can use the fewt/fute to dry your hat.
12.	Load the rubbish into the peem/peme to sort it for recycling.
13.	Put the soggy chips under the murd/mird to crisp them.
14.	If you have a tummy ache, then the glain/glane can fix it.
15.	Place the dirty flowers under the smope/smoap to polish them.
16.	Choose the best oranges before using the wrog/rhog to juice them.