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# The Effect of Spacing Versus Massing on Orthographic Learning

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**ABSTRACT**

Distributing study opportunities over time typically improves the retention of verbal material compared to consecutive study trials, yet little is known about the influence of temporal spacing on orthographic form learning specifically. This experiment sought to obtain and compare estimates of the magnitude of the spacing effect on written word form learning across three different outcome measures, administered between participants. Skilled adult readers ($N = 120$) read aloud 16 sentences containing an embedded pseudoword a total of four times. Half of the items were temporally distributed (appearing once in each of four blocks), while half were massed (read on four consecutive trials within a block). After a short delay, learning was assessed using tests of recognition (orthographic choice) or recall (spelling to dictation or letter cue spelling). There was a significant effect of spacing across all outcome measures (all $p < .001$). When the magnitude of the spacing effect was compared across these three measures, letter cue spelling showed a significantly larger spacing effect than spelling to dictation ($p = .039$) while orthographic choice did not significantly differ from either (both $p > .05$). These findings indicate that temporal spacing influences the learning of orthographic form, regardless of the outcome measure used.

Orthographic learning refers to the process of forming representations of new written words in memory, which support the development of rapid visual word recognition (Nation & Castles, 2017). For this reason, orthographic learning is generally viewed as being central to the process of transition from novice to skilled reading. Share (1995) proposed a theory of orthographic learning and introduced a paradigm for testing it. According to the *self-teaching hypothesis*, when an unfamiliar written word is encountered in print for the first time, the reader applies their phonological decoding knowledge to decipher its pronunciation. This process is posited to operate as a self-teaching mechanism that offers the reader an opportunity to learn each word's spelling. Orthographic learning paradigms mimic the experience of encountering new written words in writing for the first time by embedding novel words (either real but rare words or pseudowords) into sentences. Participants read the sentences containing the novel words on several occasions (typically four) and their learning is subsequently tested. The two most common assessments of orthographic learning evaluate *recognition* and *recall* of written word forms. Orthographic choice is a recognition task that requires the reader to identify a learned spelling (e.g., *sloak*) and distinguish it from a homophonic spelling (e.g., *sloke*) and two distractor spellings (e.g., *sloat* and *slote*). Spelling to dictation is a cued recall task in which the spoken form of a novel word is provided (e.g., /sloak/) and the participant must then produce the previously encountered spelling of that word (e.g., *sloak*). Correct responses on orthographic choice and spelling to dictation suggest that the reader has, via their reading experience, acquired item-specific knowledge of the novel written word forms



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(Nation & Castles, 2017; Share, 1999, 2004). While phonological decoding is known to be an important driver of orthographic learning (Share, 1995), it is not the only factor that influences learning.

A number of prior experiments grounded within the self-teaching framework have considered the question of whether features of the exposure conditions at the point of encountering new written words influences orthographic learning (for review see Nation & Castles, 2017). The most well-established effect is that written frequency influences learning, with more commonly seen written words being better learned than less commonly seen written words (Bowey & Muller, 2005; Nation et al., 2007; Reitsma, 1983a, 1983b, 1989). This finding mirrors assumptions present in models of skilled reading (Coltheart et al., 2001; Norris, 2006; Plaut et al., 1996) and is supported by a substantial body of empirical evidence (for review, see Brysbaert et al., 2018). A number of other distributional properties of words exist, yet much less attention has been directed toward understanding whether these features might also influence orthographic learning. For example, a very small amount of experimental work has suggested a potential role for order of acquisition and has shown that items that are encountered early are better learned than items encountered later in learning (Joseph et al., 2014). The literature on memory and learning in other cognitive domains points to another important factor that might influence orthographic learning: the degree to which encounters with new written words are spread out in time.

Temporal spacing experiments contrast conditions in which new information is presented consecutively (massed) with information that is spread out in time (spaced). A spacing effect is observed when learning outcomes are superior for the items that were temporally spread out during learning, compared to those that were experienced consecutively. Substantial evidence for an effect of temporal spacing exists within the broad domain of verbal learning, which encompasses tasks such as learning lists of familiar words, facts associated with words, unfamiliar word meanings and second language vocabulary learning (Carpenter et al., 2009; Kornell, 2009; Sobel et al., 2011). The spacing effect is both large and robust: in a recent review, Wiseheart et al. (2019) drew on two meta-analyses (Cepeda et al., 2006; Moss, 1996) to estimate the size of the spacing effect on verbal learning at $d = 0.85$.

A substantial body of work has sought to develop and evaluate different possible accounts of the spacing effect based on studies in the broad domain of verbal learning. These accounts have identified a range of factors that may play a role in the phenomenon, but no consensus has yet been reached regarding which factor or combination of factors best explains the effect (for reviews see: Cepeda et al., 2006; Wiseheart et al., 2019). Three broad classes of theoretical account can be found in the temporal spacing literature. *Deficient processing* accounts suggest that massed repetitions attract fewer attentional resources than spaced repetitions because close repetitions are perceived as highly familiar, whereas more distant repetitions are perceived as less familiar (Challis, 1993; Cuddy & Jacoby, 1982). *Study-phase retrieval* accounts suggest that temporally distant encounters are more likely to require that the previous learning experience be retrieved from memory than consecutive encounters, because recent encounters might still remain fresh in mind and therefore not require retrieval (Benjamin & Tullis, 2010; Thios & D'Agostino, 1976). *Encoding variability* accounts suggest that spaced repetitions are associated with greater variability of cues during encoding (e.g., environmental context, encoding processes applied during learning), and this variability is thought to provide more routes to retrieval than massed practice, for which there is thought to be less variability during encoding (Estes, 1955; Glenberg, 1979). Although not discussed within the temporal spacing literature, a fourth theoretical account relevant to reading specifically can be extrapolated from *activation theories of visual word recognition* (e.g., Coltheart et al., 2001; McClelland & Rumelhart, 1981; Morton, 1969; Rumelhart & McClelland, 1982). A prediction arising from these theories is that spaced experiences might be beneficial because temporally distant exposures to written words permit activation patterns to peak and then recede (to a lower resting state) prior to the next encounter with the word, whereas massed encounters might not prompt a change in activation levels beyond the first encounter because activation levels remain high. While the first three of these explanatory theories of the spacing effect were not developed to explain potential effects on reading or orthographic learning specifically, one can extrapolate from these theoretical accounts the general prediction that temporal spacing *could*, and perhaps *should*, influence orthographic learning. We will turn now to consider what evidence currently exists regarding the influence of temporal spacing on orthographic learning.

Several prior studies with skilled readers are relevant to the effect of temporal spacing on orthographic learning. Pagán and Nation (2019) monitored participants' eye movements as they silently read sentences containing rare English words, half of which were experienced under massed and half under spaced conditions during the learning phase. However, participants also encountered all of the target words, both massed and spaced, before and after the learning phase. Thus, because exposures occurred before, after, and during the learning phase, this meant that the massed items were also subject to some degree of temporal spacing (because spacing was only controlled in the learning phase). While some differences in lexical processing were noted at post-test, they are difficult to interpret with respect to spacing because the manipulation was not pure.



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In a second language vocabulary learning experiment with skilled adult readers of English, Koval (2019) began each experimental trial by providing participants with a known English word (e.g., *face*). Immediately afterwards, participants read English sentences containing a single Finnish word with the same meaning (e.g., the Finnish word *kasvot* means *face* in English). The task was to learn the new Finnish words. Participants' eye movements were monitored as they read. Each novel word was encountered four times, with half experienced in consecutive sentences within the same experimental block, while half were temporally spaced across each of four experimental blocks. At test, participants were asked to identify the target words they had read from among a series of distractors. While there was a clear benefit of spacing over massing, the task itself was not a direct measure of orthographic learning. Specifically, because the target and each distractor had different pronunciations (achieved by transposing syllables or scrambling letters within the target to construct the foils, e.g., *votkas*), participants could have simply recognized the decoded phonology of the new words, rather than learned their spelling. Spreading out exposures to new written words has also been found to boost adults' learning of new vocabulary in their second language (Nakata, 2015; Nakata & Webb, 2016), though these studies used a paired-associate, rather than an orthographic learning, paradigm.

Two studies from the developmental literature are also pertinent to the influence of temporal spacing on orthographic learning. Seabrook, Brown, and Solity (2005, Experiment 3) tested whether longer intervals between practice benefited learning more than shorter intervals. This is known as the *lag* effect, which is distinct from, but related to the spacing effect. In their study, children in Grade 1 were taught grapheme–phoneme correspondences (e.g., the letter *p* makes the /p/ sound) and how to read some high-frequency regular words (e.g., *bend*, *flip*, *stand*) within either one 6-min session per day (clustered practice) or three 2-min sessions that were spread throughout the school day (distributed practice). Instruction continued on a daily basis for 2 weeks, and when children were tested following this, those taught over three brief daily sessions outperformed children taught in a single longer daily session. This finding supports the idea that spreading out intervals between short learning sessions is associated with better learning of reading-related knowledge by young children than teaching the same information in a single longer session. Wegener et al. (2022) tested for a spacing effect within children's orthographic learning via their independent reading. Children in Grades 3 and 4 independently read sentences containing an embedded pseudoword a total of four times. Half of the items appeared in consecutive sentences and half were temporally distributed across experimental blocks. There was clear evidence of a spacing effect when learning was assessed using orthographic choice, which was administered first, but there was no effect of spacing on how well the children were able to spell the pseudowords when tested moments later.

Taken together, preliminary work with both children and adults suggests that temporal spacing may boost orthographic form learning relative to massing, but the current evidence base is limited and as yet unconvincing. Thus, this topic represents an obvious gap in our understanding of the distributional factors that might influence orthographic learning. This gap is especially striking when viewed in the broader context of more than a century of work showing that spacing influences a wide range of learning outcomes, particularly semantic learning. Understanding whether temporal spacing influences orthographic learning specifically is important in view of prior work showing that semantic and orthographic learning are predicted by discrete skills (vocabulary cf. decoding; Ricketts et al., 2011). While we may suspect that temporal spacing should influence orthographic learning outcomes, we should not assume that the influence of spacing on orthographic learning is the same as its influence on semantic learning. Therefore, there remains a need to obtain clear estimates of the spacing effect using outcome measures assessing participants' learning of orthographic form, because doing so is an important prerequisite for determining whether the spacing principle should be incorporated into recommendations for supporting written word learning outcomes in educational settings.

Orthographic learning experiments have typically assessed learning using multiple outcome measures administered in a predetermined order. This use of multiple outcome measures is frequently viewed as advantageous in orthographic learning experiments, because doing so permits the experimenter to obtain converging evidence, from tasks thought to measure the same broad construct, that *some* learning has occurred. A recognized limitation, however, is that different outcome measures may, and in fact often do, yield divergent estimates of the amount of learning that has occurred (e.g., Kyte & Johnson, 2006; Mimeau et al., 2018; Wang et al., 2011). For instance, performance is often superior when learning is measured using orthographic choice compared to when learning is measured using spelling to dictation. This pattern tends to be explained in terms of differences in the quality of the orthographic representation required to support performance, with the assumption being that a higher quality orthographic representation is required to support cued-recall as assessed using spelling to dictation than to support recognition memory as assessed using orthographic choice (Wang et al., 2011).

When orthographic learning outcome measures agree that an effect is present, differences between measures might be characterized in terms of variations in the degree of learning that has occurred. However, if outcome



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measures disagree about whether an effect is present, this is more problematic because there are several factors that might contribute to the discrepancy (for discussion of the limitations of task dissociations, see Dunn & Kirsner, 2003). For instance, divergent results could signal a real difference between the two tasks suggesting that an effect is present when tested using one outcome measure but is genuinely absent when tested using another. This is important to know because it might imply the effect is not robust enough to warrant its use outside the lab. An alternative possibility is that there could be an inadequate range of performance on the task that failed to show an effect of condition—it might be too easy or too hard—and this may obscure any differences that might have been observable had the task been of a more appropriate difficulty. A further possibility arises if we consider the spelling to dictation outcome measure specifically. It has been proposed that if a participant's memory trace is inadequate to support their spelling to dictation performance, then the cue itself—the word's phonological form—might prompt participants to rely on their knowledge of mappings between spoken speech sounds and letters to produce responses (Wegener et al., 2022). When written words are regular for reading, this approach should mean that the overall level of performance is above the floor of the task, because there are a finite number of phonologically plausible responses one might make. However, this strategy has the potential to dampen the experimental effect because other factors, such as the statistical properties of written words, likely exert some influence on spelling responses (Treiman, 2018; Treiman & Kessler, 2006, 2016).

A final possibility is that divergent results could potentially reflect an effect of test order. Some studies require participants to complete a recognition memory task (orthographic choice) prior to a cued-recall task (spelling to dictation), whereas other studies might use the reverse order of administration. It is possible that the presence of the first task influences performance on the second, and for this to be greater in one direction than the other. This type of confound is particularly problematic in a spacing experiment: by the time the participant comes to the second and any subsequent outcome measures, the massed items have no longer been experienced consecutively (Wegener et al., 2022). One way to test whether this influences estimates of the spacing effect beyond the first posttest is to explicitly test for an order effect when multiple outcome measures are administered. This would involve administering the dependent measures in every possible task order across participant groups. An alternative approach is to acknowledge that after the learning phase has been completed, the first outcome measure offers the most direct test of the effect of spacing. If one adopts this approach to obtaining estimates of the spacing effect (if present) using multiple outcome measures, then each participant is required to complete only one task at test using a between-subjects design.

This discussion of alternative interpretations of divergent outcomes provides an important context for informing experimental designs. The aim of the current experiment was to obtain estimates of the spacing effect in orthographic form learning across a range of outcome measures. For this purpose, we adopted the view that the first outcome measure offers the most direct test of the effect of spacing. Adult participants read aloud 16 sentences a total of four times, with each sentence containing an embedded pseudoword. 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 short delay, the acquisition of word-specific orthographic knowledge was assessed between-subjects using one of three measures of orthographic learning, one tapping recognition (orthographic choice) and two tapping cued-recall (spelling to dictation and letter-cue spelling). Spelling to dictation, which uses a whole word phonological cue, is one of the most common methods of testing orthographic learning. We wondered whether the absence of the spacing effect on the spelling to dictation outcome measure reported by Wegener et al. (2022) might reflect a lack of sensitivity, and so developed the letter-cue spelling task for this experiment to test whether cue type influenced the obtained estimate of the spacing effect. In line with prior work in the broad domain of verbal learning, we expected to observe a spacing effect across each of the three measures of orthographic learning. In addition, we sought to determine whether the magnitude of the spacing effect would differ as a function of how orthographic learning was measured at test. The experimental design, hypotheses, and analysis plan were preregistered (https://aspredicted.org/nh6vp.pdf).

# Method

The design was one within-subjects factor with two levels (exposure condition: spaced; massed) by one between-subjects factor with three levels (test type: orthographic choice; spelling to dictation; and letter-cue spelling). The dependent variable in each instance was response accuracy.

## *Participants*

In all, 120 undergraduate students volunteered to complete the experiment for course credit. The mean age of participants was 23.2 years (SD = 8.48) and 61 were females (51%). Participants were randomly allocated to test type: 37 participants received the orthographic choice task; 44 participants received the spelling to dictation task; and 39 participants received the letter-cue spelling task. Allocation of participants to outcome conditions was made by a



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computer programmed to perform this allocation completely at random, which is why participant numbers in each outcome condition vary somewhat.

## Materials

*Pseudowords*. Stimuli were 16 homophonic pairs (e.g., *smaup/smawp*) of 4- to 5-letter, monosyllabic pseudowords with regular pronunciations according to grapheme–phoneme rules (Rastle & Coltheart, 1999). One item from each pair was allocated to experimental list 1 and the other was allocated to experimental list 2 (see Appendix A). Each manipulated grapheme occurred with different spellings in two pseudowords within each list. For example, participants who learned List 1 encountered *smaup* and *blawm*; participants who learned List 2 encountered *smawp* and *blaum*. This was done to control for any preference participants might have for a given spelling. The manipulated grapheme was in the vowel position for 62.5% of items (e.g., *smaup/smawp*) and in a consonant position for 37.5% of items (e.g., *sleff/sleph*). In addition, each list was divided into two subsets so that allocation of item to condition could be counterbalanced (e.g., some participants learned *smaup* in the massed condition and *blawm* in the spaced condition, whereas others learned *smaup* in the spaced condition and *blawm* in the massed condition). These procedures yielded four versions of the learning phase of the experiment, and participants were randomly allocated to one version. Because the items were developed for use with skilled readers, we thought it important that the task have an appropriate level of difficulty, to guard against ceiling effects in this population. With this in mind, some of our items included uncommon graphemes (e.g., *mn* and *mb*).

*Experimental sentences*. Single line sentences were presented with the pseudowords embedded as nouns (see Appendix B). Each sentence referred to a fictional invention created by a fictional character (Professor Parsnip; Wang et al., 2011) and contained a single presentation of one pseudoword. An example is provided in sentences *a* and *b* (target words were not italicized in the experiment).

1. You should shuffle the cards with the *blawm* before every game.
2. You should shuffle the cards with the *blaum* before every game.

## Procedure

The orthographic learning and testing tasks were administered individually using the Gorilla online experiment platform (Anwyl-Irvine et al., 2020) and supervised by an experimenter via Zoom (https://zoom.us).

*Orthographic learning task*. Participants were told that they would be reading aloud some sentences referring to a series of inventions. They were instructed that they would read the sentences several times, and that they should try to remember what they read. Each trial began with a 500 ms central fixation cross. A single line sentence then appeared, centered on the screen. After reading aloud each sentence, participants pressed a button to terminate the trial. No feedback was provided regarding word reading accuracy. Half of the items were presented in the massed condition (the four sentences referring to an invention were presented on consecutive trials); half appeared in the spaced condition (the four sentences referring to an invention appeared once in each of four blocks). There were four randomized blocks of 16 trials. Items from both the massed and spaced conditions were interleaved within each block, and trial order was fixed within blocks to maintain the lag between sentences in the spaced condition. Two-and-a-half minute breaks were given between blocks in which the participants watched nonverbal cartoons. The learning phase was followed by a 7-min delay during which a nonverbal cartoon was shown.

*Testing*. Participants were randomly allocated to one of three test conditions.

*Orthographic choice*. 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., *smaup*), the homophonic spelling from the untrained list (e.g., *smawp*), and two visual distractors that are also homophonic to each other (e.g., *snaup* and *snawp*). The target appeared in each screen location an equal number of times. Trial order was randomized for each participant. The dependent variable was target recognition accuracy.

*Spelling to dictation*. Participants listened to recordings of spoken target words and spelled them by typing into a text box. They pressed the "Enter" button to submit each response. Items were randomized for each participant. The dependent variable was spelling accuracy.

*Letter-cue spelling*. Participants were shown the first and last letter of each target word and were asked to spell the whole word by typing into a text box. They pressed the "Enter" button to submit each response. Items were randomized for each participant. The dependent variable was spelling accuracy.

For both spelling tasks, responses were automatically scored by a computer program, which assigned a value of 1 when the participant's spelling matched the target spelling, and a value of 0 when one or more letters in the participant's spelling did not match the target spelling.

# Results

Data and scripts are available at: https://osf.io/3mzr4/ Data were analyzed using R (R Core Team, 2021). An omnibus model containing the fixed effects of exposure condition (massed; spaced), test type (orthographic



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choice; spelling to dictation; and letter-cue spelling), and their interaction was implemented first, using the *lme4* package (Bates et al., 2020). To test the six planned comparisons described in the preregistration, this model was then passed to the *emmeans* package (Lenth et al., 2019), where the contrasts of interest were specified and executed. Three tests were run to obtain the simple effect of condition (massing vs. spacing) at each level of test type (orthographic choice; spelling to dictation; letter-cue spelling). Another three tests were run to obtain the two-way interactions comparing the magnitude of the effect of condition across the three test types (letter-cue spelling vs. orthographic choice; letter-cue spelling vs. spelling to dictation; orthographic choice vs. spelling to dictation). The Holm–Bonferroni correction for multiple comparisons was applied to $p$ values.

Descriptive statistics are provided in Table 1, while Figure 1 visualizes both the data distributions and individual participant total scores in each condition. Model outputs with Holm–Bonferroni corrected $p$ values are provided in Table 2. There was a significant simple effect of condition at each level of test type, indicating the presence of a spacing effect on all outcome measures (all $p < .001$). Two-way interactions comparing the magnitude of the spacing effect across the three test types indicated that the spacing effect observed on the orthographic choice task did not significantly differ from that observed on either the spelling to dictation, nor the letter-cue spelling task. However, when the magnitude of the spacing effect on the spelling to dictation task was compared with the magnitude of the spacing effect on the letter-cue spelling task, the two-way interaction was significant. This finding suggests that, while the spacing effect was significant on both tasks, it was smaller on the spelling to dictation than the letter-cue spelling task.

Cronbach's alpha was calculated for each dependent measure and these appear in Table 3, along with their bootstrap 95% confidence intervals based on 1000 samples. These values were obtained using the *cronbach.alpha* function from the *ltm* R package (Rizopoulos, 2006). Cronbach's alpha is a measure of internal consistency; in an experimental context such as this, it provides information regarding the degree to which getting one item correct predicts that a participant will get another item correct. However, it should be noted that values are influenced by a number of factors, including differences in item difficulty and the number of participants and items (Agbo, 2010; Reinhardt, 1991). Items varying in difficulty were intentionally included in the current experiment because this reflects typical learning experience and because it provided some protection against ceiling effects when working with skilled readers. In addition, extensive counterbalancing of item sets across participants was employed with the aim of washing out any systematic differences related to specific items, but this had the effect of reducing the number of datapoints in the calculation of Cronbach's alpha, and is evident in the wide confidence intervals surrounding each obtained alpha value.

**TABLE 1**
**Accuracy Means and Standard Errors for Each Experimental Condition**

| | Orthographic choice | Spelling to dictation | Letter-cue spelling |
|---|---|---|---|
| Massed | 0.63 (0.03) | 0.44 (0.03) | 0.14 (0.02) |
| Spaced | 0.84 (0.02) | 0.62 (0.03) | 0.38 (0.03) |

## Discussion

Evidence for the effect of temporal spacing on learning outcomes, including semantic learning, have accrued over more than a century, yet there is a relative paucity of studies examining the influence of spacing on orthographic learning specifically. Given the known differences between semantic and orthographic learning (Ricketts et al., 2011), there is a clear need to explicitly test for the spacing effect in written word form learning so that decisions about the utility of the principle in this specific situation are based on evidence rather than assumptions. On this background, we examined the influence of spaced versus massed exposures to written pseudowords on adults' orthographic form learning via reading. Adults read meaningful sentences containing pseudowords four times, with half of the items experienced consecutively (massed exposure) while half were experienced once per block (spaced exposure). Based on the view that any effects of experimentally manipulating temporal spacing are most readily interpreted via a single post-test, participants completed one test probing their recognition (orthographic choice) or cued-recall (either spelling to dictation or letter-cue spelling) of the pseudoword spellings.

Drawing on the spacing literature, it was anticipated that spreading out exposures to written pseudowords during learning should benefit adults' ability to recognize and recall their spellings across each of the three outcome measures. This preregistered hypothesis was supported. Learned spellings were more readily distinguished from homophonic spellings when the items had been spread out over time during learning (mean accuracy = 84%) compared to when they had been read consecutively (mean accuracy = 63%), consistent with a spacing advantage in recognition memory. Learned spellings were also better retrieved in a cued-recall format when they had been experienced in a temporally distributed fashion during learning than when they were experienced consecutively. Importantly, this finding held when the cue was the whole phonological word form (mean accuracy for spaced items = 62%; massed items = 44%) and when it was a partial orthographic prompt (mean accuracy for spaced items = 38%; massed items = 14%). These findings suggest that, when a single outcome measure is used in



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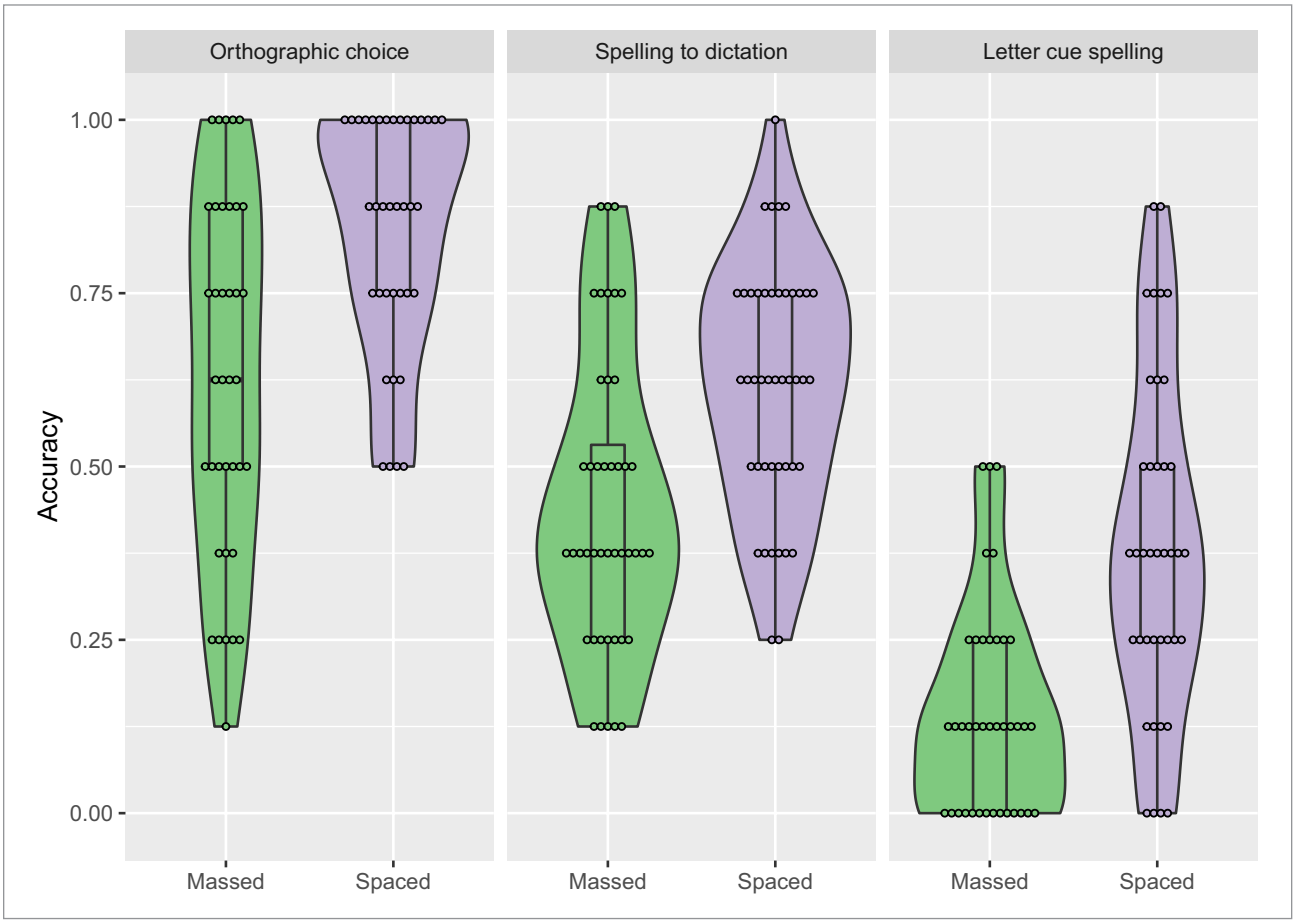
**FIGURE 1**
**Violin plots of response accuracy by condition and test type. Dots represent individual participant total scores by condition**




the context of a manipulation of temporal spacing, a significant benefit to written word form learning can be expected regardless of whether the specific outcome measure probes recognition or cued-recall, and independently of the nature of the cue (phonological or orthographic). As such, these findings also align with meta-analyses of the spacing effect within the broad domain of verbal learning (Wiseheart et al., 2019).

Turning to the magnitude of the observed spacing effect on adults' orthographic learning, we also directly compared estimates across each of the three outcome measures. Our findings showed that only the difference between spelling to

**TABLE 2**
**Output of Planned Comparisons**

| | *b* | *SE* | *z* | *p* |
|---|---|---|---|---|
| Simple effect of spacing | | | | |
| Orthographic choice | 1.28 | 0.23 | 5.53 | <.001 |
| Spelling to dictation | 0.81 | 0.18 | 4.61 | <.001 |
| Letter-cue spelling | 1.53 | 0.23 | 6.65 | <.001 |
| Two-way interactions | | | | |
| Orthographic choice vs. spelling to dictation | 0.47 | 0.29 | 1.63 | .205 |
| Orthographic choice vs. letter-cue spelling | 0.25 | 0.33 | 0.75 | .456 |
| Spelling to dictation vs. letter cue spelling | 0.72 | 0.29 | 2.49 | .039 |



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**TABLE 3**
**Cronbach's Alpha Values and, In Parentheses, Their 95% Confidence Intervals for Each Dependent Measure and Experimental Item List**

| | Orthographic choice | Spelling to dictation | Letter-cue spelling |
|---|---|---|---|
| List 1 | 0.67 (0.23–0.79) | 0.56 (0.07–0.72) | 0.63 (0.19–0.80) |
| List 2 | 0.70 (0.49–0.81) | 0.33 (−0.47–0.58) | 0.61 (0.36–0.72) |

dictation and letter cue spelling reached significance, while orthographic choice sat between these two extremes and did not significantly differ from either. Of course, as a recognition memory task, orthographic choice necessarily incorporates an element of chance and therefore may not be directly comparable to estimates obtained using cued-recall.

We included two cued-recall tests to explore whether the nature of the cue (the whole phonological word form vs. a partial orthographic cue) influenced estimates of the magnitude of the spacing effect. Our findings indicate that the nature of the cue does matter—the spacing effect is significantly smaller when the cue is the whole phonological word form than when it takes the form of a partial orthographic cue. This occurred although the spelling to dictation task *appeared* to be less difficult than the partial orthographic cue task (if we judge task difficulty using the overall proportion correct collapsed across conditions, see Figure 1), suggesting that difficulty and effect size are somewhat independent. We speculate that the reason for this could be because the whole phonological word form might have prompted participants to rely on their general knowledge of sound-print mappings to produce plausible responses when their memory trace for the precise orthographic form was weak, thereby slightly dampening the experimental effect of spacing (Wegener et al., 2022). A partial orthographic cue, on the other hand, could not on its own bring to mind the phonology of the whole word. Instead, performance on this task likely required participants to use the cue to retrieve the word's phonological and orthographic form, with possibly less interference from participants' background spelling knowledge. Regardless of what might explain the difference in the magnitude of the spacing effect when tested using spelling to dictation compared to a partial orthographic cue, from a practical standpoint, our key finding is the presence of a spacing effect across all outcome measures. This suggests that future studies could reasonably employ either orthographic choice, spelling to dictation, or letter cue spelling as outcome measures at test.

Prior experiments testing for a spacing effect within orthographic learning have been difficult to interpret. For instance, Koval (2019) used an outcome measure that did not directly measure orthographic learning because their task could have been completed by simply recognizing the decoded phonology of the novel words, rather than recognizing their spellings. Pagán and Nation (2019) used a complex experimental design with multiple phases (pre-exposure, learning, retrieval-cue) that meant the massed items were not always experienced consecutively. Wegener et al. (2022) included two outcome measures at test, leaving open the possibility that test order could have contributed to the inconsistent pattern of findings (the spacing effect was present on the first test but absent on the second). The current experiment, in contrast, used a classic orthographic choice test (including the target, a homophonic foil and 21-letter different distractors) so that participants would need to recognize the correct spelling to respond accurately. In addition, the experimental design included only a learning phase followed by a test phase. Finally, because we used a between-subjects manipulation of test type, participants completed only a single outcome measure at test, which allowed for a more direct test of the spacing effect across tasks. Together, these features of the current experiment permitted a more straightforward interpretation of the effect of spacing on adults' orthographic learning than prior work.

However, a number of outstanding questions remain to be answered in future work. In the current study, we adopted the view that the first outcome measure offers the most direct test of the influence of temporal spacing on orthographic learning. In future, it might be informative to directly evaluate whether test order influences estimates of the spacing effect. Adding a delayed post-test would also be useful as a means of investigating whether the benefit of temporal spacing observed here following a short delay conveys a robust benefit to retention over a longer period. Additionally, it will be important to extend the work reported here to developing readers – those whose early progress in learning to reading is developmentally typical and those whose progress is slower – with a view to determining whether the role of temporal spacing should be considered within reading instruction programs. In this context, it may be of interest to examine person and word-level factors, and how these might relate to the effect of spacing on orthographic learning.

Having established that spacing influences the learning of orthographic form, it is timely to draw on existing work addressing the theoretical basis of the spacing effect in the broader literature on memory and learning. Future work might use an online measure (such as eye-tracking) during the learning phase, thereby providing valuable insights into the processing that occurs each time a written word is encountered via reading under massed and spaced conditions. Although this idea is not new—Koval (2019) and Pagán and Nation (2019) found shorter fixation durations on the novel words in the massed condition relative to the spaced condition—there are opportunities to analyze such data in novel ways. For example, one possibility would be to directly link the processing that occurs during the exposure phase with performance on tests of learning such as spelling and orthographic choice. This would provide valuable



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insights into how the processing opportunities afforded by the reading episodes relate to learning, as probed by performance on subsequent tests of learning and memory.

However, a number of outstanding questions remain to be answered in future work. In the current study, we adopted the view that the first outcome measure offers the most direct test of the influence of temporal spacing on orthographic learning. In future, it might be informative to directly evaluate whether test order influences estimates of the spacing effect. Adding a delayed post-test would also be useful as a means of investigating whether the benefit of temporal spacing observed here following a short delay conveys a robust benefit to retention over a longer period. In addition, it will be important to extend the work reported here to developing readers – those whose early progress in learning to reading is developmentally typical and those whose progress is slower – with a view to determining whether the role of temporal spacing should be considered within reading instruction programs. In this context, it may be of interest to examine person and word-level factors, and how these might relate to the effect of spacing on orthographic learning.

Another potentially fruitful line of future enquiry would be to use computational modeling of eye movements during reading (see Reichle, 2021) as a means of both informing models of word identification and adjudicating between theories of temporal spacing. A key finding of orthographic learning experiments, including this one, is that participants demonstrate learning of pseudowords following very few (one to four) orthographic exposures (for review see Nation & Castles, 2017). The finding that orthographic learning can occur rapidly has obvious implications for models of word identification. For example, connectionist models require hundreds of training exposures to learn words (e.g., Plaut et al., 1996; Seidenberg et al., 1994), and would therefore have difficulty accounting for orthographic learning occurring over just a few exposures. With respect to spacing manipulations, it might be the case that spreading out orthographic exposures over time could facilitate learning by preventing the catastrophic interference that might otherwise result from later encounters with the pseudowords "overwriting" earlier ones (see McClelland, 1994). Similarly, models in which a hierarchy of processing nodes representing letters and words (e.g., Coltheart et al., 2001; McClelland & Rumelhart, 1981) might accommodate the rapid learning of new words, but only by making the assumption that thousands of new connections are generated to accurately insert a new word node into the network (Pritchard et al., 2018). Thus, with the former models, learning is slow and cannot readily scale to the rapid learning of new words, whereas with the latter models, the representations are "brittle" in the sense that the lexicon is comprised of thousands of different nodes and connections that must be precisely configured.

The one remaining alternative class of word-identification models—those predicated on instance-based learning theories (e.g., Ans et al., 1998; Kwantes & Mewhort, 1999; Reichle & Perfetti, 2003; see also Norris, 2006)—is worthy of consideration. The core assumption of these models is that all experiences—including those involving words—are encoded as discrete traces in long-term memory that can then be remembered with a degree of specificity that varies with the specificity of the retrieval cues. In the current experiment, for example, repeated exposure to pseudowords would result in a series of memory traces representing those experiences, including both the pseudowords themselves and the contexts in which they occurred (e.g., sentences, laboratory, processes applied during encoding). Because memory for the focal information tends to be more robust if it is encoded in varied contexts (Hintzman, 1986), these models would provide a natural account of the spacing effect—that it reflects the greater encoding variability that results from spaced learning trials. It should be acknowledged, however, that these models are also compatible with the deficient processing accounts in that massed encounters might also reduce the amount of effort extended to encode the pseudowords. Future experiments using eye tracking might therefore adjudicate between these two accounts using fixation durations as measures of pseudoword encoding as they are encountered during reading.

In summary, this experiment provides evidence that temporal spacing of exposures to written pseudowords boosts adults' learning of their orthographic forms. The spacing advantage is present across recognition and cued-recall memory tests. Because temporal spacing appears to exert a marked influence on the learning of new written words, this effect warrants further investigation to explore its cognitive basis and to provide an elaborated account of how it might be employed to maximize outcomes in educational settings. For now, we would suggest that, when possible, adults consider spreading out their reading of new written words as this is likely to be more effective in promoting their learning than reading the same information consecutively. Future work with developing readers will be useful for determining whether temporal spacing should be included in reading instruction programs.

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## APPENDIX A

### Experimental Novel Word Stimuli and Distractors

| Subset | List 1 | List 2 | Visual distractor 1 | Visual distractor 2 |
|---|---|---|---|---|
| a | blawm | blaum | brawm | braum |
| a | jowd | joud | jowf | jouf |
| a | fute | fewt | fube | fewb |

(Continues)



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**APPENDIX A** (Continued)

| Subset | List 1 | List 2 | Visual distractor 1 | Visual distractor 2 |
|---|---|---|---|---|
| a | chyb | chib | chyd | chid |
| a | rhup | wrup | rhop | wrop |
| a | vomb | vomn | vamb | vamn |
| a | pribe | prieb | plibe | plieb |
| a | draph | draff | dreph | dreff |
| b | smaup | smawp | snaup | snawp |
| b | zoun | zown | zoum | zowm |
| b | hewl | hule | hewt | hute |
| b | thid | thyd | thit | thyt |
| b | wrog | rhog | wreg | rheg |
| b | namn | namb | nimn | nimb |
| b | griet | grite | gliet | glite |
| b | sleff | sleph | sliff | sliph |

# APPENDIX B

### Experimental Sentences

| Number | Sentence |
|---|---|
| 1. | You should shuffle the cards with the **blawm/blaum** before every game |
| 2. | If sand sticks to your skin at the beach, use the **jowd/joud** to remove it |
| 3. | When the fish tank is dirty, use the **fute/fewt** to clean it |
| 4. | Put tennis balls into the **chyb/chib** before playing fetch with your dog |
| 5. | You can climb the wall like Spiderman with the **rhup/wrup** on your feet |
| 6. | If you cannot remember who someone is, the **vomb/vomn** will tell you |
| 7. | If you have cold feet, the **pribe/prieb** will warm them up |
| 8. | Put your meal into the **draph/draff** to take out the food you do not like |
| 9. | Birds will fly over and start singing when the **smaup/smawp** is turned on |
| 10. | Put the dirty socks into the **zoun/zown** to clean them |
| 11. | If you get caught in the rain, we can use the **hewl/hule** to dry your hat |
| 12. | Load the rubbish into the **thid/thyd** to sort it for recycling |
| 13. | Put the soggy chips under the **wrog/rhog** to crisp them |
| 14. | If you have a tummy ache, then the **namn/namb** can fix it |
| 15. | Place the dirty flowers under the **griet/grite** to polish them |
| 16. | Choose the best oranges before using the **sleff/sleph** to juice them |



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