Journal of Experimental Psychology:
Learning, Memory, and Cognition

ISSN: 0278-7393

https://doi.org/10.1037/xlm0001426

Unpacking the Sandwich: Which Mechanisms Underlie the Increase in Sandwich Priming During Word Recognition?

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Lupker and Davis (2009) introduced a modification of Forster and Davis's (1984) masked priming technique that increased the size of priming effects. The modification involved briefly presenting the target as a preprime during the priming sequence (e.g., #####-JUDGE-judge-JUDGE; the "sandwich" method). At present, the precise mechanisms underlying this increase are not well understood, at least partially because most previous experiments comparing the two procedures involved between-subject comparisons. To examine these mechanisms more fully, we conducted three lexical decision experiments with sandwich and conventional priming methods using a within-subject design. We examined two types of form-related priming: letter transpositions (Experiment 1) and letter replacements (Experiments 2 and 3). Results showed an increase in masked priming effects with the sandwich method in all three experiments. Cross-method comparisons revealed the source of this increase: The sandwich technique sped up the responses to transposed-letter pairs and one-letter replacement letter pairs, produced no latency differences for double replacement-letter pairs, and slowed down responses to unrelated pairs. Experiment 3, using a control preprime (xxxxx), showed that the change in the nature of the priming effects was not simply due to the longer lag between the pattern mask and the target stimulus in the sandwich priming method. These findings pose problems for computational activation-based models that provide accounts of masked priming effects.

Keywords: orthographic processing, masked priming, sandwich priming, lexical decision, word recognition

Supplemental materials: https://doi.org/10.1037/xlm0001426.supp

Tessa Warren served as action editor.

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All three experiments were preregistered. The preregistration, materials, scripts, outputs, and additional online materials are available at https://osf.io/b372s/?view_only=7b9c9f81bf6740f59d98eb7520acf3e2. This work was supported by Ministerio de Ciencia e Innovación (PID2020-116740 GB-I00 awarded to Manuel Perea), Conselleria de Innovación, Universidades, Ciencia y Sociedad Digital, Generalitat Valenciana (CIAICO/2021/172 awarded to Manuel Perea and CIGE2023/20 awarded to Maria Fernández-López).

Maria Fernández-López played an equal role in funding acquisition, conceptualization, data curation, formal analysis, investigation, methodology, supervision, validation, visualization, writing–original draft, and writing–review and editing. Stephen J. Lupker played an equal role in conceptualization, investigation, methodology, supervision, validation, visualization, and writing–review and editing. Pablo Gómez played an equal role in conceptualization, investigation, methodology, validation, visualization, and writing–review and editing. Melanie Labusch played an equal role in resources, software, visualization, and writing–review and editing. Colin J. Davis played an equal role in validation, visualization, and writing–review and editing. Manuel Perea played an equal role in funding acquisition, conceptualization, data curation, formal analysis, investigation, methodology, supervision, validation, visualization, writing–original draft, and writing–review and editing.

The data are available at https://osf.io/b372s/?view_only=7b9c9f81bf6740f59d98eb7520acf3e2

The experimental materials are available at https://osf.io/b372s/?view_only=7b9c9f81bf6740f59d98eb7520acf3e2

The preregistered design (transparent changes notation) is available at https://osf.io/b372s/?view_only=7b9c9f81bf6740f59d98eb7520acf3e2

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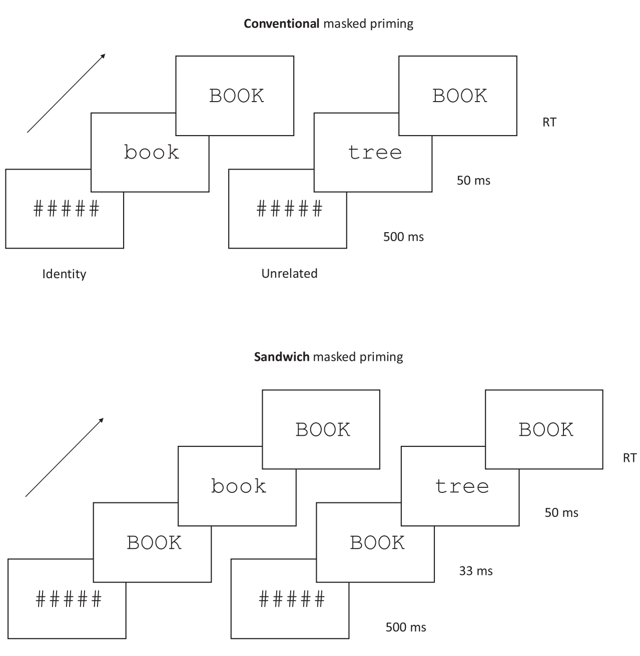
The masked priming technique (Forster & Davis, 1984; Forster et al., 1987) is the tool employed most frequently to examine the first moments of letter and word identification (see Forster, 2013; Grainger, 2008, 2018, for reviews). The conventional procedure involves the presentation of three consecutive stimuli, as depicted in the top panel of Figure 1: (a) a forward mask (a row of #s) for 500 ms, (b) a lowercase prime stimulus for a brief duration (in the range of 30–60 ms), and (c) an uppercase target stimulus remaining on the screen until the participant responds (e.g., lexical decision, semantic categorization, reading aloud, etc.).

Depending on their research questions, investigators choose the prime–target relationships that best suit their research goals. For instance, when testing the degree of flexibility of letter position coding, a common option is to select transposed-letter pairs (e.g., `jugde-JUDGE`) and compare performance to that produced by using control primes created by replacing the two critical (transposed) letters (e.g., `jupte-JUDGE`). Shorter lexical decision latencies for the word `JUDGE` when the prime is `jugde`, rather than `jupte` are interpreted as support of models that propose some degree of flexibility when encoding the order of letters during word recognition (e.g., see Davis, 2010; Gomez et al., 2008; Grainger & van Heuven, 2003; Norris & Kinoshita, 2008, 2012). Although latencies and accuracy are the typical dependent variables being evaluated when using this technique, researchers can also investigate how the priming effects unfold over time measuring event-related potentials (e.g., see Grainger & Holcomb, 2009; see also Dehaene et al., 2001, for other applications to cognitive neuroscience via neuroimaging).

Figure 1

Illustration of the Sequence of Events in the Conventional Masked Priming Technique (Top Panel) and the Sandwich Masked Priming Technique (Bottom Panel)



Note. RT = response times.

Despite the importance of the masked priming technique in examining the role of orthography, phonology, morphology, and semantics during the first moments of letter and word processing, there is an intrinsic limitation of this procedure: the sizes of priming effects are often small, around 10–20 ms in many scenarios. The only (unsurprising) exception is identity priming (i.e., the most extreme type of priming, which involves "related" primes that are nominally the same as their targets; for example, `judge-JUDGE` vs. `paint-JUDGE`). Therefore, capturing subtle differences across prime–target relationships with this technique, let alone small interactions or individual differences, is challenging.

A clear example of this situation was provided by the contrast between Guerrera and Forster's (2008) results and those of Lupker and Davis's (2009). In their masked priming lexical decision experiment, Guerrera and Forster (2008) failed to obtain statistical evidence of faster responses to a target word like `SIDEWALK`, when preceded by their "extreme transposition" primes, such as `isedawkl` (where each consecutive pair of letters from the target word was transposed) relative to a control prime like `pylinder`, failing to support the prediction of current leading models of word recognition that there would be an advantage with the transposition primes (e.g., the spatial coding model, Davis, 2010). One costly solution in this situation would be to collect tens of thousands of observations per condition in the spirit of megastudies of masked priming (e.g., Adelman et al., 2014) in order to determine whether this effect was indeed null. However, doing so is typically not a viable choice in terms of time and effort in most scenarios; furthermore, this option may not even be feasible in experiments with developing readers or special populations (e.g., deaf readers or readers with dyslexia).

In order to overcome this limitation, Lupker and Davis (2009) introduced a small variation in the conventional masked priming technique that has consistently produced larger priming effects than those produced by the conventional method. This approach, referred to as the sandwich priming method, has gained popularity in research involving masked priming experiments (e.g., see Brossette et al., 2022; Campos et al., 2021; Fernandes et al., 2022, 2024; Hasenäcker & Schroeder, 2022; Lupker & Spinelli, 2023; Schmandt et al., 2022; Spinelli et al., 2022, for recent research using sandwich priming in various laboratories and languages). In the following paragraphs, we first describe the sandwich priming technique and the initial experiments and simulations conducted by Lupker and Davis (2009), including those involving Guerrera and Forster's (2008) stimuli. Then, we examine the interpretive challenges that arise when using this procedure. Finally, we introduce the logic behind the experiments reported in this article.

The sandwich priming technique (Lupker & Davis, 2009) introduces a variation to the conventional masked priming technique by adding a fourth stimulus: a preprime. This preprime is identical to the target and is briefly presented (e.g., for 33 ms) between the initial forward mask and the prime of interest, as shown in the bottom panel of Figure 1. The rationale of the procedure is that the preprime activates the representation of the target word, and those primes that are orthographically related to the target help maintain this activation. In contrast, unrelated (UN) primes do not sustain this activation, resulting in a significant difference in target activation following related versus unrelated primes and, therefore, a more pronounced priming effect. Importantly, using the sandwich priming technique with the same materials as used by Guerrera and Forster (2008), Lupker and Davis (2009; Experiment 1b) showed a considerable latency advantage (around 40 ms) for target words like SIDEWALK when preceded by the extreme transposition prime isedawkl than when preceded by the unrelated prime pylinder. Moreover, Lupker and Davis also replicated Guerrera and Forster's (2008) result using the conventional masked priming method (a nonsignificant 7-ms priming effect).

Lupker and Davis (2009) further showed that the spatial coding model (Davis, 2010) captured the increase in priming effects with the sandwich priming technique. Note that they used "processing cycles" in the simulations of the model as an analog of response times. The simulations showed a priming effect of only five processing cycles using the conventional technique (104 vs. 109 cycles for the transposed vs. unrelated primes, respectively) that increased to 29 processing cycles with the sandwich priming technique (76 vs. 105 cycles for the transposed vs. unrelated primes, respectively). That is, according to the spatial coding model, the extreme transposition priming condition benefitted from the preprime in the sandwich priming technique (the number of processing cycles necessary to allow a response decreased from 104 to 76). In contrast, performance in the unrelated priming condition changed minimally when the preprime was presented (105 instead of 109 cycles).

In order to pursue the question of whether the priming increase created by the sandwich priming technique also occurred with other subtle manipulations (e.g., replacement-letter primes), Lupker and Davis (2009) conducted a second experiment. For the target word FACULTY, the primes could be fwculty (one replacement-letter [1-RL] prime), fwxulty (two replacement-letter prime), or bwxshkp (all letter-replacement prime).[1] In Experiment 2a, with the conventional masked priming technique, there was a small 5-ms advantage for the 1-RL priming condition (e.g., fwculty-FACULTY) over the 2-RL priming condition (e.g., fwxulty-FACULTY), and a 17-ms advantage of the double replacement-letter priming condition over the unrelated nonword condition (e.g., bwxshkp-FACULTY).

In Experiment 2b, a new group of participants were presented with the same prime–target pairs in an experiment employing the sandwich priming technique. In this case, the advantage of the 1-RL priming condition over the 2-RL priming condition increased to 24 ms (i.e., a 19-ms increase), and the advantage of the 2-RL priming condition over the unrelated condition increased to 33 ms (i.e., a 16-ms increase). As with the results of their Experiment 1, simulations using the spatial coding model (Davis, 2010) captured the overall increase in the size of the priming effects using the sandwich priming technique. In the conventional technique, the processing cycles for the 1-RL, 2-RL, and unrelated priming conditions were 70, 89, and 102, respectively. Using the sandwich priming technique, these values were 41, 56, and 99 cycles, respectively. Thus, according to the spatial coding model, the orthographically related conditions benefit considerably from the sandwich priming technique: 29 cycles for the 1-RL condition and 23 cycles for the 2-RL condition. Such is not the case for the unrelated condition: the advantage of the sandwich over the conventional technique was only three cycles.

Given the potential that the sandwich priming technique appears to have for increasing the sizes of priming effects, the technique requires further investigation, as the specific mechanisms at play and how they differ from those in the conventional technique need a more thorough examination (see Fernández-López et al., 2022; Lupker & Davis, 2009; Trifonova & Adelman, 2018, for discussion). In Lupker and Davis's (2009) experiments, the type of masked priming method (sandwich vs. conventional) was manipulated between subjects, making it difficult to empirically determine the origin of the priming increase. For instance, is the increase essentially due to a speedup of the related conditions (consistent with the predictions of the spatial coding model)? Or could it instead/also be due to a slowdown of the unrelated condition? In order to answer these questions, it is necessary to use a within-subject design.

Only Trifonova and Adelman (2018) and Fernández-López et al. (2022) employed a within-subject design when examining the sandwich versus conventional masked priming techniques. In Trifonova and Adelman's (2018) experiments, however, the focus was not so much on the above research questions but instead on whether the characteristics of the preprime could influence word processing (e.g., how a slightly different preprime, such as PROTECT, influences the processing of the target PROJECT).

More related to the present goals, Fernández-López et al. (2022) did directly compare the procedures (conventional vs. sandwich) in a within-subject design using identity priming (identity vs. unrelated primes). Results showed the expected increase in priming effects with the sandwich priming technique relative to the conventional technique (79 vs. 40 ms, respectively). The priming effect increase was partly due to a shift in the RT distributions of the identity condition, thus suggesting a head start advantage in that condition when using the sandwich priming technique similar to that in the conventional technique (see Forster, 1999; Gomez et al., 2013). Critically, however, the priming effect increase with the sandwich technique was due not only to faster responses to identity pairs (563 vs. 589 ms in the sandwich vs. conventional techniques, respectively) but also to slower responses to unrelated pairs (642 vs. 629 ms, in the sandwich and conventional techniques, respectively). That is, although the preprime aided target processing when the prime of interest was related to the target, it also hindered target processing when the prime of interest was unrelated to the target, a finding that would not be captured by the current implementation of the spatial coding model (Davis, 2010). Specifically, the model predicted a considerable speedup in the identity condition using the sandwich priming technique and a minimal speedup (rather than a slowdown) in the unrelated condition. Fernández-López et al. concluded that, when considering implications of results when using the sandwich technique, "researchers should be cautious in interpreting some of the across-condition priming effects in subtle manipulations" (p. 1391).

What is important to note, however, is that Fernández-López et al. (2022) only examined identity priming, which is the most extreme type of priming. Virtually, all the other sandwich priming experiments in the literature used other types of prime–target relationships (e.g., transposed-letter priming, replacement-letter priming). Identical primes and targets clearly share more than orthography, whereas other prime types (e.g., jugde-JUDGE, jupte-JUDGE) do not. Therefore, although their experiment provides important clues about the mechanisms underlying the sandwich priming technique when examining identity priming, the impact of the sandwich priming manipulation on other types of form-related priming (i.e., the subtler manipulations that have been more commonly used in sandwich priming experiments) may be different.

[1] Lupker and Davis (2009) also included more extreme replacement-letter conditions fwxslty (three-letter replacement prime), fwxshty (four-letter replacement prime), fwxshky (five-letter replacement prime; target: FACULTY).

The goal of the present three experiments, therefore, was to expand the work of Fernández-López et al. (2022) by examining the origin of the priming increase for two types of form-related priming effects (letter transpositions and letter replacements). Experiment 1 was conducted in Spanish and Experiments 2 and 3 were conducted in English. In all cases, we employed a within-subject manipulation of the task method.

In Experiment 1, our focus was on the transposed-letter priming effect. For a given target word (e.g., CHOCOLATE), we employed three types of primes: (a) a nonadjacent transposed-letter prime (TL prime; e.g., cholocate); (b) a nonadjacent double replacement-letter prime (2-RL prime; e.g., chotonate); and (c) an unrelated word prime (e.g., primavera [spring]). Including the transposed-letter and double replacement-letter conditions allowed us to measure the transposed-letter priming effect. In addition, by including the unrelated condition we were able to measure the effectiveness of the double replacement-letter prime. Note that in conventional masked priming, the lexicality of the unrelated prime does not affect lexical decision latency, that is, responses to a target word (e.g., WALL) are virtually the same when preceded by unrelated word prime (e.g., tree) or an unrelated nonword prime (e.g., pree; see Fernández-López et al., 2019, for a review).

In Experiment 2, we explored the increase in priming effects found with the sandwich priming technique for letter-replacement primes similar to what was done in Lupker and Davis's (2009) Experiment 2. Specifically, the first analysis in that experiment focused on the sandwich priming increase when comparing a 1-RL priming condition (e.g., chonolate-CHOCOLATE) with an adjacent 2-RL priming condition (e.g., chonelate-CHOCOLATE). In addition, we again examined the nature of any increase in the priming effect in the 2-RL condition relative to the unrelated condition (e.g., bwxshkpnz-CHOCOLATE). Note that in Experiment 1, the unrelated prime was a word, whereas in Experiment 2 was a nonword. As noted above, this change should have no implications for the contrast between experiments, as the use of words versus nonwords as unrelated primes does not alter response latencies or accuracy when using the conventional priming technique (see Fernández-López et al., 2019).

Essentially, our key question was whether the increase(s) in priming effects in the sandwich priming technique is due to faster responses in the related conditions in the sandwich priming technique or a combination of elements (i.e., faster responses for related conditions and slower responses for unrelated conditions in the sandwich priming technique; Fernández-López et al., 2022). Finally, in Experiment 3, we examined whether these patterns could be attributed to the longer mask–target interstimulus interval in the sandwich technique (caused by the presentation of the preprime), using the materials from Experiment 2.

Experiment 1: Transposed-Letter Priming and Double Replacement-Letter Priming in the Sandwich Versus Conventional Techniques

As noted above, previous research using separate groups of participants has repeatedly shown that sandwich priming increases the size of masked transposed-letter priming effects relative to the conventional technique (e.g., see Comesaña et al., 2016; Lupker & Davis, 2009). In an effort to better understand the mechanisms at play in sandwich priming, in the present experiment, we designed a masked priming lexical decision task in which we manipulated the prime–target relationship (TL prime, 2-RL prime, unrelated) and the technique (sandwich vs. conventional) using a within-subject design.

The basic predictions for this experiment were as follows. First, we expected to replicate the typical transposed-letter priming effect (i.e., shorter response times for target words when preceded by a TL prime than a 2-RL prime). Second, we expected the 2-RL primes to produce shorter target latencies than the unrelated primes. Third, we expected greater priming effects in the sandwich than in the conventional technique for both contrasts. Critically, the use of a within-subject design allowed us to examine the origin of the increase in these priming effects in the sandwich priming task: whether it is a speedup of both transposed-letter primes and (likely to a lesser degree) the double replacement-letter primes when using the sandwich priming technique and whether there is a slowdown in the unrelated prime condition, replicating Fernández-López et al. (2022).

Method

Participants

We recruited 78 native Spanish participants ($M_{\text{age}} = 29.8$ years, $SD = 8.8$ years, 43 self-identified as women) via Prolific Academia's online platform. Doing so allowed us to have 3,120 observations per condition (i.e., $78_{\text{participants}} \times 40_{\text{stimuli per condition}} = 3{,}120$), in line with Brysbaert and Stevens's (2018) suggestions concerning the required number of observations in masked priming experiments. All participants had normal vision (or corrected if necessary) and no diagnosed reading or writing problems. Participants received monetary compensation for their participation, in line with the average participant's incentive on Prolific, and gave informed consent before participating in the experiment. Experiments 1, 2, and 3 were approved by the Experimental Research Ethics Committee of the University of València.

Materials

We selected 240 Spanish word targets of 8–10 letters. The average frequency per million was 13.94 (range 0.02–180), and the average orthographic Levenshtein distance 20 (Yarkoni et al., 2008) was 2.25 (range 1.40–3.65), according to the EsPal Spanish database (Duchon et al., 2013). Each target word (e.g., CHOCOLATE) was paired with a nonadjacent TL prime (e.g., cholocate), a nonadjacent 2-RL prime (e.g., chotonate) or an unrelated word prime (e.g., primavera [spring]).[2] The preprimes in the sandwich priming technique were the same as the targets.

To act as foils, we created 240 orthographically legal pseudowords matched with the words in sublexical characteristics (e.g., length of subsyllabic elements, transition frequencies) using Wuggy (Keuleers & Brysbaert, 2010). Each target nonword (e.g., BUSEROSO) was paired with a nonadjacent TL prime (e.g., buresoso), a nonadjacent 2-RL prime (e.g., bunecoso) or an unrelated prime

[2] In the Open Science Framework preregistration, we incorrectly indicated that the unrelated primes would be nonwords. As noted in the main text (see Fernández-López et al., 2019), the use of words versus nonwords as unrelated primes in lexical decision tasks does not lead to any noticeable change in target latencies (i.e., there is no prime-target lexically based congruency effect). Note also that, in Experiments 2 and 3 of the present article, we used nonwords as unrelated primes, obtaining similar results in the unrelated condition as in Experiment 1.

(e.g., tacupale). We created six lists to counterbalance the prime–target combinations across the two techniques.

Procedure

The experiment was programmed in the PsychoPy3 software (Peirce et al., 2022) and hosted on PsychoPy's online platform Pavlovia (https://pavlovia.org/) and LimeSurvey (https://www.limesurvey.org; see Angele et al., 2023, for comparable evidence of masked priming effects with online and laboratory experiments). Participants were instructed to do the experiment in a quiet place without distractions. The task was a lexical decision task ("Is the presented string of letters a word?"). Each trial started with a pattern mask (#####) displayed for 500 ms in the center of the computer screen. Half of the trials involved the sandwich priming technique. In those trials, the uppercase target stimulus was presented for 33 ms as a preprime, followed by a 50-ms lowercase prime stimulus which, in turn, was replaced by the uppercase target stimulus which was presented until there was a response or 2 s had elapsed. On the other half of the trials, those using the conventional priming technique, the pattern mask was followed by the 50-ms prime which was then replaced by the target.

Participants were instructed to decide whether the uppercase stimulus was a word or not and to respond by pressing the "m" key ("word") or the "z" key ("nonword") with their right or left index fingers, respectively. The instructions stressed both speed and accuracy but did not mention the existence of any briefly presented primes. Twelve practice trials preceded the 480 experimental trials. Each participant received a random sequence of trials. The experiment took around 20 min, with a break after every 80 trials.

Results and Discussion

For the latency data, we excluded incorrect responses (3.42% for words; 3.21% for nonwords) and the very short (<250 ms) correct responses (11 trials overall, less than 0.01%). Time-outs (i.e., no response before the 2-s deadline) were categorized as errors. Table 1 presents the mean RTs and accuracy for each prime–target relationship in the two techniques for both word and nonword targets. As is the norm in masked priming lexical decision experiments, we focused exclusively on word targets. Note that masked priming effects for nonwords are typically small and, as anticipated, were unreliable in this task (see Table 1).

Table 1
Response Times and Accuracy in Experiment 1

Prime-target relation	Conventional technique		Sandwich technique	
	RT (*SE*)	Accuracy (*SE*)	RT (*SE*)	Accuracy (*SE*)
Words				
TL	629 (15)	97.3 (1.8)	612 (16)	96.8 (2.0)
2-RL	643 (16)	97.0 (1.9)	646 (16)	96.1 (2.2)
Unrelated	657 (16)	96.4 (2.1)	665 (15)	95.8 (2.2)
Nonwords				
TL	716 (18)	96.6 (2.0)	712 (18)	96.8 (2.0)
2-RL	724 (19)	96.7 (2.0)	718 (19)	97.3 (1.8)
Unrelated	724 (19)	96.9 (1.9)	728 (19)	96.9 (1.9)

Note. Mean correct response times (RT, in ms), percent accuracy, and standard errors (*SE*s, in parenthesis) for words and pseudowords with the conventional and sandwich masked priming techniques in Experiment 1. Standard errors were within-subject *SE*s around the mean (Cousineau, 2005). TL = Transposed letters; 2-RL = two replacement-letter.

To conduct the inferential analyses, we employed Bayesian Linear Mixed-Effects models using the *brms* package (Bürkner, 2021) in the R environment (R Core Team, 2023). This package, which uses the programming language Stan as its core, allows us to fit the maximal random-effect structure models allowed by the experimental design (see Barr et al., 2013). We created separate models for the response times and the accuracy data. We modeled the response time data with the ex-Gaussian distribution (see Ratcliff, 1993, for the rationale for using this distribution for response time data) and the accuracy data with the Bernoulli distribution (i.e., the values 1 and 0 would correspond to correct and error responses, respectively). We employed the default, noninformative priors from *brms*. Note that, given the large number of data points, the posterior distribution would, essentially, be unaffected by this choice (Bürkner, 2021). The fixed factors were (a) procedure (sandwich vs. conventional) and (b) prime–target relationship (transposed-letter prime, double replacement-letter prime, unrelated; the double replacement-letter condition was the reference as this factor was treatment coded). We chose the double replacement-letter condition as the reference level, as this allows us to compare, across procedures, the effect of transposed-letter priming (i.e., transposed-letter prime vs. 2-RL prime) on one hand, and the effectiveness of the double replacement-letter prime over the unrelated prime, on the other hand, the unrelated prime produced a slowdown in the response latency in previous research (Fernández-López et al., 2022). We used the maximal random-effect structure models: dependent variable ∼ prime × method + (1 + prime × method | subject) + (1 + prime × method | item), where the dependent variable could be reaction time or accuracy.

We conducted 5,000 iterations (1,000 for warmup) with four chains to obtain the estimates for each effect. All $\hat{R}$ values (i.e., a measure of convergence of the chains) were 1.00. Rather than offering *p* values, the output of Bayesian linear mixed-effects models indicates the value of each estimated parameter (equivalent to the median in its posterior distribution), its estimation error (equivalent to the standard error of its posterior distribution), and 95% credible interval (95% CrI, for short). This interval is the central portion of the posterior distribution of the relevant parameter which contains 95% of the values. If the CrI does not include 0 (i.e., strictly positive or negative), it would be interpreted as evidence of an effect (see Cutter et al., 2022; Danböck et al., 2023, for a similar approach). When there was evidence of an interaction, we employed the *emmeans* package (Lenth et al., 2020) to analyze simple main effect contrasts. For the *brms* models with the ex-Gaussian family (default settings), *b* reflects both the mean (mu) and skewness (β). As a result, small differences may appear between the *b* values and the raw mean RT differences, as *b* accounts for both central tendency and skewness in the RT distributions.

Latency Analysis

TL Versus 2-RL Contrast. Response times to the target words were faster following TL primes than following 2-RL primes (620 vs. 645 ms, respectively, $b = -18.69$, $SE = 2.14$, 95% CrI [−22.93, −14.50]), a TL priming effect. Notably, this difference was greater in the sandwich than in the conventional priming procedure (34 vs. 14 ms, respectively; interaction: $b = 17.13$, $SE = 4.15$, 95% CrI [9.00, 25.19]). Simple effects tests based on this interaction revealed that, for the TL condition, word latencies were faster with the sandwich priming technique than with the conventional technique (612 vs. 629 ms, respectively; $b = -16.72$, 95% CrI [−22.98, −11.06]); in contrast, for the 2-RL condition, word decision times were similar with the two techniques ($b = 0.42$, 95% CrI [−5.20, 6.17]).

2-RL Versus Unrelated Contrast. Response times to the target words were faster when they were preceded by a 2-RL prime than an unrelated prime (645 vs. 661 ms, respectively, $b = 17.86$, $SE = 2.35$, 95% CrI [13.19, 22.44]). This difference was greater in the sandwich than in the conventional priming procedure (19 vs. 14 ms, respectively, interaction: $b = -12.70$, $SE = 4.12$, 95% CrI [−20.62, −4.58]). Simple effects tests based on this interaction revealed that, in the unrelated prime condition, word decision times were slower with the sandwich than with the conventional priming technique (665 vs. 657 ms, respectively; $b = 13.11$, 95% CrI [7.32, 10.27]). As indicated above, the task procedure did not significantly affect latencies in the 2-RL priming condition.

The left panel of Figure 2 presents the posterior distributions of all the estimated effects in the latency data of word targets according to the Bayesian linear mixed-effect model. Note that these posterior distributions represent the range of plausible values for the estimates after incorporating the observed data with the noninformative priors.

Accuracy Analysis

As shown in the right panel of Figure 2, all parameter estimates were within their corresponding 95% CrIs. As shown in Table 1, accuracy was close to ceiling levels.

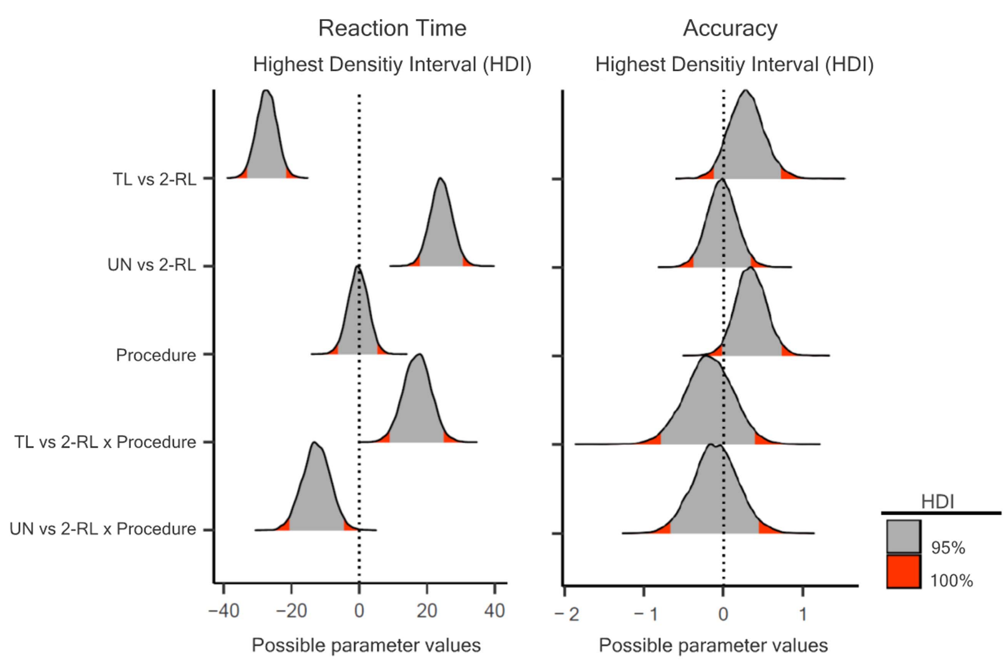
In sum, the present experiment revealed that, for word targets, the increase in transposed-letter priming (TL [e.g., `cholocate-CHOCOLATE`] vs. 2-RL [`chotonate-CHOCOLATE`]) in the sandwich technique was due entirely to the faster responses in the transposed-letter priming condition using that technique. Indeed, the response times in the double replacement-letter condition were virtually the same in the two priming techniques. We did find a small increase in double replacement-letter priming (2-RL [`chonotate-CHOCOLATE`] vs. unrelated [`primavera [spring]-CHOCOLATE`]) in the sandwich priming technique, which was due to longer latencies in the unrelated condition in the sandwich compared to the conventional priming technique (see Table 1). This latter outcome replicates Fernández-López et al. (2022) pattern with the unrelated primes.

Experiment 2: Replacement-Letter Priming in the Sandwich and Conventional Priming Techniques

The main finding of Experiment 1 was that the priming increase in the sandwich priming technique for the transposed-letter priming effect was essentially due to faster responses with that technique in the transposed-letter priming condition with there being essentially no change in the double replacement-letter condition. That is, the double replacement-letter condition was not affected by the task method. Furthermore, replicating the results from Fernández-López et al.'s (2022) experiment, the sandwich priming procedure produced a slowdown in the unrelated condition relative to the conventional method.

Figure 2

Posterior Distribution of Each of the Estimates of the Relevant Effects Based on the Bayesian Linear Mixed-Effects Analysis for the Word Targets in Experiment 1



Note. The area covered by the 95% credible intervals is presented in gray—we interpreted that there was an effect when the credible interval of the parameter estimate did not include zero. The left panel corresponds to the latency data, and the right panel corresponds to the accuracy data. TL = transposed-letter; 2-RL = two replacement-letter; UN = unrelated. See the online article for the color version of this figure.

In Experiment 2, we focused on three prime–target relationships that have often been used in examinations of orthographic priming. We used the same materials as in Lupker and Davis's, 2009, Experiment 2: 1-RL primes (e.g., chonolate-CHOCOLATE), 2-RL primes (e.g., chonelate-CHOCOLATE), and unrelated nonword primes (e.g., bwxshkpcf-CHOCOLATE).

As in Experiment 1, we used a within-subject design in which the presentation of the stimuli across priming conditions and procedure was fully randomized. We expected the difference between 2-RL and 1-RL primes to increase with the sandwich priming technique (it increased by 19 ms, from 5 to 24 ms, in Lupker & Davis's, 2009, experiment), and the difference between the 2-RL primes and the unrelated primes to also increase with the sandwich priming technique (it increased 16 ms, from 17 to 33 ms, in Lupker & Davis's, 2009, experiment). Critically, the use of a within-subject design allowed us to examine the locus of any increase in priming effects: (a) whether it was due to the conditions involving orthographically similar primes (e.g., the 1-RL primes) or (b) whether it was due to a slowdown in the unrelated condition, or (c) whether it was due to both effects.

Method

Participants

We recruited a sample of 312 participants ($M_{age} = 30.9$ years, $SD = 6.3$ years, 200 self-identified as female) with the same recruitment filters as in Experiment 1, except that all participants were native English speakers. This sample size allowed us to have more than 3,000 observations in each condition.

Materials

We selected 60 English word and 60 nonword targets from Lupker and Davis's (2009) Experiment 2. The mean frequency of the target words was 32.08 per million (range 3–224), and the mean orthographic Levenshtein distance 20 (i.e., a measure of orthographic neighborhood; Yarkoni et al., 2008) was 2.51 (range 1.80–2.90), according to the English Lexicon Project (Balota et al., 2007) database. Each target word (e.g., CHOCOLATE) was paired with a 1-RL prime (e.g., chonolate), an adjacent 2-RL prime (e.g., chonelate), or an unrelated nonword prime (e.g., bwxshkpcf). The preprimes in the sandwich priming method were the same as the targets. Each target nonword (e.g., TROBIDELA) was also paired with a 1-RL prime (e.g., twobidela), an adjacent 2-RL prime (e.g., twmbidela) or an unrelated prime (e.g., lwmhzfxtk). We created six lists to counterbalance the prime–target combinations across the two techniques.

Procedure

It was the same as in Experiment 1, except that the language of this experiment was English.

Results and Discussion

The statistical analyses were parallel to those in Experiment 1. The only difference was the substitution of the transposed-letter priming condition with a 1-RL priming condition. The percentages of errors were 2.67% and 3.70% for word and nonword targets, respectively. Only two trials (less than 0.01%) were removed because of too fast responses. Table 2 displays the average RTs and accuracy for the priming conditions across the two priming procedures for word and nonword targets. The convergence of the four chains of the models was very good, and all $\hat{R}$ values = 1.00.

Table 2
Response Times and Accuracy in Experiment 2

Prime-target relation	Conventional technique		Sandwich technique	
	RT (*SE*)	Accuracy (*SE*)	RT (*SE*)	Accuracy (*SE*)
Words				
1-RL	595 (6)	98.0 (0.8)	591 (7)	97.9 (0.8)
2-RL	606 (7)	97.8 (0.8)	605 (7)	97.4 (0.8)
Unrelated	625 (7)	96.9 (0.9)	641 (7)	95.6 (1.1)
Nonwords				
1-RL	674 (8)	96.7 (0.9)	671 (8)	96.1 (1.0)
2-RL	675 (8)	96.5 (0.9)	673 (8)	95.7 (1.1)
Unrelated	676 (7)	96.6 (1.0)	689 (8)	95.8 (1.1)

Note. Mean correct response times (RT, in ms), percent accuracy, and standard errors (*SE*s, in parenthesis) for words and pseudowords with the conventional and sandwich masked priming techniques in Experiment 2. Standard errors were within-subject *SE*s around the mean (Cousineau, 2005). 1-RL = one replacement-letter; 2-RL = two replacement-letter.

Latency Analysis

The response times for words were faster in the 1-RL condition than in the 2-RL condition (593 vs. 605 ms, respectively; $b = -12.34$, $SE = 1.28$, 95% CrI [−14.86, −9.82]). This difference between the 1-RL and 2-RL priming conditions was slightly greater with the sandwich priming technique than with the conventional technique (14 vs. 11 ms, respectively; $b = 6.36$, $SE = 2.59$, 95% CrI [1.26, 11.42]). In addition, we found a 28 ms advantage of the 2-RL primes over the unrelated primes (605 vs. 633 ms, respectively; $b = 28.32$, $SE = 2.05$, 95% CrI [24.23, 32.37]). This latter difference was greater in the sandwich priming technique than in the conventional technique (36 vs. 19 ms, respectively; $b = -21.48$, $SE = 2.77$, 95% CrI [−26.89, −16.11]).

The posterior distributions of the parameters are presented in the left panel of Figure 3. Finally, simple effects tests involving the interactions between procedure and prime–target relatedness also showed that (a) for the 1-RL primes, word decision times were slightly faster in the sandwich than in the conventional priming technique (591 vs. 595 ms, respectively; $b = -9.74$, 95% CrI [−13.63, −5.76]); (b) for the 2-RL primes, the difference in word decision times between the two methods was minimal ($b = -3.37$, 95% CrI [−7.12, 0.23]); and (c) for unrelated primes, word decision times were slower in the sandwich than in the conventional priming technique ($b = 18.10$, 95% CrI [13.96, 22.62]).

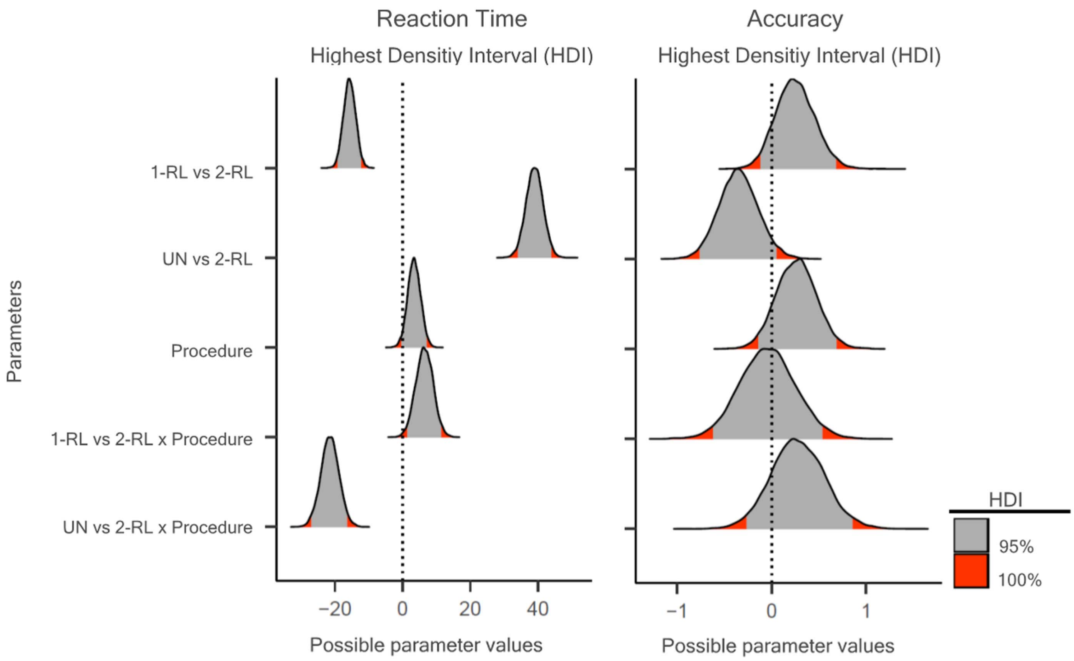
Accuracy Analyses

There was no evidence of an effect in the accuracy data: all parameter estimates were within the 95% CrIs (see the right panel of Figure 3). Again, accuracy was very high for all conditions (see Table 2).

Essentially, these results replicate the previous finding of a larger priming effect from single replacement-letter primes (e.g., chonolate-CHOCOLATE) than from double replacement-letter primes (e.g., chonelate-CHOCOLATE) with the sandwich priming technique (Lupker & Davis, 2009). Additionally, they indicate that

Figure 3

Posterior Highest Density Distributions of Each of the Effects of the Bayesian Linear Mixed-Effects Analyses for the Word Targets in Experiment 2



Note. The area covered by the 95% credible intervals is presented in gray—we interpreted that there was an effect when the credible interval of the parameter estimate did not include zero. The left panel corresponds to the latency data, and the right panel corresponds to the accuracy data. 1-RL = one replacement-letter; 2-RL = two replacement-letter; UN = unrelated. See the online article for the color version of this figure.

this increase in the priming effect was primarily due to faster responses in the 1-RL priming condition in the sandwich compared to the conventional priming technique, whereas, as also observed in Experiment 1, the response times in the 2-RL priming condition were remarkably similar in the two priming procedures. Of note, the effect of procedure (sandwich vs. conventional) in the 1-RL priming condition was also reflected in the quantile-based delta plots reported in the additional online materials (see https://osf.io/b372s/?view_only=7b9c9f81bf6740f59d98eb7520acf3e2).

In addition, we again found a small increase in priming in the 2-RL condition (e.g., `chonelate-CHOCOLATE`) relative to the unrelated control (e.g., `bwxshkpcf-CHOCOLATE`) with the sandwich priming technique. This increase was fundamentally due to the longer latencies in the unrelated condition in the sandwich compared to the conventional priming procedure (see Table 2), thus generalizing the findings of Experiment 1 with unrelated word primes to a scenario with unrelated nonword primes.

Experiment 3: Replacement-Letter Priming Adding a Control Method

Experiments 1 and 2 have shown an increase in the magnitude of transposed-letter priming and 1-RL priming in the sandwich priming technique relative to the conventional priming technique. That increase was due to both faster responding in these conditions and slower responding in the unrelated condition in sandwich priming. As the latter effect is not predicted by activation models that have been designed to model masked priming (e.g., the spatial coding model, Davis, 2010), it raises the question of why it arises. Experiment 3 was an attempt to examine one possible explanation of that effect.

One possibility is that the longer latencies with the sandwich priming technique arise because the insertion of a preprime in the sandwich technique simply creates a greater delay between the mask and the target (83 ms in the sandwich technique, in contrast to 50 ms in the conventional technique). This lag could, potentially, manifest itself by producing a small (i.e., 10–15 ms), but observable, delay in response initiation on all trials. In the highly related conditions, however, this delay would be offset by the activation created by the priming sequence. By contrast, in the unrelated condition, the impact would show up only as an overall delay in latency. In essence, the idea is that the longer latency in the unrelated condition is a timing effect, and therefore, would have no implications concerning the nature of prime or target processing.[3]

[3] One can argue that the results from Forster's (2009, 2013) experiments using the intervenor priming technique (e.g., sequences such as `#####-tiger-house-HOUSE` vs. `#####-tiger-lemon-HOUSE`) argue against the possibility that the addition of a second prime affects response initiation timing. In Forster's experiments, both identity and 1-RL priming effects were of the same size in conventional (three-stimuli sequence) and intervenor (four-stimuli sequence) priming. Although the hypothesis that the insertion of a second prime affected the timing of response initiation was ultimately not supported in Experiment 3, the above-cited intervenor experiments do not bear on the viability of that hypothesis as these experiments did not include a contrast between intervenor and conventional priming to address the main claim of the hypothesis, that a second prime delays responding overall.

In an effort to test this idea, we designed a third experiment in which we compared form–priming effects (1-RL prime: fwculty-FACULTY vs. unrelated prime: bwxshkp-FACULTY) in the conventional masked priming technique (mask, prime, target), and a novel control-variant of the sandwich priming technique in which the preprime is a letter string composed of series of xs ("control-sandwich" variant: mask, xxxxx, prime, target)— the x-string adds an extra time delay to the priming sequence without differentially affecting activation levels of the targets.[4] Moreover, we also included the basic sandwich priming technique in an attempt to again replicate our findings (i.e., to show that the sandwich priming method leads to more priming than the conventional method and, more importantly, that the increase in priming with the sandwich priming method is due to both the latencies in the 1-RL condition decreasing and the latencies in the unrelated condition increasing).

The question is simply because the insertion of the xxxxx string prolongs the priming sequence in the same way that the preprime does in the sandwich priming method, will unrelated prime latencies also be increased as they are in sandwich priming? Similarly, would there be a comparable delay in the 1-RL condition leading to a similar size priming effect in the conventional and control-sandwich conditions? If so, the implication would be that the explanation of the longer latencies in the unrelated condition in sandwich priming is that it is simply a *timing* issue. On the other hand, if the conventional and control-sandwich conditions produce essentially the same latencies, the implication would be that the longer target latencies in the unrelated condition in sandwich priming are a function of the interaction between the processing of the preprime and the unrelated primes.

Method

Participants

We recruited a new sample of 312 participants (M_{age} = 30.7 years, SD = 5.9 years, 189 self-identified as female) with the same recruitment filters as in Experiment 2.

Materials

We employed the same 60-word and 60-nonword targets as in Experiment 2. The only differences between experiments were that (a) we only used the 1-RL prime (e.g., chonolate-CHOCOLATE) and the unrelated nonword prime (e.g., bwxshkpcf-CHOCOLATE); and (b) we included a third presentation method consisting of having a preprime that consisted of a row of x*s* (xxxxxxxx). We created six lists to counterbalance the two prime–target combinations across the three techniques.

Procedure

It was the same as in Experiment 2, except that we added a third control method where the preprime was constituted by a row of x*s*.

Results and Discussion

The percentage of errors was 2.77% and 2.85% for word and nonword targets, respectively. Only one trial (less than 0.01%) was removed because of too fast response. Table 3 presents the mean RTs and accuracy for the two priming conditions across the three priming procedures for word and nonword targets. Again, the four chains of the Bayesian models converged appropriately ($\hat{R}$ values = 1.00 in all estimations).

The statistical analyses were equivalent to those in Experiments 1 and 2, except that the fixed factor prime–target relationship only contained two levels (1-RL, unrelated) and the procedure contained three levels (sandwich, conventional, control-sandwich, where control-sandwich was the reference level). In this analysis, the *emmeans* package (Lenth et al., 2020) was also used to examine the main effect of prime–target relationship across levels of procedure—the output of the brms model only provides this effect with respect to the reference level, because this factor was treatment coded.

Latency Analysis

The response times for words were faster in the 1-RL condition than in the unrelated condition (593 vs. 630 ms, respectively; b = 39.82, 95% CrI [36.14, 43.78]). Importantly, this form–priming effect occurred to a larger degree with the sandwich technique than with the control-sandwich technique (55 vs. 29 ms; interaction: b = 21.09, SE = 2.83, 95% CrI [15.53, 26.64]), whereas the conventional technique produced a comparable form–priming effect to that with the control-sandwich technique (25 vs. 29 ms; interaction: b = −3.84, SE = 2.56, 95% CrI [−8.90, 1.10]). The overall differences due to the procedure were minimal—the posterior distributions of the parameters are presented in the left panel of Figure 4. The increase in priming with the sandwich technique was due to the fact that (a) for the 1-RL primes, response times were faster in the sandwich than in both the control-sandwich technique (584 vs. 597 ms, respectively; b = 10.45, 95% CrI [6.63, 14.43]) and the conventional technique (584 vs. 599 ms, respectively; b = 19.36, 95% CrI [6,27, 14.55]), and (b) for unrelated primes, response times were slower in the sandwich than in both the control-sandwich technique (639 vs. 626 ms, respectively; b = −10.66, 95% CrI [−14,71, −6,57]) and the conventional technique (639 vs. 625 ms, respectively; b = 14.58, 95% CrI [−18.73, −10.15]).

Accuracy Analyses

Accuracy was again very high, always above 95.5% (see Table 3; see the right panel of Figure 4 for the estimates). The models only showed that the difference between related and unrelated conditions was greater in the sandwich priming technique than in the control-sandwich technique (2.3% vs. 0.5%; interaction: b = −0.66, SE = 0.30, 95% CrI [−1.27, −0.12]) due to the slightly lower accuracy in the unrelated condition for the sandwich technique than for the control-sandwich technique (95.6% vs. 97.4%, respectively).

In sum, this experiment successfully replicated the main findings of Experiment 2 and, more importantly, it also revealed that the increase in the lag between the initial pattern mask and the target

[4] In a masked priming experiment with the lexical decision task, Forster (2013, Experiment 2) used a somewhat similar control procedure as that employed here (i.e., a row of percent signs presented for 50 ms preceding the prime; e.g., ########-%%%%%%%%-mibilize-MOBILIZE). However, the results obtained using this procedure were not compared to those with the conventional masked priming paradigm—which is the goal of our experiments—but, rather, to a scenario where the row of percent signs was sandwiched between the prime and the target (e.g., ########-mibilize-%%%%%%%%-MOBILIZE). Forster (2013) found a similar pattern of results in the two scenarios.

Table 3
Response Times and Accuracy in Experiment 3

Prime-target relation	Conventional technique		Sandwich technique		Control sandwich technique	
	RT (*SE*)	Accuracy (*SE*)	RT (*SE*)	Accuracy (*SE*)	RT (*SE*)	Accuracy (*SE*)
Words						
1-RL	599 (7)	97.9 (0.8)	584 (7)	97.9 (0.8)	597 (7)	97.9 (0.8)
Unrelated	625 (6)	96.7 (1.0)	639 (6)	95.6 (1.1)	626 (6)	97.4 (0.9)
Nonwords						
1-RL	669 (8)	97.0 (0.9)	661 (8)	96.8 (0.9)	668 (8)	97.2 (0.9)
Unrelated	679 (7)	97.0 (0.9)	689 (8)	97.4 (0.8)	685 (8)	97.2 (0.9)

Note. Mean correct response times (RT, in ms), percent accuracy, and standard errors (*SE*s, in parenthesis) for words and pseudowords with the conventional and sandwich masked priming techniques in Experiment 3. Standard errors were within-subject *SE*s around the mean (Cousineau, 2005). 1-RL = one replacement-letter.

stimulus in the control-sandwich technique—in which the preprime was composed of a row of x*s*—produced virtually the same pattern as the conventional priming technique. The implication of this result is that the latency increase in the unrelated condition in sandwich priming (observed in all three of these experiments as well as by Fernández-López et al., 2022) was not due to timing issues created by adding an extra stimulus to the priming sequence.

General Discussion

A growing number of word recognition researchers currently favor the sandwich priming technique when choosing a masked priming procedure, because it increases the size of the priming effects (e.g., Brossette et al., 2022; Campos et al., 2021; Fernandes et al., 2022; Fernández-López et al., 2022; Hasenäcker & Schroeder, 2022; Lupker & Spinelli, 2023; Schmandt et al., 2022; Spinelli et al., 2022). However, the exact mechanisms responsible for this increase are not yet well understood. In an effort to better understand the relevant mechanisms, in the present research, we have directly compared priming effects using certain prime–target relationships with the two techniques using a within-subject design. Only Fernández-López et al. (2022) had previously investigated this contrast between priming techniques, comparing identity priming effects (identity vs. unrelated) with conventional versus sandwich priming techniques.[5] They found that the increase in the sandwich priming effect was due to faster responses following identity primes and—to a lesser degree—slower responses following unrelated primes.

Although Fernández-López et al.'s (2022) experiment provided insights into the mechanisms of the sandwich priming technique, it focused on identity priming, rather than the subtler priming effects that the sandwich priming technique was designed to investigate. Therefore, in the present research, we examined the origin of the increase in sandwich priming for two form-related priming manipulations: letter transpositions and letter replacements, employing a within-subject manipulation of task method. In Experiment 1, we examined the transposed-letter priming effect. Each target (CHOCOLATE) could be preceded by a TL prime (cholocate), a 2-RL prime (chotonate), or an unrelated prime (primavera [spring]). In Experiment 2, each target (CHOCOLATE) could be preceded by a 1-RL prime (chonolate), a 2-RL prime (chonelate), or an unrelated prime (bwxshkpnz), employing the same stimuli as in Lupker and Davis's (2009) Experiment 2—note than in Experiment 1, we manipulated nonadjacent letters, whereas in Experiment 2, we manipulated adjacent letters. In Experiment 3, each target (CHOCOLATE) could be preceded by a 1-RL prime (chonolate) or an unrelated prime (bwxshkpnz) and we added a third task method consisting of a variation of the sandwich technique in which the preprime was a series of x*s*.

Results in Experiment 1 showed an increase in the transposed-letter priming effect (TL vs. 2-RL) using the sandwich priming technique (e.g., cholocate-CHOCOLATE vs. chotonate-CHOCOLATE). Importantly, this increase was due only to faster responses in the transposed-letter priming condition—responses in the 2-RL condition were virtually the same with the sandwich and conventional priming methods. However, we also found a greater difference between 2-RL and unrelated conditions (e.g., chotonate-CHOCOLATE vs. primavera [spring]-CHOCOLATE), when employing the sandwich priming technique. Crucially, this increase in the size of the 2-RL priming effect was only due to an increase in latencies in the unrelated condition, when using the sandwich priming technique.

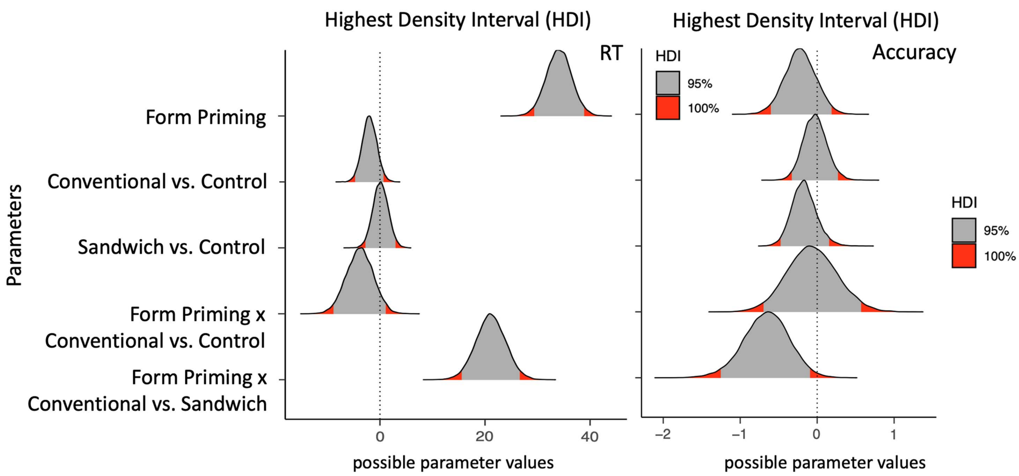
In Experiment 2, we found a small increase in the difference between targets preceded by 1-RL versus 2-RL primes (chonolate-CHOCOLATE vs. chonelate-CHOCOLATE) with the sandwich priming technique. This increase was only due to faster responses in the 1-RL priming condition in the sandwich priming technique than in the conventional priming technique—responses in the 2-RL condition were similar in the two cases, replicating the results from Experiment 1. We did find an increase in priming with the sandwich priming technique when comparing both the 1-RL and 2-RL conditions to the unrelated conditions; however, this increase for the 2-RL condition (e.g., chonelate-CHOCOLATE vs. bwxshkpnz-CHOCOLATE) was essentially due to latencies increasing in the unrelated condition with the sandwich priming technique, thus extending the findings of Experiment 1 and Fernández-López et al.'s (2022), using, for the first time orthographically illegal nonwords rather than words as primes in the unrelated condition.

In Experiment 3, we found that a control-sandwich technique in which the preprime was a series of x*s* behaved virtually the same as the conventional priming technique, in terms of both response times and accuracy, showing faster responses in the 1-RL condition than in the unrelated condition (chonolate-CHOCOLATE vs. bwxshkpnz-CHOCOLATE) as well as very similar overall latencies. We also found an increase in priming with the sandwich priming

[5] As noted, Trifonova and Adelman (2018) also compared the sandwich and conventional methods employing a within-subject design. However, some of their preprimes were not identical to their targets, unlike what is done in the typical sandwich technique.

Figure 4

Posterior Highest Density Distributions of Each of the Effects of the Bayesian Linear Mixed-Effects for the Word Targets in Experiment 3



Note. The area covered by the 95% credible intervals is presented in gray—we interpreted that there was an effect when the credible interval of the parameter estimate did not include zero. The left panel corresponds to the latency data, and the right panel corresponds to the accuracy data. RT = response times; vs. = versus. See the online article for the color version of this figure.

technique relative to both the control-sandwich technique and the conventional priming technique. Again, this increase was due both to latencies decreasing in the 1-RL condition and increasing in the unrelated condition with the sandwich priming technique.

Thus, the present experiments together with Fernández-López et al.'s (2022) experiment revealed that whereas the sandwich priming technique enhances word processing when the prime and target are orthographically quite similar (e.g., primes being either the same as the target, involving two transposed letters or a single replaced letter), it also inhibits word processing when the prime is entirely unrelated to the target word. This latter outcome appears to present some problems for the spatial coding model (Davis, 2010), as that model predicts faster responses in all scenarios, although only minimally so in the unrelated condition.

More specifically, as shown in Figure 5, using the values for the simulated data from Lupker and Davis (2009), the spatial coding model predicts faster responses in the sandwich than in the conventional priming technique for the 1-RL (e.g., `chonolate-CHOCOLATE`) and 2-RL priming conditions (e.g., `chonelate-CHOCOLATE`). In contrast, Experiment 2 only revealed a small advantage for the 1-RL priming condition and no advantage for 2-RL priming condition with the sandwich priming technique. In addition, the spatial coding model predicts a minimal advantage in the unrelated condition using the sandwich priming technique. Conversely, the data revealed slower responses in the unrelated condition with the sandwich priming technique. As the results of Experiment 3 indicate that timing issues are not the explanation for the latency increase in the unrelated condition with the sandwich technique, the reason for this discrepancy is that the interplay between the preprime, the prime, and the target in the word recognition system is more complex than the implemented version of the masked priming procedure in the spatial coding model assumes, particularly when considering what happens in the unrelated prime condition.

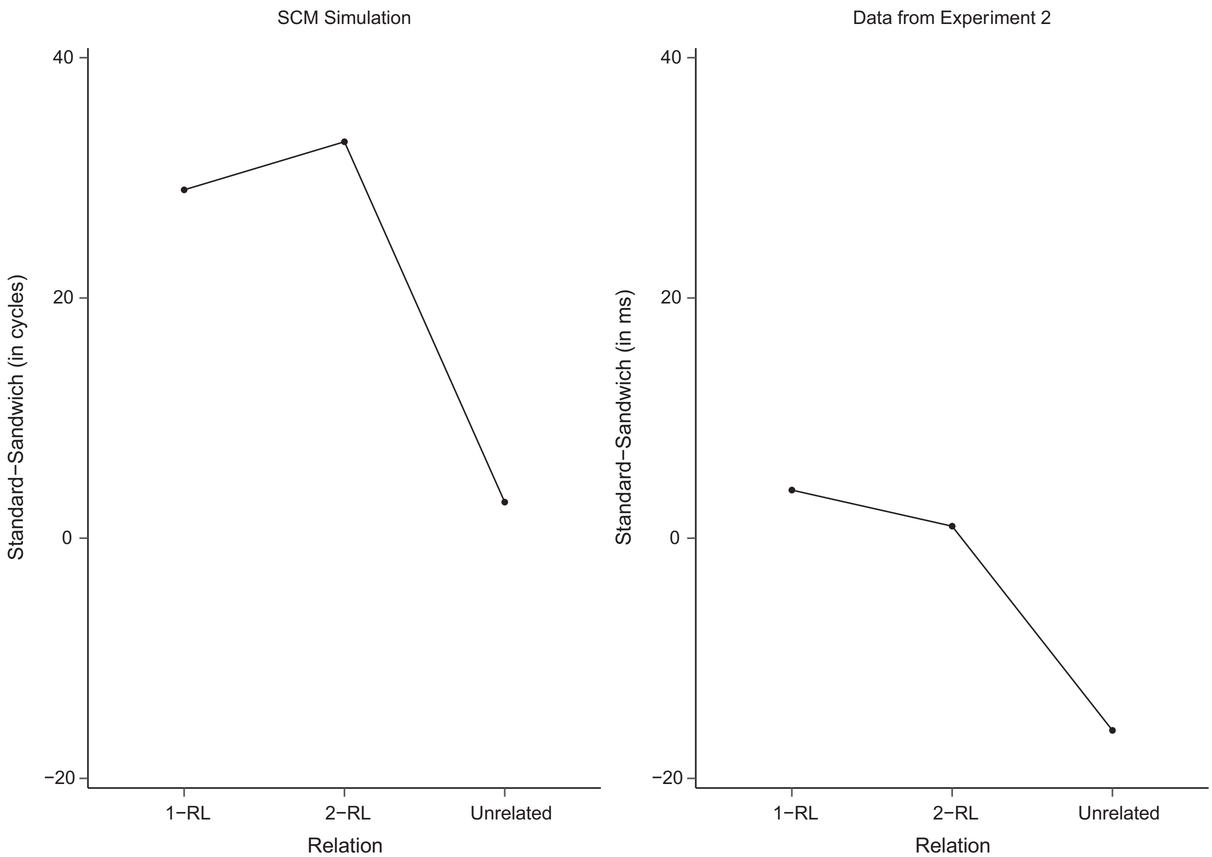
In sum, the present experiments have shown that the increase in the priming effects with the sandwich priming technique is, to some extent, due to faster responses in the more strongly orthographically related priming conditions (i.e., 2-TL and 1-RL priming conditions). Notably, the advantage of the priming effects of the sandwich over the conventional technique appears to depend on the prime and target sharing their letter identities: It is substantial for identity primes (around 39 ms [identity vs. unrelated primes]; Fernández-López et al., 2022), and it is still sizable for transposed-letter primes (around 20 ms [TL vs. 2-RL primes]; Experiment 1), whereas it is small when the prime is created by replacing one letter (around 3 ms [1-RL vs. 2-RL]; Experiment 2). Thus, in these cases, the preprimes do appear to activate the representations relevant to target processing, with those heightened activation levels being maintained or enhanced by processing a prime that activates those same representations (i.e., orthographically similar primes). The same is not the case for double replacement-letter primes, as those primes have a similar impact with the two methods, which suggests that any preactivation of the target representation does not affect the impact of a prime with a weaker orthographic relationship with the target.[6]

What is seemingly more challenging is explaining the results in the unrelated condition. That is, the unrelated prime condition had a consistent disadvantage in the sandwich priming technique

[6] In all three experiments, we also examined how the effects evolved across time using quantile-based, delta plots (de Jong et al., 1994; Ridderinkhof et al., 2004; see Fernández-López et al., 2022, for parallel analyses comparing sandwich versus conventional masked identity priming). As in previous masked priming lexical decision experiments, we found approximately flat lines across priming effects and techniques. This pattern corresponds to shifts in the RT distributions, thus suggesting differences in encoding time and not in accumulation of evidence—this latter possibility would have led to greater effects in the higher quantiles (e.g., see Fernández-López et al., 2022; Forster, 1999; Gomez et al., 2013). These analyses are given in the additional online materials (see https://osf.io/b372s/?view_only=7b9c9f81bf6740f59d98eb7520acf3e2).

Figure 5

Simulated (Spatial Coding Model) and Observed Across-Method Differences (Conventional-Sandwich) in the Priming Conditions of Experiment 2



Note. The units are expressed in processing cycles (model) and milliseconds (experiment). 1-RL = one replacement-letter; 2-RL = two replacement-letter; SCM = spatial coding model.

over the conventional method, which occurs regardless of whether the unrelated primes are words (Experiment 1; see also Fernández-López et al., 2022) or nonwords (Experiments 2 and 3). Thus, in this condition, the representation of the target actually seems to be inhibited, when the unrelated prime is presented.[7]

A question that arises here is why an unrelated prime consistently slows responding in the sandwich in comparison to the conventional masked priming procedure now that Experiment 3 has demonstrated that the effect is not a simple timing effect. Three potential explanations need to be considered, as discussed below.

As Fernández-López et al. (2022) suggested, one possible explanation for this pattern is that, given the brief presentation of the preprime and prime, they are treated as a perceptual single event (Humphreys et al., 1988), so the processing of the preprime overlaps with that of the prime. When it comes to identity primes, since the preprime and prime share all their letter identities, no problems are created for target processing. However, with unrelated primes, the preprime and prime would create a cluttered orthographic code that could impede the initial stages of target processing. Notably, the degree of this hindrance would depend on the level of orthographic overlap between the preprime and prime. In this scenario, unrelated primes create an indecipherable code that slows target processing, whereas weakly related primes (i.e., primes that do not share all or virtually all their letters with the target) produce only a somewhat cluttered orthographic code, one that does not hinder processing to a large degree. Essentially, the interference is only enough to cancel the processing advantage produced by a weakly related prime. This situation would not arise in conventional masked priming, because

[7] One might argue that our interpretation would predict a null increase with the sandwich technique when the target word `SIDEWALK` was preceded by the extreme transposition prime `isedawkl` relative to the control prime `pylinder` (see Lupker & Davis, 2009, Experiment 1). Instead, Lupker and Davis (2009) found a larger effect in a sandwich priming experiment than in a conventional priming experiment (40 vs. 9 ms, respectively). One thing to note about this priming condition, however, is that the primes and targets shared all their letters. Therefore, the preprimes (`SIDEWALK`) in the sandwich priming technique may have been able to ease the encoding of *letter position* for all of the letters in the extreme transposed primes (`isedawkl`), making those primes more effective than replacement letter primes (see Gomez et al., 2008, for a similar argument regarding the time course of letter position uncertainty). However, the use of a between-subject design, in which there were longer latencies and higher error rates in the sandwich priming experiment than in the conventional priming experiment (on average, responses were 51 ms longer and 1.8% more error-prone), suggests that the nature of processing might have been a bit different in the two experiments, making the comparison of those priming effects difficult to interpret.

there is no preprime. Importantly, this idea would explain why more weakly related primes (e.g., 2-RL primes) do not yield larger priming effects with sandwich priming.

A potential problem for this account, however, follows from Forster's (2009) findings on the intervenor effect in masked priming. Intervenor experiments involve a four-stimuli priming paradigm (mask-intervenor-prime-TARGET), making them, in that way, similar to the sandwich priming technique. The main difference between paradigms is that in the usual setup of the sandwich technique, the preprime is identical to the target (`HOUSE-house-HOUSE` vs. `HOUSE-lemon-HOUSE`), whereas, in the intervenor paradigm, an unrelated word, the "intervenor," is presented in the priming sequence. In the "adjacent" version of this technique, the most relevant version of the technique for present purposes, the intervenor is the first stimulus (`tiger-house-HOUSE` vs. `tiger-lemon-HOUSE`). If the clutter account were correct, one would expect little priming in the intervenor experiments, as both tiger and house, from the identity condition, and tiger and lemon, from the unrelated condition, would produce messy orthographic codes. Instead, Forster found a large identity priming effect (53 ms).

An alternative explanation can be framed based on the idea of "double disruption" that would affect unrelated (or more weakly related) pairs with the sandwich technique. For unrelated pairs, the prelexical activation from the preprime (e.g., `HOUSE`) would be adjusted after the presentation of the unrelated prime (e.g., `lemon` or `txnsb`) essentially robbing the target word (e.g., `HOUSE`) of activation. This sequence—shifting away from `HOUSE` to `lemon`, then back to `HOUSE`—may create a more complex context than with conventional priming, in which the transition only requires a single shift from prime to target, leading to longer word response times with the sandwich priming method. This shifting scenario may not apply when the prime and target are perceptually similar (e.g., identity pairs, transposed-letter pairs, and to lesser degree, 1-RL pairs), allowing those primes to activate their targets to a more substantial degree than the single related prime does in the conventional priming paradigm.

The third potential explanation is based on activation of letter units. The idea is that any time a new stimulus appears, its (prelexical) letters are activated, and any other letter representations are inhibited. Once this process occurs, there would presumably be a short delay before the (relevant) target letter units can be reactivated. Consequently, using a preprime (`HOUSE`) followed by an unrelated prime (`lemon` or `txnsb`), and a target (`HOUSE`) could lead to slower responses in sandwich priming than in conventional priming, as was observed.

When the prime is strongly related (`house`, `hause`), however, either the inhibition is not triggered (because it is less apparent to the system that it has a new stimulus to process) or it only affects the units for the letters not contained in the second stimulus. When the prime and target are slightly related (e.g., 2-RL primes: `haese`), both the preprime (`house`) and the prime (`haese`) would activate the target's lexical representation to some degree, producing a higher level of activation in that representation than when there is only a single prime, but the inhibition of the letter units by the two-letter different prime (after `haese`, `a` and `o` for `house` would be inhibited), slows target processing to some degree. Thus, sandwich priming would not produce larger priming effects when 2-RL primes are used nor would it lead to slower responses. Testing these hypotheses would require a technique that provides a direct measure of the time course of priming effects, including measuring the event-related potentials across various types of prime–target form-related pairs (e.g., transposition, replacement), extending the sandwich priming event-related potential data reported by Ktori et al. (2012).

To conclude, the present experiments have revealed that the processing advantage of the related priming conditions using the sandwich priming technique does appear to depend on the degree of relationship between the prime and target (e.g., large for transposed-letter primes, small for one-letter replacement-letter primes, and null for two-letter replacement-letter primes), with the lack of a prime–target relationship actually leading to slower response times when using the sandwich priming technique. As such, caution is required when interpreting priming effect increases when using the sandwich priming technique and those effects involve a contrast with an unrelated priming condition. Everything considered, these findings emphasize the importance of developing more sophisticated accounts of how primes and targets interact during word recognition in both the conventional and sandwich priming techniques.

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Received April 19, 2024
Revision received September 11, 2024
Accepted September 13, 2024 ■