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Word-final orthographic priming as a function of word frequency, prime duration, and morphological status

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Abstract

One of the key issues in visual word recognition is the role of orthographic overlap in priming. However, most research investigating this topic has focused on priming with orthographic neighbors. In this study, we investigate priming effects of word-final letter overlap and their interaction with word frequency, prime duration, and morphology. In Experiment 1 with briefly presented primes (SOA=34 ms, N = 123), we obtained similar facilitation from non-morphological overlap (*compel-TRAVEL*) and inflectional suffix overlap (*turned-CALLED*), regardless of word frequency. In Experiment 2 when primes were fully recognizable (SOA=150 ms, N=123), only non-morphological overlap showed inhibition among lower frequency prime words. These results are inconsistent with predictions of the Interactive Activation model (McCelland and Rumelhart, 1981), and suggest (i) different weights of inhibition and facilitation depending on prime duration and morphological structure of words as well as (ii) the involvement of a reset mechanism in long SOA conditions.

Keywords: visual word recognition; form priming; orthographic priming; suffix priming

Introduction

Visual word recognition is impacted by many different factors, one of which is the context where a word appears. Priming has been widely used to investigate how context modulates word processing. It is also a useful tool to reveal what information plays a role in recognizing a word, whether it be orthographic form, morphemes, or both. Previous findings are not yet conclusive as to whether prior exposure to a few letters of a word is informative enough to boost word recognition. Nor is it clear how this interacts with prime awareness and morphology. To probe this relationship systematically, the present paper investigates masked and unmasked priming effects of word-final letters as a function of word frequency, prime duration, and morphological status by comparing English past tense suffix overlap (i.e., *–ed*) and pure orthographic overlap.

Models of visual word recognition such as the Interactive Activation model (IA; McCelland and Rumelhart, 1981) predict that orthographic priming involves both facilitation and inhibition. How these two effects are manifested in behavioral responses depends on their relative strengths. Within this model, facilitation and inhibition can come into play at multiple different levels. Peressotti and Grainger (1999) argue that shared letters between primes and targets facilitate feature-letter activation while different letters inhibit it; the features of prime letters that do not match with target word letters inhibit their activation. At the word unit level, facilitation occurs when the shared letters pre-activate the target word. Inhibition also occurs at this level because the target's competitors, including the prime itself, are activated, resulting in mutual inhibition among these words. In cases of word primes, in particular, the inhibitory effect is predicted to be greater than the facilitatory effect because the activation level of the node is higher for the prime word than the target word upon target onset (Davis, 2003).

A basic assumption of the IA model is that all priming effects linearly increase as a function of prime duration, yet some studies suggest that longer prime durations involve a different processing mechanism. For example, Grainger and colleagues propose that a reset mechanism takes place when sufficient time is given between primes and targets (Grainger and Jacobs, 1999; Grainger et al., 2012). According to their explanation, once the prime's lexical representation has accumulated a significant amount of activation before the target is presented, that representation is reset to its resting level. This prevents lingering representations of the prime from interfering with target word processing. This mechanism predicts that form overlap will modulate word recognition at shorter, but not longer, prime durations.

Studies to date have yielded mixed results of form priming. De Moor and Brysbaert (2000) and Davis and Lupker (2006) report inhibitory effects of word primes in masked priming in Dutch and English, respectively, as predicted in the IA model. The results from Forster and Veres (1998) show a different trend. In masked paradigm, word primes (e.g., converse-CONVERGE) as well as nonword primes (e.g., convenge-CONVERGE) showed a facilitatory effect when nonword distractors were easy to reject as nonwords. With fully visible primes presented for 500 ms, word primes showed a null effect as opposed to nonword primes that facilitated target processing.

Some studies have shown that form priming is modulated by word frequency as well. For instance, Segui and Grainger (1990) found that high frequency primes delay target recognition in masked paradigm. Nakayama et al. (2008) report similar results in masked paradigm when primes and targets have a small number of neighbors. These results are interpreted as supporting the lexical competition component of the IA model; that is, higher frequency primes interfere with target processing more because they are stronger competitors of target words than lower frequency primes.

Note that prime words tested in the studies above are orthographic neighbors of target words, i.e., words that differ in only one letter. Form priming with a just a few

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overlapping letters is understudied, and the small set of studies that exist report null results in comparison to morpheme-based facilitatory priming effects that occur when the overlapping letters constitute a suffix (e.g., Duñabeitia et al., 2008; Crepaldi et al., 2016). In Duñabeitia et al. (2008), Spanish derivational suffixes (e.g., brevedad-IGUALDAD) showed priming effects of 33 ms in a masked priming experiment whereas purely orthographic overlap (e.g., volumen-CERTAMEN) did not show any statistically reliable effect. Similarly, Crepaldi et al. (2016) report facilitatory priming effects of English derivational suffixes (e.g., towerful-FAITHFUL) as opposed to null statistical effect of non-morphological form overlap (e.g., sportel-BROTHEL).

These findings support a morphological decomposition model (Frost et al., 1997; Stockall and Marantz, 2006) and demonstrate that certain suffixes as well as stems are subject to priming independently of orthographic overlap. Evidence that words with the same stem prime each other (e.g., *walked*-WALK) indicates that morphologically complex words are decomposed into constituent morphemes. Specifically, masked priming effects between these words occur because as the word *walked* is decomposed into its stem *walk* and the affix *–ed*, it shares the same representation with the target word WALK. Masked priming effects of derivational suffixes indicate that they are not only stripped off in early visual word processing but have mental representations in lexicon in such a way that they induce identity-based morphological priming as stems do (Marantz, 2013).

What is missing in the literature is whether inflectional suffixes show a similar pattern, i.e. whether they yield priming effects in visual word recognition that are dissociated with form priming. The current study aims to explore this question via the English inflectional suffix *–ed* while also testing the role of orthographic overlap at long and short prime durations. To this end, we conducted a series of priming experiments varying morphological status, orthographic overlap and word frequency when primes are masked (Experiment 1) versus fully visible (Experiment 2).

Experiment 1

Experiment 1 examined priming effects of word-final letters using a masked paradigm with varying morphological status of overlapping letters and word frequencies.

Participants

123 English speakers (71 females, age: mean = 34.3, SD = 13.5) participated in Experiment 1. Participants were recruited online via Prolific and spoke English as their first language. They were residing in the United Kingdom (115 participants) or United States (8 participants) at the time of participating in the study.

Stimuli

The stimuli were prime-target pairs of 150 word and 150 non-word items. Word targets were English verbs in the present tense with no overt affixation (-MORPH; e.g., TRAVEL) or with the regular past-tense suffix *-ed* (+MORPH; e.g., CALLED). Primes could be identical, share the last two letters ("Test"), or not share any form or meaning ("Control"; see Table 1). Importantly, form overlap in the Test condition constitutes an inflectional morpheme for +MORPH but not for -MORPH.

The characteristics of prime words across conditions are summarized in Table 2. Log frequency and the number of orthographic neighbors were obtained from the English Lexicon Project (Balota et al., 2007) and they were matched as much as possible across different prime and target types. –MORPH targets, however, had a higher number of orthographic neighbors compared to +MORPH targets due to the nature of the study design where prime and target words for –MORPH are all monomophemic whereas those for +MORPH are all polymorphemic. Semantic similarity between prime words and target words was calculated as the cosine distance between word vectors using the pre-trained NLTK word embeddings (Bird et al., 2009). Only primes with a cosine distance < 0.37 were included as sufficiently semantically dissimilar, following previous studies (Grainger and Frenck-Mestre, 1998; Rastle et al., 2010).

Table 1: Example stimuli.

Target/Prime Type	Prime	Target
Target: -MORPH		
(a) Identity	travel	TRAVEL
(b) Test	compel	TRAVEL
(c) Control	commit	TRAVEL
Target: +MORPH		
(d) Identity	called	CALLED
(e) Test	turned	CALLED
(f) Control	turns	CALLED

Table 2. A summary of characteristics of stimuli.

Target/ Prime Type	Word length	Log frequency	Number of neighbors	Similarity to target
Target: -MORPH				
(a) Identity	6.52 (0.95)	7.86 (1.72)	3.06 (2.65)	-
(b) Test	6.80 (0.94)	8.38 (1.54)	2.67 (2.21)	0.12 (0.09)
(c) Control	5.65 (0.95)	8.11 (1.69)	2.97 (2.40)	0.12 (0.09)
Target: +MORPH				
(d) Identity	6.23 (0.78)	9.14 (1.58)	1.66 (2.38)	-
(e) Test	6.19 (0.83)	8.29 (2.18)	1.61 (2.47)	0.12 (0.09)
(f) Control	5.97 (0.77)	7.89 (1.94)	1.55 (2.43)	0.12 (0.08)

Note. SD in parentheses

Nonword targets had the same last two letters as word targets so that half of the nonword targets were monomorphemic (e.g., PRAVEL) and the other half were polymorphemic with the past tense morpheme *-ed* (e.g., PELLED). Stimuli were counterbalanced across three lists to prevent participants from seeing the same stimulus twice.

Procedure

Participants were assigned one of the three lists and performed a lexical decision task in an online platform (https://pavlovia.org) using Psychopy (version 2020.1.3). They used their own laptop to complete the task. The experiment had two practice sessions prior to the main session. The first practice session was designed to help participants get accustomed to keyboard use and the second practice session was identical to the main session but used different stimuli. In each trial, a forward mask (#######) was presented in the center of the monitor for 30 frames (approx. 480 ms), followed by a prime word presented for two frames (approx. 34 ms), and a target word (Figure 1). Participants were asked to judge whether the target word is a real English verb or not by pressing 'z' ('yes') or 'm' ('no') on the keyboard. Frame-by-frame analysis of pilot data collected over this platform confirmed stimulus timing accuracy.

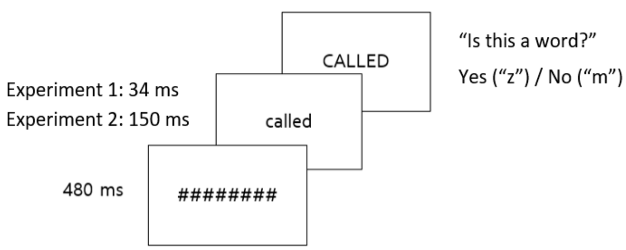

Figure 1: Experiment procedure.

Results and Discussion

One participant was excluded from data analysis because of low accuracy (< 70 %). Reaction times less than 200 ms or greater than 2000 ms were also excluded, which accounted for 2.4 % of the total data.

Table 3 shows accuracy rates and mean reaction times (RTs) for word targets across the six conditions.

For statistical analysis, a hierarchical linear regression analysis was conducted using the *lmer* function (Kuznetsova et al., 2017) in R (version 3.4.4). Log-transformed RTs were included as a dependent variable and Target type (±MORPH), Prime type (Identical, Test, Control), Target word frequency, Prime word frequency and their interaction were included as fixed effects. Target word length, Prime word length, Target orthographic neighbors, and Prime orthographic neighbors were also included as fixed covariates. All continuous variables were centered and dummy coding was used for Prime type with the Control condition as the reference. Results from the most complex model that reached convergence are reported, which included random intercepts for items and participants.

The model revealed a statistically significant main effect of Prime type, such that test primes yielded faster RTs than control primes, regardless of Target type (B = -18.76e-3, p = 0.001). No interactions reached statistical significance ($p >$ 0.168). Additional Bayes factor analysis confirmed that the priming effect of +MORPH target types is not greater than -MORPH target type (BF_{10} = 0.21). Summary of the full regression model is provided in Table 5 (left panel).

In summary, in Experiment 1, primes with word-final letter overlap facilitated target word processing to the same extent for non-suffix and suffix overlap. Neither prime word frequency nor target word frequency had a statistically reliable influence on priming. As some studies (Grainger and Jacobs, 1999; Grainger et al., 2012; Forster and Veres, 1998) suggest, priming mechanisms may be different depending on prime duration (i.e., awareness). Hence, Experiment 2 was conducted using an unmasked, longer duration, protocol.

Experiment 2

Experiment 2 used the same stimuli as Experiment 1, except that prime words were presented for a longer duration so that they were fully visible to participants.

Participants

123 English speakers (51 females, age: mean = 30.3, SD = 12.1) participated in Experiment 2. Participants were recruited online via Prolific and self-reported their first language to be English. They were residing in the United Kingdom (86 participants) or United States (27 participants) at the time of participating in the study.

Stimuli

Stimuli were the same as Experiment 1.

Procedure

Procedure was the same as Experiment 1, with the exception of the prime duration of nine frames (approx. 150 ms).

Results and Discussion

Ten participants were excluded from data analysis due to low accuracy rates (< 70 %). Reaction times below 200 ms and above 2000 ms were also excluded (3.2 % of the total data).

Table 4 presents accuracy rates and mean latencies for word targets in Experiment 2.

A hierarchical linear regression model was fitted in the same manner as in Experiment 1, with log-transformed RTs as a dependent variable, Target type (±MORPH), Prime type (Identical, Test, Control), Target word frequency, Prime word frequency and their interaction as fixed effects, and Target word length, Prime word length, Target orthographic neighbors, and Prime orthographic neighbors as fixed covariates. Random effects included random intercepts for items and participants.

Table 3. Accuracy rates and mean latencies for word targets in Experiment 1 (SD in parenthesis).

Target/Prime Type	Accuracy rate (%)	Reaction time (ms)	Priming effect (ms)
Target: -MORPH			
(a) Identity	97.7 (3.44)	735.3 (238.38)	35.7 (Control-Identity)
(b) Test	96.0 (4.69)	761.7 (235.28)	9.3 (Control-Test)
(c) Control	95.4 (5.80)	771.0 (240.90)	
Target: +MORPH			
(d) Identity	96.7 (3.92)	743.0 (250.60)	39.7 (Control-Identity)
(e) Test	94.8 (5.45)	773.8 (253.41)	9.0 (Control-Test)
(f) Control	95.7 (4.91)	782.8 (248.57)	

Table 4. Accuracy rates and mean latencies for word targets in Experiment 2 (SD in parenthesis).

Target/Prime Type	Accuracy rate (%)	Reaction time (ms)	Priming effect (ms)
Target: -MORPH			
(a) Identity	96.6 (5.83)	741.7 (272.27)	44.4 (Control-Identity)
(b) Test	94.4 (6.60)	801.5 (280.69)	-15.4 (Control-Test)
(c) Control	95.5 (6.23)	786.1 (271.95)	
Target: +MORPH			
(d) Identity	96.3 (4.34)	746.9 (281.08)	49.8 (Control-Identity)
(e) Test	93.8 (6.35)	797.0 (272.58)	-0.3 (Control-Test)
(f) Control	94.0 (5.51)	796.7 (269.29)	

Table 4. Model summary of log-transformed RT in Experiment 1 and Experiment 2.

	Experiment 1			Experiment 2		
	Estimates ($\times 10^{-3}$)	Std. error ($\times 10^{-3}$)	*p*	Estimates ($\times 10^{-3}$)	Std. error ($\times 10^{-3}$)	*p*
Target type	6.35	15.41	0.680	2.90	14.80	0.845
Prime type (Test vs Control)	-18.76	0.58	0.001*	12.37	6.61	0.061
TF (Target frequency)	0.02	4.12	0.953	4.12	3.94	0.296
PF (Prime frequency)	1.17	2.28	0.609	9.95	2.59	<0.001*
Target orthographic neighbors	3.84	2.43	0.116	3.66	2.24	0.105
Prime orthographic neighbors	-1.59	0.09	0.087	-1.68	1.06	0.114
Target word length	10.44	7.90	0.187	22.05	7.52	0.003*
Prime word length	7.74	4.44	0.081	-6.34	4.97	0.202
Target type * Prime type	-13.41	10.73	0.211	-21.79	12.26	0.075
Target type * TF	-6.72	8.30	0.999	2.03	7.92	0.798
Target type * PF	6.87	4.50	0.127	6.67	5.11	0.191
Prime type * TF	0.00	2.80	0.800	-4.45	3.20	0.165
Prime type * PF	-3.24	3.07	0.289	-8.73	3.48	0.012*
Target type * TF * PF	-0.09	2.91	0.758	7.49	3.28	0.022*
Prime type * TF * PF	-0.57	1.68	0.736	1.84	1.91	0.335
Target type * Prime type * TF	0.07	5.53	0.906	0.00	6.31	0.988
Target type * Prime type * PF	-7.19	6.11	0.240	-3.92	6.95	0.572
Prime type * Target type * TF * PF	0.11	3.34	0.974	-8.88	3.76	0.019*
Marginal R^2	0.01			0.02		
Conditional R^2	0.33			0.34		

Note. * $p < 0.05$

(A) (B)

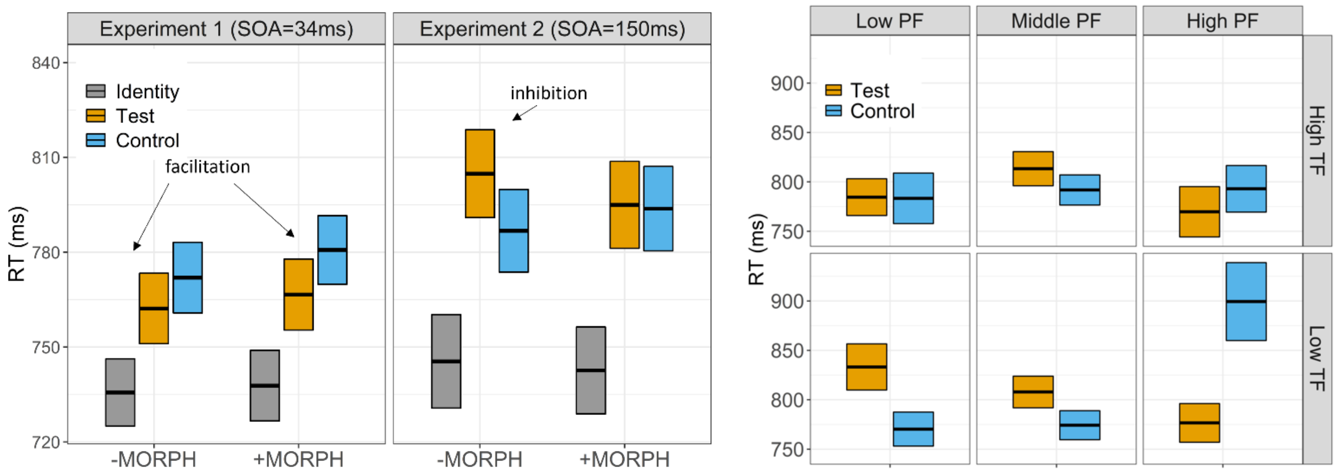

Figure 2: (A) Mean RTs (± standard error) across Identity, Test, and Control prime types for -MORPH and +MORPH target types. (B) Mean RTs (± standard error) for the interaction between Prime Frequency (PF), Target Frequency (PF) and prime time (Test, Control) for -MORPH target type in Experiment 2.

The main effect of Prime type was statistically marginal (B = 12.37e-3, p = 0.061) but the four-way interaction of Target type, Prime type, Target word frequency and Prime word frequency was statistically reliable (B = -8.88e-3, p = 0.019). The outcome of the full model is summarized in Table 5 (right panel).

Follow-up analyses revealed that +MORPH target words show no reliable RT difference between test and control primes (B = 1.03e-3, p = 0.924). –MORPH target words, on the other hand, showed a main effect of Prime type (B = 22.41e-3, p = 0.003) such that test primes yielded longer RTs than control primes. Additionally, -MORPH target type had a statistically significant interaction between Prime type, Target word frequency, and Prime word frequency (B = 0.01, p = 0.003). In simple slopes analyses, while both low frequency primes (below 1 SD) and high frequency primes (above 1 SD) have a significant interaction between Prime type and Target word frequency ([low] B = -21.34e-3, p = 0.003 ; [high] B = 17.56e-3, p = 0.016), the inhibitory effect of test primes is statistically reliable only for low frequency primes (B = 47.04e-3, p < 0.001) but not for high frequency primes (B = -2.77e-3, p = 0.835) (Figure 2B).

In short, with fully visible primes, Experiment 2 showed different trends for suffix priming versus pure form overlap priming. While suffix primes did not show any priming effects, non-morphological orthographic primes slowed target processing and this inhibition interacted with word frequency such that the effect was only evident for lower frequency primes.

General Discussion

The present study aimed to test priming effects of word-final letter overlap and their interaction with word frequency, prime duration, and morphological status. Consequently, we compared pure letter overlap with the English past tense morpheme *–ed* in words of varying frequency with short (Experiment 1) and long (Experiment 2) prime durations.

Our results in Experiment 1 show that the two letter word-final overlap between masked primes and targets facilitates target word processing. This facilitation did not interact with morphological status or word frequency. Instead, the amount of facilitatory priming effect between non-morphological and morphological form overlap was comparable across words of all frequency bands. This result contrasts with previous studies that report significant priming effects for suffixes but not for pure form overlap. One possible reason for this discrepancy is different numbers of participants. Duñabeitia et al. (2008; Experiment 3), who tested priming effects with Spanish derivational suffixes, analyzed just twenty-eight participants. Crepaldi et al. (2016), who examined English derivational suffix priming, analyzed forty-five participants; about a third of the number of participants in the current study. In fact, the form overlap in Crepaldi et al. (2016) showed a trend of facilitatory priming effects of 16 ms although it did not reach statistical significance. Therefore, it could be that the relatively small number of participants in these studies contributed to null findings for form priming.[1]

Another factor to consider is that unlike the two above-mentioned studies, the suffix in question in this study was inflectional. Different results between derivational versus inflectional suffixes may be understood on the basis of the

[1] Simulation-based power analysis conducted using noise parameters estimated from our data indicates that a masked orthographical priming effect of 10 ms could be detected with just 0.18 power in a sample of forty participants, compared to 0.65 with one hundred and twenty.

information theory (Shannon, 1948) as stemming from their different probabilistic distribution in language. Derivational suffixes are generally less productive than inflectional suffixes, which means that there is a smaller pool of possible words during lexical search that contain a specific derivational suffix. On the other hand, since the range of word candidates for an inflectional suffix is very broad, it follows that inflectional suffixes might have less impact in word recognition, leading to minimal priming effects (see Sainz et al. 2018 for more discussion on the application of the information theory to morphology). Another possibility is that the two types of suffixes are represented in a fundamentally different way in the mental lexicon. Anderson (1992), for example, distinguishes word formation rules that govern inflection versus derivation, in that the former operates outside the lexicon interacting with the syntax and the latter operates inside the lexicon. It may be the case that such divergence in the realm of rule operation leads to distinct priming effects. Since the current result is based on one morpheme in English, more research with other types of inflectional morphemes is desirable to test its generalizability.

Finally, we did not find any reliable interaction between priming effects and word frequency when primes were masked (Exp. 1). This is not consistent with a simple interpretation of the IA model. One possible hypothesis is that unlike orthographic neighbors, masked primes with less form overlap do not directly inhibit target words at the level of lexical units. Recall that the interaction between priming effects and word frequency found in Segui and Grainger (1990) and Nakayama et al (2008) was due to orthographic neighbor primes of high frequency inhibiting target word processing. This occurs because orthographic neighbors are strong competitors of each other during lexical access. Primes with form overlap only at the word-final position, however, are not so strong candidates of targets as to inhibit them upon brief presentation. Under these circumstances, form-based facilitation outweighs inhibition. That the priming effects we found in Experiment 1 were facilitatory rather than inhibitory supports this view.

In contrast, the results from Experiment 2 show that overt primes with word-final letter overlap delay target processing as a function of word frequency. Importantly, this effect was constrained to non-morphological letter overlap. When the overlapping letters constitute a suffix, they did not impact target processing either in a facilitative or inhibitive manner.

The interaction between inhibition and word frequency found in non-morphological overt primes aligns well with the reset mechanism of Grainger and Jacobs (1999) and Grainger et al. (2012). Grainger et al. (2012) found that an increase in the stimulus-onset asynchrony (SOA) between primes and targets can induce a reset mechanism to occur especially for high frequency primes. In a series of experiments that tested masked repetition priming with event-related potentials, the authors found that the priming effects on N250 are similar between low frequency words and high frequency words with a short SOA (Experiment 2, 50 ms) but diminish for high frequency words when the SOA is longer (Experiment 1, 70 ms). In a similar vein, the absence of inhibitory effects for high frequency words in our results suggests that the SOA of 150 ms may have been enough to reset the activation level of high frequency primes. Low frequency primes, however, take more time to process so they remain activated and thus impact target word processing. Although the current design does not allow us to assess the exact locus of this inhibition, given that the reset mechanism in Grainger et al. (2012) impacted the N250 component known to relate to sublexical processing, it is plausible that inhibition is at the level of features, rather than word-level units. This implies that the weights of facilitation and inhibition at the sublexical level may change depending on SOA, the details of which warrant further investigation.

Suffix overlap showed a null result for unmasked priming; this result was unexpected. We speculate that this is a consequence of form-based inhibitory effects and morpheme-based facilitatory effects canceling each other (cf. Allen & Badecker 2002; Stockall & Marantz 2006), but more research is needed in this direction.

Taken together, our results with masked and unmasked primes indicate that word-final orthographic overlap yield priming effects, facilitatory in the short SOA condition and inhibitory in the long SOA condition. Our results contrast with earlier less well-powered studies. From the perspective of the IA model, this indicates that masked orthographic primes with a varying degree of shared letters differently affect target processing; less overlap produces more facilitation than inhibition. When primes are overt, however, inhibition becomes stronger. Furthermore, its interaction with word frequency implies the presence of the reset mechanism in such circumstances.

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