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ScienceDirect
Journal of Memory and Language 58 (2008) 327–346
Journal of Memory and Language
www.elsevier.com/locate/jml

Priming English past tense verbs: Rules or statistics? ☆

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Received 4 April 2006; revision received 23 October 2007

Abstract

A key question in language processing concerns the rule-like nature of many aspects of grammar. Much research on this topic has focused on English past tense morphology, which comprises a regular, rule-like pattern (e.g., *bake-baked*) and a set of irregular forms that defy a rule-based description (e.g., *take-took*). Previous studies have used past tense priming to support the theory that the two forms are processed using different cognitive mechanisms. In the present study we investigated this distinction more closely, focusing specifically on whether the regular/irregular distinction is categorical or graded. Priming for regular and irregular forms was compared, as well as for forms that are irregular but display a partial regularity (suffixed irregular verbs, e.g., *sleep-slept*). Participants performed a lexical decision task with either a masked visual (Experiment 1) or an auditory prime (Experiment 2). We also manipulated prime-target ISI (0 vs. 500 ms), given previous studies indicating this factor might also influence the magnitude and quality of effects. We observed priming effects for both regular and irregular verbs, however the degree of priming of both was influenced by prime modality and processing time. When the prime was masked and presented for 66 ms regulars and suffixed irregulars patterned together, and were different from vowel change irregular forms. As the processing time increased (using longer ISI or cross-modal presentation), all morphologically related words showed facilitation. The results suggest that priming arises as a convergence of orthographic, phonological and semantic overlap that is especially strong for morphologically related words.

Keywords: Past tense; Crossmodal priming; Visual priming; Single-system theory; Dual-mechanism theory

Human language is characterized by a grammar of highly regular patterns that apply in a rule-like fashion. One of the key issues in cognitive science has been to understand the cognitive basis of these patterns. The theoretical debate has centered on the distinction between traditional views of mental computation, which characterize language as a mental grammar containing a set of symbolic rules (Pinker, 1991, 1997), and a distributed systems approach that operates subsymbolically and eschews rules in favor of statistics (Rumelhart & McClelland, 1986; Seidenberg, 1997).

The English past tense has been a focus of this debate because it involves both a rule-like pattern (e.g., *kicked*, *bugged*, *tested*) and a set of irregular forms that defy this

☆ We would like to thank Mark Seidenberg for useful discussion of the theoretical issues examined in this work. We also thank Janet Aucoin and Lisa Spiegel for assistance with participant recruitment and data collection. This research was funded by an NSERC Postgraduate Scholarship and Ontario Graduate Scholarship to A.K., an NSERC Discovery Grant to M.F.J. and NIH Grant MH6051701A2 HD 53136 and MH605170 to M.H.
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0749-596X/$ - see front matter
doi:10.1016/j.jml.2007.10.002

rule (e.g., *took*, *slept*, *went*). Most English past tenses are generated by adding the affix *-ed* to the verb stem. (This affix is pronounced /d/, /t/, or /Id/ depending on the phonological form of the stem). The pattern is rule-like, in that it applies in a predictable way to most verbs in English. However, exceptions to this pattern also exist: Depending on one's dialect, there are somewhere between 120 and 180 irregular verbs that form their past tenses in more idiosyncratic ways. These involve a stem vowel change (*sing-sang*), the change or addition of a final consonant (*build-built*), some combination of the two (*teach/taught*), no change at all (*hit-hit*), or even total suppletion (*go-went*). Because the degree of predictability for these changes is smaller it seems unlikely that irregular past tenses are created through rules applied to their stems (though see Halle & Mohanan, 1985, for a different view).

Accounts of morphological representation

A central question has been whether descriptive linguistic differences such as this reflect genuine differences in mental representations. One approach to the issue claims that they do. This "dual mechanism" account, best articulated by Pinker and colleagues, posits two distinct mechanisms for processing past tense inflections (Pinker, 1991, 1997; Pinker & Ullman, 2002; Prasada & Pinker, 1993). The first, a rule-based system, blindly adds the suffix *-ed* to regularly inflected verbs. This process is seen as automatic and obligatory, and is thus not influenced by non-grammatical characteristics of a stem such as phonology or frequency. (In comprehension, a similar procedure is used to strip the suffix from the stem.) Irregular verbs, by contrast, are relegated to an associative memory system that encodes their past tense forms as wholes. One consequence of this account is that regular verbs only have a lexical entry for the stem, and their past tense forms are derived by the affixation rule. Irregular past tenses, on the other hand, are learned and stored in a pattern-association network separately from their stems. This dual mechanism theory makes a categorical distinction between rule-generated regular past tense verbs and exceptions, and therefore predicts that these two forms will show strong dissociations in processing.

A number of other accounts of the regular/irregular difference exist, some of which make less categorical claims. Marslen-Wilson and Tyler (1998) suggest that regulars differ from irregulars not because they are formed by rule, but because they require a process of phonological assembly (or disassembly, in comprehension). Irregulars, which generally lack any obvious morpho-phonological structure, are accessed through a separate full-form route, like monomorphemic words. Thus, irregular past tenses have a close semantic relationship with their stems, but do not share one lexical representation. (Regular past tenses are strongly semantically related to their stems as well, by virtue of sharing a single lexical entry.) These representational differences can account for dissociations between the regular past tense on the one hand, and irregular past tense verbs on the other. Unlike the dual-mechanism account, this approach also notes that both regular and irregular past tenses have a morphological relationship with their stems, allowing for similarities across the two verb classes.

Other researchers also adopt the assumption of an explicit morphological relationship in the lexicon, without necessarily positing shared lexical representations for morphologically related words. In a series of priming studies, Fowler, Napps, and Feldman (1985) found no difference in the extent to which regular or irregular inflected and derived forms prime their stems. In most cases, in fact, these primes were as effective as identity priming by the stem itself. The authors conclude that morphemes, whether stems or affixes, are shared across separate words, but morphologically complex words do not share a lexical entry with their stems.

Schreuder and Baayen (1995) described a parallel dual-route model in which lexical access is attempted in parallel on the basis of the full form of a complex word and also on the basis of its constituents. On this account the lexicon contains access representations both for full forms of multi-morphemic words, and for their constituent morphemes, and recognizing a word involves decomposing it into its constituent parts. The meaning of complex words is computed from the meaning of these parts (Baayen, Dijkstra, & Schreuder, 1997; Baayen & Schreuder, 1999). The whole-word route, which matches the entire word to the stored orthographic representation, competes for access with a decomposition route, and the choice of winner depends on the frequency, predictability and transparency of the words. For more frequent words the whole-word route will allow access before the decomposition route. Note that this approach does not necessarily posit a categorical distinction between regular and irregular forms, since it allows the possibility that even regular and productive morphologically complex words might have lexical representations (Baayen et al., 1997).

Connectionist approaches offer yet another interpretation. On this view both regular and irregular verbs are processed within single integrated system (e.g., Plunkett & Marchman, 1993; Rumelhart & McClelland, 1986). Morphemes are not explicitly represented, and there is no symbolic rule specifying how the past tense should be formed. Instead, the representation of the past tense emerges through statistical regularities in the semantic and phonological relationships among words (Gonnerman, Seidenberg, & Andersen, 2007; Joanisse & Seidenberg, 1999; Seidenberg & Gonnerman, 2000).

On these accounts differences in the processing of regular and irregular verbs arise from tradeoffs in the role of phonology and semantics in producing and processing different forms. As one example, although phonological factors are involved in the generation of both regular and irregular regular past tenses, regulars are predicted to rely more heavily on phonology than irregulars are. Up to the suffix, the regular past tense form is phonologically identical to the stem, and the correct form of the suffix itself (either /t/, /d/ or /Id/) depends on phonological characteristics such as the voicing and place of articulation of the stem-final phoneme. The phonology of the stem thus entirely predicts that of the suffixed form. In contrast, the phonological relationship between irregular present/past forms is relatively arbitrary. Although phonologically related clusters of irregular verbs do exist (e.g., *sink* → *sank, drink* → *drank*), these relationships are not reliably predictive (e.g., *think* → *thought, link* → *linked*, not *thank* or *lank*). Instead, the relationship between present and past tense irregulars tends to rely more heavily on semantic information (e.g., Joanisse & Seidenberg, 1999; see also Marslen-Wilson & Tyler, 1997).

Although this approach proposes that formal and semantic factors are weighted differently for regular and irregular verbs, it does not make a categorical distinction between verb classes. Instead, the same type of distributed and statistical process applies to both regular and irregular forms. Nor does it predict simple additive effects of formal and semantic factors. As we will show in more detail in the General Discussion, the account assumes a non-linear interaction between semantic and orthographic/phonological representations.

Behavioral data

The different accounts of regularity in inflectional morphology have generated a large amount of discussion and debate. This has resulted in a large body of behavioral and neuropsychological data, most of which can be accommodated by both single and dual-mechanism approaches. Behavioral tasks have included auditory same-different judgment (Tyler, Randall, & Marslen-Wilson, 2002), sentence completion (Patterson, Lambon Ralph, Hodges, & McClelland, 2001; Ullman et al., 1997) and priming (Allen & Badecker, 2002; Longworth, Marslen-Wilson, Randall, & Tyler, 2005; Marslen-Wilson, Hare, & Older, 1993; Pastizzo & Feldman, 2002). A number of fMRI studies have also measured brain activation during priming or verb generation/repetition tasks (Joanisse & Seidenberg, 2005; Marslen-Wilson & Tyler, 1998; Tyler, Marslen-Wilson, & Stamatakis, 2005). In this paper we focus on the priming data.

In priming tasks, it has generally been found that the response to a target word (e.g., *bake*) is facilitated when it is preceded by a morphologically related prime (e.g., *baked*, *baking*, *baker*; Feldman & Soltano, 1999; Marslen-Wilson et al., 1993; Marslen-Wilson, Komisarjevsky-Tyler, Waksler, & Older, 1994; Pastizzo & Feldman, 2002; Rastle, Davis, Marslen-Wilson, & Tyler, 2000). Results tend to be inconsistent, however, on the question of whether priming is found for both irregular and regular verbs. In one of the first studies of this kind, Stanners, Neiser, Hernon, and Hall (1979) used repetition priming in a visual lexical decision task. They found significant priming between regularly inflected past tense forms and theirs stems (e.g., *walked* priming *walk*), which was in fact equivalent to the identity condition (e.g., *walk* priming *walk*). In contrast, irregular past tense verbs produced weaker priming than in the identity condition (e.g., *shake* was facilitated less by *shook* than by *shake* itself). Napps (1989) found a similar effect, again using visual lexical decision, with lags of 0, 1, or 10 words between items. Although there was no effect of lag and no interaction between lag and prime type, Napps noted that unlike regulars (but like semantically related pairs) irregular verbs showed decreased priming at longer lags.

Results like these have been taken to indicate that regularly inflected forms share a lexical entry with their stem, while irregulars do not. But note that irregular inflections do not always lead to reduced priming. Forster, Davis, Schoknecht, and Carter (1987), using a masked visual lexical decision task with a 60 ms. ISI, found that irregularly inflected nouns and verbs primed their stems as much as identity primes. More recently, Pastizzo and Feldman (2002) also found both regular and irregular priming in a masked visual lexical decision task, though not in all conditions.

Results in the auditory modality are equally inconsistent. In a long-lag priming study with auditory primes and targets, Kempley and Morton (1982) found priming for regular but not for irregular forms. In more recent auditory priming studies, however, Longworth et al. (2005) found priming for both regular and irregular past tense verbs, as did Marslen-Wilson and Tyler (1997) with neurologically intact control participants. Such participants also showed priming for regular and irregular verbs and semantically related pairs in auditory lexical decision (Tyler et al., 2002).

Both dual- and single-mechanism approaches can account for differences in regular and irregular priming results. On a dual mechanism account, regular past tenses should prime their stems because the stem and inflected form share a lexical entry. This also suggests irregular past tense verbs should not prime—at least not to the same extent as regulars—because they are stored separately from their present tense forms.

However, regularity is generally confounded with formal overlap in English inflection. Regularly inflected forms (whether nouns or verbs) involve the addition of a suffix to an unaltered stem, while irregular forms consistently undergo a stem alternation. Formal overlap is known to influence priming (e.g., Forster et al., 1987; Pastizzo & Feldman, 2002). This finding is highly consistent with the connectionist approach (e.g., Joanisse & Seidenberg, 1999), which argues that morphological priming is driven by overlap in the representations of prime and target. This predicts that differences in representational overlap will lead to differences in priming effects for regular and irregular verbs.

Suffixed irregular verbs

To summarize, priming studies have been inconclusive about the status of regular and irregular verbs. They generally find facilitation for regularly inflected items, but results for irregulars have been more inconsistent, variously showing full priming, reduced priming, or no priming at all. Accounts disagree on the implications of these findings. Dual mechanism accounts argue that dissociations between regular and irregular verbs fall out of the fact that these represent distinct classes, with the first derived by rule and the second stored in memory. On a single-mechanism account, on the other hand, the apparent dissociations result from differences in formal and semantic properties of the verbs themselves, rather than an *a priori* categorical distinction between regular and irregular.

One way of testing whether the second approach is correct would be to find a set of clearly *irregular* verbs that nonetheless resembled regulars in their formal properties. If such verbs patterned with regulars (and in opposition to other irregulars) in primed lexical decision studies, it would argue strongly that the differences in behavior found in earlier priming tasks resulted from differences in the properties of the stem and inflected form, not a categorical divide between regular and irregular.

One interesting test case involves the *suffixed irregular* class verbs, which are what some linguists have referred to as *semi-weak*. These are verbs like *mean-meant* or *weep-wept*, which are non-controversially irregular yet also take a version of the regular alveolar past tense suffix. These further resemble regular verbs by preserving, on average, more overlap between stem and past tense than other irregulars do.

On a dual mechanism account, suffixed irregular verbs should pattern with other irregulars. On a single mechanism account, however, there should be a continuum from complete stem overlap in the inflected form to completely suppletive inflections like *went*. Suffixed irregulars are closer to regulars than vowel change irregulars like *take-took* are, and consequently should occupy an intermediate position on the continuum, patterning with regular verbs in crucial ways. They should be processed more like regulars than vowel change irregulars.

Previous studies involving suffixed irregular verbs support this proposal. Joanisse and Seidenberg (2005) used functional magnetic resonance imaging (fMRI) to measure neural activation while listeners covertly generated past tenses of regulars, irregulars and suffixed irregulars (their study referred to these items as 'pseudo-regulars', however this difference is strictly notational). It was found that although a region of left inferior frontal gyrus (LIFG) showed greater activation for regulars than full irregulars, this effect did not occur for suffixed irregulars, which showed activation similar to that of regular verbs. If we assume that LIFG plays some role in processing the phonological aspects of verbs, it would appear that irregular forms that share formal aspects of regularity rely on phonology to a degree similar to that of regulars, consistent with the predictions of a connectionist account.

Furthermore, in an earlier study involving cross-modal lexical decision, Marslen-Wilson et al. (1993) found priming for regular verbs, but significant interference for vowel change irregulars like *give-gave*. Suffixed irregulars such as *burnt-burn* showed an intermediate effect (facilitation, though not statistically significant). The authors interpreted these results as indicating that irregular past tenses and their base forms inhibit one another for lexical activation. However, the fact that only the vowel change irregulars showed this pattern argued that a strict regular/irregular dichotomy was an oversimplification, predicting as it did that all irregular verbs should behave alike. In later modeling work, Hare and Marslen-Wilson (1997) confirmed that a connectionist network sensitive to phonological overlap, with no explicit inhibition between irregular bases and past tenses, successfully modeled these results.

In this paper we will present a series of lexical decision studies testing whether, and under what conditions, suffixed irregular verbs behave more like regulars or classic vowel change irregulars. In these studies we manipulate prime modality (masked visual or auditory) and the delay between prime and target. The manipulation of the temporal relationship between prime and target has a potential to reveal the time course over which orthographic, phonological and semantic effects occur, and how these factors relate to morphological processing. Previous studies have shown that the effect of orthographic and/or phonological overlap in priming is sensitive to the processing time of the prime. Effects of formal overlap tend to decrease as the processing time of the prime increases, whereas prime duration has an opposite effect on semantic similarity; semantic effects tend to increase with longer processing time (Feldman, 2000; Feldman & Prostko, 2002; Feldman & Soltano, 1999). Manipulation of processing time can reveal contributions of formal and semantic dimensions to morphological processing and how the magnitudes of these factors change over time and with particular task parameters. The effect of formal similarity tends to influence word recognition at short prime durations. As the processing time increases the effect of formal overlap is likely to decrease and the dynamic interaction between form and meaning dimensions of similarity will lead to morphological effects.

If words are processed on a continuum of formal and semantic overlap then we should observe a pattern where suffixed irregulars will be processed more similarly to regulars compared to other irregulars. The degree to which suffixed irregulars overlap with regulars or vowel change irregulars will depend on the task sensitivity to the semantic and ortho/phonological similarity between words.

Experiment 1 will use masked visual priming with lexical decision. This task is of interest for two reasons. First, previous work by Rastle et al. (2000) has proposed a time course for morphological priming that makes predictions relevant to the current questions. Second, investigations of masked priming (Forster et al., 1987; Pastizzo & Feldman, 2002) have shown that this task is highly sensitive to orthographic overlap between primes and targets with phonological factors playing a smaller role. As a result, this paradigm offers a good testing ground for the claim that differences in priming effects in earlier studies may have been more due to formal than to morphological factors. Suffixed irregular verbs, on average, overlap more with their stems than vowel change irregulars do. Thus, their behavior in the masked priming task might help tease apart the effects of regularity from formal factors.

Experiment 2 will use cross-modal lexical decision. One reason for choosing this task is for consistency with previous work on the topic involving cross-modal presentation. More importantly, however, if prime and target are presented in different modalities one expects weaker effects of orthographic overlap than in masked visual studies. This will allow us to compare the results of Experiment 1 with those found when orthographic effects are reduced. Orthography and phonology are correlated, of course, so one does not expect to entirely eliminate effects of formal overlap. But if the pattern changes when the input modality does, this will be informative about the extent to which orthographic and phonological effects influence morphological priming. We note that the change in the input modality will also somewhat change the temporal dynamics of the task, because the auditory prime, unlike a visual one, unfolds over time.

In all studies we will contrast priming effects in morphologically related items with the effects of shared meaning or shared form alone. The purpose of examining these forms was to verify that the observed priming effects are not simply the independent, additive effects of formal or semantic overlap between prime and target, but are in fact representative of the correlation between the two that one finds in morphological relationships.

Experiment 1: Visual–visual priming

Method

Participants. In total, 53 native English speakers by self-report with no hearing impairment and normal to-corrected to normal vision participated in Experiment 1. Participants were recruited from The University of Western Ontario community and received either course credit or $10 for taking part in the study. The participants were assigned randomly to either Experiment 1A (short ISI) or Experiment 1B (long ISI), described below. Within each experiment, participants were randomly assigned to one of two experimental lists.

Materials. The experiment consisted of seven sets of prime-target pairs. In the first three conditions a past tense verb primed a corresponding present tense target: 20 regulars (e.g., *walked-walk*), 20 vowel change irregulars (*drank-drink*), and 18 suffixed irregulars (*slept-sleep*). There were three formally-related conditions: 20 regular pseudo-past pairs (*chest-chess*), formed by analogy to the regular verbs; 16 irregular pseudo-past pairs (*coke-cake*), formed on analogy to vowel change irregular verbs, and a phonological condition consisting of 20 word pairs related in form (*beef-bee*) but not in a way that resembled an inflectional relationship.

The semantic condition consisted of 20 prime-target pairs that were semantically related but phonologically and morphologically unrelated (*jacket-coat*). The items in this condition were selected from among prime target pairs rated on semantic similarity as a part of another study: Forty-four students from the University of Western Ontario community rated possible prime-target pairs and unrelated fillers on a scale from 1 ("extremely unrelated") to 9 ("extremely related"). All items chosen for the semantic condition had a semantic relatedness ratings of 7 or higher ($M = 7.79$, $SD = .40$; see Appendix A). Finally, a word-nonword filler condition was also created consisting of 132 orthographically legal and pronounceable nonword targets derived by changing one or two of the letters of a familiar English word. Half of the nonword targets were phonologically related to the prime (e.g., *cube-hube*,) and half were not (*lamp-stoom*).

The target items were matched across conditions for frequency (CELEX, Baayen, Piepenbrock, & Gulikers, 1995) as well as phonological and orthographic length (see Table 1 and Appendix A). The orthographic overlap was defined as number of letters shared in the same posi-

Table 1
Stimulus characteristics (Means and *SD*s) of word items in Experiments 1 and 2

	Morphologically related		
	Regulars *baked-bake*	Vowel change irreg *sang-sing*	Suffixed irreg *kept-keep*
Length			
Target	4.25 (0.44)	4.20 (0.62)	4.28 (0.46)
Prime	6.05 (0.69)	4.20 (0.62)	4.56 (0.51)
Frequency[a]			
Target	4.14 (1.19)	3.87 (1.15)	3.89 (1.45)
Prime	3.79 (0.90)	3.63 (1.16)	3.86 (1.27)
Neighborhood (*N*)[b]			
Target	8.50 (4.16)	9.20 (4.58)	7.94 (3.89)
Prime	4.95 (2.56)	9.65 (5.37)	5.39 (4.33)
Prime-target overlap (%)			
Orthography[c]	71 (5)	65 (19)	69 (13)
Phonemes	73 (5)	69 (4)	61 (12)
Stem	100 (0)	66 (2)	74 (2)

	Morphologically unrelated			
	Phonological *dollar-doll*	PP-reg *mend-men*	PP-irreg *coke-cake*	Semantic *jacket-coat*
Target	3.50 (0.51)	3.60 (0.75)	4.25 (0.45)	4.65 (0.88)
Prime	5.15 (0.88)	4.30 (0.47)	4.06 (0.57)	5.65 (1.14)
Frequency[a]				
Target	4.20 (1.38)	3.84 (1.85)	3.28 (1.38)	3.89 (0.94)
Prime	3.52 (1.03)	3.42 (1.45)	3.15 (1.47)	3.93 (1.49)
Neighborhood (*N*)[b]				
Target	12.50 (4.96)	9.30 (6.00)	11.00 (6.44)	4.80 (3.40)
Prime	4.40 (4.12)	7.55 (4.66)	11.44 (4.62)	2.45 (4.07)
Prime-target overlap (%)				
Orthography[c]	69 (8)	60 (20)	49 (22)	3 (9)
Phonemes	70 (9)	72 (5)	64 (11)	5 (11)

[a] Log frequency of values from CELEX.
[b] Number of orthographic neighbors (N-Watch; Davis, 2005).
[c] Number of letters shared in the same position between prime and target.

tion between prime and target, divided by the number of letters in the longer word. The frequency values obtained from CELEX were converted to natural logarithm. The exact matching on length was not possible for all stimuli due to the fact that English regular verbs, on average, are longer than irregulars and other monomorphemic words. Priming effects were calculated by comparing reaction times to targets preceded by a related prime to RTs for the same target following an unrelated prime. Therefore unrelated items were created by pairing a target word in one pair with the prime word from another pair (e.g., regulars: *printed-talk*; irregulars: *hung-drink*).

To avoid repeating target items in a single participant, two lists of the 266 prime-target pairs were constructed. All primes were used in each list such that half the word targets were paired with the related prime (*slept-sleep*) and half with an unrelated prime word (*took-sleep*), with items alternating across lists so that each prime-target pair appeared only once per list. Each participant was tested on only a single list.

Procedure. Participants were tested individually in a quiet room and were randomly assigned to either Experiment 1A (short ISI) or 1B (long ISI), and to one of the two experimental lists. Stimulus presentation and response collection was controlled by a Pentium IV PC using E-prime software (Version 1.1; Schneider, Eschman, & Zuccolotto, 2002), using a 17-in. CRT monitor set to a 60 Hz scan rate. Primes and targets were presented visually using a forward masking procedure as follows: At the beginning of each trial a fixation cross appeared in the center of the screen for 1 s. This disappeared and was replaced by a pattern mask (##########) for 500 ms. Immediately after the masking pattern, the prime word (in lower case) appeared for 67 ms (same as used in Perea & Gotor, 1997). The target item was then presented in uppercase, either immediately after the prime (Experiment 1A, ISI = 0 ms) or after a 500 ms delay (Experiment 1B, ISI = 500 ms; recall that ISI was manipulated between-participants). Both prime and target were presented in a black font on a white background. Participants indicated whether the visual target was an English word by pressing specified keys on the keyboard placed in front of them. The experiment began with a practice block of 22 trials.

Results: Experiment 1A (Masked visual priming, short ISI)

In total 27 participants were recruited for this experiment. Two of these participants were removed due to equipment malfunction resulting in low accuracy; another participant was removed due to low accuracy relative to other participants (63%) on at least one condition. Reaction time and error data were preprocessed in the following ways: Reaction times greater than 3 *SD* from mean were removed and treated as errors (2% of the trials). Only correct responses were used in the reaction time analyses. The average error rates for each item in each condition and ISI were examined and data from items with error rates greater than 25% across participants were also excluded from subsequent analyses. This procedure excluded data from the pp-regular target "*rye*".

The reaction time and accuracy data from 24 participants were entered into repeated measures ANOVAs with relation type (seven levels: regular, irregular, pseudo-regular, phonological, pp-regular, pp-irregular, semantic) and priming relatedness (two levels: related, unrelated) as within-subjects factors. The data were analyzed both by subjects (F_1) and items (F_2), with which we also computed minF'. In the by subjects analysis, relation type and priming relatedness were treated as ISI within-subjects factors and in the by items analysis, priming relatedness was treated as A within subject factor and relation type as AN unrepeated factor. Interactions were investigated with planned comparisons using repeated measures ANOVAs comparing related and unrelated responses for each condition separately.

The mean reaction times and accuracy data for each word condition are presented in Table 2. The analysis revealed significant main effects of relation type and relatedness both by subjects and by items, (relation type: $F_1(6, 138) = 13.24$, $MSE = 2118$, $p < .01$, $F_2(6, 126) = 4.85$, $MSE = 4865$, $p < .01$, min$F'(6, 210) = 3.55$, $p < .01$; relatedness: $F_1(1, 23) = 14.07$, $MSE = 2169$, $p < .01$, $F_2(1, 126) = 13.95$, $MSE = 1897$, $p < .01$, min$F'(1, 78) = 7.01$, $p < .01$). There was also a significant interaction between relatedness and relation type, ($F_1(6, 138) = 5.32$, $MSE = 2051$, $p < .01$, $F_2(6, 126) = 4.40$, $MSE = 1897$, $p < .01$, min$F'(6, 259) = 2.41$, $p < .05$).

Table 2
Mean latency (ms) (*SD*) and accuracy (%) (*SD*) data for Experiments 1A and 1B

Word type	Short ISI		Long ISI	
	RT	Accuracy	RT	Accuracy
Morphologically related				
Regular				
Primed	559 (79)	97 (7)	499 (85)	100 (0)
Unprimed	612 (74)	98 (4)	578 (101)	99 (5)
Difference	+53**	−1	+79*	+1
Vowel-change irregular				
Primed	587 (69)	99 (4)	539 (88)	99 (4)
Unprimed	596 (65)	97 (5)	575 (92)	97 (6)
Difference	+9	+2	+36**	+2
Suffixed irregular				
Primed	595 (79)	97 (6)	551 (90)	100 (2)
Unprimed	646 (87)	97 (6)	598 (108)	96 (7)
Difference	+51*	0	+47*	+4*
Morphologically unrelated				
Semantic				
Primed	608 (86)	98 (4)	591 (110)	99 (5)
Unprimed	647 (73)	97 (5)	590 (81)	97 (6)
Difference	+39**	+1	+1	+2
Phonological				
Primed	628 (95)	96 (5)	589 (104)	97 (8)
Unprimed	628 (70)	96 (6)	591 (98)	94 (9)
Difference	0	0	+2	+3
Regular pseudo-past				
Primed	665 (89)	91 (9)	617 (109)	95 (6)
Unprimed	636 (74)	93 (7)	621 (94)	95 (8)
Difference	−29*	−2	+4	0
Irregular pseudo-past				
Primed	638 (77)	93 (8)	624 (84)	94 (9)
Unprimed	647 (61)	96 (7)	649 (108)	95 (6)
Difference	+9	−3	+25	−1

* $p < .05$.
** $p < .01$.

Planned comparisons showed that for the morphologically related items, regular past tenses primed their stems (53 ms facilitation, CI: 21–85; $F_1(1, 23) = 11.52$, $MSE = 2942$, $p < .01$, $F_2(1, 19) = 16.66$, $MSE = 1786$, $p < .01$, min$F'(1, 42) = 6.81$, $p < .05$), but vowel change irregulars did not (9 ms; all Fs < 1). This cannot be strictly an effect of regularity, however, because priming was found for the suffixed irregulars (51 ms, CI: 31–71; $F_1(1, 23) = 27.70$, $MSE = 1136$, $p < .01$, $F_2(1, 17) = 8.19$, $MSE = 2873$, $p < .05$, min$F'(1, 27) = 6.32$, $p < .05$).

Furthermore, an analysis of the difference scores (unrelated RTs—related RTs) found that priming effects for regulars and suffixed irregulars did not differ (all Fs < 1), and both were significantly larger than those of vowel change irregular verbs (regular/VC irregular: $F_1(1, 23) = 8.15$, $MSE = 2855$, $p < .01$, $F_2(1, 38) = 5.57$, $MSE = 1667$, $p < .05$, $\min F'(1, 61) = 3.31$, $p > .05$; suffixed/VC irregular: $F_1(1, 23) = 8.99$, $MSE = 2361$, $p < .01$, $F_2(1, 36) = 3.434$, $MSE = 2174$, $p = .072$, $\min F'(1, 56) = 2.49$, $p > .05$).

Priming effects also differed among the non-morphological conditions. Semantically related word pairs showed significant priming (40 ms, CI: 11–68; $F_1(1, 23) = 8.37$, $MSE = 2234$, $p < .01$, $F_2(1, 19) = 13.81$, $MSE = 1186$, $p < .01$, $\min F'(1, 41) = 5.21$, $p < .05$), but there were no effects for the phonologically related or irregular pseudo-past pairs [all Fs < 1]. Regular pseudo-pasts, by contrast, showed 29 ms inhibition (CI: 2–55), which reached significance in the by subject analysis although it was only marginally significant by items, $F_1(1, 23) = 4.80$, $MSE = 2063$, $p < .05$, $F_2(1, 18) = 3.72$, $MSE = 1718$, $p = .07$, $\min F'(1, 39) = 2.10$, $p > .05$.

Accuracy. The accuracy data in the visual priming experiment were analyzed in the same way as were latency data. There was main effect of relation type, $F_1(6, 138) = 6.89$, $MSE = .003$, $p < .01$, $F_2(6, 126) = 2.90$, $MSE = .006$, $p < .05$, $\min F'(6, 219) = 2.04$, $p > .05$, but no main effect of relatedness or interaction between the two [all Fs > 1]. The main effect of relation type was due to the high false negative response rate to the regular pseudo-past targets (accuracy 92%), regardless of the prime.

Results: Experiment 1B (Visual priming long ISI)

A total of 26 students at The University of Western Ontario, recruited as above, participated in this experiment. One was excluded as a non-native speaker of English, while two others were removed due to low accuracy (50% and 63%) in at least one condition, for a total of 23 participants included in the analyses below. The stimuli and procedure were identical to those in Experiment 1A, with the exception of a 500 ms ISI between prime offset and target onset. As in Experiment 1A, prime duration was 67 ms.

Data were preprocessed as in Experiment 1A. Only correct responses were entered into the RT analysis, with RTs greater than 3 *SD* from the mean removed and treated as errors (2% of data points excluded). The average error rates for each item in each condition and ISI were examined, and data from those items with error rates over 25% across participants were excluded. This procedure excluded data from two targets in the pseudo-past regular condition: *rye* and *grin*; one in the semantic condition: *notion* and one in the regular condition: *greet*.

Accuracy and RT data were submitted to repeated measures ANOVAs as above. Here again we observed main effects of both relation type and priming relatedness both by subjects and by items, (relation type: $F_1(6, 132) = 24.43$, $MSE = 2180$, $p < .01$, $F_2(6, 123) = 10.10$, $MSE = 4219$, $p < .01$, $\min F'(6, 212) = 7.14$, $p < .01$; relatedness: $F_1(1, 22) = 30.02$, $MSE = 2027$, $p < .01$, $F_2(1, 123) = 12.41$, $MSE = 3688$, $p < .01$, $\min F'(1, 126) = 8.78$, $p < .01$). The interaction was significant by participants, $F_1(6, 132) = 4.42$, $MSE = 2211$, $p < .01$, but only marginal by items $F_2(6, 123) = 2.00$, $MSE = 3689$, $p = .07$, $\min F'(6, 218) = 1.38$, $p > .05$.

Planned comparisons confirmed that regular past tenses facilitated recognition of their stems (79 ms priming, CI: 59–99); $F_1(1, 22) = 67.94$, $MSE = 1053$, $p < .01$, $F_2(1, 18) = 26.76$, $MSE = 2013$, $p < .01$, $\min F'(1, 31) = 19.20$, $p < .01$, as did the vowel change irregular verbs (38 ms priming, CI: 9–64); $F_1(1, 22) = 7.58$, $MSE = 1999$, $p < .05$, $F_2(1, 19) = 4.64$, $MSE = 2938$, $p < .05$, $\min F'(1, 37) = 2.88$, $p > .05$. The priming effect of 47 ms (CI: 13–81) for suffixed irregulars was also significant by subjects but not by items, $F_1(1, 22) = 8.30$, $MSE = 3079$, $p < .01$, $F_2(1, 17) = 2.76$, $MSE = 7037$, $p > .05$, $\min F'(1, 28) = 2.07$, $p > .05$.

An analysis of the difference scores (unrelated RT—related RT) revealed that as in Experiment 1A the priming effects for regular verbs did not differ from those of the suffixed irregulars (regulars/suffixed: ($F_1(1, 22) = 3.55$, $MSE = 3262$, $p > .05$, [$F_2 < 1$], $\min F'(1, 54) = 0.694$, $p > .05$)), but were significantly larger than those for vowel change irregulars by subjects but not by items, $F_1(1, 22) = 10.25$, $MSE = 2036$, $p < .01$, $F_2(1, 37) = 2.89$, $MSE = 2488$, $p = .098$, $\min F'(1, 54) = 2.252$, $p > .05$. There was no difference between the vowel change and suffixed irregulars [all Fs < 1].

The analogous comparisons for morphologically unrelated conditions revealed no significant priming effects for the semantic condition, and none of the form related conditions [all Fs < 1.0].

Accuracy. The analysis of the accuracy data revealed a significant main effect of relation type and priming by subjects and by items, (relation type: $F_1(6, 132) = 5.51$, $MSE = .003$, $p < .01$, $F_2(6, 123) = 3.38$, $MSE = .004$, $p < .05$, $\min F'(6, 237) = 2.09$, $p > .05$; relatedness: $F_1(1, 22) = 7.53$, $MSE = .002$, $p < .05$, $F_2(1, 123) = 3.98$, $MSE = .004$, $p < 05$, $\min F'(1, 112) = 2.60$, $p > .05$), but no interaction [all Fs < 1]. These results indicate that responses to targets preceded by related primes were more accurate than responses to targets preceded by unrelated primes in all conditions. The main effect of relation type was due to the overall lower accuracy in the regular pseudo-past and irregular pseudo-past conditions, regardless of the prime. In addition, the morphologically related conditions were more accurate overall.

Discussion

We investigated the extent to which morphological status, semantics and orthographic overlap influence priming. The results indicate that the nature of these priming effects was modulated by ISI. In Experiment 1A, with a 67 ms prime and an ISI of 0, we observed a pattern that has been taken to argue for representational differences due to morphological regularity: Strong priming for regular verbs in the absence of any effects whatsoever for vowel change irregulars. Clearly, however, this pattern cannot be due to a categorical difference in regularity, because the priming effects for the suffixed irregular verbs are nearly identical to those of the regulars. In addition, significant priming is found for the semantically-related pairs, and significant inhibition in the regular pseudo-past items. There were no effects in the other formally-related pairs. Experiment 1B differed from 1A only in the addition of a 500 ms delay between the presentation of the prime and the appearance of the target. In this case one finds priming for all of the morphologically related conditions, and none of the others. The pattern observed in the morphologically related conditions is clearly incompatible with any account that draws a categorical distinction between regulars and irregulars. In Experiment 1A, suffixed irregular verbs patterned with regulars, in opposition to other irregulars. In 1B, the suffixed irregulars showed intermediate behavior: Priming effects for the regular and vowel change irregular verbs differed significantly from each other, but the suffixed irregulars were statistically identical to both.

If the priming effects for regulars are and suffixed irregulars are due to the purely morphological relationship between prime and target then we should also see priming in the vowel change irregular verbs. However, this was not found. Instead, we argue that the results reflect the representational overlap between prime and target, as influenced by the contingencies of masked priming. In particular, effects of orthographic overlap have consistently been found in masked visual priming at both long and short prime durations (Forster et al., 1987: Expt. 1, 60 ms; Pastizzo & Feldman, 2002: prime duration 48 ms; Rastle et al., 2000: Expt. 1 43 ms; Expt. 2, 230 ms). As noted in the Introduction, regularity distinctions in English morphology are consistently marked by differences in the amount of orthographic and phonological overlap between morphological relatives, and the past tense is no exception. In addition, mismatch early in the word has been found to be more disruptive to masked priming than mismatch in medial or final positions (Forster et al., 1987; Giraudo & Grainger, 2000; see also Coltheart & Rastle, 1994, for related findings in reading aloud).

It is thus unsurprising that Experiment 1A found significant facilitation for regulars and the suffixed irregulars, but not for vowel change irregulars. In our stimuli, the morphological classes do not differ in semantic relatedness, but as Table 1 and Appendix A show, they differ in the extent to which the target overlaps orthographically with the prime. The regular and suffixed irregular verbs have the highest overall degree of stem overlap, and the largest percentage of initial overlap as well. For all of the regular verbs, and 11/18 suffixed irregulars (61%), prime and target are identical up to the final segment or 2-segment suffix. The vowel change irregulars, on the other hand, not only have less orthographic overlap than the other two, but mismatch occurs, by definition, at the stem vowel. The lack of priming in the formal non-morphological conditions is also consistent with this. As noted above, the degree of orthographic overlap between prime and target is lower for the regular pseudo-past, irregular pseudo-past, and phonological pairs than for any of the morphologically related conditions, giving little reason to expect orthographic priming. The fact that the irregular pseudo-past items show very much the same small degree of facilitation as the vowel change irregulars that they were modeled on is also suggestive in this regard.

The effect of semantic relationship was also investigated in this experiment. Semantically related pairs showed priming in Experiment 1A, although not in 1B. Semantic effects such as those found here are somewhat rare in masked priming, but do occur (Gonnerman & Plaut, 2000; Sereno, 1991). For instance, Perea and Gotor (1997) report semantic priming in Spanish at the same SOA used here. Semantic priming has been found at even shorter SOAs of 40 ms, in a lexical decision study by Fischler and Goodman (1978). Similarly Sereno (1991) found facilitation of 41 ms for associatively related words with lexical decision at 60 ms SOA. In a set of studies more directly relevant to morphological priming, Rastle et al. (2000, Expt. 1) found only marginal effects of semantic relatedness at SOAs of 72 and 230 ms, although semantic priming occurred at the 230 ms SOA in their Experiment 2. These differences across studies highlight the somewhat fragile nature of semantic effects in the context of masked priming, and suggest that our own findings are not out of step with prior research. In the present study significant semantic priming was observed at an SOA of 67 ms but it was attenuated at an SOA of 567 ms. The failure to find a semantic effect in Experiment 1B indicates that the automatic semantic activation dissipates at longer SOAs. Similarly, Fischler and Goodman (1978) have suggested that automatic activation might decrease some time before the attentional mechanism influences processing.

One initially surprising result is the significant inhibition in the regular pseudo-past condition. However, inhibition has been observed in other studies using similar priming parameters and stimulus pairs analogous to our regular pseudo-past items, (Drews & Zwitserlood, 1995; Grainger, Cole, & Segui, 1991; Laudanna, Badecker, & Caramazza, 1989). The regular pseudo-past items in the present study were constructed so that they resembled regular verbs (*chest-chess* vs. *pressed-press*). Primes fully contained targets and additional past tense suffix-like letters. Studies that report interference for orthographically similar items suggest that the inhibition arises from the competition between two lexical entries at the level of form representation. The interference for orthographically similar pairs might therefore be explained on the account that the prime is lexically decomposed and that the lexical representation of the prime inhibits activation of the target (Laudanna et al., 1989).

Similar results have been observed in masked priming studies of derivational morphology for semantically opaque derivations in English (*apartment-apart*) and French (*baguette-bague*). At short prime durations of about 40 ms, opaque forms produced facilitation in masked priming. However, when the SOA increased to about 70 ms the effect decreased (Longtin, Segui, & Halle, 2003; Rastle et al., 2000). Because these effects were observed only for words that shared "morphemic" units but not for items that were orthographically related (e.g., *electrode* contains *elect* but *-rode* is not a suffix in English) these results were interpreted as reflecting an early morphological decomposition process. According to this account morphological surface structure triggers an automatic process of decomposition into morpheme-like units leading to facilitation at the short SOAs of about 40 ms. At longer SOAs this effect is cancelled and the facilitation diminishes. This view could account for the inhibition in the regular pseudo-past condition.

An alternative explanation is suggested by the fact that the regular pseudo-past condition closely resembles the +morphology, −semantics, +orthography and the −morphology −semantics +orthography conditions of Rastle et al. (2000). Our regular pseudo-past pairs were not related historically, but like the +M −S +O pairs in the earlier study they share the formal characteristics of morphologically related pairs without any semantic overlap or synchronically discernable morphological relationship. In the Rastle et al. study there was inhibition at 230 ms, significant for the −M −S +O pairs, and numerical for the +M −S +O items. The authors suggested that the inhibition effects were due to the lack of a transparent semantic relationship between words of the latter type.

If this is correct, it predicts not only the inhibition in our regular pseudo-past items, but also the difference in the timing of the inhibition effect in their study and our own. In Rastle et al. (2000), facilitation for the +M −S +O pairs decreases and moves towards inhibition as semantic facilitation increases. In the current study, semantic effects are stronger, and are found at an earlier point—and, consistent with the pattern in Rastle et al.'s Experiment 1, inhibition for the regular pseudo-pasts is found at this point as well. This suggests that if we had tested with a shorter SOA (as the earlier study did) we might have found no inhibition in this condition. It is also consistent with our finding that as semantic effects faded at a longer ISI in Experiment 1B, the inhibitory effects in the pseudo-pasts faded as well.

Experiment 1B differed from 1A only in the addition of a 500 ms delay between the disappearance of the prime and the appearance of the target. In this study one finds priming for all of the morphologically related conditions, and none of the others. One continues to see graded effects of formal overlap, with the most facilitation for regular verbs (79 ms), somewhat less for suffixed irregulars (47 ms) and the least for the vowel change irregulars (36 ms). But despite these differences the priming effects were significant for all three verb types, and although the amount of priming is numerically lower in the suffixed irregulars than regular verbs, the two are statistically identical.

In contrast to the morphological conditions, there is no priming when the overlap is purely formal (as in the phonological, regular pseudo-past, or irregular pseudo-past pairs) or purely semantic. Instead priming is found for all and only those conditions in which a semantic relationship correlates with a formal one. This suggests that the longer processing time strengthened the correlation, reducing the effects of formal overlap. (See also Rastle et al., 2000, who argue that effects due to formal overlap are found at short SOAs, but are cancelled at longer ones).

A second possibility, however, is that the longer interval encouraged participants to develop strategies which, while not overtly conscious, nonetheless influenced the strength of the constraints used in the lexical decision task. If so, the results might reflect a reliance on the formal characteristics that predict a prime-target relationship. Two reasons make this proposal unlikely: First, although it would correctly predict the greater degree of facilitation found in the regular and suffixed irregular verbs, it would incorrectly predict increased inhibition in the regular pseudo-past items, and decreased facilitation in the vowel change irregular verbs. Here one sees precisely the opposite. More importantly, the pattern of effects we observe is identical to that found by Marslen-Wilson and Tyler (1998), using a long-lag, single-presentation paradigm, which is known to discourage or eliminate strategic effects. There is thus reason to believe the results accurately reflect aspects of lexical organization.

In summary, the results of Experiment 1B are as predicted on an account in which the interaction between form and meaning overlap leads to facilitation. Priming is influenced by the degree of orthographic overlap, but only for morphologically related words since these also share semantic relationship. This suggests the possibility that morphological priming arises as a confluence of form and meaning information, which is strongest for morphologically related words. In Experiment 2, we will test whether this pattern can be replicated in a different modality.

Experiment 2: Cross-modal presentation

If we are correct in assuming that the results at the short lag in Experiment 1A are influenced by formal overlap, then the pattern of results should change if prime and target are presented in different modalities. In Experiment 2, we will test this idea with cross-modal priming, using an auditory prime and visually presented target. It has been suggested that priming in the cross-modal task is mediated at the level of the modality-independent lexical entry. Whether or not this is the case, this technique is arguably less susceptible to some sources of form-based effects such as low-level acoustic-phonetic or visual overlap. We begin with Experiment 2A, which uses an immediate presentation of the target at the offset of the spoken prime, and contrast the results with those of Experiment 2B, in which a longer interval is used between prime and target. If the difference in prime modality eliminates the differences between the vowel change irregulars and the other verb classes, we can say with more confidence that the earlier difference was indeed due to representational differences among the verbs, not morphological regularity.

Method

Participants. In total, 50 participants were recruited for Experiment 2, and randomly assigned to either 2A (ISI = 0 ms) or 2B (ISI = 500 ms). Within each experiment, participants were randomly assigned to one of two experimental lists. Participants were native English speakers with no hearing impairment and normal or corrected to normal vision. They were recruited from the University of Western Ontario community and received a course credit or $10 for taking part in the study.

Materials and procedure. Conditions and stimulus items were identical to those of Experiment 1. The procedure was also similar, but in Experiment 2 the prime was auditory rather than visual. Each trial began with a fixation cross displayed at the center of a computer screen for 1 s. The auditory prime was then played binaurally over headphones as the fixation cross remained on the screen. The visual target was then presented in uppercase letters using a black font on white background. The target appeared either immediately at offset of the prime (Expt. 2A, 0 ms ISI) or following a 500 ms delay (Expt. 2B, 500 ms ISI). Trials were presented in a different random order for each participant. Participants made lexical decision to a target by pressing a key on the computer keyboard.

Results: Experiment 2A (Cross-modal priming, short ISI)

In total 25 volunteers were recruited for this experiment. One participant was excluded from the 0 ISI condition because of a self-reported significant hearing loss, leaving 24 participants. Data were preprocessed as in Experiment 1, as follows: RTs 3 *SD* from the mean were removed from the analysis and treated as errors (2%). Only correct responses were used in the reaction time analyses. Next the average error rates for each item in each condition and ISI were examined and data from

Table 3
Mean latency (ms) (*SD*) and accuracy (%) (*SD*) data for Experiments 2A and 2B

Word type	Short SOA		Long SOA	
	RT	Accuracy	RT	Accuracy
Morphologically related				
Regular				
Primed	521 (92)	98 (4)	548 (77)	99 (3)
Unprimed	567 (85)	97 (6)	589 (87)	97 (5)
Difference	+46**	+1	+41**	+2
Vowel-change irregular				
Primed	528 (77)	100 (0)	551 (79)	100 (2)
Unprimed	566 (74)	97 (6)	591 (106)	99 (4)
Difference	+38**	+3*	+40**	+1
Suffixed irregular				
Primed	537 (78)	98 (5)	577 (81)	99 (5)
Unprimed	575 (84)	96 (8)	613 (84)	95 (8)
Difference	+38*	+2	+36**	+4
Morphologically unrelated				
Semantic				
Primed	569 (95)	98 (5)	571 (85)	98 (4)
Unprimed	580 (83)	95 (8)	608 (93)	99 (4)
Difference	+11	+3	+37*	−1
Phonological				
Primed	568 (81)	96 (5)	609 (91)	97 (6)
Unprimed	575 (86)	96 (7)	613 (86)	97 (6)
Difference	+7	0	+4	0
Regular pseudo-past				
Primed	616 (103)	94 (10)	626 (98)	94 (8)
Unprimed	598 (88)	93 (9)	616 (80)	97 (8)
Difference	−18	+1	−11	−3
Irregular pseudo-past				
Primed	586 (95)	97 (5)	617 (84)	94 (9)
Unprimed	595 (82)	94 (8)	630 (81)	96 (9)
Difference	+9	+3	+13	−2

* $p < .05$.
** $p < .01$.

those items with error rates over 25% were excluded. This procedure excluded data from one item in the phonological condition: *part*.

RT and accuracy data were entered into repeated measures ANOVAs with relation type and prime relatedness as repeated factors and analyzed by subjects and items. Mean RT and accuracy for each condition are presented in Table 3. The analysis revealed significant main effects of relation type and prime relatedness both by subjects and items, (relation type: $F_1(6, 138) = 18.50$, $MSE = 1407$, $p < .01$, $F_2(6, 126) = 7.29$, $MSE = 3188$, $p < .01$, $\min F'(6, 214) = 5.230$, $p < .01$; relatedness: $F_1(1, 23) = 28.64$, $MSE = 1029$, $p < .01$, $F_2(1, 126) = 18.03$, $MSE = 1464$, $p < .01$, $\min F'(1, 106) = 11.064$, $p < .01$). Priming was found in all morphological conditions, but in none of the non-morphological ones, resulting in a significant interaction between relatedness and relation type ($F_1(6, 138) = 4.53$, $MSE = 1384$, $p < .01$, $F_2(6, 126) = 3.09$, $MSE = 1464$, $p < .01$, $\min F'(6, 250) = 1.838$, $p > .05$).

Planned comparisons revealed that regular past tenses primed their stems (46 ms, CI: 29–63); $F_1(1, 23) = 31.59$, $MSE = 805$, $p < .01$, $F_2(1, 19) = 12.56$, $MSE = 1772$, $p < .01$, $\min F'(1, 33) = 8.985$, $p < .01$, as did both classes of irregular verbs (suffixed irregulars: 38 ms, CI: 20–56; $F_1(1, 23) = 20.24$, $MSE = 876$, $p < .01$, $F_2(1, 17) = 7.23$, $MSE = 1905$, $p < .05$, $\min F'(1, 29) = 5.325$, $p < .05$, and vowel change irregulars: 38 ms, CI: 19–56; $F_1(1, 23) = 18.16$, $MSE = 955$, $p < .01$, $F_2(1, 19) = 8.29$, $MSE = 1731$, $p = .01$, $\min F'(1, 34) = 5.69$, $p < .05$). None of the non-morphological conditions approached significance [all Fs < 1]. Analysis of difference scores revealed that there were no significant differences in the magnitude of priming effects for any of the morphological conditions [all Fs < 1].

Accuracy. The analysis of the accuracy data revealed a significant main effect of relation type that was significant by subjects, $F_1(6, 138) = 4.02$, $MSE = .003$, $p < .01$, but not by items, $F_2(6, 126) = 1.59$, $MSE = .006$, $p > .05$, $\min F'(6, 215) = 1.14$, $p > .05$. This was due to the lower accuracy for the regular pseudo-past targets, independent of prime type. The main effect of relatedness was also significant, $F_1(1, 23) = 4.80$, $MSE = .004$, $p < .05$, $F_2(1, 126) = 4.38$, $MSE = .003$, $p < .05$, $\min F'(1, 83) = 2.29$, $p > .05$, and did not interact with relation type [all Fs > 1], indicating that responses were consistently more accurate in the related conditions.

Results: Experiment 2B (Cross-modal priming, long ISI)

Twenty-five participants were recruited into the experiment as described above. Two participants with accuracy less than 60% on at least one condition were removed, leaving 23 in the study. RTs greater than 3 *SD* from the mean were removed from the analysis and treated as errors (about 2% of data points excluded). The average error rates for each item in each condition and SOA were examined and data from items with error rates over 25% were excluded. This procedure excluded data from one item in the semantic condition: *notion*. Only reaction times for correct responses were entered into reaction time analyses.

Repeated measures ANOVAs were performed, both by subjects (F_1) and by items (F_2). The analyses revealed significant main effects of both relation type and priming relatedness by subjects and by items (relation type: $F_1(6, 132) = 19.74$, $MSE = 1173$, $p < .01$, $F_2(6, 126) = 7.24$, $MSE = 3206$, $p < .01$, $\min F'(6, 209) = 5.296$, $p < .01$; relatedness, $F_1(1, 22) = 32.59$, $MSE = 1287$, $p < .01$, $F_2(1, 126) = 17.11$, $MSE = 1784$, $p < .01$, $\min F'(1, 114) = 11.218$, $p < .01$). The interaction between the two was also significant, $F_1(6, 132) = 3.30$, $MSE = 1464$, $p < .01$, $F_2(6, 126) = 2.31$, $MSE = 1784$, $p < .05$, $\min F'(6, 248) = 1.359$, $p > .05$, indicating that priming effects were not equivalent across conditions.

The interaction was investigated with planned comparisons, which revealed a pattern of results similar to that of Experiment 2A. There was significant facilitation in all three morphologically-related conditions: regulars (41 ms, CI: 22–59), $F_1(1, 22) = 19.95$, $MSE = 951$, $p < .01$, $F_2(1, 19) = 10.63$, $MSE = 1563$, $p < .01$, $\min F'(1, 36) = 6.936$, $p < .01$; vowel change irregulars (40 ms, CI: 14–66), $F_1(1, 22) = 9.95$, $MSE = 1818$, $p < .01$, $F_2(1, 19) = 8.60$, $MSE = 1569$, $p < .01$, $\min F'(1, 40) = 4.612$, $p < .05$, and suffixed irregulars (36 ms, CI: 16–56), $F_1(1, 22) = 13.93$, $MSE = 1089$, $p < .01$, $F_2(1, 17) = 10.33$, $MSE = 1269$, $p < .01$, $\min F'(1, 36) = 5.933$, $p < .05$. As in Experiment 2A, an analysis of the difference scores found no differences in the magnitude of the priming effects between the morphologically related conditions [all Fs < 1].

There was also a significant priming effect in the semantic condition (37 ms, CI: 2–72); $F_1(1, 22) = 4.68$, $MSE = 3279$, $p < .05$, $F_2(1, 18) = 5.74$, $MSE = 1789$, $p < .05$, $\min F'(1, 40) = 2.578$, $p > .05$. None of the formally related conditions showed priming, however (all Fs < 1 for regular pseudo-pasts, irregular pseudo-pasts, phonological).

Accuracy. The analysis of the accuracy data revealed a significant main effect of relation type, $F_1(6, 132) = 3.25$, $MSE = .003$, $p < .01$, $F_2(6, 126) = 2.71$, $MSE = .004$, $p < .05$, $\min F'(6, 255) = 1.478$, $p > .05$, but no significant effect of relatedness [all Fs < 1]. The interaction between the two was marginally significant by participants, $F_1(6, 132) = 2.12$, $MSE = .003$, $p = .05$, and significant by items, $F_2(6, 126) = 2.26$, $MSE = .002$, $p < .05$, $\min F'(6, 258) = 1.108$, $p > .05$. This interaction was investigated using a repeated measures analysis of variance comparing related and unrelated responses for each condition separately. This analysis reveled a marginally significant effect for suffixed irregular verbs, $F_1(1, 22) = 4.18$, $MSE = .004$, $p = .053$, $F_2(1, 17) = 3.97$, $MSE = .001$, $p = .063$,

$\min F'(1, 38) = 2.037, p > .05$, indicating greater accuracy for related than for the unrelated targets. No other comparisons were significant [all Fs < 1].

Discussion

Experiment 2 was designed to reduce the effects of orthographic overlap found in masked visual priming. This was achieved by presenting the prime and target in different modalities. In Experiment 2A, we observed significant and equal facilitation in the three morphologically related conditions, in the absence of any such effects in the non-morphological items. These results differ from the 0 ms ISI masked visual priming (Experiment 1A) in a number of respects. Notably, they show robust priming in the vowel change irregular verbs, coupled with only small and non-significant inhibition in the regular pseudo-past pairs. This is very different from the pattern found in the immediate masked visual study, supporting the argument that the earlier effects were influenced by the degree of representational overlap, which was greatest for the morphologically related conditions.

In Experiment 2B we again found significant and equal facilitation in the regular, suffixed irregular, and vowel change irregular verbs, but none in the formally-related items. Purely semantically related pairs also primed at the longer interval, but not in the immediate condition, showing (as in Experiment 1B) that priming in the irregular verbs does not derive exclusively from their semantic or formal relationship, but rather from a nonlinear interaction between the two.

General discussion

Previous studies have identified morphological priming effects, such that recognition of the stem is speeded when its past tense form precedes it. These effects have however been influenced by verb regularity, as well as by methodological factors. Overall, our results clearly show that priming is not unique to regularly inflected pairs, as we have also seen it in both classes of irregular verbs.

In the visual priming study we found clear effects of formal overlap at 0 ms ISI with a masked prime. The visual priming results were also influenced by orthographic overlap at the longer ISI, but this is unlikely to have driven the entire pattern of effects. When prime and target differed in modality—again lowering the effect of formal overlap—we found significant and equal priming for all three morphological conditions, independent of purely semantic or purely formal priming. We interpret this pattern as reflecting the convergence of overlapping semantic and orthographic/phonological representations, consistent with a connectionist account of morphological relatedness (Joanisse & Seidenberg, 1999; Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997; Seidenberg & Gonnerman, 2000).

How would other approaches account for these data? On the best-established dual mechanism account (Pinker, 1997; Pinker & Ullman, 2002), the regular past tense is produced and recognized through a rule-based system that concatenates (or separates) a morphological affix and a stored stem. Irregular past tenses, on the other hand, are learned individually and stored in the lexicon as full forms, as are their stems. Irregular past tenses thus have a semantic relationship with their stem, but do not share a lexical entry as regulars do. Priming is expected for regular verbs because a single lexical entry is used to encode both uninflected and inflected forms; thus recognition of a regular past tense involves decomposing it into a stem and suffix (Pinker & Ullman, 2002). In contrast, no priming is expected for irregular verbs because their present and past tense forms are stored separately in the lexicon, linked by associative connections (Münte, Say, Clahsen, Schiltz, & Kutas, 1999; Pinker, 1991; Weyerts, Münte, Smid, & Heinze, 1996). If irregular forms do prime their stem, it is through their close semantic relationship, like priming effects in other semantically related words.

Are the current results consistent with these predictions? In Experiment 1A, when a masked prime was presented for 67 ms, immediately followed by a visual target, we did observe significant priming in the regular verbs, coupled with no priming for the vowel change irregulars. This cannot be interpreted as a regularity-based dissociation, however, because the suffixed irregular verbs patterned with the regulars. In Experiment 1B, when the visual target appeared after a 500 ms interval, we observed numerically greater priming in the regular verbs than for any other condition. This also hints at a regularity advantage, but in fact the priming effects in the regular verbs were again statistically equivalent to those of the suffixed irregulars. The results of the two studies are hard to reconcile with the dual-route account, which states that all irregulars are processed alike, and differently from regulars.

Furthermore, the dual-route theory suggests that true morphological priming (i.e., priming that occurs over and above the effects of formal or semantic overlap) only occurs for regulars. Consequently, priming for irregular forms and semantically related pairs are both entirely due to the full-form route, and these should therefore always consistently pattern together. In our experiments, they did not: In Experiment 1A, we observed semantic priming, but no priming for the vowel change irregulars; in 1B, the vowel change irregulars primed, but the semantically-related pairs did not; finally, in Experiments 2A and 2B both irregular verb classes primed consistently, while semantic priming was found in the second but not in the first. These data indicate that the priming that we observed for irregulars cannot be accounted for strictly on the basis of the semantic relatedness of the prime and target. Similarly, formal overlap alone cannot account for these findings since we did not observe priming in the 'irregular pseudo-past' condition, which was equivalent to the irregular conditions with respect to the nature and degree of orthographic and phonological overlap between prime and target.

Thus a strict dual-route model fails because of the firm distinction it draws is between rule-governed and idiosyncratic forms. However, other related approaches to past-tense morphology make more subtle or sophisticated distinctions. Marslen-Wilson and Tyler (1998) offer one such model. As described earlier, this account incorporates the numerous dimensions of similarity or difference between regular and irregular verbs. These differ in that regular verbs (unlike irregulars) require phonological assembly or disassembly, while irregular verbs (unlike regulars) can be accessed through a full-form route. However, the two are also similar in some respects, and the similarity is reflected in the fact that they have morphological relationships with their stems.

This model can explain attested dissociations between regular past tense, on the one hand, and irregular past tenses and semantically related items, on the other. It can also potentially account for the somewhat intermediate status of the suffixed irregulars: Because these verbs involve affixation, they might arguably be accessed as regulars are, through the phonological assembly route. Affixation is idiosyncratic, however, because the stem often undergoes a vowel change as well. These factors implicate full-form access, and consequently the suffixed irregulars might be predicted to sometimes pattern with the vowel change irregulars instead. Furthermore, as note above, both regular and irregular past tenses are assumed to have a morphological relationship with their stems—that is, to map onto that underlying morpheme in similar ways. Thus, unlike the dual-route model described earlier, this model can accommodate the results of Experiments 1B 2A and 2B, in which regular and irregular verbs consistently prime, independent of priming in the semantically related pairs.

In contrast, this model would not offer a morphologically-based explanation of the pattern seen in Experiment 1A. Recall that in this experiment we found that regular verbs (or verbs requiring phonological disassembly) patterned with semantic pairs, in contrast to vowel change irregulars. This is not a result that the Marslen-Wilson and Tyler model would predict; however, these results arguably reflect degree of form overlap more strongly than morphological relatedness. Thus such data might not be problematic for this view. Indeed, later versions of this model (e.g., Rastle et al., 2000) suggest an approach very compatible with what we argue for here, in which priming effects are diagnostic of overlapping representations between prime and target.

Finally, it has been argued that morphological effects cannot be viewed as the convergence of semantic and orthographic/phonological representations, because one finds morphological priming in studies (such as our own) where equivalent priming is not found in purely semantic or purely orthographic or phonological conditions. For example, Napps (1989) and Napps and Fowler (1987) finds results very similar to ours—priming for morphologically-related items, but not for synonyms or formally-related pairs—and conclude, like Feldman (2000) and Stolz and Besner (1998), that morphological priming represents a distinct process that is different from additive effects of semantic and phonological overlap. Note however that such conclusions assume, contrary to the dynamics of network models, that morphological effects should be additive and independent of semantic and orthographic effects. In reality, the convergence of codes approach views the production of the past tense as a constraint satisfaction problem in which the correct form is determined by a conjunction of probabilistic linguistic constraints (MacDonald, Perlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994). Morphemes, like words or suffixes, are a consistent mapping between sound and meaning, and consequently the past tense is computed as the convergence of semantic, phonological, and orthographic codes, with an unusually strong mapping among them (Gonnerman et al., 2007; Joanisse & Seidenberg, 1999; Plaut & Gonnerman, 2000; Seidenberg & Gonnerman, 2000). Input from the different types of representation interact to determine the output, so that one expects to find greater activation for items where formal overlap correlates with semantic overlap. The same is not the case for pairs reflecting only one of these cues. For example, the word *bead* overlaps with past tense forms phonologically - but not orthographically or semantically. It is thus not predicted to prime *bee* in the same way that *baked* would prime *bake*. Similarly, the word *yesterday* overlaps with past tense forms in semantics, but not with phonology or orthography.

Morphological priming, in contrast, results from the interaction of both factors, and is thus best seen as emergent from the systematicity of the mapping among different types of linguistic information. As we have observed in the present study, these are dynamic effects influenced by a number of factors including the overlap, modality of presentation, and temporal delay between a prime and target.

Conclusion

The English past tense has been widely studied because of its potential to address questions about the status of rules in mental grammars. Priming has often been used to investigate these questions, resulting in a number of dissociable effects for regular and irregular forms in studies of normal processing (Marslen-Wilson et al., 1993) neuroimaging (Münte et al., 1999) and aphasia (Marslen-Wilson & Tyler, 1998; Tyler et al., 2002). One possibility is that such effects reflect differences in the cognitive and neural systems used to process rule-like forms and exceptions. On the other hand, the present study suggests some caution in how one interprets morphological priming effects, given that they are highly susceptible to task parameters, and that observed differences between regulars and irregulars are more graded than has previously been suggested.

Our findings further suggest that morphological priming cannot be explained by orthographic, phonological or semantic overlap alone. Instead, such effects are due to the interaction among these factors; priming occurs because the prime and target are related both with respect to form (orthography, phonology) *and* meaning (semantics). The degree of orthographic and phonological similarity is confounded with regularity in English, leading to potential differences in priming effects for regular and irregular verbs. Regular present and past tenses tend to have a greater degree of overlap; in addition, there is a more predictable relationship between the present and past tense forms. We believe that the most fruitful approach to understanding the representation and processing of morphologically related forms is to investigate factors such as these that underlie the differences between them, rather than to impose distinctions in the processor itself.

Appendix A

Prime and target pairs used in Experiments 1 and 2 matched for log frequency values from CELEX, neighborhood ratings (N-watch), orthographic length and percent phonological and orthographic overlap

Regular verb									
Prime				Target				Phon overlap	Ortho overlap
	Log frequency	Length	*N*		Log frequency	Length	*N*		
wiped	2.93	5	4	wipe	2.35	4	8	75.00	80.00
cleared	3.34	7	3	clear	5.46	5	2	80.00	71.43
filled	4.35	6	9	fill	3.73	4	15	75.00	66.67
flowed	2.30	6	4	flow	3.76	4	8	75.00	66.67
greeted	2.95	7	0	greet	2.03	5	3	66.67	71.43
hated	3.60	5	8	hate	4.03	4	14	60.00	80.00
hoped	4.08	5	9	hope	5.25	4	13	75.00	80.00
lifted	3.71	6	4	lift	3.82	4	9	66.67	66.67
passed	4.93	6	6	pass	4.60	4	12	75.00	66.67
played	4.73	6	6	play	5.62	4	5	75.00	66.67
pressed	3.64	7	2	press	4.92	5	4	80.00	71.43
printed	3.28	7	3	print	3.26	5	2	71.43	71.43
pulled	4.48	6	9	pull	4.20	4	13	75.00	66.67
reached	4.93	7	4	reach	4.53	5	7	75.00	71.43
rented	2.29	6	4	rent	3.76	4	12	66.67	66.67
saved	3.60	5	7	save	4.20	4	13	75.00	80.00
showed	4.63	6	7	show	5.45	4	8	75.00	66.67
walked	5.04	6	4	walk	4.80	4	4	75.00	66.67
yelled	2.44	6	2	yell	1.38	4	9	75.00	66.67
Mean	3.79	6.05	4.95		4.14	4.25	8.50	72.91	70.53
SD	0.90	0.69	2.56		1.19	0.44	4.16	5.01	5.26

(*continued on next page*)

Appendix A (*continued*)

Vowel change irregular verb									
Prime				Target				Phon overlap	Ortho overlap
	Log frequency	Length	*N*		Log frequency	Length	*N*		
blew	3.07	4	5	blow	3.70	4	8	66.67	75.00
drew	4.08	4	4	draw	4.14	4	5	66.67	75.00
drank	3.55	5	5	drink	4.78	5	3	80.00	80.00
drove	4.15	5	4	drive	4.49	5	1	75.00	80.00
fell	4.75	4	13	fall	4.70	4	12	66.67	75.00
gave	5.66	4	14	give	6.18	4	6	66.67	75.00
grew	4.25	4	5	grow	4.54	4	6	66.67	75.00
hung	4.02	4	8	hang	3.54	4	11	66.67	75.00
rang	3.58	4	14	ring	4.19	4	11	66.67	75.00
ran	4.71	3	16	run	5.44	3	14	66.67	66.67
shook	4.22	5	3	shake	3.18	5	10	66.67	40.00
dove	1.09	4	13	dive	1.69	4	10	66.67	75.00
sang	2.94	4	15	sing	3.19	4	13	66.67	75.00
spoke	4.75	5	5	speak	4.85	5	4	75.00	40.00
stole	2.37	5	7	steal	2.52	5	4	75.00	40.00
stung	1.21	5	4	sting	1.66	5	6	75.00	80.00
tore	2.71	4	18	tear	2.89	4	16	66.67	25.00
woke	3.17	4	7	wake	3.45	4	15	66.67	75.00
wore	4.10	4	19	wear	4.22	4	14	66.67	25.00
won	4.25	3	14	win	4.13	3	15	66.67	66.67
Mean	3.63	4.20	9.65		3.87	4.20	9.20	69.00	64.67
SD	1.16	0.62	5.37		1.15	0.62	4.58	4.27	18.85

Suffixed irregular verb									
Prime				Target				Phon overlap	Ortho overlap
	Log frequency	Length	*N*		Log frequency	Length	*N*		
leapt	2.36	5	3	leap	2.56	4	7	50.00	80.00
dealt	3.12	5	1	deal	5.17	4	16	50.00	80.00
fled	2.81	4	8	flee	1.73	4	8	50.00	75.00
slept	3.52	5	2	sleep	4.79	5	5	60.00	60.00
kept	5.34	4	2	keep	5.86	4	9	50.00	50.00
lent	2.20	4	14	lend	2.51	4	10	75.00	75.00
sold	4.04	4	8	sell	4.00	4	11	50.00	50.00
meant	4.97	5	2	mean	6.04	4	9	50.00	80.00
heard	5.65	5	4	hear	5.23	4	15	66.67	80.00
built	4.85	5	3	build	4.30	5	2	75.00	80.00
bent	3.72	4	14	bend	3.05	4	10	75.00	75.00
crept	2.35	5	3	creep	2.11	5	3	60.00	60.00
swept	3.41	5	3	sweep	2.67	5	4	60.00	60.00
burnt	2.94	5	2	burn	3.32	4	7	75.00	80.00
sent	5.04	4	13	send	4.43	4	8	75.00	75.00
felt	6.00	4	7	feel	5.92	4	9	50.00	50.00
spent	4.95	5	3	spend	4.47	5	2	80.00	80.00
wept	2.23	4	5	weep	1.87	4	8	50.00	50.00
Mean	3.86	4.56	5.39		3.89	4.28	7.94	61.20	68.89
SD	1.27	0.51	4.33		1.45	0.46	3.89	11.74	11.99

Appendix A (*continued*)

Regular pseudo-past									
Prime				Target				Phon overlap	Ortho overlap
	Log frequency	Length	*N*		Log frequency	Length	*N*		
chest	3.77	5	3	chess	2.69	5	4	75.00	80.00
mold	5.15	4	11	mole	1.35	4	14	75.00	75.00
tent	3.60	4	15	ten	5.42	3	16	75.00	75.00
feed	3.96	4	13	fee	2.58	3	15	66.67	75.00
wild	4.46	4	7	while	6.42	5	4	75.00	25.00
mild	3.19	4	5	mile	3.55	4	18	75.00	75.00
trade	5.11	5	2	tray	2.99	4	7	75.00	60.00
grind	1.69	5	2	grin	2.54	4	6	80.00	80.00
cold	5.20	4	10	coal	3.75	4	6	75.00	50.00
mend	1.53	4	8	men	6.49	3	13	75.00	75.00
ride	3.54	4	14	rye	1.67	3	7	66.67	25.00
hide	3.47	4	10	high	5.90	4	2	66.67	50.00
skid	1.12	4	6	ski	1.83	3	1	75.00	75.00
raid	2.49	4	7	ray	2.56	3	19	66.67	50.00
fluid	2.66	5	0	flu	1.47	3	1	60.00	60.00
wide	4.58	4	14	why	6.43	3	5	66.67	25.00
card	3.83	4	12	car	5.62	3	18	75.00	75.00
feud	0.11	4	2	few	6.37	3	11	66.67	50.00
short	5.26	5	7	shore	3.18	5	13	75.00	80.00
guide	3.61	5	3	guy	4.03	3	6	66.67	40.00
Mean	3.42	4.30	7.55		3.84	3.60	9.30	71.58	60.00
SD	1.45	0.47	4.66		1.85	0.75	6.00	5.14	19.53

Irregular pseudo-past									
Prime				Target				Phon overlap	Ortho overlap
	Log frequency	Length	*N*		Log frequency	Length	*N*		
bell	3.67	4	13	ball	4.53	4	18	66.67	75.00
bet	3.57	3	18	beat	3.97	4	19	66.67	66.67
belt	3.05	4	10	bill	4.65	4	15	50.00	50.00
boat	4.02	4	9	bite	2.83	4	9	66.67	25.00
blank	2.86	5	6	blink	1.34	5	5	80.00	80.00
book	5.62	4	12	bake	1.71	4	16	66.67	25.00
brave	2.98	5	5	brief	3.83	5	1	50.00	40.00
coke	1.74	4	12	cake	3.06	4	18	66.67	75.00
core	2.83	4	21	care	5.16	4	22	66.67	75.00
glue	1.12	4	6	glow	2.76	4	4	66.67	50.00
gram	0.64	4	7	grim	2.71	4	8	75.00	75.00
lot	5.77	3	17	link	3.36	4	12	33.33	33.33
poke	1.43	4	10	peak	3.14	4	11	66.67	25.00
pole	2.70	4	15	peel	2.36	4	8	66.67	25.00
note	4.41	4	9	night	6.06	5	8	66.67	25.00
store	4.03	5	13	stair	1.03	5	2	75.00	40.00
Mean	3.15	4.06	11.44		3.28	4.25	11.00	64.38	49.06
SD	1.47	0.57	4.62		1.38	0.45	6.44	11.25	22.01

(*continued on next page*)

Appendix A (*continued*)

Phonological									
Prime				Target				Phon overlap	Ortho overlap
	Log frequency	Length	*N*		Log frequency	Length	*N*		
agent	3.76	5	0	age	5.51	3	9	40.00	60.00
barn	2.34	4	12	bar	4.22	3	16	75.00	75.00
beef	2.81	4	6	bee	1.89	3	13	66.67	75.00
bullet	2.55	6	4	bull	3.25	4	15	60.00	66.67
party	5.92	5	6	part	6.21	4	17	80.00	80.00
corner	4.62	6	1	corn	3.22	4	10	80.00	66.67
dollar	2.69	6	1	doll	2.86	4	11	60.00	66.67
dragon	2.02	6	0	drag	2.93	4	7	66.67	66.67
farm	4.19	4	6	far	6.25	3	17	75.00	75.00
bitter	3.58	6	8	bit	5.48	3	17	75.00	50.00
lawn	3.02	4	7	law	5.12	3	16	66.67	75.00
market	4.89	6	2	mark	4.41	4	12	80.00	66.67
seat	4.36	4	15	sea	5.08	3	10	66.67	75.00
needle	2.35	6	0	need	6.14	4	7	75.00	66.67
paint	3.70	5	6	pain	4.33	4	10	75.00	80.00
panel	2.99	5	1	pan	3.37	3	19	75.00	60.00
pillow	2.62	6	2	pill	2.57	4	14	75.00	66.67
planet	3.22	6	2	plan	4.58	4	3	66.67	66.67
army	4.68	4	2	arm	4.66	3	5	75.00	75.00
match	4.04	5	7	mat	2.02	3	22	66.67	60.00
Mean	3.52	5.15	4.40		4.20	3.50	12.50	70.00	68.67
SD	1.03	0.88	4.12		1.38	0.51	4.96	9.37	7.62

Semantic										
Prime				Target				Phon overlap	Orth overlap	Semantic relatedness (/9)
	Log frequency	Length	*N*		Log frequency	Length	*N*			
battle	4.29	6	3	fight	4.55	5	8	25.00	0.00	7.98
clean	4.50	5	3	wash	3.69	4	12	0.00	0.00	7.40
doctor	4.89	6	0	nurse	3.50	5	2	0.00	0.00	7.20
fire	5.03	4	15	smoke	4.07	5	4	0.00	0.00	7.23
fast	4.62	4	11	quick	4.23	5	2	0.00	0.00	8.24
forest	4.22	6	0	woods	3.47	5	6	0.00	33.33	7.73
injury	3.12	6	1	hurt	4.05	4	4	16.67	0.00	8.02
jacket	3.54	6	2	coat	3.96	4	9	0.00	0.00	8.22
large	5.92	5	2	huge	4.68	4	1	33.33	0.00	8.29
aroma	1.11	5	0	smell	4.10	5	5	0.00	0.00	8.09
ancient	4.41	7	0	old	6.62	3	1	0.00	0.00	7.91
profit	3.61	6	0	gain	3.87	4	8	0.00	0.00	7.67
sofa	3.00	4	3	couch	2.21	5	6	25.00	25.00	8.24
disease	4.15	7	0	cancer	4.33	6	4	0.00	0.00	7.62
water	6.07	5	7	steam	2.89	5	3	0.00	0.00	7.20
fortune	3.36	7	0	wealth	4.06	6	1	0.00	0.00	7.78
rotate	1.23	6	0	spin	2.08	4	5	0.00	0.00	7.96
idea	5.61	4	0	notion	3.60	6	4	0.00	0.00	7.64
evidence	5.02	8	0	proof	3.42	5	0	0.00	0.00	8.27
carton	0.99	6	2	box	4.37	3	11	0.00	0.00	7.11
Mean	3.93	5.65	2.45		3.89	4.65	4.80	5.00	3.00	7.79
SD	1.49	1.14	4.07		0.94	0.88	3.40	11.00	9.00	0.40

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