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Are CORNER and BROTHER Morphologically Complex? Not in the Long Term

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Abstract

Previous studies haves shown that under masked priming conditions, CORNER primes CORN as strongly as TEACHER primes TEACH and more strongly than BROTHEL primes BROTH. This result has been taken as evidence of a purely structural level of representation at which words are decomposed into morphological constituents in a manner that is independent of semantics. The research reported here investigated the influence of semantic transparency on *long-term* morphological priming. Two experiments demonstrated that while lexical decisions were facilitated by semantically transparent primes like TEACHER, semantically opaque words like CORNER had no effect. Although differences in the nonword foils used in each experiment gave rise to somewhat different patterns of results, this difference in the effects of transparent and opaque primes was found in both experiments. The implications of this finding for accounts of morphological effects on visual word identification are discussed.

In the past three decades, the processing of morphologically complex words has received considerable attention in psycholinguistic investigation. Evidence that morphological constituents play a role in word recognition has been obtained in a variety of tasks and in a variety of languages. (For reviews of these findings, see Feldman, 1991, Henderson, 1985, Sandra, 1994, and Seidenberg & Gonnerman, 2000). While the conclusion that morphological structure influences word recognition is relatively uncontroversial, how and why this influence comes about remains a matter of much debate.

One prominent issue concerns how morphological structure is represented. One view holds that that there is a level of representation at which each morphemic constituent of a multimorphemic word is represented by a distinct representational unit, and thus that the recognition process involves the decomposition of a word into its morphemic constituents. Whole-word (or full-listing) accounts (e.g., Feldman & Fowler, 1987; Lukatela, Gligorijevic, Kostic, & Turvey, 1980), in contrast, hold that each morphologically complex word has its own representation, and that these representations are organized such that morphological relationships affect processing (e.g. through an excitatory feedback process). Connectionist models offer a third alternative. According to these models, words are represented by distributed patterns of activation, and these representations are more-or-less componential in a way that reflects morphological structure (Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999; Seidenberg & Gonnerman, 2000).

Another major issue concerns the level of representation at which morphological structure is captured. For example, some decompositional accounts hold that the parsing of a word into its morphological constituents occurs early—before lexical access occurs. For these *pre-lexical* decomposition models (e.g., Taft, 1994), morphemes serve as the "access units" for

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word recognition. In contrast, in the supralexical model (Giraudo & Grainger, 2001) morphemic representations are located between representations of whole-word form and higher-level semantic representations. Thus, according to this model morphological decomposition occurs after lexical access and reflects the role of morphological structure in accessing semantic information. Like the supralexical model, connectionist models also emphasize the role of morphological regularities in mapping representations of word form to representations of word meaning. However, due to the nature of the learning process that attunes the word recognition system to these regularities, the connectionist account holds that morphological structure is captured in the patterns of activation that represent visual word form—a level of representation that is comparable to the access units of pre-lexical decomposition models (Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999; Seidenberg & Gonnerman, 2000).

One contrast between these accounts concerns their treatment of words like CORNER and TREATY. Orthographically, CORNER and TREATY appear to be morphologically complex. That is, they can be exhaustively parsed into components (CORN/ER, TREAT/Y) that clearly function as root and affix morphemes in other words. In this respect, they resemble words that are unambiguously morphologically complex such as TEACHER and CREAMY and differ from words such as BROTHEL and QUARTZ, which contain letter sequences that sometimes act as root morphemes (BROTH, QUART) but which cannot be exhaustively parsed into a morphemic segments. (Neither –EL nor –Z are morphological affixes in English.) In contrast, at the semantic level CORNER and TREATY appear to be morphologically simple. That is, whereas the meaning of TEACHER is transparently related to the meaning of TEACH, no such relationship exists between the meanings of CORNER and CORN. Thus, in terms of meaning CORNER and TREATY pattern with BROTHEL and QUARTZ rather than TEACHER and CREAMY.

Given this contrast, “semantically opaque” words such as CORNER and TREATY can be used to explore the role of morphological structure in reading. Specifically, if printed words are parsed into their morphological components early in the recognition process—at a pre-lexical (and pre-semantic)—level of representation, then readers should act as if CORNER is morphologically complex. In contrast, if the influence of morphological structure derives from its role in processes that map written words onto their meanings, these processes will treat semantically opaque words differently than semantically transparent words.

Recently, a number of studies employing the masked priming paradigm have yielded results suggesting that the word recognition process treats semantically transparent and semantically opaque words alike. In the masked priming paradigm, target words are preceded by primes that vary in their relationships to the targets. The primes are presented for a very brief duration (e.g., 50 ms) and are both pre-masked (by a visual pattern such as a role of hash marks) and post-masked (by either the target word or a visual pattern that intervenes between the prime and the target). Under these conditions, the primes are often virtually invisible to the participant, yet their effects on the participant’s behavior are readily detectable.

In a representative study using this paradigm, Rastle et al. (2004) found as much priming (relative to an unrelated-prime baseline condition) for semantically opaque prime-target pairs (CORNER-CORN) as for semantically transparent pairs (CLEANER-CLEAN). In contrast, there was no facilitation from orthographically related primes that cannot be exhaustively decomposed into morphemic constituents (“form-related” pairs such as BROTHEL-BROTH). The fact that there was no priming for the form-related pairs implies that the effects of the transparent and opaque primes cannot be attributed to orthographic similarity alone, but must instead be related to the fact that words like CLEANER and CORNER can be parsed into a sequence of morphological constituents.

Equivalent levels of priming from semantically transparent and semantically opaque words have now been observed in a number of studies. Like Rastle et al. (2004), several of these studies used masked priming and English materials (Pastizzo & Feldman, 2002; Rastle & Davis, 2003; Rastle et al., 2000). Similar results have also been reported in masked-priming studies of skilled readers of French (Longtin & Meunier, 2005; Longtin, Segui, & Halle, 2003) and Serbian (Feldman, Barac-Cikoja, & Kostic, 2002), and in a study with English materials (Feldman & Soltano, 1999) in which primes were not forward masked but were presented at short stimulus-onset asynchronies (SOAs). In addition, a recent event-related potential (ERP) study of masked priming has yielded neurophysiological evidence that readers respond to semantically opaque words as if they are morphologically structured (Lavric, Clapp, & Rastle, 2007).

Despite the consistency of the results of the studies just reviewed, not every experiment has found that semantic transparency has no effect on priming. For example, Diependaele, Sandra, and Grainger (2005) examined the effects of semantic transparency using Dutch stimuli and a masked cross-modal priming technique in which masked visual primes preceded spoken word targets. They found priming from semantically transparent primes, but not from semantically opaque primes or their orthographic controls. In another experiment Diependaele et al. used French materials (with both primes and targets presented visually) in an incremental priming paradigm (see Jacobs, Grainger, & Ferrand, 1995) in which the duration of the prime gradually increases, starting from a duration that is too short to influence target processing. In this experiment semantically opaque primes had a stronger effect that their orthographic controls, but semantically transparent primes produced more facilitation and at shorter prime durations. Similarly, in an experiment using masked priming and English stimuli, Morris, Frank, Grainger, and Holcomb (2007) also found a graded priming effect—both behavioral and electrophysiological measures (response times and ERPs, respectively) suggested that the effects of semantically opaque primes fall between those of semantically transparent and orthographic control primes.

Other experiments have shown that an effect of semantic transparency on priming emerges as the duration of the prime increases. For example, although Rastle et al. (2000) found no difference between transparent and opaque primes when the primes were presented for 43 ms, they found more facilitation from transparent primes than from opaque primes at SOAs of 72 and 230 ms. They also observed that the emergence of a semantic transparency effect parallels the emergence of semantic priming (i.e., facilitation for semantically related prime-target pairs, such as WATER-OCEAN): semantic priming was absent in the 43 ms condition and largest in the 230 ms condition. (See Feldman & Soltano, 1999, and Raveh, 2002, for related findings). This pattern has been taken to suggest processes at the semantic level act to mask the behavioral manifestations of a semantically blind morphological decomposition process (Rastle & Davis, 2003).

In sum, the empirical evidence to date suggests that in certain respects readers treat semantically opaque words such as CORNER and TREATY as if they are morphologically complex. However, transparent and opaque words appear to be functionally equivalent in a limited set of circumstances, and even within these boundary conditions there are a few discrepant findings. The experiments reported below were not intended to address these discrepancies, but instead were designed to broaden our understanding of the conditions under which semantic transparency does or does not influence behavior. In particular, the present experiments asked whether semantic transparency affects *long-term* morphological priming.

Long-term priming experiments are similar to masked priming experiments in that in both are designed to measure how the response to a target word is influenced by the prior presentation of a stimulus that is related to the target in a particular way (e.g., morphologically, semantically, etc.). However, whereas the lag between the prime and target in the masked priming paradigm usually ranges from, say, 15–70 ms, in long-term priming experiments the prime and target are presented seconds, minutes, or even days apart, with any number of intervening events.

Murrell and Morton (1974) were the first to show that long-term priming occurs between morphologically related primes and targets. In the priming phase of their experiment, subjects studied a short list of words with the expectation that their memory for these words would later be tested. Shortly after the study phase, an identification task was administered. The accuracy with which words were identified during this task varied as a function of their relationships with words on the study list. Specifically, repeated words were identified more easily than unprimed words (i.e., words that were not related to any of the study words), as were words that had been preceded by a morphologically related prime (e.g., CARS at study, CAR at test). Thus, both identity (repetition) priming and morphological priming facilitated identification. In contrast, no priming was observed for words that were preceded by morphologically unrelated primes that were similar in spelling and pronunciation (e.g., CARD-CAR).

In the years since their seminal study, Murrell and Morton's (1974) results have been replicated and extended in a variety of ways. (See Feldman, 1991, Henderson, 1985, Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997, for reviews.) Morphological priming has been demonstrated in a variety of languages (including Hebrew, Bentin & Feldman, 1990, Serbo-Croatian, Feldman & Fowler, 1987, and Italian, Burani & Carramazza, 1987, to name just a few). Moreover, although morphologically related words are usually related in form (i.e., spelling and pronunciation) and meaning, the inclusion of various control conditions has revealed that morphological priming cannot be attributed solely to similarity along these dimensions (Bentin & Feldman, 1990; Napps, 1989; Napps & Fowler, 1987; Stolz & Feldman, 1995).

The present experiments sought to determine if long-term priming mirrors masked priming in its indifference to the semantic transparency of “morphologically” related prime-target pairs. Long-term priming is of particular interest because, like masked priming, it is thought to reflect a relatively early level of processing. One line of evidence suggesting that masked priming has an early locus involves the effects of semantic relatedness discussed above. Although priming based on semantic overlap (e.g., WATER-OCEAN) is sometimes observed in masked-priming experiments (e.g., Sereno, 1991), these effects are not robust and are unlikely to be found at shorter SOAs—SOAs that are sufficiently long to yield morphological priming (Frost et al., 1997; Rastle et al., 2000). Thus, under appropriate circumstances masked priming appears to tap into an early, ‘pre-semantic’ level of representation.

Similarly, long-term priming is also thought to reflect the contribution of early, ‘pre-semantic’ processes (Schacter, 1992). A large number of studies have found that semantic priming is generally not found if the prime and target are separated by one, or at most two, trials (c.f., Davelaar & Coltheart, 1975; Joordens & Besner, 1992; Masson, 1991; McNamara, 1992; Ratcliff & McKoon, 1988). In addition, levels-of-processing manipulations typically have little effect on long-term priming (e.g., Jacoby & Dallas, 1981; for reviews, see Challis & Brodbeck, 1992, and Roediger & McDermott, 1993), also suggesting that long-term facilitation is relatively impervious to the influence of processes involving word meaning. There are exceptions to this pattern. For example, long-term semantic priming is fairly reliably found in category exemplar generation and other tasks that require extensive semantic processing (e.g., Srinivas & Roediger, 1990; Vaidya et al., 1997). However, in tasks that are more typically used to investigate morphological priming, such lexical decision (e.g., Feldman 1991; Stanners et al., 1979) and fragment completion (Rueckl et al., 1997; Rueckl & Galantucci, 2005), long-term priming is generally not observed outside of a limited range of circumstances specifically designed to induce it (Becker, Moscovitch, Berhmann, & Joordens, 1997; Joordens & Becker, 1997). Of particular relevance here is the fact that manipulations of semantic similarity have little effect on the magnitude of long-term morphological priming. For example, both Napps (1989) and Raveh and Rueckl (2000) found that inflections and derivations are equally effective (long-term) primes, despite that fact that inflected forms are more closely related to the meaning of their roots than are derived forms. It is noteworthy that inflections and derivations do differ in their effectiveness as short-term primes, but only at SOA's that also yield semantic priming (Raveh, 2002).

Another line of evidence suggesting that masked priming reflects an early stage of processing involves the comparison of same- and cross-modal priming. Although masked visual primes have been shown to influence the processing of spoken targets (Diependaele et al., 2005; Kouider & Dupoux, 2001; Grainger, Diependaele, Spinelli, Ferrand & Farioli, 2003), these effects are less robust than those that occur when both the primes and targets are presented visually. For example, Diependaele et al. (2005) found that cross-modal priming only emerged at a relatively long (67 ms) SOA. Within-modality priming had a stronger effect at this SOA and was also found at an SOA (40 ms) that was too short to yield cross-modal priming. These differences between within-and cross-modal masked priming have been taken as evidence that within-modality priming taps into a modality-specific level of representation (Kouider & Dupoux, 2001).

As noted by Kouider and Dupoux (2001), modality effects in masked priming parallel those observed in long-term priming paradigms. Here too, primes can be shown to influence the processing of targets that are presented in another modality, but an oft-replicated observation is that priming is substantially stronger if the prime and target are presented in the same modality (for reviews, see Kirsner, Dunn, & Standen, 1989, and Roediger & McDermott, 1993; for one notable exception, see Lukatela, Eaton, Moreno, & Turvey, 2007). This pattern has been taken as evidence that long-term identity priming occurs (at least in part) at an early, modality-specific level of representation (Kirsner et al., 1989; Schacter, 1992).

With regard to modality effects in long-term priming, a finding of particular relevance to the present study was reported by Rueckl and Galantucci (2005). Their experiments contrasted same-modality morphological priming with cross-modality identity priming. (Identity primes were used to maximize the contribution of priming from abstract, modality-independent processes.) Priming was substantially stronger in the same-modality morphological condition. Moreover, a statistical technique called survival analysis revealed that the time course of morphological priming was similar to that of visual identity priming and that both morphological and visual identity priming had earlier influences than did cross-modal priming. Thus, these results indicated that morphological priming, like repetition priming more generally, involves an early, modality-specific level of processing.

A third line of evidence suggesting parallels between masked- and long-term morphological priming comes from neuroimaging studies. The available evidence indicates that masked priming influences the activation of a variety of cortical regions, including in particular a occipitotemporal/posterior fusiform region known as the "visual word form area" (Dehaene et al., 2001; Devlin et al., 2006). It has been suggested that this region houses modality-specific orthographic representations of the sort thought to subserve masked priming

(Dehaene et al., 2005; McCandliss et al., 2003). Most critically, both Devlin et al. (2006) and Gold and Rastle (2007) reported that activation in this region was modulated by masked morphological primes, although both the specificity of this effect the contribution of other cortical regions remains a matter of debate.

Similarly, neuroimaging results suggest that long-term priming also influences the activation of a network of cortical regions (see Henson, 2003, and Schacter & Badgaiyan, 2001 for reviews), including in particular the visual word form area (Katz et al., 2005; Pugh et al., in press). Critically, in an experiment similar in many respects to the ones presented below Rueckl et al. (2005) found that activation in this region was modulated by long-term morphological priming, as would be expected if long-term priming is the manifestation of changes to modality-specific representations of the structure of written words. It should be noted, however, that in a recent study Bozic, Marslen-Wilson, Stamatakis, Davis, & Tyler (2007) failed to find an effect of long-term priming in this region. (At this point the basis for this discrepancy remains unclear.) Thus, at least some preliminary results suggest that both masked- and long-term morphological priming influence the operation of a cortical region that is strongly implicated in skilled reading, although more research is needed to evaluate this conclusion.

In sum, there are a number of intriguing parallels between masked- and long-term priming. Semantic relatedness (in the absence of similarity of form) tends to have little effect in either paradigm. In contrast, in both cases priming is weaker if the prime and target are presented in different modalities. Finally, neuroimaging results suggest that both forms of priming are correlated with changes in the activation of posterior fusiform regions. Taken together, these lines of evidence suggest that both masked- and long-term priming reflect the operation of early, pre-semantic, modality-specific processes.

Experiment 1

Given the considerations discussed above, we decided to investigate the effect of semantic transparency on long-term morphological priming. To date, only a handful of studies have addressed this issue and collectively they have yielded a conflicting set of results. Bentin and Feldman (1990) studied morphological priming in Hebrew, comparing the effects of primes that shared the same root as a target but differed in semantic relatedness. They found that lexical decisions were facilitated as much by primes that were semantically unrelated to their targets (semantically opaque primes) as by primes that were closely related in meaning. Bozic et al. (2007) reported similar results an fMRI study using English materials, although the priming effects were smaller (~15 ms) than are typically observed in experiments of this sort. While the Bentin and Feldman and Bozic et al. results suggest that long-term priming is indifferent to semantic transparency, the results of a study by Drews and Zwitserlood (1995) suggest the opposite. In their study, which used German materials, lexical decisions were facilitated by morphological primes that were semantically related to their targets, but not by semantically opaque primes. (In fact, responses in this condition were actually slower than baseline, albeit not significantly.)

Following Rastle et al. (2004) and others, our stimuli included primes and targets that share a semantically transparent morphological relationship (TEACHER-TEACH), primes and targets that share an apparent morphological relationship but no semantic relationship (e.g., CORNER–CORN), and primes and targets that are related orthographically (e.g., BROTHEL–BROTH). Based on previous studies (Henderson et al., 1984; Dannenbring & Briand, 1982, Raveh & Rueckl, 2000), we thought it unlikely that our design and procedure would engender long-term semantic priming, but to confirm this we included a set of semantically related prime-target pairs (e.g., OCEAN-WATER). We also included an identity priming manipulation, both to provide a scale against which the effects of the related primes could be evaluated and as an additional check that the items in the various conditions did not differ in unintended ways.

The primary question posed by this experiment was whether long-term priming resembles masked priming in its apparent indifference to semantic transparency. If so, semantically opaque primes should facilitate responses to the same extent as morphologically related, semantically transparent primes. Both transparent and opaque primes should give rise to more facilitation than the form-related primes.

Method

Participants—The participants were 24 undergraduate students enrolled in an introductory psychology course at the University of Connecticut who participated for course credit. All were native speakers of American English.

Design and materials—The materials (listed in the appendix) included three sets of prime-target pairs. In the *transparent* condition the primes were morphologically and semantically related to their targets (e.g., TEACHER-TEACH). Primes in the opaque condition appeared to contain two morphemes—a root (the target) and a suffix—but the meaning of each prime was unrelated to that of its target (e.g. CORNER-CORN). In the form-related condition each target word was also embedded in its corresponding prime, but in this case the remaining letters in the prime did not form an English suffix (e.g., BROTHEL-BROTH). There were 40 prime-target pairs in each of these conditions. The majority of them (30 transparent, 30 opaque, and 25 form-related) were taken from Rastle et al. (2004); other materials from that study were excluded because they seemed likely to be unfamiliar to some of our participants or were otherwise deemed to be problematic. Additional words were selected from candidate lists generated using the English Lexicon Project database. The target words were matched in Kučera-Francis (1967) frequency (transparent: 44.8; opaque: 47.7; orthographic: 41.1; $F(2,120) = .071$, n.s,). The targets were also matched in length (4.7, 4.8, 4.6, $F(2,120) =.418$, n.s.) and neighborhood size (3.7, 3.8, 4.4; $F(2,120) =.257$, n.s.). The primes were matched in frequency (30.7, 38.5, 28.7; $F(2,120) = .207$, n.s,) and length (7.2, 7.4, 7.3; $F(2,120) = .253$, n.s,). An additional set of 40 prime-target pairs was constructed to look for the effects of semantic priming. These items were drawn from Joordens and Becker (1997)—one of the few studies to find long-term semantic priming in the lexical decision task. Given the rationale for including these stimuli and the various constraints on the selection of items, the items in the semantic condition were not matched to the items in the other conditions on frequency or length.

For counterbalancing purposes, the stimuli were partitioned into two sublists, with half of the targets from each condition (transparent, opaque, form, and semantic) assigned to each list. For a given participant, the targets from one list were primed by their related words (TEACHER-TEACH, CORNER-CORN, etc.) and the targets in the other list were also used as identity primes (TEACH-TEACH, CORN-CORN, etc.). Across participants each sublist was assigned to the related and identity conditions equally often.

The materials also included 104 pronounceable nonword targets, each of which was created by changing one letter from a real word that was not itself a stimulus in the experiment. For half of these nonwords, an “affixed pseudoword”[i] related prime was constructed by combining it with an English suffix (e.g., JESHED-JESH). For the remaining nonwords, a

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[i] To the extent possible, the labels for our nonword conditions are consistent with the terminology used by Longtin and Meunier (2005).

"non-morphological pseudoword" prime was constructed by adding a non-morphemic letter sequence such as those at the end of the form-related word primes (e.g., CAFTEL-CAFT). As with the words, each nonword target was primed by either itself or by its related prime, and the assignment of items to priming condition was counterbalanced by creating two sublists, each of which included half of the affixed pseudoword (JESHED) primes and half of the non-morphological pseudoword (CAFTEL) primes.

Procedure—Participants were tested individually in a quiet room. After giving informed consent, they were told that they would see a series of letter strings presented one at a time and that they would be required to decide as quickly and accurately as possible whether or not each string was a word. Following the instructions, the participants completed a practice session of 20 trials, were given a chance to ask questions, and then completed the rest of the trials. On each trial a fixation point (a cross) was presented for 500 ms, followed by a letter string that remained on the screen for 2000 ms or until a response was made. Participants responded by pressing designated computer keys with the index finger of either hand, with the "yes" response assigned to the dominant hand. The inter-trial interval was 500 ms.

The trials during the main session of the experiment were arranged in a quasi-random order with 7–13 intervening trials (mean = 10) between each prime and its corresponding target. The order was also constrained so that targets of each type were distributed evenly throughout the session. Participants were offered the opportunity to take a short break after every 90 trials.

Stimulus presentation and data collection was controlled using the E-prime software package running on a Pentium 4 personal computer.

Results

Reaction time (RT) analyses were conducted only on correct responses. Responses that were more than 2.5 standard deviations above the corresponding cell mean were treated as outliers and replaced with the cutoff value. (Overall, 0.3% of the responses were treated as outliers.) Table 1 displays the mean RTs and error rates as a function of priming condition and stimulus type. In this table (and in the analyses below) the prime trials in the identity priming condition constitute the baseline condition against which both identity and related priming are computed.

The data were analyzed using analyses of variance (ANOVA). In each analysis, type was treated as a within-subjects and between-items factor and priming condition as a within-subjects and within-items factor. In addition, to increase the power of the analyses counterbalancing condition (in the subjects analysis) and sublist (in the items analysis) were included as nuisance variables. (Because responses to the related primes (e.g., TEACHER, CORNER, BROTHEL) are not comparable to responses to the targets, they do not factor into the analyses and hence are not reported here.)

The primary analyses involved the effects of the related primes. As is readily apparent in Table 1, responses were facilitated by morphological primes, but not by opaque or form primes. The results of the statistical analyses are consistent with this conclusion. In the RT analysis, there were significant effects of priming condition (baseline vs. related), $F_1(1,22) = 10.623$, $MS_e = 1018.170$, $p < .01$, $F_2(1,114) = 7.862$, $MS_e = 2959.098$, $p < .01$, and stimulus condition, $F_1(2,22) = 22.423$, $MS_e = 1666.126$, $p < .01$, $F_2(2,114) = 5.807$, $MS_e = 11801.181$, $p < .01$, as well as a significant interaction of priming condition and stimulus condition, $F_1(2,22) = 6.844$, $MS_e = 1550.087$, $p < .01$ $F_2(2,114) = 7.840$, $MS_e = 2959.098$, $p < .001$. Two sets of planned comparisons confirmed the basis of this interaction. One set of analyses examined the effects of priming within each stimulus condition separately.

Compared to the baseline condition, related primes facilitated responses to transparent targets ($F_1(1,22) = 50.939$, $MS_e = 624.800$, $p < .001$, $F_2(1,38) = 25.548$, $MS_e = 2663.023$, $p < .001$), but not to opaque ($F_1 < 1$, $F_2 < 1$) or form targets ($F_1 < 1$, $F_2 < 1$). Another set of comparisons contrasted the priming effects for each pair of stimulus conditions. There was significantly more priming in the transparent condition than in either the opaque or form conditions (transparent vs. opaque: $F_1(1,22) = 7.277$, $MS_e = 1641.927$, $p < .05$, $F_2(1,76) = 8.739$, $MS_e = 3043.755$, $p < .01$; transparent vs. form: $F_1(1,22) = 27.097$, $MS_e = 1072.109$, $p < .001$, $F_2(1,76) = 15.176$, $MS_e = 2726.403$, $p < .001$). In contrast, there was no difference between opaque and form priming ($F_1 < 1$, $F_2 < 1$).

An analysis of the error data revealed a similar pattern. There was a significant interaction of priming condition and stimulus type ($F_1(2,22) = 3.451$, $MS_e = 0.160$, $p < .05$, $F_2(2,114) = 3.402$, $MS_e = 0.006$, $p < .05$). Priming reduced the error rate in the transparent condition ($F_1(1,22) = 11.497$, $MS_e = 0.017$, $p < .01$, $F_2(1,38) = 8.680$, $MS_e = 0.003$, $p < .01$). In contrast, in the opaque and form conditions the error rates were numerically higher for primed targets, but in neither case was this difference significant. Finally, pairwise comparisons showed that the effect of priming was greater in the the transparent condition than in either the opaque or form conditions (transparent vs. opaque: $F_1(1,22) = 6.772$, $MS_e = 0.003$, $p < .05$, $F_2(1,76) = 8.946$, $MS_e = 0.004$, $p < .01$; transparent vs. form: $F_1(1,22) = 4.542$, $MS_e = 0.003$, $p < .05$, $F_2(1,76) = 3.276$, $MS_e = 0.006$, $p < .08$). There was no difference between opaque and form priming ($F_1 < 1$; $F_2 < 1$).

In addition to the analyses of related priming, we also conducted subsidiary analyses that were intended primarily as checks on the experimental methodology. The analysis of identity priming compared responses in the identity and baseline conditions. In the RT analysis, there was a significant effect of stimulus type in the subjects analysis, $F_1(2,44) = 5.014$, $MS_e = 1150.109$, $p < .05$, but not in the items analysis $F_2(2,114) = 1.150$, $MS_e = 7589.782$, *ns*.[ii] As expected, there a large priming effect, $F_1(1,22) = 87.429$, $MS_e = 1607.727$, $p < .001$, $F_2(1,114) = 95.189$, $MS_e = 3095.938$, $p < .001$, and most importantly, identity priming did not vary across stimulus types, $F_1(2,44) = 1.143$, $MS_e = 1080.187$, ns, $F_2 < 1$. In the analysis of the error rates, responses were significantly more accurate in the identity condition than in the baseline condition ($F_1(1,22) =15.799$, $MS_e = 0.002$, $p < .001$, $F_2(1,114) = 7.651$, $MS_e = 0.656$, $p < .01$), but neither the effect of stimulus type ($F_1(1,22) =1.520$, $MS_e = 0.003$, *ns*, $F_2 < 1$) nor the interaction of type and priming condition ($F_1(2,22) =1.708$, $MS_e = 0.001$, *ns*, $F_2 < 1$) was significant. In sum, these results suggest that identity priming has a similar effect on the recognition of targets in all three stimulus conditions, providing further assurance that the difference in the effects of transparent and opaque primes did not arise because the transparent targets were for some reason generally easier to prime.

The final set of analyses examined semantic priming. The 6 ms difference between the mean RTs in the related and baseline condition did not approach significance, ($F_1 < 1$, $F_2 < 1$). Similarly, semantic priming did not reduce the error rate—indeed, numerically there were more errors in the related condition, although this difference was not statistically reliable ($F_1(1,22) =1.664$, $MS_e = 0.001$, *ns*, $F_2(1,38) = 1.281$, $MS_e = 0.002$, *ns*). Thus, there was no hint that semantic priming influenced responses.

[ii] In the baseline condition, responses were slowest for form targets and fastest for transparent targets. The same pattern was found by Rastle et al. (2004), where the differences were more pronounced.

Discussion

The results of Experiment 1 are clear. Long-term priming facilitated responses in the transparent condition (TEACHER-TEACH), but not in the opaque (CORNER-CORN) or form (BROTHEL-BROTH) conditions. Thus, although the evidence from masked priming suggests that the word recognition process treats semantically opaque words as if they are morphologically structured, the present results point to the opposite conclusion. It is noteworthy that there was no evidence of long-term semantic priming in the first experiment, because it has been suggested that the effect of semantic transparency under certain masked priming conditions (e.g., with sufficiently long prime durations) can be attributed to the influence of semantic processes that also give rise to semantic priming (Rastle & Davis, 2003). In Experiment 1 priming was modulated by semantic transparency even though there was not a hint of semantic priming.

Experiment 2

The primary purpose of Experiment 2 was to replicate and extend the results of the first experiment. In addition, we took this experiment as an opportunity to explore the effects of nonword context on morphological priming. While it is well-established that lexical decisions to real words can be influenced by the properties of the nonword foils presented over the course of an experiment (e.g., Grainger& Jacobs, 1996; Pugh, Rexer, & Katz, 1994; Stone & Van Orden, 1993), the influence of nonword context on morphological effects in word recognition has not been systematically studied. However, a recent finding by Taft (2004) is suggestive in this regard. Taft observed that the effect of the frequency of a word's root morpheme differed depending on the structure of the nonwords presented during the experiment. All else being equal, lexical decisions were faster for words with higher-frequency root morphemes in a context of affixed pseudowords— pseudowords comprised of attested affixes and pseudoroots (e.g., KOSSLED, JESHED). In contrast, root frequency and response latency were positively correlated in the context of nonwords formed by novel combinations of extant roots and affixes (e.g., KETTLED, REDLY). (Following Longtin and Meunier, we will refer to these as "non-interpretable morphological pseudowords".) Thus, in Taft's experiment nonword context reversed the effects of a morphological variable (root frequency).

In the first experiment some of the nonwords were affixed pseudowords (e.g., JESHED) but none had the quasimorphological structure of nonwords such as KETTLED. In Experiment 2 we asked whether the inclusion of non-interpretable morphological pseudowords would change the pattern of results. In particular, given that the structure of these nonwords mirrors that of semantically opaque words such as CORNER, it is not implausible to suppose that the processing of opaque words would be particularly affected by the presence of quasimorphological nonwords. One might imagine that the inclusion of quasimorphological nonwords would encourage morphological parsing and thus give rise to more facilitation from opaque primes than was observed in Experiment 1. Alternatively, perhaps parsing a non-interpretable morphological pseudoword incurs a cost that also extends to semantically opaque words, giving rise to an inhibitory priming effect in that condition. At this point, it is not clear that any theory is sufficiently developed to yield a specific prediction about these circumstances. Thus, we note these possibilities as an indication that the inclusion of quasimorphological nonwords in Experiment 2 could create circumstances that bring out effects of the apparent morphological structure of semantically opaque words.

Method

Participants—The participants were 24 undergraduate students enrolled in an introductory psychology course at the University of Connecticut who participated for course credit. All were native speakers of American English.

Design and Materials—The primary difference between Experiments 1 and 2 involved the structure of the nonwords. The stimuli in Experiment 1 included 104 pairs of nonwords. The 52 affixed pseudoword pairs were constructed by appending an English suffix to a monosyllabic pseudoword (e.g., JESHED-JESH). The 52 non-morphological pseudoword pairs were constructed by adding a non-morphemic letter sequence to each base form (e.g., CAFTEL-CAFT). In Experiment 2 the affixed pseudoword pairs (e.g., JESHED-JESH) were replaced with non-interpretable morphological pseudowords such as KETTLED and REDLY. There were 104 of these nonwords, 56 of which were taken from Taft (2004) with the remaining 48 constructed by us. It should be noted that the "roots" of the non-interpretable pseudowords were not presented as word targets at any point in the experiment. Thus, the participants saw the nonwords KETTLED and REDLY, but not the words KETTLE and RED.

The only other change in the method was that four non-interpretable morphological pseudowords were presented during the block of 20 practice trials. In all other respects, the design, materials, and procedure of Experiment 2 were identical to those of Experiment 1.

Results

The results of the second experiment are displayed in Table 2. The data were analyzed in the same manner as the previous experiment.

The primary analyses examined the effects of related primes. In the RT analysis, there were significant effects of priming condition ($F_1(1,22) = 13.913$, $MS_e = 1702.626$, $p < .01$; $F_2(1,114) = 3.438$, $MS_e = 3775.351$, $p = .07$), and stimulus condition, ($F_1(2,22) = 18.402$, $MS_e = 1702.626$, $p < .001$; $F_2(2,114) = 9.744$, $MS_e = 11420.308$, $p < .001$). The interaction of priming condition and stimulus condition was significant in the items analysis $F_2(2,114) = 5.211$, $MS_e = 3775.351$, $p < .01$ and approached significance in the subjects analysis, $F_1(2,22) = 2.112$, $MS_e = 1702.626$, $p = .13$. Planned comparisons examined the effects of priming within each stimulus condition separately. Compared to the baseline condition, related primes facilitated responses to transparent targets ($F_1(1,22) = 13.251$, $MS_e = 1442.947$, $p < .01$, $F_2(1,38) = 14.670$, $MS_e = 2598.026$, $p < .001$), but opaque primes had no effect of response times ($F_1 < 1$, $F_2 < 1$). Somewhat surprisingly, responses to primed form targets were 21 ms faster than in the baseline condition—a difference that approached significance in both analyses ($F_1(1,22) = 3.049$, $MS_e = 1674.422$, $p = .09$, $F_2(1,38) = 2.808$, $MS_e = 4436.215$, $p = .10$). The pairwise comparisons confirmed that there was significantly more priming in the transparent condition than in the opaque condition ($F_1(1,22) = 4.54$, $MS_e = 1648.420$, $p < .05$, $F_2(1,76) = 4.679$, $MS_e = 3483.369$, $p < .05$). In contrast, the priming effect in the form condition was not significantly different from the effects in either the transparent condition or the opaque condition (form vs. transparent: $F_1(1,22) = 1.428$, $MS_e = 1563.984$, *ns*, $F_2 < 1$; form vs. opaque: $F_1 < 1$, $F_2(1,76) = 1.120$, $MS_e = 4452.464$, *ns*).

With regard to accuracy, the mean error rate was numerically lower when the target words were preceded by related primes (see Table 2). However, the main effect of priming condition was not significant, nor was the effect of stimulus type or the interaction of these variables.

Turning to the subsidiary analyses, the effect of identity priming in this experiment was similar to that in Experiment 1. Responses were faster for repeated words than for unprimed words ($F_1(1,22) = 112.734$, $MS_e = 1518.533$, $p < .001$, $F_2(1,114) = 93.188$, $MS_e = 3751.938$, $p < .001$), and the effect of stimulus type was significant in the subjects analysis ($F_1(2,44) = 8.266$, $MS_e = 1518.533$, $p < .01$) and approached significance in the items analysis ($F_2(2,114) = 2.374$, $MS_e = 8442.465$, $p = .09$). Critically, the interaction of priming condition and stimulus type was not significant ($F_1 < 1$, $F_2 < 1$). Similarly, error rates were lower for repeated words than for unprimed words ($F_1(1,22) = 13.410$, $MS_e = 0.002$, $p < .001$, $F_2(1,114) = 12.606$, $MS_e = 0.003$, $p < .001$), the effect of stimulus type approached significance in the subjects analysis ($F_1(2,44) = 2.976$, $MS_e = 0.003$, $p = .06$; $F_2(2,114) = 1.044$, $MS_e = 0.015$, *ns)*, and most importantly, the interaction of priming condition and stimulus type was not significant ($F_1 < 1$, $F_2 < 1$).

The analyses of the semantic priming results yielded a somewhat surprising finding. As can be seen in Table 2, responses were 19 ms faster when the targets in the semantic condition were preceded by a related word than when they were not. This difference is statistically significant by subjects ($F_1(1,22) = 4.581$, $MS_e = 949.748$, $p < .05$) but not by items ($F_2(1,38) = 1.956$, $MS_e = 3632.482$, $p = .17$). The difference in error rates was not significant ($F_1 < 1$, $F_2 < 1$). While this pattern of results may not support a strong conclusion about long-term semantic priming, it does suggest that the presence of non-interpretable morphological pseudowords in the experimental context might create an experimental condition that gives rise to long-term semantic priming. (See Joordens & Becker, 1997, for a related discussion.)

Finally, to get some indication of whether the structure of the non-interpretable morphological pseudowords influenced the participants, we examined response times and error rates for the complex pseudowords. On average, correct responses to non-interpretable morphological pseudowords (e.g., KETTLED) took 940 ms and the error rate was 28%, whereas the mean RT for non-morphological pseudowords (e.g. CAFTEL) was 838 ms and the error rate was 10%. For comparison, in Experiment 1 the means for the non-morphological pseudowords were 771 ms and 7% and the means for the affixed pseudowords (e.g. JESHED) were 793 ms and 7%. Thus, as reported by Taft (2004), the lexicality of non-interpretable morphological pseudowords is relatively difficult for participants to determine. However, whereas Taft found that manipulating the pseudoword context changed the pattern of responses to real words in a qualitative manner, in the present study nonword context had no effect on the primary finding (i.e., the dissociation between priming in the transparent and opaque conditions), and although there was the suggestion of some intriguing differences between the experiments (e.g. in terms of semantic priming), these differences were weak and not statistically reliable.

General Discussion

The purpose of this study was to investigate the effect of semantic transparency on long-term morphological priming. Our results clearly indicate that long-term morphological priming is modulated by semantic transparency: In both experiments responses were facilitated by morphologically related primes that shared semantically transparent relationships with their targets (e.g., TEACHER-TEACH), but not by semantically unrelated words that shared apparent morphological relationships (e.g., CORNER-CORN). In the first experiment, the semantically opaque primes patterned with the form-related primes: In contrast to the transparent condition, there was no hint of facilitation from either opaque or form primes. In the second experiment (in which the words were presented in a context of quasimorphological nonwords), the relationship between the effects of opaque and form primes was less clear-cut. Again there was no evidence of facilitation from opaque primes.

However, while the effect of the form primes was not significant, there was a numerical trend suggesting that form primes facilitated responses in this nonword context.

In conjunction with the results of several previous studies, our results reveal that masked and long-term morphologically priming differ in their sensitivity to semantic transparency. In a number of masked priming experiments (e.g., Rastle et al., 2004; Longtin et al, 2003), semantically transparent and semantically opaque primes have had equivalent effects. However, in the present experiments, which examined long-term priming, they did not. This contrast is particularly interesting because, as noted in the Introduction, masked- and long-term priming are similar in several important respects. Both forms of priming are thought to index the operation of early, modality-specific components of the word recognition process, and both are thought to be largely insensitive to processes that are concerned with word meaning. (However, for both measures there are boundary conditions on this indifference to semantic processes. In the case of masked priming, the influence of semantic processes (as indexed by semantic priming) grows as the duration of the prime increases (Rastle et al., 2000). In the case of long-term priming, the results of Experiment 2 suggest that the long-term semantic priming can be observed given certain nonword contexts; also see Joordens & Becker, 1997.)

Thus, a challenge for theories of word recognition is to explain the differential effects of semantic transparency on masked and long-term morphological priming. One possibility is that morphological structure is captured at more than one level of representation and that the two forms of priming are differentially sensitive to processes occurring at these different levels. The idea that morphological structure might be relevant to more than one level of representation does not seem to be particularly contentious—advocates of a variety of otherwise competing accounts have acknowledged this possibility (e.g., Diependaele et al., 2005, Rastle & Davis, 2003; Rueckl & Galantucci, 2005). However, given the similarities between masked and long-term priming noted above, the hypothesis that these forms of priming index processes at *different* pre-semantic, modality-specific levels of representation seems unappealing.

A more plausible account is that masked and long-term priming are the consequence of different processing mechanisms that operate at the same level of representation. Indeed, for both the decompositional and connectionist approaches, candidate mechanisms have already been proposed to account for other findings. In decompositional models (e.g., Rastle et al., 2004; Taft, 1994), short-term (e.g., masked) priming effects are generally attributed to a transient change in the activation of the representation of the target word (or its morphemes) that results from the processing of the prime. Residual activation might also be used to account for long-term priming, but a perhaps more plausible account involves a change in either the threshold (Morton, 1979) or baseline activation (Bowers, 1996) of the relevant representations. In the connectionist approach, short-term priming is also modeled as an effect of the residual activation that results from the processing of the prime (Plaut & Gonnerman, 2000; Harm & Seidenberg, 2004), although according to this account the effect of the prime is to partially activate the pattern of activation (rather than the single processing unit) that represents the target word. Long-term priming, in contrast, is considered to be a manifestation of the learning process that adapts the network's pattern of connectivity to the regularities in its environment (McClelland & Rumelhart, 1986; Rueckl, 2002).

Thus, both the decompositional and connectionist frameworks are already equipped with theoretical constructs that could conceivably explain why masked priming is indifferent to semantic transparency but long-term priming is not. However, further development of each account will be needed to fully evaluate the adequacy of these explanations. The key question for the decompositional account concerns why there is no long-term priming for semantically opaque prime-target pairs. On occasion semantic transparency has modulated masked priming (e.g., when the prime duration is relatively long—Rastle et al., 2000) and it has been suggested that under these circumstances the effect of semantic transparency arises from semantic-level processes that either add to or mask the effects of priming at the level of pre-lexical (and pre-semantic) morphological representations (Rastle & Davis, 2003). However, this sort of account does not appear to be a viable explanation of the present results—especially those of Experiment 1, where there was no hint of a long-term semantic priming effect.

This leaves the question of why CORNER primes CORN in masked priming experiments but not long-term priming experiments. One possibility is that this difference is related to the fact that in masked priming experiments the primes are not fully identified but in long-term priming paradigms they are. For example, to explain the masked priming results, the decompositional account assumes that the representation of the morpheme CORN is initially activated when a reader sees the word CORNER. Perhaps when the word CORNER is fully identified, the fact that CORNER and CORN are semantically unrelated triggers a process that deactivates the morpheme CORN. This deactivation process could explain why CORNER does not prime CORN in the long term, but the assumption that such a process exists raises other issues. One issue concerns the computational function served by the deactivation process. Presumably, if a deactivation process occurs it occurs because there is a processing cost associated with the activation of units representing semantically unrelated morphemes. Yet, evidence of such a processing cost is weak at best (see Henderson, 1985, for an extended discussion). Another issue for this account concerns the nature of the learning mechanism that establishes the morphological representations in question. The decompositional account as described here decouples the mechanisms responsible for learning and for long-term priming.[iii] While this sort of decoupling is certainly not without its advocates (e.g., Morton, 1979; Bowers, 1996), there are a number of reasons to suppose that the same process underlies priming and other manifestations of learning (Rueckl, 2002). But even if the assumption that different mechanisms underlie long-term priming and learning is granted, the decompositional account is not yet sufficiently developed to explain whether the mechanism invoked to explain long-term priming serves any computational purpose other than to explain long-term priming results, or whether a learning process that creates representations of form without regard to semantic considerations can give rise to a computational device that behaves like skilled readers.

While the primary challenge for the pre-lexical decomposition model is to explain why transparent and opaque words sometimes give rise to different behavioral effects, the main issue for the connectionist approach is to explain why they sometimes do not. Simulations of connectionist networks have demonstrated that as a network learns the mapping between orthographic and semantic representations, its pattern of connectivity (and hence, its behavior) is shaped by morphological regularities (Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999). This influence of morphological structure on the network's organization is a consequence of the fact that the weight changes resulting from each learning experience are superimposed on the same set of connections. Given the kinds of activation and learning functions that are typically used and the assumption that words that are similar in spelling or meaning will be represented by similar patterns of activation over the corresponding (orthographic or semantic) layer, the weight changes that are made as the result of learning

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[iii] By 'learning' here we mean the process that results in the creation on new lexical representations. Although adjustments in thresholds or baseline activation values could be seen as learning in the sense that these adapt a reader to his or her environment, these sorts of mechanisms entail that lexical representations already exist, and thus activation accounts of decouple priming from the processes involved in the acquisition of new representations.

about one word will have largely (although not entirely) beneficial effects on the subsequent processing of other words that are similar in both spelling and meaning (Rueckl, 2002).

Because morphological effects arise in this way, they should be graded by semantic (and orthographic) similarity. A simulation by Plaut and Gonnerman (2000) illustrates this point. Plaut and Gonnerman trained a network with a corpus of words that were meant to capture key characteristics of English morphology, including in particular the fact that morphologically complex words vary in semantic transparency. They then tested their network using a (short-term) morphological priming paradigm with complex words as primes and root words as targets. The degree to which the prime facilitated settling time (the network equivalent of reaction time) was a function of semantic similarity: transparent primes (TEACHER-TEACH) resulted in the most facilitation, moderately related primes (DRESSER-DRESS) had moderate effects, and opaque primes (CORNER-CORN) neither facilitated nor inhibited the processing of their targets. In addition to illustrating the graded nature of morphological effects in connectionist network, these findings also capture the behavioral results reported by Gonnerman (1999), who investigated morphological priming using a cross-modal paradigm with a stimulus-onset asynchrony (on the order of several hundred milliseconds). In the present context, however, Plaut and Gonnerman's simulation results raise the question of whether a network will exhibit the indifference to semantic transparency observed in masked priming experiments.

While a definitive answer awaits further development of the model, there is reason to think that a network might exhibit this pattern if the primes are presented for a shorter duration than was the case in the Plaut and Gonnerman simulations. First, in the masked-priming paradigm the activation generated by the prime has a limited opportunity to propagate through the network. Thus, the locus of masked-priming effects is primarily in the early part of the network (the hidden units in the Plaut & Gonnerman network, and the "orthographic" units in the broader theory—see Rueckl & Seidenberg, in press). This would tend to mitigate the effects of semantic transparency, as the earlier layers of the system will tend to be influenced more (but not exclusively) by orthographic similarity. (See Harm et al., 2003, and Plaut et al.,1996, for simulations demonstrating this principle in a related task—mapping orthography to phonology). Second, the temporal dynamics of the flow of activation within a network exhibits both cooperative and competitive components. That is, the forces that pull the network towards the pattern of activation representing the *prime* include both components that pull the network towards the representation of the *target* (because similar words are represented by similar patterns of activation) and components that pull the network *away* from the target representation (because similar words are not represented by *identical* patterns of activation). These forces have different temporal dynamics, and based on simulations of other phenomena, it can be expected that in the case of semantically opaque primes, the cooperative (facilitative) forces would have the earlier effect (Raveh, 2002). Conceivably the result would be that transparent and opaque primes would have equivalent effects under the conditions of a masked priming study, although we acknowledge that further development will be needed to determine whether this is actually the case.

Another open question for the connectionist approach concerns differences in long-term priming across language. The present results demonstrated that semantic transparency modulates long-term morphological priming in English. Drews and Zwitserlood (1995) reported a similar result in a study of long-term priming in German. In contrast, Bentin and Feldman (1990) found that semantic transparency had no effect on long-term morphological priming in Hebrew. There are some methodological considerations that make us somewhat hesitant about relying too heavily on this result. (E.g., There were only 4 items per condition per subject, which suggests that the experiment had relatively little power to detect a difference between the transparent and opaque conditions.) This being said, morphological effects in Hebrew and English appear to differ on a number of other dimensions as well, and it has been argued that these differences are a consequence of differences in the morphological "complexity" (Frost et al., 2005) or "richness" (Plaut & Gonnerman, 2000) of these languages. Given this, it is not implausible that the effect of semantic transparency on long-term priming would differ as well.

The Plaut and Gonnerman (2000) study cited above provide some evidence that the connectionist approach can account for these language-related differences. As an added wrinkle, they compared the behavior of a network trained on a morphologically impoverished (English-like) vocabulary with one that learned a morphologically rich (Hebrew-like) training set. They found that (short-term) morphological priming was modulated by semantic transparency in both networks, but priming effects were generally stronger for the Hebrew-like language, and whereas opaque primes had no effect on the network trained on the English-like language, they did facilitate settling times for the network trained on the morphologically rich training set. These results do not in themselves demonstrate that the connectionist approach can explain the apparent difference in the effect of semantic transparency on long-term morphological priming in English (or German) and Hebrew, but they do suggest an avenue for the future development of the theory.

In sum, the results reported here provide definitive evidence that long-term morphological priming (in English) varies with semantic relatedness. Responses were facilitated by semantically transparent, morphologically related primes (TEACHER-TEACH), but not by semantically unrelated primes that have the orthographic structure of a morphological relative (CORNER-CORN). The conjunction of this finding and the fact that transparent and opaque primes are often equally facilitative in masked priming experiments poses a challenge for both decompositional and connectionist accounts. Possible ways for each approach to address this challenge were discussed.

Before ending, two additional aspects of the results deserve further consideration. First, while our experiments yielded definitive evidence that semantically transparent primes facilitated responses more than semantically opaque primes, it would be premature to conclude that the apparent morphological structure of words like CORNER is irrelevant to the process that gives rise to long-term priming. In Experiment 1, there was no hint of an effect of either semantically opaque primes like CORNER or form-related primes like BROTHEL. However, the results of Experiment 2 suggest that the word identification process may differ somewhat for the opaque and form-related primes—although the effect of semantically opaque words was negligible, there was some suggestion (albeit a non-significant trend) that the form-related primes facilitated the recognition of their targets. Given that this effect was not statistically reliable, and given too it is not clear why the change in nonword context from Experiment 1 to Experiment 2 might promote priming in the form-related condition, we believe that whether long-term priming differs in the opaque and form-related conditions is still an open question.

The final point we wish to consider involves the nonword-context manipulation. Although this sort of manipulation has sometimes been used to study the processes involved in phonological recoding (Pugh et al., 1994; Stone & Van Orden, 1993), the effect of the nonword context has received little consideration in experiments concerned with morphology. One exception is the study by Taft (2004), who showed that the effect of root-morpheme frequency depends on the kind of nonwords presented during the experiment. Taft concluded that the presence of non-interpretable morphological nonwords (e.g., JUMPEST) places more emphasis on a recombination process that occurs after a word has been decomposed into its constituent morphemes, and that high-frequency roots facilitate the decomposition process but slow the recombination process. In the present experiments, there were no statistically reliable effects of the nonword context manipulation on responses to the target words. However, there were several intriguing numerical trends: As noted in the previous paragraph, there was some evidence of form-related priming in the second experiment but not the first, and perhaps most strikingly, there was some evidence of long-term semantic priming in the context of quasimorphological nonwords. Because these trends were not statistically significant, we do not wish to speculate at this point about precisely how a reader adapts to different nonword contexts. However, we do wish to note that these results suggest that the nonword-context manipulation could prove to be a useful tool for investigating the role of morphology in reading. We also wish to note that even if the structure of the nonwords is not manipulated, these results highlight the importance of fully considering, and adequately reporting, the characteristics of the nonwords presented during a lexical decision experiment.

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Appendix

Transparent Words (Experiments 1 and 2)

ACIDIC/ACID, ACREAGE/ACRE, ADOPTED/ADOPT, AGREEMENT/AGREE, ALARMING/ALARM, ANGELIC/ANGEL, BARELY/BARE, BEARDED/BEARD, BOMBER/BOMB, CRITICAL/CRITIC, DIETARY/DIET, DREAMER/DREAM, EMPLOYER/EMPLOY, ERUPTION/ERUPT, FILLING/FILL, FIZZLE/FIZZ, FLOATER/FLOAT, GOLFER/GOLF, GOVERNMENT/GOVERN, GREENER/GREEN, HEIGHTEN/HEIGHT, KINGDOM/KING, LEGENDARY/LEGEND, LOUDNESS/LOUD,

MOURNER/MOURN, NAMELESS/NAME, NORTHERN/NORTH, POETRY/POET, QUIETLY/QUIET, REACTION/REACT, RENEWABLE/RENEW, SCALDING/SCALD, SEEKING/SEEK, SOFTLY/SOFT, SUITABLE/SUIT, TEACHER/TEACH, TOASTER/TOAST, TRAINEE/TRAIN, WEARING/WEAR, WIDOWED/WIDOW

Opaque Words (Experiments 1 and 2)

ACCORDION/ACCORD, AMENABLE/AMEN, ARCHER/ARCH, AUDITION/AUDIT, BOUNDER/BOUND, BRISKET/BRISK, BUZZARD/BUZZ, CORNER/CORN, COURTEOUS/COURT, CROOKED/CROOK, CRYPTIC/CRYPT, DEPARTMENT/DEPART, DISCERN/DISC, FACETIOUS/FACET, FLEETING/FLEET, FLICKER/FLICK, FOUNDATION/FOUND, GINGERLY/GINGER, GLOSSARY/GLOSS, GRUELING/GRUEL, HELMET/HELM, INFANTRY/INFANT, INVENTORY/INVENT, MASSAGE/MASS, MASTER/MAST, NUMBER/NUMB, ORGANIC/ORGAN, PIGMENT/PIG, PLANET/PLAN, PORTLY/PORT, QUESTION/QUEST, RATIONAL/RATION, SECRETARY/SECRET, SHOWER/SHOW, SIGNET/SIGN, SNIPER/SNIP, SPLINTER/SPLINT, TROLLEY/TROLL, TRUMPET/TRUMP, WHISKER/WHISK

Form Words (Experiments 1 and 2)

BANDIT/BAND, BREADTH/BREAD, BROTHEL/BROTH, BUTTON/BUTT, CANDIDACY/CANDID, COLONEL/COLON, COMMAND/COMMA, DEMONSTRATE/DEMON, ELECTRIC/ELECT, EXTRACT/EXTRA, FORCEPS/FORCE, FREEZE/FREE, FUSELAGE/FUSE, GALAXY/GALA, HARMONY/HARM, LABORATORY/LABOR, MARKET/MARK, MOMENTUM/MOMENT, PARENTHESIS/PARENT, PLAINTIFF/PLAIN, PROPERTY/PROPER, PULPIT/PULP, SALMONELLA/SALMON, SINGLE/SING, SKILLET/SKILL, SMUGGLE/SMUG, SPINACH/SPIN, STAMPEDE/STAMP, STARTLE/START, STIRRUP/STIR, STUBBORN/STUB, STUDIO/STUD, SURFACE/SURF, SURGEON/SURGE, TAILOR/TAIL, TRICKLE/TRICK, TWINKLE/TWIN, VILLAIN/VILLA, WITCH/WIT, YELLOW/YELL

Semantically Related Words (Experiments 1 and 2)

SUM/ADD, CHIME/BELL, FIRE/BLAZE, ECSTASY/BLISS, GLOAT/BRAG, TAXI/CAB, FINISH/CEASE, FAMILY/CLAN, WASH/CLEAN, CATTLE/COW, CRADLE/CRIB, PLATE/DISH, NURSE/DOCTOR, PLIERS/DRILL, INGEST/EAT, DONATE/GIVE, HAPPY/GLAD, SHEEP/GOAT, MOUNTAIN/HILL, BLUES/JAZZ, BARREL/KEG, CIRCLE/LOOP, DESIRE/LUST, CREAM/MILK, CROWD/MOB, DOLLAR/MONEY, ENGINE/MOTOR, SLOGAN/MOTTO, CUP/MUG, SPIKE/NAIL, STROKE/PAT, HANDBAG/PURSE, MOUSE/RAT, CEILING/ROOF, DOLPHIN/SHARK, BEACH/SHORE, SAUNA/SPA, CITY/TOWN, JUNK/TRASH, HORNET/WASP

Non-Morphological Pseudowords (Experiments 1 and 2)

AUSPONTRA/AUSPON, BALVEM/BALVE, BEELT/BEEL, BLIDON/BLID, CAFTEL/CAFT, CHUBEL/CHUBE, CLISST/CLISS, CUSKIT/CUSK, EGONIP/EGON, EIVERLIN/EIVER, FETEL/FET, FOPEK/FOPE, GRINESH/GRINE, HAMEM/HAME, JIMPLOR/JIMP, LEBIN/LEB, LENCELT/LENCE, LIRTIM/LIRT, LOCURPS/LOCUR, LURVEX/LURVE, LUTHIN/LUT, MIRTUS/MIRT, NOOMIS/NOOM, NORFRAN/NORF, NOUTROW/NOUT, NUPPITE/NUPP, NUVLE/NUV, ORDIFRO/ORDIF, PELP/PEL, PLAWN/PLAW, PLICKOL/PLICK, PLORTLEW/PLORT, QUONTIS/QUONT, RARF/RAR, RUNKIR/RUNK, SHULEC/SHULE, SLOMPIT/SLOMP, SMISTOCH/

SMIST, SORNIN/SORN, STRIND/STRIN, TADEO/TADE, TALART/TALA, THEEKIN/THEEK, TRAVEK/TRAVE, TULOP/TUL, VAPEM/VAPE, VARFLOO/VARF, VOLLMER/VOLL, VORET/VORE, WOOPON/WOOP, ZABELTH/ZABEL, ZARDNIP/ZARD

Affixed Pseudowords (Experiments 1)

AINER/AIN, ALGOWIAN/ALGOW, BISTS/BIST, BRINS/BRIN, CHIRS/CHIR, COSKS/COSK, DERISM/DER, DESHED/DESH, DRILES/DRILE, DUPLY/DUP, FETHS/FETH, FIPED/FIP, FOATS/FOAT, FONGIST/FONG, GARS/GAR, GOAMED/GOAM, GRACTED/GRACT, HINS/HIN, JESHED/JESH, JILMS/JILM, LARS/LAR, LERMISH/LERM, LINGS/LING, LONDER/LOND, MILNS/MILN, NARMED/NARM, NARS/NAR, NIDLY/NID, NOLTS/NOLT, PARBES/PARB, PRUTES/PRUTE, RABS/RAB, RILMS/RILM, SARDED/SARD, SEFER/SEF, SHABED/SHABE, SHAMPER/SHAMP, SILER/SILE, SLIGED/SLIG, SMOLED/SMOL, STENED/STEN, SUKED/SUKE, TISHER/TISH, TOLTS/TOLT, TUPED/TUP, VADES/VADE, VISKED/VISK, VOOKS/VOOK, WEFER/WEF, WERFED/WERF, YICTLY/YICT, ZINTS/ZINT

Non-Interpretable Morphological Pseudowords (Experiments 2)

BAKEFUL, BARLEYS, BARNING, BIGLY, BUSHISH, BUYED, CATTLES, CHESSES, CHILDS, CIGARED, CLAIMLY, CLAYERN, COSTISH, CURBEST, CUTFUL, DAMPS, DEPTHING, DIRTED, DOUBLEST, FAITHOUS, FEWLY, FIVELY, FOGFUL, FORTUNING, FRAILING, FRESHES, FRICTIONS, FRIDGING, FUNS, FURNITURES, FUZZIES, GAINLY, GIANTLY, GIRLING, GLOWLY, GOLDED, GRAPING, HAIRISH, HEALTHS, HEARTING, HITTED, INFLUENZAS, ISLANDED, JOBFUL, JOINOUS, JOYING, JUMPEST, KETTLED, LEFTING, MAKED, MIRTHS, MUSICS, OFTENLY, OLDING, OXYGENS, PALACED, PATHING, PLENTIES, PROSES, PROUDING, REDLY, RIVERING, SADS, SATINS, SHEEPS, SHYERN, SILVEREST, SOUPING, SPEECHING, STOCKOUS, STOUTING, SUMNESS, SUNFUL, SWEEPED, SWIMMINGS, TARTED, TAXNESS, THEFTED, TRIBED, TROUTS, VASTING, WOOLS, WRISTING, YEARING

Table 1

Mean response times (in milliseconds), error rates (% errors) and priming effects in Experiment 1.

	Stimulus Condition							
	Transparent		Opaque		Form		Semantic	
Priming Condition	**RT**	**% Error**	**RT**	**% Error**	**RT**	**% Error**	**RT**	**% Error**
Baseline	650	5.6	668	6.3	675	5.8	642	2.3
Identity	591	1.5	613	4.8	601	3.3	591	1.7
Related	598	1.9	664	8.8	678	6.7	636	3.5
Priming effect								
Identity	59	4.2	55	1.5	74	2.5	50	0.6
Related	52	3.8	3	−2.5	−3	−0.8	6	−1.3

Table 2

Mean response times (in milliseconds), error rates (% errors) and priming effects in Experiment 2.

	Stimulus Condition							
	Transparent		**Opaque**		**Form**		**Semantic**	
Priming Condition	**RT**	**% Error**	**RT**	**% Error**	**RT**	**% Error**	**RT**	**% Error**
Baseline	660	5.0	696	7.5	691	6.5	651	3.3
Identity	599	1.9	615	4.2	613	5.2	594	2.1
Related	620	3.5	691	6.3	670	5.6	632	2.9
Priming effect								
Identity	61	3.1	81	3.3	78	1.3	57	1.3
Related	40	1.5	5	1.3	21	0.8	19	0.4