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Are Morphological Effects Distinguishable From the Effects of Shared Meaning and Shared Form?

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Effects of orthographically and semantically related primes were compared with morphologically related primes in an immediate (Experiment 1) and a long-term (Experiment 2) lexical decision task. Morphological relatedness produced facilitation across a range of prime durations (32–300 ms) as well as when items intervened between prime and target, and its magnitude increased with prime duration. Semantic facilitation and orthographic inhibition arose only in the immediate priming task. Moreover, morphological effects were significantly greater than the sum of semantic and orthographic effects at a stimulus onset asynchrony of 300 ms but were not reliably different at shorter durations. The adequacy of an account that describes morphological relatedness as distinct from the composite effects of semantic and orthographic similarity must account for changes in additivity across prime durations.

Morphologically related words are regularly formed from a common base (or root) morpheme but differ with respect to the affixes (prefixes, suffixes) that are appended to it. In a variety of languages (e.g., Serbian[1]: Feldman, 1994; Hebrew: Bentin & Feldman, 1990; English: Feldman, 1992; Fowler, Napps, & Feldman, 1985; Stanners, Neiser, Hernon, & Hall, 1979; and American Sign Language: Hanson & Feldman, 1989) and in a variety of word recognition tasks, prior exposure to a morphological relative can facilitate processing of a target word. Morphological facilitation as a result of a shared base morpheme also arises under a variety of presentation conditions. For example, it occurs when the prime or target is presented auditorily (e.g., Fowler et al., 1985; see also Emmorey, 1989; Kirsner, Milech, & Standen, 1983; Marslen-Wilson, Tyler, Waksler, & Older, 1994) or when targets are preceded by primes with forward masks (e.g., Deutsch, Frost, & Forster, 1998; Forster, Davis, Schoknecht, & Carter, 1987; Frost, Forster, & Deutsch, 1997). Because regular relatives are, by definition, formed from a common morphemic unit, morphological relatedness necessarily entails some degree of similarity with respect to form and meaning.

Investigators of morphological processing (e.g., Murrel & Morton, 1974) sometimes contrast effects of shared morphology with effects of shared orthographic and phonological form (overlap) in the absence of morphological relatedness. Analogously, investigators (Henderson, Wallis, & Knight, 1984) sometimes contrast effects of a shared base morpheme with those resulting from semantic similarity between words. As is evident from inspection of Table 1, however, studies in which effects of shared form and shared meaning have been contrasted concurrently with effects of morphological relatedness are relatively rare.

In the present study, conducted with English materials, I contrast morphological effects with the effects of shared meaning and shared form. Accordingly, within each experiment, there are three dimensions of similarity (orthographic, semantic, morphological) that primes can share with targets. Incorporating three types of similarity for the same target within a single experiment makes it possible to compare magnitudes of facilitation for the various dimensions of similarity. As the review of the literature reveals, it is also the case that the effects of orthographic and semantic similarity appear to differ in the long- and short-term (immediate) priming tasks. Therefore, across experiments, I examine both long and short-term priming effects. Moreover, within the immediate priming task, I vary the temporal relation between visual prime and visual target. A manipulation of processing time for the prime has the potential to reveal the time course over which effects of various dimensions of similarity occur.

To motivate the present study, I summarize the experimental literature that contrasts the effects of either semantic or orthographic similarity with morphological relatedness.

Morphological and Semantic Relatedness Contrasted

Morphologically related words typically share a base morpheme. These bases are meaningful. It follows that two words that are morphologically related tend to have similar meanings. It is possible, therefore, that facilitatory effects obtained when morphologically related primes precede targets could reflect the semantic relationship between prime and target. In a recent exposition of morphological facilitation, Frost et al. (1997) examined this interpretation. Using a forward-masking paradigm with a visual lexical decision task for Hebrew materials, Frost et al. (1997) elegantly

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[1] At the time of publication, we referred to this language as Serbo-Croatian.

Table 1
Studies Contrasting Morphological Facilitation With Orthographic or Semantic Facilitation

Experiment	Difference in target RT: morphological vs. Orthographic	Difference in target RT: morphological vs. Semantic	Task and prime duration/lag
Bentin & Feldman (1990)[a]		−4 ms	LD, Lag 0
		−28 ms	LD, LT
Deutsch, Frost, & Forster (1998)[b]	−13 ms (Exp. 3)		LD, FM 42 ms
	−9 ms (Exp. 3)		NAM FM 42 ms
Drews & Zwitserlood (1995)[c]	−83 ms (Exp. 2A)		LD, 300 ms
	−73 ms (Exp. 4C)		LD, FM
	−34 ms (Exp. 2B)		LD, FM 66 ms
Feldman & Andjelković (1992)[d]	−40 ms		LD, LT
Feldman & Moskovljević (1987)[e]	−24 ms (Exp. 2)		LD, LT
Frost, Forster, & Deutsch (1997)[f]	−13 ms (Exp. 2)		LD, FM 50 ms
Grainger, Colé, & Segui (1991)[g]	−35 ms (Exp. 2)		LD, FM
Hanson & Wilkenfeld (1985)[h]	−6 ms		LD, LT
Henderson, Wallis, & Knight (1984)[i]	−81 ms	−19 ms	LD Lag 0, ISI 1,000 ms
	−88 ms	−33 ms	LD Lag 0, ISI 4,000 ms
Laudanna, Baedecker, & Caramazza (1989)[j]	−32 ms (Exp. 2)		DD
	−84 ms (Exp. 2)		
Marslen-Wilson, Tyler, Waksler, & Older (1994)[k]	−53 ms (Exp. 1)	−8 ms (Exp. 2)	Auditory-visual LD ISI 0
Murrell & Morton (1974)[l]	12.2%		Recognition task
Napps (1989)[m]		−11 ms (Exp. 3)	LD, 1,000 ms (morphological is identical repetition)
		−27 ms (Exp. 3)	LD, LT
Napps & Fowler (1987)[n]	−44 ms, −82 ms (Exp. 1)		LD, 350 ms and greater
Rueckl, Mikolinski, Raveh, Miner, & Mars (1997)[o]	−8%		FC % completions as target
Stolz & Feldman (1995)[p]	−15 ms (Exp. 1)		LD, LT
	−76 ms (Exp. 2A)		LD, 250 ms
	−67 ms (Exp. 2B)		

Note. LD = lexical decision; FM = forward mask; LT = long term; FC = fragment completion; DD = double lexical decision; RT = reaction time; ISI = interstimulus interval; NAM = naming; Exp. = Experiment. Effects represent either the difference between related primes and their unrelated forms or the difference in target latencies following two types of related primes. Positive values indicate target latencies in the morphological condition are slower than those in the orthographic or semantic condition. Negative values indicate that target latencies in the morphological condition are faster than those in the orthographic or semantic condition.
[a] Hebrew: ספרן ספריה (*librarian-library*); קריאה ספריה (*reading library*). [b] Hebrew: הלביש התלבש (*he got dressed-he dressed*); הלביש התביש (*got shy-he dressed*). [c] Dutch and German: *KERSEN-KERS* (*cherries-cherry*); *KERST-KERS* (*Christmas-cherry*). [d] Serbian: *BOR-BOROVI* (*pine-pines*); *BORAMA-BOROVI* (*wrinkles-pines*). [e] Serbian: *STANČIĆ-STAN* (*little apartment-apartment*); *STANICA-STAN* (*station-apartment*). [f] Hebrew: זמר תזמורת (*root sing-orchestra*); תמר תזמורת (*date-orchestra*). [g] French: *DEFORMÉ-REFORMÉ* (*deformed-reformed*); *AFFIRMÉ-REFORMÉ* (*affirmed-reformed*). [h] English: *MOST-MORE; MORAL-MORE.* [i] English: no items provided. [j] Italian: *POSTO-POSTI* (*place-places*); *CONTARE-CORTA* (*to count-short*); *PORTARE-PORTE* (*to carry-doors*). [k] English: *FRIENDLY-FRIEND; TINSEL-TIN.* [l] English: *CARS-CAR; CARD-CAR.* [m] English: *PAIN-PAIN; ACHE-PAIN.* [n] English: *RIBBED-RIB; RIBBON-RIB.* [o] English: *MARKER-MARK; MARKET-MARK.* [p] English: *MARKER-MARK; MARKET-MARK.*

demonstrated that morphological facilitation is not easily described as an effect of semantic relatedness. Primes were forward masked (pattern mask duration 500 ms) and presented for 50 ms. They were followed by a target that appeared for 500 ms. Relative to an unrelated prime matched for orthographic similarity, primes formed from the same root morpheme as the target facilitated target recognition under conditions in which semantically related primes had no effect. Accordingly, they argued that morphological relatedness can be differentiated from semantic relatedness.

An earlier study, also conducted with Hebrew materials, contrasted facilitation from semantically related words with and without a common base morpheme and from morphologically words with and without extensive semantic similarity (Bentin & Feldman, 1990). Visual targets were preceded by visual primes that were related morphologically (but not semantically), semantically, or both morphologically and semantically. The same items were presented at long and at short lags, defined by the number of intervening items. In that study, the magnitude of facilitation after morphologically related primes did not vary statistically across lags. Semantically related primes produced facilitation only in the 0-lag condition. Most important, the effect of semantic relatedness among morphological relatives was sensitive to the time interval between prime and target. At Lag 0, facilitation was greater for the morphological plus semantic condition (+51 ms) than for the morphological condition (+21 ms), whereas at Lag 15 statistically equivalent facilitation was obtained for the morphological plus semantic condition (+23 ms) and the morphological condition (+19 ms). The outcome of the Bentin and Feldman (1990) study showed a supplemental advantage of semantic relatedness among morphological relatives only when a short temporal interval separated prime and target. Generally, in Hebrew, semantic relatedness contributed little over and above morphological relatedness when relatives were presented with lags of intervening items. The effect of semantic relatedness was absent under the same conditions (viz., lag) that failed to produce an effect of semantic association.

Similarly with English materials, results suggest that semantic relatedness has no effect on word recognition at long lags. Facilitation was absent between antonyms such as *COLD-HOT* even when semantics was the only dimension of relatedness between primes and targets and the only plausible basis of a strategic intervention (Fowler, cited in Feldman, 1992). Moreover, semantic relatedness contributed little to long-term facilitation over and above the effect of shared morphology. Feldman and Stotko (cited in Feldman, 1992) reported robust facilitation (+93 ms) to target decision latencies for identity (e.g., *CREATE-CREATE*) repetitions and smaller effects after morphologically related primes. The magnitude of facilitation did not vary significantly depending on whether the prime was a close relative of the target such as *CREATION-CREATE* (+36 ms) or a distant relative (+30 ms) such as *CREATURE-CREATE.* This outcome is consistent with the claim that the degree of semantic similarity between a morphologically related prime and its target does not affect the magnitude of facilitation when relatives are separated by several intervening items.

Semantic relatedness does reduce target decision latencies among morphological relatives when primes and targets occur in immediate succession, however. Differences after semantically opaque (*ACCORDION-ACCORDANCE*) and transparent (*ACCORDINGLY-ACCORDANCE*) primes that were morphologically related to the target arose under the same conditions that give rise to effects of semantic association (viz., cross-modal presentations and visual presentations at a stimulus onset asynchrony [SOA] of 250 ms). Moreover, they were absent under those conditions (viz., forward mask at an SOA of 68 ms and visual presentations at an SOA of 48 ms) that tend not to show semantic effects (Feldman, 1999a; Feldman & Soltano, 1999; Feldman, Soltano, Pastizzo, & Francis, 2000). In particular, in the immediate priming task, the effects of semantic association are limited by the temporal interval between prime and target. That is, the magnitude of the reduction in decision latencies resulting from semantic relatedness decreased as SOA decreased (e.g., De Groot, 1984; Lorch, 1982). In addition, the effects of other semantic variables such as relatedness proportion were eliminated when SOAs were shorter than 250 ms (e.g., den Heyer, Briand, & Dannenbring, 1983).

Taken collectively, the results just summarized suggest that semantic effects are temporally limited, whereas morphological effects are less so. When processing time for the prime (or perhaps prime visibility) is limited (i.e., forward masked and SOA on the order of 50 ms) or when items intervene between prime and target (average lag 10 items), effects of semantic relatedness are generally absent, whereas morphological effects are preserved (see Table 1). However, under those conditions in which morphological and semantic effects are evident, the magnitude of morphological facilitation is sensitive to the degree of semantic similarity.

A related issue when interpreting the differing magnitudes of morphological and semantic relatedness is how to assess the degree of semantic relatedness of prime and target. Relatedness is not generally equated across morphologically related and semantically related pairs despite the evidence that magnitude of semantic facilitation varies with the degree of relatedness (Lupker, 1984; McCrae & Boisvert, 1998). To the extent possible, it would be advantageous to equate primes on their degree of semantic relatedness to the target when contrasting the magnitudes of the effects of morphological and semantic relatedness.

Morphological Relatedness and Orthographic (and Phonological) Overlap Contrasted

Morphologically related words share a base morpheme, and morphemes presented in print are typically also orthographic units. Accordingly, two words that are morphologically related tend to have similar forms. It was once suggested (e.g., Seidenberg, 1987) that the effects obtained when morphologically related primes precede targets could reflect the orthographic overlap between morphological relatives. However, morphological and orthographic relatedness have distinct effects on word recognition.

Morphological and orthographic similarity have been contrasted systematically in German and in Dutch (Drews & Zwitserlood, 1995). In that study, orthographic primes (morphologically simple) as well as morphological primes (morphologically complex) were matched for frequency and had final letter sequences that could function as morphemes (e.g., *EN, T, S, TE*). Moreover, targets (e.g., *KERS*) were fully nested within both the orthographic (e.g., *KERST*) and morphological (e.g., *KERSEN*) primes. At long lags between prime and target, morphologically related primes facilitated and orthographically similar primes had no significant effect on target decision latencies in either German or in Dutch (Drews & Zwitserlood, 1995; Exp. 2). Similar results have been reported in Serbian for *STANČIĆ-STAN* (morphological) as contrasted with *STANICA-STAN* (orthographic) type pairs (Feldman & Moskovljević, 1987). In addition, in Serbia, where two alphabets were used interchangeably, equivalent facilitation arose for targets preceded by morphologically related primes printed in an alphabet different from or the same as that of the target.

Finally, some data from English suggest that morphological facilitation at long lags is not sensitive to phonological overlap either. Statistically equivalent facilitation was observed for morphological relatives in which the base morpheme of both prime and target are pronounced similarly (e.g., *HEALER-HEAL*) and for those in which the prime and target (e.g., *HEALTH-HEAL*) are pronounced differently (Fowler et al., 1985). Similar results have been reported when the base morpheme of morphological relatives differs in spelling as well as pronunciation (e.g., *DECISION-DECIDE*) both in English (Fowler et al., 1985) and in Serbian (Feldman & Fowler, 1987). Generally, neither phonological nor orthographic similarity enhances the effect of morphological relatedness when relatives are separated by long lags.

By contrast, when primes and targets were presented in immediate succession at an SOA of 300 ms, morphological primes facilitated and orthographic primes inhibited decision latencies in Dutch and German (Drews & Zwitserlood, 1995) and in Serbian (Feldman & Andjelković, 1992; Exp. 2). It appears that at an SOA of 300 ms in the lexical decision task, the effects of orthographic similarity and morphological relatedness are most distinct. Most notably, orthographic similarity of prime and target tends to inhibit target decision latencies whereas morphological similarity tends to facilitate.

In summary, the pattern exhibited by orthographically similar prime-target pairs without a shared morpheme and orthographically similar prime-target pairs with a shared morpheme are distinct and vary depending on the temporal separation of (unmasked) prime and target. Orthographically similar but morphologically unrelated primes generally have no effect on target responses when there is at least one intervening item although orthographically similar morphological relatives produce facilitation (Feldman & Andjelković, 1992; Forster et al., 1987; Grainger, Colé, & Segui, 1991). When primes immediately precede targets at SOAs in the range of 300 ms, morphological facilitation persists; however, orthographic inhibition is also reliable (Feldman & Andjelković, 1992; Grainger, 1990; Grainger et al., 1991; Grainger, O'Regan, Jacobs, & Segui, 1989; Segui & Grainger, 1990). In particular, inhibition for orthographically similar but morphologically unrelated prime-target pairs is magnified when the prime has a lower frequency than the target, has no mask, and precedes the target with an SOA on the order of 300 ms (Segui & Grainger, 1990).

As is apparent from the examples in Table 1, orthographic overlap can be defined from the beginning of the word (e.g., Drews & Zwitserlood, 1995; Ferrand & Grainger, 1994), from the end of the word (Ferrand & Grainger, 1994; Grainger et al., 1991), or with respect to a discontinuous sequence of letters (Frost et al., 1997, Exp. 1). Moreover, when overlap is specified from the beginning of the word, word length of prime and target may or may not be matched, and the target may be fully formed inside the prime (e.g., *KERST-KERS*) or not (e.g., *CHAR-CHAT*). Whereas orthographic similarity appears to have no significant effect at long lags, inhibition arises across a variety of types of orthographically similar forms in the immediate priming task at SOAs on the order of 300 ms.

It is worth noting that under some circumstances, even in alphabetic writing systems, orthographic and phonological dimensions of similarity are not fully redundant. This has implications for the evaluation of the influence of primes that are similar in form but morphologically unrelated. In concatenative languages such as English, Dutch, and Serbian, morphological formation entails the addition of affixes either before or after a base morpheme so that the base morpheme is typically preserved as a unit. In Hebrew, however, morphological relatives do not necessarily preserve the base (or root) morpheme as an orthographic or a phonological unit. Because the word pattern (morpheme) is infixed inside of the root morpheme, the integrity of the root morpheme as an orthographic unit may be disrupted (see Feldman & Bentin, 1994). The situation in Hebrew is rendered even more complex because not all of the phonemes that comprise the word pattern are transcribed by letters. Some are diacritical marks that appear below or above the letters of the root.

In brief, critical for interpreting an effect as evidence of morphological processing is the inclusion of a morphologically unrelated condition, matched with respect to orthographic similarity with the target. Differences resulting from morphological relatedness when orthographic similarity is matched can be interpreted as evidence of morphological processing. When the orthographic and phonological dimensions of similarity are not fully consistent (e.g., Frost et al., 1997), matching primes and targets on orthographic similarity and matching on phonological similarity present distinct challenges.

Additive Effects

Despite differences in their time courses, phonological, orthographic, semantic, and perhaps morphological processes in word recognition cannot be fully autonomous. Although accounts can differ on the time course and autonomy of processes, typically, various sources of information can combine at some point in the process of recognizing a word. By some accounts, the activation patterns are discrete (e.g., Caramazza, 1997). By others, they interact (see Van Orden, Jansen op de Haar, & Bosman, 1997). Some patterns of activation are strictly unidirectional so that "later" sources of information cannot modify "earlier" ones (e.g., Massaro & Cohen, 1994). Others allow bidirectional activation between sources of information (e.g., Stone, Vanhoy, & Van Orden, 1997).

There is evidence that the effects of two semantically related primes can combine in a systematic manner (Balota & Paul, 1996). That is, target facilitation after two primes that were both related to the target but not to each other (*KIDNEY-PIANO-ORGAN*) could be predicted from the sum of the two separate semantic effects. Additive influences of two semantically related primes were robust and were demonstrated at SOAs of 199 ms and of 1,166 ms in the lexical decision task. It is worth noting that recognition processes that combine the effects of multiple sources of relatedness are not unique to Balota and Paul (1996). For example, Thompson-Schill, Kurtz and Gabrieli (1998) compared the magnitude of facilitation in a naming task for word pairs that were associatively as well as semantically related (e.g., *ENGINE-CAR*) and for pairs that were associatively but not semantically related (*FIRE-TRUCK;* see also Lupker, 1984; Schreuder, Flores D'Arcais, & Glazenborg, 1984). The combinatorial logic in these studies extends that of Balota and Paul in that they asked whether manipulating the number of dimensions on which prime and target are related influences the magnitude of facilitation.

In the present study, I sought to replicate, and to compare within the same experiment, the differential effects on target decision latencies of primes that were related either morphologically, orthographically, and phonologically or semantically. I examined the patterns of facilitation and inhibition for the various dimensions of similarity in the immediate priming task over a range of SOAs and in the long-term repetition priming task. Materials were matched with respect to the degree of (orthographic) overlap between morphologically related and orthographically related primes and (semantic) relatedness between morphologically related and semantically related primes. Further, following from the insight that morphological relatives tend to share similar form and similar meaning, the design permitted a preliminary exploration of one simple version of combinatorial logic. Adapting the additive logic but not the precise double prime procedure of Balota and Paul (1996), I probed the adequacy of describing morphological effects as the sum of orthographic and semantic effects. A pattern of morphological facilitation that reliably differentiates itself from the combined effects of orthographic and semantic similarity only at longer prime durations suggests that morphological effects take time to emerge. A characterization of facilitation as varying over time would present a new challenge to traditional accounts of morphological processing.

Experiment 1

In Experiment 1, participants made lexicality judgments to visually presented targets in a primed lexical decision task. Words that were morphologically, orthographically, or semantically related to their target served as visual primes. All dimensions of similarity were presented in the same experiment. Processing time for the prime was varied across experiments to look at the time course of activation. Experiments 1A to 1C used primes presented for durations of 16, 66, and 250 ms, respectively and followed by a blank for 50 ms. (In the text, I refer to these conditions as SOAs of 66, 116, and 300 ms, respectively.) To reduce the SOA below 66 ms (16 ms + 50 ms blank), Experiment 1D used a prime presented for 32 ms and followed immediately by the target.[2] Finally, in Experiment 1E, the prime was presented for 250 ms and was followed by a pattern mask for 50 ms to limit processing time for the prime.

Methods

Participants. All participants were undergraduate students at the University at Albany, State University of New York (SUNY), and all were native speakers of English. Some participated in partial fulfillment of the course requirements for an introductory psychology course. Others were paid $5 for their participation. The 66-ms SOA experiment (Exp. 1A) had 95 participants (data from 1 were eliminated). There were 96 participants in the 116-ms SOA in Experiment 1B (data from 5 were eliminated) and, in the 300-ms SOA with no mask (Exp. 1C), there were 96 participants (data from 2 were eliminated). The 32-ms prime duration experiment (Exp. 1D) included 108 participants (data from 4 were eliminated). Finally, in the 250-ms prime duration experiment with a 50-ms mask (Exp. 1E), 95 students participated. No one viewed more than one prime duration. The criterion for eliminating data from participants was an accuracy rate equal to or lower than 65% on word trials.

Materials. Fifty-four sets of materials were created. Each included one target and six primes. Critical primes were related to targets along one of three dimensions. They were morphologically related (e.g., *VOWED-VOW*), orthographically related (e.g., *VOWEL-VOW*), or semantically related (e.g., *PLEDGE-VOW*). Mean frequencies (and *SD*) were 25 (50), 20 (34), and 34 (71) for the morphological, orthographic, and semantic conditions, respectively. For each of the three related primes, a separate unrelated prime (e.g., *SAVES, TORSO,* and *SCRAPE,* respectively) was selected to match the frequency, length, and morphological structure (simple or complex) of its related pair. Unrelated control prime frequencies (and *SD*) were 25 (50), 23 (34), and 34 (71), respectively. Mean target frequency was 108 (159). Following Grainger (1990), all primes were of lower frequency than their target. Frequency matching was done item by item.

Items were constructed such that the orthographically related and morphologically related primes were matched (item by item) for orthographic and phonological overlap with the target. Following the procedure of Drews and Zwitserlood (1995), orthographic (e.g., *VOWEL*) as well as morphological (e.g., *VOWED*) primes always contained all of the letters that made up the target (e.g., *VOW*). Mean letter overlap was 5.8 (SD = 1.1) in both the orthographically and morphologically related prime conditions. Mean phoneme overlap with the target was 3.0 (SD = .70 and .67 respectively) in both the orthographically and morphologically related prime conditions. In 44 of 54 instances, orthographic primes also shared their first syllable with the target (e.g., *PADDLE-PAD*). In 25 of 54 instances, morphological primes also shared their first syllable with the target (e.g., *PADDED-PAD* but not *SEEN-SEE*). Orthographic and morphological primes had average syllable lengths of 1.9 (SD = 0.5) and 1.5 (SD = 0.6), respectively. Because they were matched on number of shared orthographic (and phonemic) units, any differences obtained between the morphologically and orthographically related prime-target pairs cannot be attributed to differing degrees of orthographic (phonemic) overlap between the morphologically and orthographically related prime-target pairs. However, phonological influences at the level of the syllable cannot be dismissed.

An additional constraint on item construction was that the semantically related and morphologically related primes were matched for semantic relatedness to the target. Accordingly, 54 SUNY undergraduates rated each of the three types of pairs for the semantic relatedness of prime and target using a 7-point scale. The semantic relatedness score was 5.9 (SD = 0.81) for morphological, 5.7 (SD = 0.94) for semantic, and 1.7 (SD 0.81) for the orthographic conditions, respectively. Because morphological and semantic primes were matched for semantic similarity to the target, if it can be assumed that the rating data are valid (for discussion, see Feldman & Larabee, in press), any differences in facilitation cannot be attributed to differing degrees of meaning overlap between prime and target.

Pseudoword targets were also constructed by taking a morphologically simple word that ended with a sequence of letters that elsewhere functions as an affix and deleting the potential affix. Conditions for the word-pseudoword prime-target pairs were analogous to the word conditions. There were "morphologically/orthographically related" pairs (e.g., *GENDER-GEND*) and unrelated pairs (e.g., *TRUANT-GEND, ORNATE-GEND*) conditions. One third of pseudoword pairs consisted of morphologically/orthographically related, and two thirds were unrelated by form and by meaning.

Design. Each list contained 144 prime-target pairs. For words, there were nine items in each of the six word conditions, resulting in 54 critical word-word pairs. In addition, to be consistent with more traditional studies of morphological processing, there were 18 word-word filler pairs in which prime and target were identical. Pseudowords consisted of 24 morphologically/orthographically related word-pseudoword pairs and 48 unrelated word-pseudoword pairs, thereby mirroring the proportion of form-related pairs among words. In all, there were six lists. Lists differed as to which prime preceded a particular target, but across lists each target followed all six types of primes. No participant viewed a prime or a target more than once. That is, each list included all prime types (morphological, orthographic, semantic) and both levels of relatedness (related or frequency control).

Procedure. In Experiment 1A, primes appeared for 16 ms and were followed by a blank of 50 ms (total SOA = 66 ms) before onset of the target. In Experiment 1B, primes appeared for 66 ms and were followed by a blank of 50 ms (total SOA = 116 ms) before onset of the target. In Experiment 1C, primes appeared for 250 ms and were followed by a blank of 50 ms before onset of the target (total SOA = 300 ms). In Experiment 1D, primes appeared for 32 ms before the onset of the target. In Experiment 1E primes appeared for 250 ms and were followed by a pattern mask of 50 ms before onset of the target. In all of these experiments, participants made a lexical decision. At all prime durations, targets appeared for 1,500 ms or until the participant responded. A fixation pattern ("+") appeared for 500 ms before presentation of the prime. The intertrial interval was 1,000 ms.

The order of items was randomized for each subject, and items were presented on a Macintosh SE 20 computer. Participants indicated their response by pressing the right button of a keyboard for word and the left button for pseudoword responses.

Results

The mean decision latencies and accuracy rates for Experiment 1 are summarized in Table 2. Analyses of variance

[2] The 32-ms SOA was run after the longer SOAs. Accordingly, 50-ms blank was eliminated to reduce the SOA below 66 ms.

Table 2
Target Latencies and Accuracy Rates for Targets Following Morphologically, Orthographically, and Semantically Related Primes and Their Frequency-Matched Controls

		Morphological		Orthographic		Semantic	
		VOWED-VOW		*VOWEL-VOW*		*PLEDGE-VOW*	
Prime duration	Relatedness	Latency	Accuracy	Latency	Accuracy	Latency	Accuracy
66[a]							
	Critical	585	86	595	80	592	89
	Control	614	89	613	87	614	87
	Facilitation	29	−3	18	−7	22	2
116[a]							
	Critical	615	90	665	84	625	89
	Control	650	84	657	85	655	86
	Facilitation	35	6	−8	−1	30	3
300[a]							
	Critical	587	90	659	84	604	88
	Control	636	84	641	86	637	86
	Facilitation	49	6	−18	−2	33	2
32[b]							
	Critical	623	91	652	84	641	93
	Control	655	91	662	89	653	89
	Facilitation	32	0	10	−5	12	4
300[c]							
	Critical	612	93	665	87	630	93
	Control	650	91	660	89	654	89
	Facilitation	38	2	−5	−2	24	4

Note. Latency values are expressed in milliseconds; accuracy values are expressed in percentage correct.
[a] Prime duration includes 50-ms blank. [b] Prime duration includes no blank or mask. [c] Prime duration includes 50-ms mask.

(ANOVAs) treating subjects (F_1) and items (F_2) as random variables were performed. Reaction times greater than 3 *SD* from the mean (approximately 1%) were excluded and treated together with incorrect responses as errors. Across all prime durations, decision latencies to targets after morphological and semantic primes were reduced relative to their respective unrelated controls (facilitation), and morphological facilitation was greater in magnitude than semantic facilitation. By contrast, target latencies after orthographically related primes were reduced at the shorter prime durations and increased at the longer prime durations. Results of the ANOVA were consistent with this account. Because of their identical presentation formats (viz., the 50-ms blank), Experiments 1A to C were analyzed together.

Effects of prime type. Results of an ANOVA for targets after critical and control primes for the three types of primes (morphological, orthographic, semantic) revealed a significant effect of prime type (morphological, orthographic, semantic) for both the latency, $F_1(2, 566) = 31.88$, $MSE = 2{,}737$, $p < .0001$, $F_2(2, 106) = 35.89$, $MSE = 2{,}142$, $p < .0001$, and the accuracy measure, $F_1(2, 566) = 18.04$, $MSE = 0.80$, $p < .0001$, $F_2(2, 106) = 8.08$, $MSE = 2.90$, $p < .0005$. The effect of relatedness was also significant but only with the latency measure, $F_1(1, 283) = 65.05$, $MSE = 2{,}888$, $p < .0001$, $F_2(1, 53) = 26.72$, $MSE = 34{,}028$, $p < .0001$. Finally, the interaction of prime type by relatedness was significant both with the latency, $F_1(2, 566) = 25.32$, $MSE = 2{,}547$, $p < .0001$, $F_2(2, 106) = 26.78$, $MSE = 1{,}949$, $p < .0001$, and the accuracy measures, $F_1(2, 566) = 16.16$, $MSE = 0.79$, $p < .0001$, $F_2(2, 106) = 7.78$, $MSE = 2.27$, $p < .001$.

Responses to targets after (morphologically and semantically) related primes tended to be faster and more accurate than responses to targets after control primes. By contrast, responses to targets after orthographic primes tended to be slower and less accurate relative to controls. In particular, planned comparisons on the latency data indicated that facilitation (for critical primes relative to their controls) was significant for morphological primes, $F_1(1, 566) = 79.82$, $p < .0001$, $F_2(1, 106) = 63.74$, $p < .0001$, and semantic primes, $F_1(1, 566) = 44.59$, $p < .0001$, $F_2(1, 106) = 42.39$, $p < .0001$. Orthographic primes had no significant effect, however, $F_1(1, 566) = 0.50$, $p < 1.0$, $F_2(1, 106) = 2.64$, $p < .11$. Similarly, the difference in accuracy rates was significant by subjects for semantic primes, $F_1(1, 566) = 6.86$, $p < .01$, $F_2(1, 106) = 3.40$, $p < .07$, and by subjects for morphological primes, $F_1(1, 566) = 12.98$, $p < .0003$, $F_2(1, 106) = 1.86$, $p < .18$. With the accuracy measure, inhibition after orthographic primes was also significant, $F_1(1, 566) = 14.01$, $p < .0002$, $F_2(1, 106) = 10.30$, $p < .002$.

Effects of SOA. The manipulation of SOA (66, 116, and 300, each of which included a 50-ms blank) affected latencies, $F_1(2, 283) = 6.35$, $MSE = 40{,}954$, $p < .002$, $F_2(2, 106) = 12.74$, $MSE = 10{,}606$, $p < .0001$, but not accuracy, $F_1(2, 283) = .02$, $MSE = 1.9$, $p < .98$, $F_2(2, 106) = 30.03$, $MSE = 16.46$, $p < .0001$, such that recognition was faster at a prime duration of 66 ms than at the other SOAs. SOA interacted with prime type but only for the latency measure, $F_1(4, 566) = 6.10$, $MSE = 2{,}737$, $p < .0001$, $F_2(4, 212) = 5.06$, $MSE = 1{,}562$, $p < .0007$.

More important is that prime type and relatedness interacted with SOA in the subjects analysis with both the latency measure,

$F_1(4, 566) = 4.46$, $MSE = 2{,}547$, $p < .002$, $F_2(4, 212) = 2.31$, $MSE = 1{,}831$, $p < .06$, and the accuracy measure, $F_1(4, 566) = 3.39$, $MSE = 0.796$, $p < .01$, $F_2(4, 212) = 1.84$, $MSE = 1.81$, $p < .15$. In particular, the magnitude of the difference between control and critical items was positive and tended to increase over SOA after morphological and semantic prime types. The latency difference between control and critical items after orthographic primes, however, changed from positive (facilitation) to negative (inhibition) as SOA increased. Difference scores better capture this pattern, however.

Difference scores. The magnitude of facilitation (and inhibition) was assessed by subtracting reaction times to targets preceded by critical primes from those of their frequency-matched control primes. The difference was computed for each of the prime types, and this constitutes the analysis based on difference scores. Results are redundant with the interaction of prime type by relatedness reported previously, although the planned comparisons on SOAs of 66 ms and 300 ms are informative.[3]

Planned comparisons with the latency measure revealed that facilitation after semantically related primes did not increase significantly over SOA. However, facilitation after morphologically related primes did, $F_1(1, 283) = 3.47$, $p < .06$, $F_2(1, 212) = 5.54$, $p < .02$. Perhaps most distinctive, the effect of orthographic similarity shifted from facilitation to inhibition as SOA increased, $F_1(1, 283) = 9.73$, $p < .002$, $F_2(1, 106) = 1.63$, $p < .20$. Because neither orthographic primes nor their controls were semantically related to the target, it is unlikely that a semantic mismatch influences the effect of orthographic similarity. Analogously, neither semantic primes nor their controls were orthographically related to the target. Therefore, it is unlikely that an orthographic mismatch influences the effect of semantic similarity. The patterns of facilitation and inhibition are generally consistent with the results of the earlier studies that examined unmasked morphological, semantic, and orthographic effects at short lags (e.g., Drews & Zwitserlood, 1995). Results of the difference analysis are plotted in Figure 1, and significance levels of planned comparisons are summarized in Table 3.

Additive effects. Because the design of the present study incorporated three types of primes and their respective unrelated controls within the same experiment, it was possible to probe conditions under which morphological effects differ from the combined effects of semantic and orthographic similarity. The general pattern from an analysis of the difference scores suggests

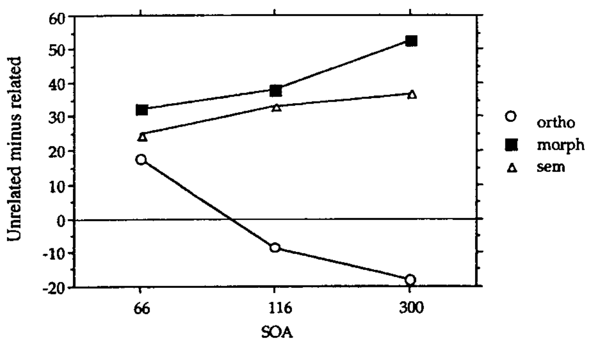

Figure 1. Facilitation as a function of stimulus onset asynchrony (SOA) after orthographic (ortho), semantic (sem), and morphologically (morph) related primes.

that morphological effects (M) were significantly greater than orthographic (O) effects but only numerically greater than semantic (S) effects. In a final set of analyses, for each subject and each item, the sum of semantic and orthographic facilitation was compared with the magnitude of morphological facilitation at SOAs of 66 and 300 ms.

Results of an ANOVA comparing the latencies for morphological effects with the sum of semantic and orthographic effects over SOA revealed a significant interaction, $F_1(1, 188) = 7.15$, $MSE = 6{,}302$, $p < .01$, $F_2(1, 53) = 3.21$, $MSE = 3{,}131$, $p < .08$. With the accuracy measure, morphological facilitation tended to be greater than the combined effects of orthography plus semantics in the subjects analysis, $F_1(1, 188) = 4.06$, $MSE = 2.03$, $p < .05$, $F_2 < 1.0$, and the outcome did not interact with SOA. Both patterns suggest that morphological effects cannot simply be described as the linear sum of semantic and orthographic effects (Figure 2). Significance levels for planned comparisons are summarized in Table 3.

Effects at prime duration of 32 ms. Latencies were longer when primes appeared for 32 ms than when they appeared for 16 ms and were followed by a blank, although the overall pattern was quite similar. Results of an ANOVA based on mean latencies and errors for targets after critical and control primes for the three types of primes revealed a significant effect of prime type for both the latency measure, $F_1(2, 214) = 5.64$, $MSE = 3{,}056$, $p < .004$, $F_2(2, 106) = 5.48$, $MSE = 2{,}012$, $p < .005$, and the accuracy measure, $F_1(2, 214) = 13.33$, $MSE = 0.78$, $p < .0001$, $F_2(2, 106) = 10.55$, $MSE = 1.97$, $p < .0001$. The effect of relatedness was also significant but only for the latency measure, $F_1(1, 107) = 18.08$, $MSE = 2{,}863$, $p < .0001$, $F_2(1, 53) = 10.23$, $MSE = 2{,}828$, $p < .002$. Finally, the interaction of prime type by relatedness was marginal for the latency measure, $F_1(2, 214) = 2.66$, $MSE = 2{,}827$, $p < .07$, $F_2(2, 106) = 2.76$, $MSE = 1{,}857$, $p < .07$, but significant for the accuracy measure, $F_1(2, 214) = 11.90$, $MSE = 0.66$, $p < .0001$, $F_2(2, 106) = 8.20$, $MSE = 1.93$, $p < .0005$.

Difference scores revealed that when primes were presented for 32 ms (without a mask) facilitation was significantly greater after morphologically related primes than after orthographically related primes, $F_1(1, 214) = 4.12$, $MSE = 5{,}654$, $p < .07$, $F_2(1, 106) = 5.35$, $MSE = 3{,}715$, $p < .02$, and facilitation was marginally greater after morphological than semantic primes, $F_1(1, 214) = 3.8$, $MSE = 5{,}654$, $p < .05$, $F_2(1, 106) = 2.3$, $MSE = 3{,}715$, $p < .13$. The difference between the sum of the orthographic and semantic effects and the morphological effect was not significant, however ($Fs < 1$).

Effects at prime duration of 250 ms plus mask. The magnitudes of relatedness effects were attenuated when primes appeared for 250 ms and were followed by a pattern mask of 50 ms compared with when they were followed by a 50-ms blank. Nevertheless, results of an ANOVA based on mean latencies and errors

[3] Differences were computed by subtracting reaction times to targets preceded by critical primes from that of their frequency-matched control primes. Facilitation varied significantly by type of prime with both the latency, $F_1(2, 966) = 31.00$, $MSE = 5{,}559$, $p < .0001$, $F_2(2, 106) = 34.34$, $MSE = 3{,}947$, $p < .0001$, and the accuracy, $F_1(2, 966) = 31.24$, $MSE = 1.5$, $p < .05$, $F_2(2, 106) = 19.33$, $MSE = 4.03$, $p < .0001$, measure.

Table 3
Significance Levels[a] for Morphological, Orthographic, and Semantic Effects at Each Stimulus Onset Asynchrony

Prime duration (ms)			Morphological *VOWED-VOW*	Orthographic *VOWEL-VOW*	Semantic *PLEDGE-VOW*	M vs. O + S
66[b]						
Facil			29 (−3)	18 (−7)	22 (2)	29 vs. 40
	RT	p_1	.0001	.005	.0005	*ns*
		p_2	.0001	.005	.0001	*ns*
	Corr	p_1	.05	.0001	*ns*	*ns*
		p_2	.07	.005	*ns*	*ns*
116[b]						
Facil			35 (6)	−8 (−1)	30 (3)	35 vs. 22
	RT	p_1	.0001	*ns*	.0005	*ns*
		p_2	.0001	*ns*	.001	*ns*
	Corr	p_1	*ns*	.10	*ns*	.05
		p_2	*ns*	*ns*	*ns*	*ns*
300[b]						
Facil			49 (6)	−18 (−2)	33 (2)	49 vs. 15
	RT	p_1	.001	.02	.001	.02
		p_2	.001	.05	.005	.01
	Corr	p_1	.0001	*ns*	*ns*	.02
		p_2	.005	*ns*	.005	.20
66 vs. 300[b]						
Facil			29 (−3) vs. 49 (6)	18 (−7) vs. −18 (−2)	22 (2) vs. 33 (2)	(29 vs. 40) vs. (49 vs. 15)
	RT	p_1	.06	.002	*ns*	.01
		p_2	.02	.20	*ns*	.08
	Corr	p_1	.0001	.03	*ns*	.05
		p_2	.05	*ns*	*ns*	*ns*
32[c]						
Facil			32 (0)	10 (−5)	12 (4)	32 vs. 22
	RT	p_1	.0001	*ns*	.15	*ns*
		p_2	.0001	*ns*	.06	*ns*
	Corr	p_1	*ns*	.0001	.01	.05
		p_2	*ns*	.006	.05	*ns*
300[d]						
Facil			38 (2)	−5 (−2)	24 (−4)	38 vs. 19
	RT	p_1	.001	*ns*	.005	*ns*
		p_2	.0005	*ns*	.01	*ns*
	Corr	p_1	.10	.10	.005	*ns*
		p_2	.12	.10	.005	*ns*

Note. Facilitation (Facil) values not in parentheses are latencies, expressed in milliseconds; Facil values in parentheses are accuracies, expressed in percentage correct. RT = reaction time; Corr = percentage correct; M = morphological; O = orthographic; S = semantic.
[a] Conclusions are based on a per comparison α level of .05 with no experimentwise error correction. [b] Prime duration includes 50-ms blank. [c] Prime duration includes no blank or mask. [d] Prime duration includes 50-ms mask.

for targets after critical and control primes for the three types of primes revealed a significant effect of prime type for both the latency measure, $F_1(2, 186) = 12.61$, $MSE = 3{,}974$, $p < .0001$, $F_2(2, 106) = 9.72$, $MSE = 3{,}537$, $p < .0001$, and the accuracy measure, $F_1(2, 186) = 9.05$, $MSE = 86$, $p < .0002$, $F_2(2, 106) = 6.62$, $MSE = 67$, $p < .002$. The effect of relatedness was also significant with the latency measure, $F_1(1, 93) = 12.51$, $MSE = 4{,}016$, $p < .0006$, $F_2(1, 53) = 14.66$, $MSE = 2{,}714$, $p < .0003$. In addition, the interaction of prime type by relatedness was significant both with the latency measure, $F_1(2, 186) = 6.41$, $MSE = 3{,}441$, $p < .002$, $F_2(2, 106) = 5.12$, $MSE = 3{,}009$, $p < .008$, and the accuracy measure, $F_1(2, 186) = 6.37$, $MSE = 96$, $p < .002$, $F_2(2, 106) = 5.37$, $MSE = 65$, $p < .006$. Finally, the sum of the orthographic and semantic effects was not significantly different in magnitude from that of the morphological effect ($F_1 < 1.5$, $F_2 < 1$).

Discussion

In the immediate priming variant of the lexical decision task, the main effects of prime type and relatedness as well as their interaction were significant. The overall pattern was captured most efficiently using the difference between control and critical conditions as an index of facilitation (and inhibition). Decision latencies were reduced significantly after morphological primes and semantic primes and, for morphological primes, across Experiments 1A and C the magnitude of the effect increased as SOA increased. By contrast, decision latencies to targets after orthographically related primes revealed facilitation with the latency measure at short durations of the prime and inhibition at longer durations (although inhibition in the error data may compromise the short duration facilitation). In addition, morphological primes produced numerically greater facilitation than did semantic primes.

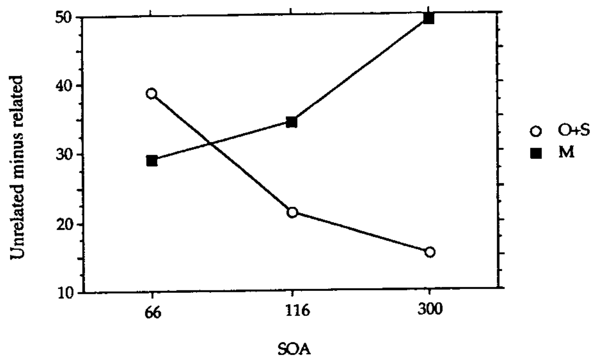

Figure 2. Morphological (M) facilitation contrasted with the sum of orthographic (O) and semantic (S) facilitation, as a function of stimulus onset asynchrony (SOA).

This pattern was evident across all durations and presentation conditions, although it reached significance only in an analysis that combined Experiments 1A to E.[4]

As a rule, in the data from the present study, morphological effects could be distinguished unequivocally from the effects of orthographic similarity and more tentatively from those of semantic similarity. The differing pattern after morphological and orthographic primes is consistent with the claim that similarity of form alone cannot underlie facilitation among morphological relatives. Importantly, planned comparisons across Experiments 1A to C indicated that the superiority of morphological facilitation relative to the combined effects of orthographic and semantic similarity depended on SOA. More specifically, at the 300-ms SOA, the magnitude of the morphological effect was statistically greater than the combined magnitudes of the orthographic and semantic effects. At the 66-ms SOA, however, the topology of the pattern differed. One conclusion is that it is essential to consider variation across prime durations when investigating the roles of morphological, semantic, and orthographic similarity in word recognition. In essence, studies that restrict prime duration to a single value may fail to capture critical aspects of the overall pattern.

In summary, in Experiment 1, the time courses over which semantic and orthographic similarity affected target decision times were compared with that of morphological relatedness. Neither dimension alone could account for the pattern of morphological facilitation. Moreover, the magnitude of the effect of morphological similarity tended to be greater than the combined effects of orthographic and semantic similarity. At SOAs on the order of 300 ms, when the effect of orthographic similarity was inhibitory, morphological facilitation was statistically greater than the combined effects of orthographic and semantic facilitation. However, when targets immediately followed primes at shorter prime durations in the short-term lexical-decision task additivity (M = O + S) could not be discounted. Generally, prolonged target latencies (inhibition) between orthographically similar primes and targets appear to coincide with the underadditivity of the orthographic and semantic effects in lexical decision.

In Experiment 2, the influence of various dimensions of relatedness is examined again, this time at long lags for which, based on existing literature, inhibitory orthographic effects are not anticipated.

Experiment 2

In the long-term repetition priming variant of the lexical decision task, primes and targets are presented visually with an average lag of 10 intervening items. At long lags, facilitation arises between morphological relatives but is absent between semantic relatives in Hebrew (Bentin & Feldman, 1990) and between antonyms such as *COLD-HOT* in English (Fowler, cited in Feldman, 1992). Importantly, orthographically similar but morphologically unrelated forms tend to have no effect or to facilitate target recognition, although not significantly, in English (Stolz & Feldman, 1995), Dutch, and German (Drews & Zwitserlood, 1995). Similarly, in the lexical decision task, long-term facilitation between morphological relatives is not sensitive to the degree of similarity between the phonological and orthographic forms of the prime and of the target. For example, in English, facilitation of *MARK* after *MARKED* is statistically equivalent to facilitation of *SPEAK* after *SPOKE* (Stolz & Feldman, 1995). Analogous results have been reported for inflected noun forms in Serbian (Feldman & Fowler, 1987). Moreover, patterns of facilitation for Hebrew forms do not differ depending on whether the word pattern does or does not visually disrupt the letter sequence that forms the root (Feldman & Bentin, 1994). Generalizing across a variety of languages, at long lags in the lexical decision task, orthographic facilitation is severely attenuated and semantic effects are absent. Morphological facilitation is, nevertheless, significant. Therefore, it is unlikely that morphological facilitation can be described as the sum of an orthographic and a semantic effect.

In Experiment 2, target latencies in long-term repetition priming were examined after primes that are related orthographically, morphologically, or semantically. Significant effects of neither shared semantics nor shared orthography were anticipated in this paradigm. Accordingly, under conditions in which orthographic inhibition as well as semantic facilitation should not be significant, I examined morphological processing.

Method

Participants. One hundred twenty college students from an introductory psychology course at the University at Albany, SUNY participated in Experiment 2 in partial fulfillment of course requirements. All were native speakers of English.

Materials. From the original set of English materials, 36 sets were selected. Each set included one target and six primes. As in Experiment 1, critical primes were related to targets along one of three dimensions. They were morphologically related (e.g., *VOWED-VOW*), orthographically related (e.g., *VOWEL-VOW*), or semantically related (e.g., *PLEDGE-VOW*). The selection procedure entailed ranking the original 54 sets according to the magnitude of semantic facilitation in lexical decision at a prime duration of 300 ms. Then every third item was deleted. The mean magnitude of semantic facilitation for 54 items was 39 ms (*SD* = 59). The mean

[4] Planned comparisons collapsed over prime duration revealed that facilitation was greater for morphologically related prime-target pairs than for semantically related pairs with the latency measure, $F_1(1, 966) = 6.81$, $p < .01$, $F_2(1, 106) = 3.54$, $p < .06$. That is, morphological facilitation tended to be greater in magnitude than semantic facilitation.

semantic facilitation for the 36 items that were presented in Experiment 2 was 32 ms (SD = 57 ms).[5]

Design. Because primes and targets require separate presentations in the long lag procedure, inclusion of the full set of 54 critical items would have created a test order that was 216 items long before the inclusion of fillers. Therefore, only a subset of the critical items from Experiment 1 were selected for presentation. Three test orders, each containing 154 items, were created. Half of the items were words and half were pseudowords. Words and pseudowords were presented equally often as first presentations (primes) and as targets. In addition, five filler words and five filler pseudowords were introduced to maintain the requisite lags. Each test order included six tokens of each of the three types of related primes (viz., orthographic, morphological, semantic) and each of their frequency- and length-matched controls. Across the six test orders, each target was preceded by all six (Type of Prime × Relatedness) prime conditions. Participants were randomly assigned to one of the six test orders, and the same practice list of 13 items preceded each experimental list. Primes and targets were separated by an average of 10 intervening items (range = 7–13).

Procedure. Materials were presented on a Macintosh SE 20 computer. The presentation sequence was modified from that of the previous experiment. Each experimental trial consisted of a fixation signal "+" for 450 ms followed by a blank field for 50 ms and then by the letter string. Items remained visible until the participant responded or until 1,500 ms had elapsed. The intertrial interval was 1,500 ms.

Results and Discussion

The mean decision latencies and accuracy rates for Experiment 2 are summarized in Table 4. Inspection of means indicates that morphological primes facilitated target latencies relative to their frequency controls but that semantic and orthographic primes had no significant effect. In ANOVAs, the effect of prime type (morphological, orthographic, semantic) was significant, $F_1(2, 238) = 8.23$, $MSE = 806$, $p < .005$, $F_2(2, 74) = 7.14$, $MSE = 2{,}037$, $p < .005$, as was the effect of relatedness (critical, frequency control), $F_1(1, 119) = 10.99$, $MSE = 2{,}745$, $p < .005$, $F_2(1, 37) = 11.19$, $MSE = 1{,}009$, $p < .005$. Most important, prime type interacted with relatedness, $F_1(2, 238) = 3.67$, $MSE = 2{,}946$, $p < .05$, $F_2(2, 74) = 3.02$, $MSE = 1{,}975$, $p < .055$. Finally, planned comparisons (Table 5) indicated that only morphological primes differed from their controls, $F_1(1, 238) = 15.67$, $p < .0001$, $F_2(1, 37) = 11.19$, $MSE = 1{,}009$, $p < .005$. Neither semantic nor orthographic similarity had a significant effect ($Fs < 1.0$).

Table 4
Target Latencies and Accuracy Rates for Targets After Morphologically, Orthographically, and Semantically Related Primes and Their Frequency-Matched Controls at Long Lags (Exp. 2)

	Morphological		Orthographic		Semantic	
	VOWED-VOW		*VOWEL-VOW*		*PLEDGE-VOW*	
Relatedness	Latency	Accuracy	Latency	Accuracy	Latency	Accuracy
Critical	580	87	610	81	609	85
Control	608	81	619	85	610	83
Facilitation	28	6	9	−4	1	2

Note. Latency values are expressed in milliseconds; accuracy values are expressed in percentage correct.

Table 5
Significance Levels[a] for Morphological, Orthographic, and Semantic Effects in Experiment 2

	Morphological	Orthographic	Semantic	
Variable	*VOWED-VOW*	*VOWEL-VOW*	*PLEDGE-VOW*	M vs. O + S
Facil	28 (6)	9 (−4)	1 (2)	28 vs. 10
RT p_1	.001	*ns*	*ns*	.15
p_2	.005	*ns*	*ns*	.20
Corr p_1	.02	.02	*ns*	.02
p_2	.06	.10	*ns*	.07

Note. Facilitation (Facil) values not in parentheses are latencies, expressed in milliseconds; Facil values in parentheses are accuracies, expressed in percentage correct. RT = reaction time; Corr = percentage correct; M = morphological; O = orthographic; S = semantic.
[a] Conclusions are based on a per comparison α level of .05 with no experimentwise error correction.

The accuracy scores revealed no effect of prime type (morphological, orthographic, semantic) and no effect of relatedness (critical, frequency control). The interaction of prime type by relatedness was significant, however, $F_1(2, 238) = 6.22$, $MSE = 199$, $p < .005$, $F_2(2, 74) = 3.43$, $MSE = 104$, $p < .05$. Planned comparisons indicated that orthographic primes produced a significant reduction in accuracy, $F_1(1, 238) = 5.98$, $p < .05$, $F_2(1, 74) = 2.9$, $p < .06$, and that morphological primes enhanced accuracy, $F_1(1, 238) = 5.69$, $p < .05$, $F_2(1, 74) = 3.64$, $p < .06$.

Additive effects. Differences in target decision latencies after related compared with control primes revealed that morphologically related primes significantly reduced target decision latencies, whereas target decision latencies after orthographic and semantic primes were not significantly reduced. Results of an ANOVA comparing morphological facilitation with the sum of semantic and orthographic facilitation indicated that, at long lags, the difference between morphological latencies and the sum of the latter two latencies only approached significance, $F_1(1, 119) = 2.11$, $MSE = 7{,}893$, $p < .15$, $F_2(1, 37) = 1.87$, $p < .20$. Morphological facilitation was greater than the combined effects of semantics and orthography with the accuracy measure, however, $F_1(1, 119) = 5.57$, $MSE = 509$, $p < .02$, $F_2(1, 37) = 3.4$, $MSE = 245$, $p < .07$.

Taken collectively, the data of Experiment 2 reflect another experimental context in which morphological effects are reliable and tend to be greater than the sum of semantic and orthographic effects. With the accuracy measure, once again, the superiority of morphological facilitation relative to the combined effects of semantic and orthographic relatedness was evident under conditions in which orthographic inhibition was present.

General Discussion

Facilitation based on morphological, semantic, and orthographic similarity was examined by comparing, within the same experiment, the differences in target decision latencies after critical primes and unrelated primes matched item by item for frequency,

[5] The rationale for sampling maintained the average magnitude of semantic facilitation while reducing the number of items.

length, and morphological structure to a critical prime. In Experiment 1, a short-term priming study, processing time for the prime ranged from 32 ms to 300 ms, and no more than 12% of word-word pairs shared any dimension of relatedness. In Experiment 2, a long-term repetition priming study, primes and targets were separated by an average of 10 intervening items. In both tasks, the prior presentation of a morphological relative made responses to targets faster and more accurate than did an unrelated prime. Moreover, the magnitude of morphological facilitation increased with SOA, at least in the range of 66 to 300 ms. Like morphologically related primes, semantically related primes also reduced target decision latencies relative to unrelated controls. Semantic facilitation was restricted to the short-term priming task, however. Facilitation resulting from morphological relatedness was numerically and sometimes even statistically greater than that of semantic relatedness. The results are consistent with the outcomes of other studies that contrasted morphological with semantic effects (see Table 1).

The effect of orthographic similarity in the short-term lexical-decision task was distinctive because direction (viz., facilitation or inhibition) depended on prime duration. For immediate primes presented at short prime durations (i.e., 32 ms + no blank, 16 ms + 50-ms blank), orthographically similar primes reduced target latencies but increased error rates so that the potential of a speed–accuracy trade-off cannot be ignored. At a prime duration of 116 ms (with a 50-ms blank) and under masked presentation conditions (consisting of a prime displayed for 250 ms and followed by a mask for 50 ms), significant orthographic inhibition was absent. Critically, however, at relatively longer time scales (i.e., 300 ms, including a 50-ms blank), orthographically similar primes significantly slowed target decision latencies.

The shift from apparent facilitation to inhibition for orthographically related pairs was not totally unanticipated. In the work of Segui and Grainger (1990), for example, an unmasked prime presented for a duration of 350 ms and requiring a lexical-decision judgment produced inhibition. The outcome is typically interpreted as evidence of lexical competition among orthographically similar but morphologically unrelated forms (e.g., Drews & Zwitserlood, 1995; Ferrand & Grainger, 1992; Grainger & Ferrand, 1994; Segui & Grainger, 1990). That is, when the relative frequency of the target is greater than that of the prime, a prime duration of 350 ms is sufficient to identify the prime, which then interferes with recognition of the target. At an SOA of 60 ms with a forward mask, by contrast, the same orthographically related primes and targets produced nonsignificant facilitation. Grainger et al. suggested that, under restricted viewing conditions, activation from primes and from targets is not differentiable and that both contribute to one "event." Described within a general interactive activation framework, the outcome of Experiment 1 reveals that facilitatory sublexical events predominate when processing time is restricted (viz., prime duration of 32 ms; 16 + 50-ms blank condition). However, as processing time for a prime that is orthographically but not semantically similar to its target increases, prime recognition progresses sufficiently so as to interfere with recognition of the target. Interestingly, at an SOA of 300 ms, the substitution of a mask in place of a blank serves to attenuate activation because of semantic, morphological, or orthographic similarity.

It is evident that orthographic similarity cannot account for morphological facilitation. In addition, if inhibition among orthographically similar forms reflects some variant of competing activation, then the reliability of morphological facilitation indicates that morphologically related forms with similar meanings do not function as competing lexical entities. Apparently, the lexical system handles orthographic similarity in conjunction with semantic similarity (viz., morphological relatives) and with attenuated or absent semantic similarity (viz., nonrelatives) in a different manner.

The long-lag latency results (Exp. 2) are also noteworthy because morphological facilitation was evident under conditions in which significant effects of neither semantic nor orthographic similarity were present. This outcome replicates aspects of several of the studies summarized in Table 1 and is consistent with the claim (Bentin & Feldman, 1990; Raveh & Rueckl, 2000) that long-term priming entails a mechanism that differs from that of short-term priming. One deviation from previous results, however, is that in the accuracy data there was evidence of orthographic inhibition.

In summary, under the immediate priming conditions of Experiment 1, the effect of processing time for the prime interacted significantly with prime type. The influence of orthographic similarity on target decision latencies changed direction with increases in processing time. Morphological and semantic relatedness systematically facilitated target processing. The magnitude of morphological facilitation tended to be greater than that of semantic facilitation, and that difference reached statistical significance in an analysis across Experiments 1A to E. Under the long-lag priming conditions of Experiment 2, morphological facilitation arose when semantic effects were absent and when an inhibitory orthographic effect was evident only with the accuracy measure. In conclusion, at both long and short lags, morphological facilitation could not be reduced to an effect of either orthographic or semantic similarity (see also Stolz & Feldman, 1995).

Does Morphological Facilitation Reflect the Combined Effects of Shared Meaning and Shared Form?

Results from a second set of analyses comparing the magnitude of morphological facilitation with the summed effects of semantic and orthographic relatedness (see Figure 2) provide support for the claim that morphological facilitation cannot be described simply as the "sum" of a semantic and an orthographic effect. In particular, analyses comparing latency differences (unrelated minus related) over SOAs of 66 and 300 ms revealed a significant interaction. The sum of the semantic and orthographic effects did not differ from that of morphological facilitation at an SOA of 66 ms. In fact, the morphological effect was slightly smaller than the combined effect. They did differ at an SOA of 300 ms, however, for which the morphological effect was significantly larger. In long-term priming, differences between the magnitudes of the morphological effect and the sum of the latter two (nonsignificant) latency effects only approached significance. The comparison was significant with the accuracy measure for which, again, there was some indication of inhibition after orthographically similar primes. In summary, the presence of orthographic inhibition seems to define conditions under which morphological effects differ from the simple sum of orthographic and semantic effects. More specifically, when orthographic similarity in the absence of shared meaning slows recognition, morphological facilitation is statistically distinct and cannot be described as the combination of a semantic and an orthographic effect.

Only at longer time scales in short-term lexical decision was the magnitude of morphological facilitation greater than the combined effects of orthographic and semantic relatedness. Nevertheless, it is unlikely that this outcome reflects strategies introduced by the participant. Multiple dimensions of relatedness were present within the same experimental setting at all time scales. Consequently, the design of the present study effectively reduces the utility of selectively strategizing with respect to one dimension of relatedness (viz., semantic) to the exclusion of the others. Moreover, it is not clear that an SOA of 300 ms would be sufficient to implement a strategy. The relation between M and O + S may reflect another aspect of semantic processing, however.

The influence of semantic factors (among morphologically unrelated forms) may be graded so that facilitation typically becomes greater as processing time for the prime increases (e.g., Lorch, 1982; Raveh, 1999). Greater magnitudes of semantic facilitation at longer SOAs, although not statistically different in the present study, are consistent with this claim. Another manifestation of progressive semantic processing of the prime is that primes that share morphological relatedness and those that share only orthographic similarity produce outcomes that become more distinct as SOA increases. Similarly, the magnitude of slowing as a result of orthographic similarity with mismatching semantics increases as processing time for the prime increases. At very short SOAs, semantically related primes produce facilitation. Nevertheless, orthographic inhibition is not reliable. Accordingly, the effect of semantic mismatch appears not to be sufficiently strong so as to override the effect of orthographic similarity. By this account, the magnitude of semantic facilitation as well as the weighting of orthographic and semantic processes change over SOA. Consequently, orthographic and semantic effects do not combine in the way that two semantic effects can sum (see Balota & Paul, 1996).

In conclusion, graded effects of semantic similarity (viz., mismatch) across SOA appear to play a critical role in differentiating effects of morphological and orthographic similarity as well as in describing the interaction with SOA for orthographically similar prime-target pairs. Consequently, the validity of describing morphological facilitation as the combination of a semantic and an orthographic effect appears to hinge on the fate of orthographically similar primes. In the present study, morphological facilitation tends to be greater than the combined effects of orthographic and semantic similarity, and one might conclude that morphological relationships are explicitly represented in the lexicon. Crucially, however, the reliability of the finding depends on processing time for the prime.

Graded Effects

The effect of similarity among morphologically related words poses a second challenge to the claim that morphological effects are distinct because they cannot be described as the sum of orthographic and semantic effects. Evidence that orthographic similarity affects morphological processing derives predominantly from tasks that emphasize the perceptual aspects of word processing such as short-term priming in lexical decision and the fragment completion tasks. Degree of similarity among morphological relatives formed by past tense inflection influences the magnitude of morphological facilitation in the lexical decision task under both cross-modal (Allen & Badecker, 2000; Plaut & Gonnerman, 1999) and purely visual presentation conditions (Feldman, 1999b). Specifically, facilitation was greatest for *LISTED-LIST* type pairs but also differed for *FELL-FALL* type pairs relative to *BOUGHT-BUY* type pairs. Similarly, in a variation of the fragment completion task (Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997), the likelihood that a fragment was completed as a particular target was enhanced when a morphological relative of the target was presented in the study phase that preceded it. In summary, for inflected forms, the degree of morphological facilitation is sensitive to the degree of orthographic similarity.

Analogous to the orthographic effect reported by Rueckl et al. (1997), degree of semantic similarity influences the magnitude of morphological facilitation (Feldman & Soltano, 1999; Feldman et al., 2000). Semantically transparent derivational relatives (e.g., *CASUALLY*) facilitated target (e.g., *CASUALNESS*) decision latencies significantly more than semantically opaque relatives (e.g., *CASUALTY*). This outcome was observed at a prime duration of 250 ms and under cross-modal presentation conditions but not at a prime duration of 48 ms or at a prime duration of 68 ms with a forward mask. An effect of degree of semantic transparency among morphological relatives in the short-term lexical decision task implies that all morphological derivations are not equivalent. In addition, interactions with SOA reveal that semantic influences on morphological processing depend on processing time for the prime.

In summary, effects of degree of orthographic and semantic similarity among morphological relatives have been documented, and they are not anticipated by traditional accounts of explicit morphological representation. They may be more compatible with an account whereby morphological effects emerge from conjoint influences of orthographic and semantic similarity that stabilize over time (e.g., Rueckl et al., 1997). Of course, the relative contributions of the orthographic and semantic dimensions of similarity may vary as a function of the semantic sensitivity of the particular task (Raveh & Rueckl, 2000) as well as processing time for the prime.

Debates as to whether or not morphological relationships are explicitly represented in the lexicon cannot be resolved by a single investigation. The primary contribution of the present study is to delineate the time course over which particular dimensions of similarity influence the processes of word recognition. Ideally, morphologically and orthographically related primes should match on degree and perhaps position of form overlap with the target, and morphologically and semantically related primes should match on degree of meaning similarity with the target. The selection of materials for the present study entailed rigorous efforts at matching along these dimensions.

Another issue explored here focuses on the SOAs at which the magnitudes of morphological relatedness differ from the combined effects of orthographic and semantic similarity. At shorter prime durations in the immediate lexical decision task, morphological facilitation was numerically but not statistically less than the summed effects of semantic and orthographic similarity. At the longest prime duration in the immediate lexical decision task, however, the effect of M was significantly greater the combined effects of O + S. Evidently, processing time for the prime plays a crucial role in differentiating morphological effects from the combined effects of orthography and semantics, and this pattern must be explained. Moreover, because they index the extent of semantic processing, the influence of orthographically similar but semantically dissimilar prime-target pairs provides a key to the constraints on additivity.

Finally, it is improbable that an approach comparing the effects of morphological similarity with the linear combination of the effects of semantic and orthographic similarity at individual SOAs will ever yield unequivocal evidence for or against the claim that morphology is explicitly represented in the lexicon. What is required is a characterization of morphological processing that accommodates more complex and time-varying contributions of semantic and orthographic similarity so as to justify why morphological relationships emerge as autonomous at longer time scales.

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