

## Graded Aspects of Morphological Processing: Task and Processing Time

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Effects on targets of orthographically (O) and semantically (S) related primes were compared with morphologically related (M) primes in the lexical decision, naming, and go/no go naming tasks. The overall pattern typified the graded nature of morphological processing. Morphological relatedness produced facilitation whose magnitude varied across a range of stimulus onset asynchronies (SOAs of 66–300 ms) and tasks. The effect of semantic and orthographic similarity also depended on SOA and on task. Importantly, the effects of morphological relatedness and orthographic similarity diverged along a time course that reflected semantic processing but could only be approximated by the effect of semantic relatedness between prime and target. © 2001 Elsevier Science (USA)

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In a variety of languages (e.g., Serbian:<sup>1</sup> Feldman, 1994; Feldman, Barac-Cikoja, & Kostić, 2000; Hebrew: Bentin & Feldman, 1990; English: Feldman, 1992; Fowler, Napps, & Feldman, 1985; Fowler et al., 1985; Stanners, Neiser, Herson, & Hall, 1979; and American Sign Language: Hanson & Feldman, 1989), and word recognition tasks, prior exposure to a word formed from a base morpheme that appears in both prime and target can facilitate processing of a target word. Facilitation due to a shared base morpheme (morphological facilitation) arises under a variety of presentation conditions. For example, morphological facilitation occurs when primes and/or targets are presented auditorily (e.g., Fowler et al., 1985; see also Emmorey, 1989; Kirsner, Milech, & Standen, 1983; Marslen-Wilson, Tyler, Waksler, & Older, 1994), when targets are preceded by primes with forward masks (e.g., Deutsch, Frost, & Forster, 1998; Forster, Davis, Schoknecht, & Carter, 1987; Frost, Forster, & Deutsch, 1997), and when prime and target are separated by a number of intervening items (Feldman, 2000; Stanners et al., 1979).

Morphological facilitation depends on a priming methodology. Some researchers view priming as a tool to study the mechanisms that underlie memory and word recognition. Others emphasize the symbolic or associative knowledge structures that guide performance in recognition tasks. The latter are inclined to interpret similar patterns over various experimental tasks as revealing about shared lexical structures

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<sup>1</sup> At the time of publication, we referred to this language as Serbo-Croatian.

that underlie performance. For example, morphological facilitation may reflect activation of a common morpheme in prime and in target. When discrepant findings arise, accounts often invoke task-specific components or stages. By a similar logic, within a task, it is instructive to track the time course over which particular dimensions of linguistic knowledge influence target recognition. A problem arises, however, because of the dichotomous nature of hypothesis testing. Its emphasis on whether an effect of facilitation is “statistically significant” may conceal more continuous aspects of processing.

Two of the most popular tasks with which to investigate morphological processing are the long-term repetition priming and the forward masked priming paradigms. Each is appealing because it reveals morphological relatedness in contexts in which effects of another associated dimension of similarity (e.g., semantic, orthographic, or phonological) appears to be absent. The long-term repetition and forward masked priming results are not equivalent, however. They differ in crucial ways that invite the introduction of task-specific contributions to morphological processing, thereby obscuring the role of underlying knowledge structures that are shared.

In the long-term priming procedure, words are presented individually with a lag of intervening items, and participants make a decision to both prime and target (Staners et al., 1979). In this task, words that have similar orthographic and phonological forms, but do not share a base morpheme, do not significantly influence lexical decision latencies to the target. In Dutch (and also German), morphologically related primes (e.g., KERSEN) facilitated target (e.g., KERS) decision latencies, while orthographically similar primes (e.g., KERST) had no significant effect (Drews & Zwitserlood, 1995; Experiment 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 English, morphological relatives whose base morpheme is pronounced similarly in prime and target (e.g., HEALER–HEAL) and those (e.g., HEALTH–HEAL) whose base morpheme is pronounced differently both produced significant and statistically equivalent facilitation (Fowler et al., 1985). Similar results arise when the shared base morpheme differs in spelling as well as pronunciation (e.g., DECISION–DECIDE) both in English (Fowler et al., 1985), and in Serbian (Feldman & Fowler, 1987). To summarize, in the domain of long-term repetition priming, the morphological and orthographic dimensions of similarity are not interchangeable. Moreover, preservation of the form of the base morpheme is not necessary in order to detect effects of morphological relatedness at long lags. Finally, gradations in the degree of similarity produce only small and nonsignificant differences in the magnitude of long-term morphological facilitation (Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997). Apparently, the morphological structures that underlie long-term facilitation must entail representations that can tolerate orthographic and phonological alterations to the base morpheme without significantly altering the pattern of facilitation.

Results look very different with a forward masked priming methodology. Typically, morphological primes are matched to orthographic primes for similarity to the target and the focus is on the difference in target latency following morphological and orthographic primes. In one study (Pastizzo & Feldman, in press), morphological primes were matched to orthographic primes for number of neighbors, length, and for position sensitive number of shared letters with the target. Primes were forward masked and presented at a stimulus onset asynchrony (SOA) of 48 ms. There were regular and two types of irregular primes, and the magnitude of morphological facilitation varied in systematic ways across type of morphological relation. Relative to an orthographic control (e.g., FILL, TAUNTS, or HATCHET), facilitation for irregular forms that matched in length and had a high degree of overlap with the target

(e.g., FELL–FALL) was significant (33 ms), but facilitation following irregular pairs (e.g., TAUGHT–TEACH) that differed in length and overlap was not (15 ms). Facilitation (44 ms) was greatest following regular primes (e.g., HATCHED–HATCH). The relation between degree of overlapping form between a past tense prime and its present tense target and the magnitude of morphological facilitation is difficult to reconcile with an account of morphological facilitation based on reactivation of a shared base morpheme. In essence, despite elaborate matching, as long as degree of form overlap varies among morphological relatives, all pairs, more specifically, all inflectionally related prime–target pairs, do not produce equivalent facilitation. These differences are not consistent with a mechanism of morphological facilitation that relies on successive activation of a common base morpheme, nor do they replicate the findings in long-term priming.

The pattern of morphological facilitation takes on yet another dimension when primes are presented only briefly (30 ms) and are preceded (60 ms) and followed (30 ms) by different pattern masks (Feldman, unpublished data). The two-mask procedure produces significant morphological facilitation (25 ms) relative to an orthographically matched baseline. More crucially, among morphological derivations, targets that more completely preserved the phonology as well as the spelling of the base morpheme (e.g., ATTRACT–ATTRACTIVE) underwent significantly greater facilitation relative to frequency matched unrelated primes than did targets whose base accepted allomorphy (e.g., ATTRACT–ATTRACTION). That is, ATTRACT–ATTRACTIVE produced significant facilitation (35 ms) relative to SLENDER–ATTRACTIVE [ $F_1(1, 58) = 5.22, MSE = 4123, p < .04; F_2(1, 31) = 5.88, MSE = 4334, p < .05$ ], whereas the difference (4 ms) between ATTRACT–ATTRACTION and SLENDER–ATTRACTION was not significant ( $F_s < 1$ ). To our knowledge, only one other study that examined phonological contributions to morphological facilitation under visual presentation conditions appears in the literature (Tsapkini, Kehayia, & Jarema, 1999). Because base morphemes are not specified in a manner that distinguishes between the final “T” of ATTRACT in ATTRACT + (T)ION and in ATTRACT + IVE, the outcome is not easily accommodated by a mechanism of base morpheme activation. At present, its impact on models of morphological processing is limited, however, because the phonological effect has only been demonstrated in one experimental task. Specifically, when forward and backward masks severely restrict orthographic input. Notwithstanding, the foregoing provides evidence that morphological facilitation in the visual domain is not necessarily isolated from an effect of phonological form.

Effects of form similarity among morphological relatives seem to suggest that the knowledge structures that produce long-term morphological facilitation (e.g., HEALTH–HEAL) may be more abstract than those that govern forward masked facilitation (e.g., FELL–FALL) which, in turn, may be more abstract than those of two-mask facilitation (e.g., ATTRACT–ATTRACTION). That is, the three tasks potentially differ in their sensitivity to form-related dimensions of similarity between words, in particular morphological relatives. To elaborate, phonology and allomorphy may influence two mask recognition, whereas orthographic factors may override phonological factors in forward masked settings. By contrast, orthographic as well as phonological contributions to long-term repetition priming appear negligible. In summary, an emphasis on similarities across tasks and patterns of graded effects may provide new insights into the continuous aspects of morphological processing so that lexical knowledge structures do not appear to be created anew for specific experimental tasks.

Stated generally, a research focus on graded effects emphasizes continuity by focusing on the contribution of particular dimensions of similarity to word recognition

and on how the magnitudes of those contributions might vary. Degree of form overlap can be examined across experimental materials, as in the studies described above, and may permit an interpretation based on contrasting lexical structures. Alternatively, however, degree of overlap may suggest an interpretation grounded in the activation dynamics associated with the systematic relation between form and meaning that exists for words formed from a common base morpheme (Plaut & Gonnerman, 2000; Rueckl et al., 1997). Gradations in the magnitude of an effect also arise across processing time within a task. Such a pattern may be consistent with the claim that shared lexical structures underlie word recognition, but that processing time and perhaps processing demands of a particular experimental context can alter the salience of particular dimensions of similarity. Once again, however, effect size may depend on the time course over which the systematicity of the mapping between form and meaning emerges (Plaut & Gonnerman, 2000; Rueckl et al., 1997). By any workable account, a characterization of the lexical events that underlie morphological processing must accommodate time varying patterns. Similarly, it must account for gradations in the magnitude of the same effect across experimental tasks that emphasize common underlying knowledge structures modulated by task. In the remainder of this article we concentrate on graded effects of meaning that generalize over task as well as SOA and that invite an account that emphasizes dynamic lexical events. We contrast the outcomes from three tasks that vary in their semantic demands: lexical decision, naming, and go/no go naming. A coordinated set of experimental materials appeared in all three studies. The lexical decision data have been published previously (Feldman, 2000). Therefore, those procedures and data are described only briefly. For the two variants of the naming task, however, we report the results more completely.

#### GRADED SEMANTIC EFFECTS: LEXICAL DECISION

Recently, the first author contrasted morphological effects with the effects of shared meaning and shared form with English materials and the lexical decision methodology (Feldman, 2000). Within each experiment, there were three dimensions of similarity (orthographic, semantic, and morphological) that primes shared with targets. Incorporating three types of similarity for the same target within a single experiment made it possible to compare systematically magnitudes of facilitation (unrelated minus related) for each dimension of similarity. In addition, she varied the temporal relation between visual prime and visual target so as to reveal the time course over which particular dimensions of similarity influenced target recognition.

Fifty-four sets of materials were created. Each included one target and six primes. All primes were of lower frequency than their target. 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). Each of the three critical primes had its own unrelated control (e.g., SAVES, TORSO, and SCRAPE, respectively) that was matched for frequency, length, and morphological structure (simple or complex). Stimulus attributes are summarized in Table 1.

Items were constructed so that the orthographically related and morphologically related primes were matched (item by item) for orthographic and phonological overlap with the target. Because they were matched on number of shared orthographic (and phonemic) units, any differences between the morphologically and orthographically related prime–target pairs could not be attributed to differing degrees of orthographic (phonemic) overlap between members of the morphologically and orthographically related prime–target pairs. Judgements on a 7-point scale were used to

TABLE 1  
Attributes of Morphological, Orthographic, and Semantic Primes in English  
(from Feldman, 2000)

	Type of prime		
	Morphological	Orthographic	Semantic
Critical prime	VOWED	VOWEL	PLEDGE
Control prime	SAVES	TORSO	SCRAPE
Target	VOW	VOW	VOW
Frequency ( <i>SD</i> )	24 (46)	26 (41)	42 (67)
Target frequency ( <i>SD</i> )	84 (133)	84 (133)	84 (133)
Semantic relatedness ( <i>SD</i> )	5.9 (.81)	1.7 (.81)	5.7 (.94)
Morphological structure	Complex	Simple	Simple
Letter overlap ( <i>SD</i> )	5.8 (1.1)	5.8 (1.1)	
Phoneme overlap ( <i>SD</i> )	3.0 (.67)	3.0 (.7)	
Syllable length	1.9 (.5)	1.5 (.6)	

match semantically related and morphologically related primes for semantic relatedness to the target.

Participants (in each experiment, defined by prime duration) were approximately 90 native speakers of English who were students at The University at Albany, SUNY. Mean decision latencies and accuracy rates are summarized in Table 2. Analyses of variance (ANOVA) treating subjects (*F*1) and items (*F*2) as random variables were performed after outliers (more extreme than 3 *SD*) were excluded.

TABLE 2  
Target Decision Latencies (and Accuracy Rates) for Targets Following Morphologically, Orthographically, and Semantically Related Primes and Their Frequency Matched Controls (from Feldman, 2000)

Prime duration	Relatedness	Type of prime		
		Morphologic (VOWED-VOW)	Orthographic (VOWEL-VOW)	Semantic (PLEDGE-VOW)
32	Critical	623 (91)	652 (84)	641 (93)
	Control	655 (91)	662 (89)	653 (89)
	Facilitation	32* (0)	10 (-5)	12 (4)
66 <sup>a</sup>	Critical	585 (86)	595 (80)	592 (89)
	Control	614 (89)	613 (87)	614 (87)
	Facilitation	29* (-3)	18* (-7)	22 (2)
116 <sup>a</sup>	Critical	615 (90)	665 (84)	625 (89)
	Control	650 (84)	657 (85)	655 (86)
	Facilitation	35* (6)	-8 (-1)	30* (3)
300 <sup>a</sup>	Critical	587 (90)	659 (84)	604 (88)
	Control	636 (84)	641 (86)	637 (86)
	Facilitation	49* (6)	-18* (-2)	33* (2)

<sup>a</sup> Prime duration includes a 50-ms blank.

\*  $p < .05$  by subjects and by items.

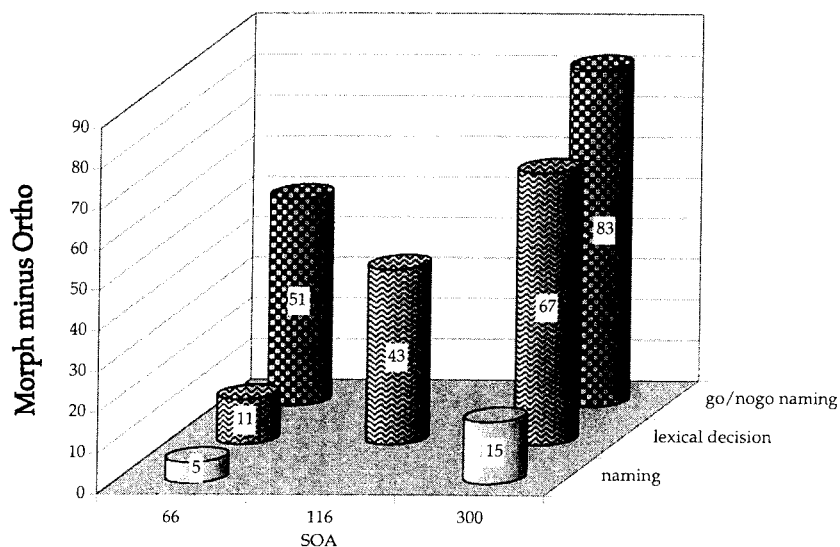
### *Effects of Prime Type*

The primary lexical decision data focused on the time course over which each dimension of similarity influenced the processes of word recognition. This consisted of contrasting decision latencies following unrelated and critical primes for each dimension at each prime duration. In brief, all dimensions of similarity influenced decision latencies and morphological facilitation was distinct from the effect of either semantic or orthographic similarity (see also Stolz & Feldman, 1995). When processing time for the prime ranged from 66 to 300 ms and no more than 12% of word–word pairs shared any dimension of relatedness, the magnitude of morphological facilitation increased. Like morphologically related primes, semantically related primes also reduced target decision latencies relative to unrelated controls. Facilitation due to morphological relatedness was numerically greater than that of semantic relatedness and across prime durations the difference was statistically significant. The results are consistent with the outcomes of earlier studies (e.g., Bentin & Feldman, 1990; Henderson, Wallis, & Knight, 1984; Napps, 1989) that contrasted morphological with semantic effects in immediate variants of the lexical decision task.

The effect of orthographic relatedness was distinctive because direction (*viz.*, facilitation or inhibition) depended on processing time for the prime. At a duration of 66 ms, orthographically similar primes reduced target latencies almost as much as did morphologically related primes. At a duration of 300 ms, however, orthographically similar primes significantly slowed target decision latencies. The shift from facilitation to inhibition following orthographically related primes as processing time increased is also consistent with earlier work (e.g., Drews & Zwitserlood, 1995; Ferrand & Grainger, 1992; Napps & Fowler, 1987).

### *Time Varying Semantic Processing*

Following from the insight that morphological relatives tend to share similar form and similar meaning, the design of the study permitted a focus on the divergence of morphological and orthographic relatedness with processing time for the prime. In Fig. 1, we plotted the difference in facilitation for target latencies after morphologi-



**FIG. 1.** Differences in facilitation following morphologically and orthographically related primes across SOA and task.

cally and orthographically related primes in the lexical decision task. A salient pattern is that the difference in latencies to targets that followed morphological as compared to orthographic primes diverged more as processing time for the prime increased [ $F_1(2, 283) = 7.09$ ,  $MSE = 10657$ ,  $p < 0.001$ ;  $F_2(2, 106) = 3.81$ ,  $MSE = 6364$ ,  $p < .05$ ]. Planned comparisons indicated that the difference in lexical decision latencies (11 ms) was not significant at 66 ms but was significant (67 ms) at 300 ms [ $p_s < .05$ ].

The pattern of divergence between morphological and orthographic target decision latencies was particularly informative. Insofar as morphological and orthographic primes were matched for similarity to the target, their differentiation is consistent with the claim that the influence of semantic similarity of the prime on target decision latencies increases with processing time for the prime (Segui & Grainger, 1990). The outcome is not unlike that of conventional semantic relatedness among orthographically unrelated forms. Its magnitude also tended to increase with processing time for the prime (e.g., Lorch, 1982; Raveh, 1999). In the lexical decision task, semantic facilitation (22 ms) was not significant at the 66-ms duration but its magnitude (33 ms) increased to a level of significance at the 300-ms duration.

In the lexical decision task, processing time for the prime played a crucial role in differentiating morphological effects from orthographic effects and we interpreted this as evidence that the measure indexes the extent of semantic processing when form similarity is held constant (Feldman, 2000). Moreover, contributions of meaning to morphological processing appeared to be graded. This outcome was not anticipated by traditional mechanisms of morphological facilitation that are grounded in multiple activations of a shared base morpheme. Nevertheless, Feldman, Soltano, Pastizzo, and Francis (2001) have reported that the difference in target (e.g., CASUALNESS) decision latencies following semantically transparent (e.g., CASUALLY) and semantically opaque (e.g., CASUALTY) morphological relatives also depended on SOA. Specifically, at a 250-ms SOA targets that followed transparent and opaque primes differed significantly (40 ms) but at a 48-ms SOA they did not (–6 ms). Evidently, the contribution of semantics to morphological processing does vary with processing time (see also Feldman & Soltano, 1999; Rueckl et al., 1997).

A potential limitation of the present study is that it may be misleading to investigate the time course of semantic contributions to morphological processing with the lexical decision task. Requirements of the lexical decision task may promote semantic analysis, thereby forcing the early differentiation of orthographic from morphological primes. This could arise because semantics necessarily plays a role in deciding whether a letter string is a real word or because it is difficult to evaluate target lexicality devoid of the semantic relatedness between prime and target. Furthermore, in the lexical decision task, the relation between dimensions may be such that the potential benefit of form similarity is severely diminished because meaning similarity is essential. That is, consistent with the semantic demands of the lexical decision task, semantic dissimilarity may override any contribution of shared form. In follow-up experiments with variants of the naming task, we tested the generality of the time course pattern we observed in the lexical decision task.

#### GRADED SEMANTIC EFFECTS: NAMING

The traditional naming task, in which participants read aloud targets, provided a second perspective on the processes that underlie morphological aspects of word recognition and it differed from the lexical decision task in several potentially useful ways. First, orthographically as well as morphologically and semantically related

primes all tend to speed performance in the naming task (Drews & Zwitserlood, 1995; Pastizzo & Feldman, this volume). Second, semantic effects generally are attenuated in the naming task. This applies both to the semantic relatedness between prime and target that is conventionally investigated in semantic priming studies as well as to the (backward) semantic relationship between target and prime (e.g., Balota & Chumbley, 1984; De Groot, 1984; Neely, 1991). Of course, it is not generally the case that semantic relationships play no role in the naming task. An alternative is that similarity based on form just assumes greater importance in naming than does semantic relatedness. Finally, the naming task does not involve a binary decision that may be tied to the relatedness of prime and target.

Participants in each experiment were approximately 90 native speakers of English who were students at The University at Albany, SUNY. They named aloud visually presented target words that were preceded by visually presented morphologically, orthographically, or semantically related primes. Experimental materials were identical to those used in the lexical decision experiment. Replicating the design of the original lexical decision study (Feldman, 2000) summarized above, all dimensions of similarity were presented in the same experiment. The prime appeared for durations that ranged from 32 to 300 ms in order to track the time course of activation. Participants spoke the target item aloud as quickly and as accurately as possible. Finally, participants were instructed to name aloud all targets, whether or not they were real words in English.

Naming latencies more extreme than 3 *SD* from the mean (approximately 2% of responses) were excluded and treated together with incorrect articulations as errors. The mean naming latencies and accuracy rates are summarized in Table 3. ANOVAs indicated that across all prime durations, naming latencies to targets following critical primes were reduced relative to their respective unrelated controls [ $F(1, 281) = 206$ ,  $MSE = 694$ ,  $p < .0001$ ;  $F(1, 50) = 91.6$ ,  $MSE = 970$ ,  $p < .0001$ ]. Similarly, target naming was more accurate following critical primes relative to their respective unrelated controls [ $F(1, 281) = 4.49$ ,  $MSE = .004$ ,  $p < .05$ ;  $F(1, 50) = 3.84$ ,  $MSE = .003$ ,  $p < .05$ ]. Planned comparisons revealed that collapsed over SOA, naming latencies were significantly slower following unrelated than critical primes

TABLE 3  
Naming Latencies (and Accuracy Rates) for Targets Following Morphologically, Orthographically, and Semantically Related Primes and Their Frequency Matched Controls

Prime duration	Relatedness	Type of prime		
		Morphologic (VOWED-VOW)	Orthographic (VOWEL-VOW)	Semantic (PLEDGE-VOW)
32	Critical	538 (97)	539 (98)	554 (98)
	Control	563 (97)	565 (96)	558 (97)
	Facilitation	25* (0)	26* (2)	4 (1)
66	Critical	585 (98)	597 (96)	607 (95)
	Control	606 (97)	612 (96)	615 (96)
	Facilitation	21* (1)	15* (0)	8 (-1)
300	Critical	558 (94)	574 (95)	584 (93)
	Control	595 (93)	595 (93)	591 (94)
	Facilitation	37* (1)	21* (2)	7 (-1)

\*  $p < .05$  by subjects and by items.



for the morphological, orthographic, and semantic dimensions of relatedness, respectively [ $p_s < .05$ ].

### *Effects of Prime Type*

The magnitude of facilitation was assessed by subtracting reaction times to targets preceded by critical primes from those of their unrelated primes. The difference was computed for each of the prime types and this provided the basis for an analysis based on difference scores. An analysis of variance conducted on difference scores confirmed that the effect of prime type (orthographic, morphologic, or semantic) was significant with the latency measure [ $F1(2, 562) = 27.91, MSE = 1229, p < .0001; F2(2, 100) = 13.49, MSE = 1245, p < .0001$ ], but not with the accuracy measure. The main effect of SOA missed significance [ $F1(2, 28) = 2.56, MSE = 1387, p < .08; F2(2, 100) < 1$ ]. Finally, the interaction between prime type and SOA was significant by participants [ $F1(4, 562) = 2.36, MSE = 1229, p < .05; F2(4, 200) = 1.5$ ].

Morphological facilitation varied in magnitude from 25 ms at an SOA of 32 ms to 37 ms at an SOA of 300 ms and was significant at each SOA [ $p_s < .05$ ]. Planned comparisons at SOAs of 66 and 300 ms indicated that the magnitude of morphological facilitation increased significantly with SOA [ $p_s < .05$ ]. In the lexical decision task, by comparison, comparable conditions produced 32 and 49 ms of facilitation, respectively. Target naming latencies following orthographically similar primes tended to reduce target naming times. Facilitation was significant and varied between 26 and 22 ms. In the lexical decision task, comparable conditions produced 10 ms of facilitation at the 32-ms duration and 18 ms of inhibition in the 300-ms condition. Finally, primes related semantically to their targets reduced naming latencies by 3–8 ms and the effect was not significant at any SOA. In lexical decision, those magnitudes ranged from 12 to 33 ms and increased with processing time. Planned comparisons at SOAs of 66 and 300 ms indicated that semantic and orthographic effects did not change with SOA. Stated succinctly, morphological facilitation generalized to the naming task. Unlike the lexical decision task, however, orthographic similarity also facilitated naming latencies. Semantically related primes produced nonsignificant facilitation even at the longest SOA.

### *Time Varying Semantic Processing*

Morphological and orthographic primes were matched for onset similarity to the target and the semantic requirements of the naming task are purportedly negligible. Nevertheless, target naming latencies following morphological and orthographic primes tended to diverge more as processing time for the prime increased [ $F1(2, 281) = 2.67, MSE = 2452, p < .07; F2(2, 100) = 2.0, MSE = 2836, p < .14$ ]. Perhaps more compelling, planned comparisons indicated that the difference between orthographic and morphological conditions varied with SOA. It increased from a 1-ms effect at an SOA of 32 ms ( $F_s < 1$ ) to a difference of 15 ms at the 300-ms SOA [ $F1(1, 202) = 8.3; F2(2, 106) = 8.04; p_s < .005$ ]. To reiterate, only at the 300-ms SOA was the difference of divergence significant. The pattern is depicted in Fig. 1.

Overall, effect sizes were attenuated in the naming task relative to the lexical decision task. In the naming task, semantic facilitation was not significant even at the 300-ms SOA although it reached significance when pooled over all SOAs. Similarly, discrepancies in naming latencies between the morphological and orthographic conditions were reduced in the naming task relative to the lexical decision task. Notably, despite overall differences in magnitude across tasks, in the naming task as in the

lexical decision task, targets that followed morphological and orthographic primes diverged more as processing time for the prime increased.

Essential to an interpretation of the difference between the lexical decision and the traditional naming data is the influence of orthographically similarity. At short SOAs in both tasks, shared form in the absence of shared meaning (e.g., VOWEL-VOW) was statistically indistinguishable from morphological relatedness (e.g., VOWED-VOW), but as SOA increased, the two progressively diverged. Although shared form in the absence of shared meaning speeded target recognition in the naming task and slowed recognition in the lexical decision task, changes in both over SOA invite an interpretation based on the progress of semantic processing that eventually offsets an effect of shared form. In the final study, we asked whether semantic effects are enhanced and whether benefits of phonological similarity were eliminated in variants of the naming task that force greater semantic analysis (Segui & Grainger, 1990).

#### GRADED SEMANTIC EFFECTS: GO/NO GO NAMING

In the go/no go naming task, participants named aloud only those targets that were real words in English. Naming latencies more extreme than 3 *SD* from the mean (approximately 2%) were excluded and treated together with incorrect articulations as errors. Participants in each experiment were approximately 85 native speakers of English who were students at The University at Albany, SUNY. Mean decision latencies and accuracy rates for the go/no go naming experiments are summarized in Table 4.

Across all prime durations, decision latencies to targets that followed critical primes were reduced relative to their respective unrelated controls [ $F1(1, 281) = 206, MSE = 694, p < .0001; F2(1, 50) = 91.6, MSE = 970, p < .0001$ ]. Similarly, naming targets that followed critical primes was more accurate relative to their respective unrelated controls [ $F1(1, 281) = 4.49, MSE = .004, p < .05; F2(1, 50) = 3.84, MSE = .003, p < .05$ ]. Planned comparisons collapsed over SOA revealed that naming latencies were significantly slower following unrelated than critical primes when the dimension of relatedness was morphological or semantic. Orthographically similar primes, however, significantly slowed go/no go naming latencies.

TABLE 4

Go/No Go Naming Latencies (and Accuracy Rates) for Targets Following Morphologically, Orthographically, and Semantically Related Primes and Their Frequency Matched Controls

Prime duration	Relatedness	Type of prime		
		Morphologic (VOWED-VOW)	Orthographic (VOWEL-VOW)	Semantic (PLEDGE-VOW)
66	Critical	731 (95)	794 (92)	745 (97)
	Control	759 (95)	771 (94)	768 (95)
	Facilitation	28* (0)	-23* (-2)	23* (2)
300	Critical	640 (98)	722 (96)	666 (98)
	Control	701 (97)	701 (97)	697 (97)
	Facilitation	61* (1)	-21* (-1)	31* (1)

\*  $p < .05$  by subjects and by items.

### *Effects of Prime Type*

As in the lexical decision and traditional naming experiments, the magnitude of facilitation in go/no go naming was assessed by subtracting reaction times to targets preceded by critical primes from those of their unrelated primes, and the difference was entered into an analysis of variance. Morphological facilitation varied from 28 ms at an SOA of 66 ms to 61 ms at an SOA of 300 ms. In the traditional naming task, comparable conditions produced 21 and 37 ms of facilitation, respectively. Primes related semantically to their targets reduced go/no go naming latencies by 23 ms at an SOA of 66 ms and by 32 ms at an SOA of 300 ms. In traditional naming, those magnitudes were approximately 7 ms. Finally, orthographically similar primes slowed go/no go target naming latencies. Inhibition was 23 and 22 ms, respectively at SOAs of 66 and 300 ms and there was no increment with SOA. In the traditional naming task, comparable conditions produced facilitation that ranged between 16 and 22 ms.

An analysis of variance conducted on difference scores indicated that the effect of prime type (orthographic, morphologic, and semantic) was significant [ $F(2, 342) = 48.06$ ,  $MSE = 4386$ ,  $p < .0001$ ;  $F(2, 98) = 37.93$ ,  $MSE = 5518$ ,  $p < .0001$ ], but the main effect of SOA missed significance [ $F(1, 171) = 4.18$ ,  $MSE = 6552$ ,  $p < .05$ ;  $F(2, 49) = 2.48$ ,  $MSE = 5836$ ,  $p < .12$ ]. As in the traditional naming task, the interaction between prime type and SOA missed significance [ $F(2, 342) = 2.64$ ,  $MSE = 4386$ ,  $p < .07$ ;  $F(2, 98) < 1$ ]. Nonetheless, planned comparisons at SOAs of 66 ms and 300 ms indicated that the magnitude of morphological facilitation increased significantly with SOA [ $p < .05$ ] while semantic and orthographic effects did not.

### *Time Varying Semantic Effects*

Variability across the morphological, semantic, and orthographic dimensions of similarity characterized performance in the go/no go naming task. Naming latencies were reduced significantly following semantic as well as morphological primes and the magnitude of semantic facilitation was comparable to that observed in lexical decision. Interestingly, at the 66 ms SOA, orthographic primes in go/no go naming produced significant inhibition (23 ms), whereas in lexical decision they produced facilitation. In sum, neither the magnitude of semantic facilitation nor that of orthographic inhibition increased significantly over SOA when the task was go/no go naming. Surprisingly, however, the magnitude of the divergence of morphological from orthographic similarity was salient at the 66-ms SOA and continued to increase with SOA [ $F(1, 171) = 4.52$ ,  $MSE = 4591$ ,  $p < .05$ ;  $F(2, 49) = 2.70$ ,  $MSE = 849$ ,  $p < .12$ ]. These findings are consistent with the observation that as processing time increases, forms that look alike but share no base morpheme with the target become more distinct from primes that look alike and do share a base morpheme. Nonetheless, because semantic facilitation did not increase comparably over the same SOAs, the interaction between morphological and orthographic similarity and SOA could be only crudely approximated by the magnitude of the effect of conventional semantic relatedness. Finally, no time varying effect of semantic mismatch was evident following orthographically similar primes.

## GENERAL DISCUSSION

Facilitation based on morphological, semantic, and orthographic similarity was examined by comparing, within the same experiment, the differences in word recog-

nition latencies following critical primes and unrelated primes matched for frequency, length, and morphological structure. Across experiments, processing time for the prime ranged from 32 to 300 ms. In both the traditional and go/no go variants of the naming task, as well as in the lexical decision task, 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 significantly with processing time for the prime in the lexical decision, naming, and go/no go naming tasks. Stated generally, we have documented facilitation following a morphologically related prime in the go/no go naming task and replicated it in the traditional naming and lexical decision tasks. Accounts based on conventional priming mechanisms and multiple activations of a shared base morpheme could assert that activation increases with processing time in order to accommodate patterns where the magnitude of morphological facilitation increased with SOA. Further modifications would be necessary, however, to account for variation across experimental tasks. A general observation is that single task studies and studies that restrict prime duration to a single value necessarily fail to capture the systematic and time-varying nature of morphological facilitation.

#### *Comparisons Across Task and SOA*

Facilitation due to morphological relatedness was numerically and statistically greater than that of semantic relatedness in the lexical decision and go/no go naming tasks. Like morphologically related primes, semantically related primes reduced target decision latencies relative to unrelated controls. The magnitudes of both morphological and semantic facilitation were reduced in the naming relative to the lexical decision task. In fact, semantic facilitation failed to reach significance at any single SOA in the naming task. Attenuated effects in the traditional naming as compared to the lexical decision task have been reported previously for both the semantic and morphological dimensions of similarity (e.g., Drews & Zwitserlood, 1995). In go/no go naming, by contrast, morphological and semantic facilitation reached magnitudes that were comparable to those in the lexical decision task.

The direction of the effect of orthographic similarity depended on task and sometimes on prime duration as well. Orthographically similar primes speeded target naming latencies. Insofar as orthographic primes shared form but differed semantically from the target, this finding is consistent with the intuition that effects of semantic relatedness are weak in the naming task but that effects of shared form are robust. Similarly, at durations of 32 and 66 ms, orthographically similar primes reduced target decision latencies. At a prime duration of 300 ms, by contrast, orthographically similar primes significantly slowed target decision latencies. Our interpretation of this pattern is that inhibition following orthographically similar primes derives from the semantic mismatch between prime and target, an effect that depends on processing time for the prime (Feldman, 2000). Finally, the effect of orthographic similarity in the go/no go naming task was similar to that in lexical decision (at least at longer SOAs) insofar as orthographically similar primes significantly slowed target naming.

At a duration of 66 ms, the lexical decision and the go/no go naming tasks both showed magnitudes of semantic facilitation of approximately 22 ms and the effect increased to about 32 ms at a duration of 300 ms. Semantic facilitation in the traditional naming task was quite different, however. In fact, there was no significant semantic facilitation at any SOA. Evidently, the requirements of the go/no go naming task are more similar to those of the lexical decision task than to those of the traditional naming task. This conclusion was unanticipated. Whereas both variants of the naming task require articulation of the target when it is a word, in the lexical decision

task, lexicality judgments are signaled by tapping a key and therefore require no overt articulation. Notwithstanding, in the lexical decision task and in the go/no go naming task, key presses and articulations respectively are contingent on deciding whether the target is a real word and this decision is fundamentally semantic. Varying magnitudes of semantic facilitation suggest a continuum of semantic processing where the go/no go naming and the lexical decision tasks necessitate greater semantic processing than does the traditional naming task.

*Graded Semantic Effects in Morphological Processing: Morphological and Orthographic Similarity Diverge*

The distinct patterns following morphological and orthographic primes not only corroborate the claim that similarity of form is not adequate to account for facilitation among morphological relatives. It also demonstrates that among prime–target pairs, the outcome of orthographic similarity in conjunction with semantic similarity (viz., VOWED–VOW) and without semantic similarity (VOWEL–VOW) are distinct. The difference analyses depicted in Fig. 1 provide insights into the nature of processes that underlie morphological facilitation in three experimental tasks. Graded contributions of semantics across task and SOA appear to underlie the divergent influences of morphological and orthographic similarity. Similarly, gradations in the magnitude of conventional semantic facilitation (e.g., Lorch, 1982; Raveh, 1999) across SOAs in the present study show that semantic processing is gradual and proceeds over time. Nevertheless, the magnitude of the effect of conventional semantic relatedness between a prime and a target provide an inadequate measure of the semantic aspects of morphological processing. In the remaining paragraphs, we discuss the task space and the time course over which the effects of morphological and orthographic similarity diverge and what it reveals about the fundamental role of semantics in morphological processing. Then we speculate about the relatively weak correspondence between the divergence pattern and the magnitude of the effect of conventional semantic relatedness.

The difference between the morphological and orthographic effects was smallest at the shortest duration and greatest at an SOA of 300 ms in each task. The pattern is consistent with claims that semantic processing is enhanced as processing time for the prime increases. Correspondingly, difference scores were smallest in the naming task, intermediate in the lexical decision task, and greatest in the go/no go naming task. The ordering is not inconsistent with the general understanding about the semantic demands of various experimental tasks. We speculate that longer latencies overall in the go/no go naming than in the lexical decision task may have permitted semantic processes to approach asymptote.

Presumably, the overall interaction of task and SOA reflects semantic aspects of processing, yet the corresponding magnitudes of conventional semantic facilitation over the same time period were substantially less. Semantic facilitation was approximately 22 ms in the lexical decision task in the 66-ms condition and reached 33 ms in the 300-ms conditions. By contrast, the difference in target latencies for VOWEL–VOW and VOWED–VOW type pairs was 11 ms in the 66-ms condition and increased to 67 ms. Similarly, across SOAs, semantic facilitation in the go/no go task only ranged between 23 and 32 ms while the morphological minus orthographic difference increased from 51 to 83 ms. Finally, comparable values in traditional naming were 3 and 7 ms and the differences between the morphological and orthographic conditions were 5 and 15 ms, respectively. Evidently, the effect of semantic relatedness defined over prime–target pairs provides only a very approximate measure of the semantic aspects of morphological processing.

An alternative conceptualization of semantic processing in the morphological domain focuses on semantic analysis of the orthographic (and phonological) portion of the prime that overlaps with the target (e.g., VOW). Here, semantic similarity in conjunction with shared form is computed over many words thereby capturing the fundamental morphological relation between prime and target. This perspective is consistent with the observation (Feldman et al., 2001; see also De Jong, Schreuder, & Baayen, 2000) that words formed from a base morpheme that enters into many combinations and therefore has a large morphological family show greater morphological facilitation (and greater effects of semantic transparency among morphological relatives) than do words from small families. Specifically, the difference in target decision latencies following transparent and opaque primes correlated significantly with family size but not with ratings of semantic relatedness. By implication, this measure treats the base morpheme as a statistical regularity that captures the systematic mapping between form and meaning.

To conclude, the primary empirical contribution of the present study was to document the divergence of morphological relatedness from effects of orthographic similarity over SOA and task. Because morphological and orthographic primes were matched for similarity to the target, graded differences between the effects of morphological and orthographic relatedness provided an index of semantic processing when form similarity was controlled. This interaction is not anticipated by traditional accounts of morphological facilitation based on activation of a shared base morpheme in prime and in target. It appears to be more compatible with a dynamic account where morphological effects emerge from conjoint influences of orthographic and semantic similarity that stabilize over time (e.g., Rueckl et al., 1997). Finally, gradations in semantic aspects of morphological processing could only be approximated by the effect of conventional semantic relatedness between prime and target and invite instead a more complex semantic conceptualization, computed over many words that are similar in form and in meaning.

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