

What do graded effects of semantic transparency reveal about morphological processing?[☆]

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Accepted 2 December 2003

Available online 4 February 2004

Abstract

We examined the influence of semantic transparency on morphological facilitation in English in three lexical decision experiments. Decision latencies to visual targets (e.g., CASUALNESS) were faster after semantically transparent (e.g., CASUALLY) than semantically opaque (e.g., CASUALTY) primes whether primes were auditory and presented immediately before onset of the target (Experiment 1a) or visual with an stimulus onset asynchrony (SOA) of 250 ms (Experiment 1b). Latencies did not differ at an SOA of 48 ms (Experiment 2) or with a forward mask at an SOA of 83 ms (Experiment 3). Generally, effects of semantic transparency among morphological relatives were evident at long but not at short SOAs with visual targets, regardless of prime modality. Moreover, the difference in facilitation after opaque and transparent primes was graded and increased with family size of the base morpheme. © 2003 Elsevier Inc. All rights reserved.

Keywords: Semantic transparency; Morphological processing; Morphological decomposition; Cross-modal lexical decision; Visual short-term lexical decision; Derivations; Morphological family size; Graded morphological facilitation

1. Introduction

In the present study we examined patterns of facilitation among morphologically related prime–target pairs that vary along a semantic dimension and we looked for systematic variation across items. The pattern of lexical decision latencies informs us about the processes that underlie a speaker's ability to understand language and in particular to appreciate the relation among words.

[☆] This study was supported by fund from National Institutes of Child Health and Development Grant HD-01994 to Haskins Laboratories. We thank Witina Siok for help with stimulus construction, Christopher Anderson, Donald Graves, Carrie Johnson, Brendon Prostko, and Amy Tal for help with data collection, and Steve Frost for help on data analyses. Portions of this study were presented at the Cross-linguistic Perspectives on Morphological Processing Conference in Aix en Provence, France in May 1999 and at the First International Conference on the Mental Lexicon in Edmonton, Canada in 1998.

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Systematically graded effects across items have special significance because they provide evidence that is inconsistent with accounts of recognition that posit distinct processes for different types of morphological formations where the choice of options purportedly depends on whether or not morphological structure is represented explicitly in the lexicon such that words composed of more than one morpheme (morphologically complex) can have lexical entries that are decomposed. Among those who posit an explicit representation of morphological structure, some (e.g., Marslen-Wilson, Tyler, Waksler, & Older, 1994; Taft & Forster, 1975) claim that various properties of words may influence whether or not there is decomposition. For example, decomposition is more evident when surface frequency is low (Burani & Laudanna, 1992; Bybee, 1995), or is low relative to that of the base morpheme (Baayen, Dijkstra, & Schreuder, 1997; Hay, 2001) and when constituents tend to appear in novel combinations (Schreuder, Burani, & Baayen,

2003). Others (e.g., Butterworth, 1983) claim that morphologically complex words are represented in the lexicon as whole word units.

The formulation of complex forms in concatenative languages such as English typically entails the addition of an affix to a base morpheme. The meaning of some forms (e.g., SWEATY) is predictable from the meaning of its base morpheme and its affixes (e.g., SWEAT + Y) and therefore, morphological relatives such as SWEATY and SWEAT are comparatively close in meaning. The meaning of other relatives (e.g., SWEATER) is not fully predictable from its components and therefore, morphological relatives such as SWEATER and SWEAT are comparatively remote in meaning. Compound words are also composed of multiple morphemes whose contribution to the meaning of the whole word can vary. For both complex and compound words, those that retain the meaning of the base morpheme are semantically transparent relative to opaque or partially transparent relatives whose meanings tend to be more remotely related to that of the base. The extent to which the meaning of the whole word can be composed from that of its morphological constituents may also influence decomposition (Baayen, Burani, & Schreuder, 1996; Schreuder & Baayen, 1995, 1997; Baayen & Schreuder, 1999).

Patterns of facilitation among morphologically related prime–target pairs in the lexical decision task tell us about the representation of morphologically complex words in the lexicon. Several positions have been articulated, two of which assume that facilitation in the lexical decision task entails activation within a lexical architecture that includes morphologically decomposed entries. In contrast to an account that captures morphology in the organization among whole word forms (Lukatela, Gligorićević, Kostić, & Turvey, 1980), the two decomposition accounts differ with respect to the role of semantics. Both opaque and transparent morphological relatives in Hebrew reduced target decision latencies in a forward masked priming task. Accordingly, Deutsch, Frost, and Forster (1998) have proposed a model of the (Hebrew) lexicon in which “all words derived from the same root are clustered via a shared representation of the root morpheme. [Moreover,] this organization is independent of semantic factors” (p. 1250). In contrast, when transparent and opaque word primes have different effects on a morphologically related target, it is sometimes argued that all morphologically complex words may not be represented in the same manner within the lexicon. In particular, facilitation for visual targets after transparent but not opaque auditory primes led Marslen-Wilson et al. (1994) to claim that in English, only those derivations that are semantically transparent with respect to their constituents are decomposed in the lexicon. By this account, facilitation derives from activation of a shared base morpheme in prime and then in target and opaque forms do not produce facilitation because they are not represented in a

decomposed manner. In contradistinction, Rueckl and his associates (Raveh & Rueckl, 2000; Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997) have argued that decomposition of lexical entries into morphological constituents and the activation of constituents is irrelevant to morphological facilitation. Rather, recognition depends on complex and distributed patterns that capture systematicity in the mapping between word form and word meaning as well as the time for patterns to stabilize. In essence, opaque and transparent forms differ along a semantic continuum but are processed by the same system. By this account, graded differences in facilitation among morphological relatives are anticipated and they are characteristic of the degree of similarity in the mappings between form and meaning for prime and target (see also Gonnerman, 1999; Plaut & Gonnerman, 2000; Seidenberg & Gonnerman, 2001). Finally, aspects of morphological processing may benefit from correlations between form and meaning that recur across many words relative to those that occur only rarely.

If patterns of facilitation reflect decomposed lexical entries, a juxtaposition of the outcomes of Deutsch et al. (1998) with those of Marslen-Wilson and his associates (1994) might lead one to infer that languages differ with respect to semantic influences on the lexical representation of morphologically complex words. All words would be decomposed in Hebrew but only transparent words would be decomposed in English. Consistent with the spirit of cross-languages differences, Plaut and Gonnerman (2000) have argued that the different experimental outcomes in Hebrew and English reflect variation in their “morphological richness,” that is, the tendency for almost all or relatively few base morphemes to combine with other morphemes so as to form words. An alternative interpretation for the failure to observe differences between semantically transparent and opaque morphological relatives in Hebrew but not in English, hinges on the particular experimental procedures that the researchers in each study employed (viz., cross-modal vs. forward masked priming).

Investigations into the role of semantic transparency in morphological processing have been conducted in a variety of languages including Bulgarian (Nikolova & Jarema, 2002), Dutch (Sandra, 1990; Zwitserlood, 1994), Spanish (Sanchez-Casas, Igoa, & Garcia-Albea, 1999), and Serbian (Feldman, Barac-Cikja, & Kostić, 2002) as well as English (Feldman & Pastizzo, 2004; Feldman & Stotko, cited in Feldman, 1992; Marslen-Wilson et al., 1994; Rastle, Davis, Marslen-Wilson, & Tyler, 2000) and Hebrew (Bentin & Feldman, 1990; Frost, Forster, & Deutsch, 1997; Raveh & Feldman, 1998). As is evident in Table 1, although these studies were similar in that each asked whether semantically opaque and transparent relatives produced different magnitudes of morphological facilitation, their methodologies varied along several potentially relevant di-

Table 1
Overview of semantic contributions to morphological facilitation

Lag	Modality of prime and target	SOA (ms)	Mask	Language	Stimuli	Transparency effect
IMMEDIATE						
Bentin and Feldman (1990)	VV	0 item lag	No	Hebrew	DO DT S	O ≠ T ^a
Feldman et al. (2002)	VV	250	No	Serbian	DO DT	O ≠ T
		48			DO DT	O = T
Feldman and Pastizzo (2004)	VV	250	No	English	DO DT	O ≠ T ^b
Frost, Deutsch, Gilboa, Tannenbaum, and Marslen-Wilson (2000)	AV			Hebrew	DT DO	O ≠ T
Libben, Gibson, Yoon, and Sandra (1997)	VV	150	No	English	CO ^c CT ^c	O = T
Marslen-Wilson et al. (1994)	AV	At prime offset	No	English	DT DO	O ≠ T
					DO DT S	O = T
Rastle et al. (2000)		43	No	English	DO DT S	O = T
		250	No	English	DO DT S	O ≠ T
Raveh and Feldman (1998)	AV	At prime offset	No	Hebrew	I D	I ≠ D
	VV	250	Backward	Hebrew	I DT	I ≠ D
Zwitserlood (1994)	VV	300	No	Dutch	CO CT	O ≠ T
MASK						
Frost et al. (1997)	VV	50 ms	Forward	Hebrew	DT DO	O = T
Nikolova and Jarema (2002)	VV	70 ms	Forward mask	Bulgarian	DT DO	O = T prefixed only
LONG TERM						
Bentin and Feldman (1990)	VV	15 item lag	No	Hebrew	DO DT	O = T
Feldman and Stotko (1990)	VV	10 item lag	No	English	DO DT	O = T
Sandra (1990)	VV	RSI (~1 s)	No	Dutch	CO CT	O = T

D, derivation; C, compound; O, opaque; T, transparent; S, semantic associate.

^a Statistically significant with latency measure $p < .05$.

^b Statistically significant with accuracy measure $p < .05$.

^c TT and OT conditions were statistically different from TT and TO.

mensions. The absence of facilitation due to semantic association in some experimental contexts demonstrates that all tasks are not equally sensitive to semantics (Raveh, 1999). Therefore, irrespective of language, other

types of semantic relatedness such as transparency effects in morphological facilitation should be more reliable under those experimental conditions that typically reveal non-morphological semantic effects as well.

1.1. *Effects of semantic transparency vary across tasks*

Under cross-modal presentation conditions with auditory (A) primes and visual (V) targets in English, target decision latencies relative to unrelated controls were faster after primes (e.g., CRIME) that were semantically associated to their target (e.g., PUNISH). Likewise, morphologically complex primes (e.g., PUNISHMENT) reduced target decision latencies relative to orthographically and morphologically unrelated controls (Marslen-Wilson et al., 1994, Experiment 3). By contrast, primes that shared the base but were not semantically transparent (e.g., DEPARTMENT) did not reduce target (e.g., DEPART) latencies. Interestingly, in that study, morphological facilitation failed to arise among semantically transparent forms when targets as well as primes shared a base morpheme but had different suffixes (Marslen-Wilson et al., 1994). Recent work suggests that the absence of facilitation may have depended on the choice of an unrelated relative to an orthographic baseline as well as to other particulars of the presentation condition, however (Pastizzo & Feldman, 2002a, 2002b). Similarly in Hebrew (Feldman & Raveh, 2003; Frost et al., 2000), significantly reduced, nevertheless significant facilitation arose after relatively opaque as contrasted with relatively transparent morphological primes. In brief, in both English and Hebrew cross-modal presentations of prime and target produced morphological facilitation whose magnitude varied with the degree of semantic transparency between prime and target.

Under purely visual and unmasked presentation conditions, target decision latencies also differed after morphologically opaque and transparent primes. In one Hebrew study (Bentin & Feldman, 1990), participants responded to primes as well as targets and each item appeared for 1000 milliseconds (ms). Some prime–target pairs (e.g., NUMBER–LIBRARY) shared morphology only (M). They were formed from the same base morpheme, ספר (SPR) but their full forms were not semantically related in any obvious way. Other word pairs (e.g., LIBRARIAN–LIBRARY) shared both morphology and semantics (MS) and the balance (e.g., READING–LIBRARY) shared semantics only (S). In immediate priming, the magnitude of facilitation was graded. That is, facilitation was greater after MS related primes than M primes. Semantically related items (S) also produced significant facilitation. Likewise, Raveh (1999) reported differences in facilitation after morphological relatives that varied in the degree of semantic similarity to the target. Moreover, effects tended to be significant at a long but not at a short stimulus onset asynchrony (SOA). Stated generally, in the immediate priming lexical decision task, semantic effects among morphological relatives and effects of semantic association tended to increase with SOA (see also Rastle et al., 2000).

By contrast, two variants of the primed lexical decision tasks have failed to provide evidence of semantic influences on facilitation. In English, effects of semantic relatedness were absent in the masked priming task (Forster & Davis, 1984). Similarly in Hebrew, opaque and transparent forward masked morphological primes produced comparable magnitudes of facilitation and there was no effect of semantic association (Frost et al., 1997). Finally, in Bulgarian, opaque and transparent forms that followed prefixed morphological relatives (e.g., POPI–POPIX vs. IZPI–IZPIX) did not differ (Nikolova & Jarema, 2002). Likewise, the outcomes of long-term repetition priming studies have tended not to reveal semantic effects, either of association or transparency. For example, in addition to an immediate priming format, Bentin and Feldman (1990) presented the same visual primes and visual targets separated by a lag that averaged 15 items. At that lag, opaque and transparent prime–target pairs in Hebrew produced statistically equivalent morphological facilitation (viz., +24 ms vs. +28 ms). Analogously with English materials, researchers [Feldman and Stotko (1990, cited in Feldman, 1992)] failed to find a difference in the magnitude of morphological facilitation at long lags for targets (e.g., CREATE) that followed semantically transparent primes (e.g., CREATION) as compared with semantically less transparent (e.g., CREATURE) primes (see also Raveh & Rueckl, 2000).

In summary, effects of semantic transparency and of semantic association are difficult to detect in either the masked or the long-term priming task. The failure to find an effect of degree of semantic transparency among morphological relatives in masked priming or at long lags is consistent with the claim that some lexical decision procedures are relatively insensitive to semantics. Note that although facilitation due to semantic association between prime and target has been unreliable under conventional long lag presentation conditions (Feldman, 2000), it did appear in a context that necessitated deeper semantic analysis (e.g., Becker, Moscovitch, Behrmann, & Joordens, 1997).

Collectively, an overview of the experimental literature on the contribution of semantic transparency to morphological processing confirms that variation in patterns of facilitation over experimental tasks is more reliable than variation across languages. Across varying tasks and presentation formats, cross-language contrasts between opaque and transparent morphological relatives appear to emerge. Within an experimental task, however, there is little compelling evidence that semantic transparency differentially influences morphological processing across languages. Stated succinctly, differences in target recognition latencies after morphologically opaque and transparent relatives point to semantic influences on morphological processing. However, systematic differences over tasks raise questions about

alleged differences across languages with respect to semantic constraints on the morphological decomposition of lexical entries.

1.2. Semantic transparency and the locus of morphological processing

In the current study, we investigated the role of semantic transparency among derivationally related forms in English across a variety of experimental procedures that are differentially sensitive to semantics. Primes and targets consisted of suffixed words formed from a common base morpheme. By necessity, because they differed with respect to a meaning-altering (viz., derivational) suffix, complex pairs tended to be less related semantically than were complex forms with their base. In addition to reducing semantic relatedness overall, the introduction of suffixed word forms allowed us to compare two constructions both of which failed to produce morphological facilitation when presentations were cross-modal (Marslen-Wilson et al., 1994).

In parallel with our manipulation of semantic transparency between primes, we probed for systematic variation among targets. For both complex and compound words presented in isolation, when frequency was controlled, decision latencies were faster for targets composed of a base morpheme that recurred in many words (large family size) as compared with targets whose base morpheme appeared in relatively few words (De Jong, Feldman, Schreuder, Pastizzo, & Baayen, 2002; De Jong, Schreuder, & Baayen, 2000). In essence, there is evidence from the single word recognition task that *family size*, an index of the morphological productivity of the base morpheme, influenced recognition times for targets presented in isolation. When morphological family is defined only by those relatives that are semantically transparent with respect to the base morpheme (transparent family size), correlations strengthened. In the present study, we examined the relation between transparent family size (TFAM) and semantic transparency. Significant correlations of TFAM with morphological facilitation would be important because they would represent an extension of the influence of family size into the priming domain. A correlation between target decision latencies (semantic transparency) and the tendency for a base morpheme to enter into many word formations (viz., family size) would attest to facilitation that is fundamentally morphological, yet cannot be defined simply in terms of activation of a shared base morpheme in a prime and its target.

Our working hypothesis, following from the findings of Raveh and Rueckl (2000; Raveh, 1999), is that in English, only those experimental procedures that reliably produce effects of semantic association will reveal effects of semantic transparency on morphological processing

(see also Feldman & Prostko, 2002). All experiments used the same experimental materials and some variant of the lexical decision task but experiments differed with respect to the presentation format of the prime. In Experiment 1, our point of departure (Exp. 1a), we employed the cross-modal procedure of Marslen-Wilson, then we manipulated the modality of the prime (Exp. 1b). In Experiment 2 we presented unmasked primes at a short SOA (48 ms) and in Experiment 3, we based our presentation format on the forward masked prime procedure of Forster and Davis (1984) and of Frost et al. (1997). In each experiment, the design permitted us to contrast the effect of opaque and transparent primes on the same target.

2. Experiments 1a and b

In Experiment 1a, we followed the cross-modal presentation procedure preferred by Marslen-Wilson and his colleagues (1994). We presented suffixed auditory primes immediately before suffixed visual targets. In Experiment 1b, visual primes and visual targets were presented at an SOA of 250 ms. Our primary comparison was target decision latencies after opaque relative to transparent primes as this provides an index of the semantic contribution to morphological processing. Secondly, we tracked transparent facilitation relative to the unrelated baseline condition for comparison with the outcome of the Marslen-Wilson et al. (1994) study. Taken together, Experiments 1a and b allowed us to evaluate the role of prime modality in morphological processing.

2.1. Methods

2.1.1. Participants

Sixty participants participated in Experiment 1a (AV) and 68 participated in Experiment 1b (250 ms SOA). Participants were recruited from the University at Albany, State University of New York. All were native English speakers with normal or corrected-to-normal vision and no known reading disorders. One hundred twelve students participated in exchange for partial course credit and 16 were paid \$5.00 each.

2.1.2. Materials

Morphologically complex words were selected as primes and as targets. Thirty-three words were selected as critical targets. More than half of them overlapped with the materials of Marslen-Wilson et al. (1994). Primes were paired with each target to create three conditions: semantically transparent base morpheme (e.g., ACCORDING–ACCORDANCE), semantically opaque base morpheme (e.g., ACCORDION–ACCORDANCE), and unrelated but morphologically

complex (e.g., DICTATION–ACCORDANCE). The average frequency (and standard deviation) of primes was 32 (61) for the transparent condition, 32 (47) for the opaque condition, and 32 (42) for the unrelated condition (Kučera & Francis, 1967). In each set, prime frequencies were higher than target frequencies (24 (32)).

All related primes shared the base morpheme with the target and were matched for letter overlap with the target. The average position sensitive letter overlap of prime with target (and standard deviation) was 6.0 (1.9) for the transparent condition and 5.9 (1.8) for the opaque condition. A rating study ($N = 60$) indicated that the mean prime-target semantic relatedness rating on a seven-point scale was higher for its transparent prime (mean = 5.3, $SD = 0.9$, range = 3.3–6.5) than for its opaque prime (mean = 2.8, $SD = 1.2$, range = 1.3–5.5) and overall, the difference was statistically significant. Finally, for both morphological primes, ratings were greater than for unrelated primes (mean = 1.8, $SD = 0.5$, range = 1.1–3.0). The rating study was conducted concurrently with the lexical decision study but with different participants.¹ Responses to five items (CHRONICALLY, FACTUAL, PHYSICIST, SANCIFY, and SEEDLESS) were deleted from all analyses because their ratings did not meet the criteria for differentiating transparent and opaque items. The items were re-coded as fillers in this and in later experiments and were not included in the data analyses.

Two-thirds of the critical word–word pairs (22) were related and one third of the pairs (11) were unrelated in any one list. To reduce the overall proportion of related trials, filler trials in which the prime and target did not match on form or meaning were introduced. The inclusion of forty filler word–word trials and twenty-nine filler word–pseudoword trials reduced the relatedness proportion for word–word trials to 30% (and the proportion for all trials to 15%). Finally, forty-four morphologically complex pseudoword targets were included. Two types of morphologically complex word primes were paired with each pseudoword target. One was a morphologically complex real word prime that shared a base with the pseudoword target (e.g., WISHFUL–WISHAL). The other was a morphologically complex real word prime that did not overlap orthographically or phonologically with the pseudoword target (e.g., ILLUSORY–WISHAL).

Each auditory prime (Exp. 1a) was digitally recorded by a female native English speaker with Sound Edit 16

and sampled at a rate of 44 kHz. Stimuli were then edited and stored on computer disk as individual files for playback during the experiment.

2.1.3. Design

Three experimental lists each containing 146 trials were constructed. Primes were counterbalanced across the three lists so that each list included all types of primes. If a particular target appeared with a particular prime in one experimental list, it was paired with a different prime in each of the other two lists. No target was repeated within an experimental list.

2.1.4. Procedure

In Experiment 1a, immediately following the offset of a 250 ms fixation cross (+), an auditory prime was presented. At prime offset, a visual target printed in lowercase letters appeared. The target remained on the screen until the participant made a lexical decision response or until 3000 ms had elapsed. A 750 ms inter-trial interval followed each trial. In Experiment 1b, a fixation cross was visually presented on the computer monitor for 250 ms. Then a visual prime appeared in lowercase letters for 200 ms. After a 50 ms blank screen, the target was presented one line below the prime in lowercase letters. In other respects, the procedure was identical to that of Experiment 1a.

Responses were registered on a Psyscope response box. Participants depressed the right button for word responses and the left button for non-word responses and latencies were measured from the onset of the target. All participants were tested individually on a Power Macintosh 6100/60AV personal computer. Each session began with eight practice trials to acquaint the participant with the task.

2.2. Results and discussion

Incorrect key presses and outliers (defined as 3 or more SD from each participant's mean) were classified as errors. (Outliers constituted about 1% of responses). In this and subsequent experiments, data from five items (AUTHORSHIP, COMPREHENSIBLE, EMERGENT, IMPORTER, and LAXITY) were deleted because of a high error rate (approximately 40%) in at least one condition. The data from two participants were dropped from Experiment 1a and one from Experiment 1b due to a high (>40%) error rate. Mean participant response times, accuracies and difference scores (unrelated minus related) for all experiments are reported in Table 2.

2.2.1. Experiment 1a

The overall one way analysis of variance (ANOVA) indicated that the main effect of type of auditory prime on decision latencies to visual targets was significant by participants (F_1) and items (F_2) [$F_1(2, 114) = 4.36$,

¹ Instructions provided examples of synonyms (YELL–SCREAM) as well as morphological relatives (INSTRUCTOR–INSTRUCT) that were rated as semantically close and pairs that shared form but no meaning (SCHEME–SCREAM) that were rated as unrelated. About half of the items selected by Marslen-Wilson and his colleagues (1994) failed to meet the rating criterion and could not be included in the study.

Table 2
Mean decision latencies (% accuracies) and differences for Experiments 1, 2, and 3

SOA (ms)	Modality		Prime type	Prime type		
	Prime	Target		Unrelated Dictation Accordance	Transparent Accordingly Accordance	Opaque Accordion Accordance
Experiment 1						
At prime offset	A	V	Facilitation	817 (94)	791 (94)	842 (92)
250	V ^a	V		776 (94)	743 (94)	783 (93)
Experiment 2						
48	V	V	Facilitation	747 (94)	733 (94)	727 (92)
Experiment 3						
83 ^b	V	V	Facilitation	896 ^c (89)	874 (94)	881 (91)

^a V, visual presentation; A, auditory presentation.

^b Forward mask preceded the prime.

^c Orthographically similar unrelated control.

$MSE = 8212, p < .05$; $F_2(2, 44) = 4.95, MSE = 7431, p = .01$]. Planned comparisons showed a significant effect of transparency. Latencies to visual targets after auditory primes that were transparent (791, $SD = 222$) were significantly faster than after those (842 ms, $SD = 253$) that were opaque [$F_1(1, 114) = 8.72, p < .005$; $F_2(1, 44) = 9.54, p < .0051$].² The differences in latencies after transparent vs. unrelated (817 ms, $SD = 242$) primes as well as those after opaque vs. unrelated primes missed significance.³

Results of the present study replicated Marslen-Wilson et al. (1994) in that target latencies after both semantically transparent and semantically opaque morphological relatives failed to differ significantly from an unrelated baseline. An advantage of the present design is that we could assess the effect of semantic transparency by comparing latencies to the *same* target after transparent and opaque primes. Crucially, latencies differed significantly after transparent as compared with opaque primes.

2.2.2. Experiment 1b

The overall ANOVA on the latency data revealed an effect of visual prime type on decision latencies for visual targets. It reached significance in the analysis by participants but missed significance in the analysis by

items [$F_1(2, 132) = 3.30, MSE = 9121, p < .05$; $F_2(2, 44) = 2.41, MSE = 3533, p = .10$]. Planned comparisons revealed that decision latencies to targets (743 ms, $SD = 151$) that followed transparent primes were reduced relative to those (783 ms, $SD = 170$) that followed opaque primes [$F_1(1, 132) = 5.89, p < .05$; $F_2(1, 44) = 4.31, p < .05$]. The planned comparison for targets after transparent vs. unrelated (776 ms, $SD = 187$) primes was significant only by participants [$F_1(1, 132) = 3.78, p = .05$; $F_2 < 1$]. Latencies after opaque and unrelated primes did not differ [$F_1 < 1$; $F_2(1, 44) = 2.72, p = .11$].

2.2.3. Combined analyses

We compared difference scores for items in Experiments 1a and b in order to evaluate the role of prime modality. Results of a combined analysis indicated that facilitation for visual targets was not influenced by the modality of the prime [$F_s < 1$] but was influenced by its semantic transparency [$F_1(1, 123) = 14.73, MSE = 8497, p < .0005$; $F_2(1, 22) = 11.23, MSE = 6759, p < .005$].

For all pairs (both transparent and opaque) we computed the correlation between ratings of semantic relatedness (see Methods above) and the magnitude of facilitation relative to the unrelated baseline. Although the correlations were non-significant both when primes were auditory and when they were visual [$r_{44} = .22, p < .162$ and $r_{44} = .15, p < .35$, respectively]⁴ in sub-

² In this and in all subsequent planned comparisons, MSE are redundant with that of the effect or interaction from which means are derived. Therefore, they are not restated.

³ When outliers were defined separately for each condition, inhibition after opaque primes was significant [$F_1(2, 116) = 5.29, MSE = 9969, p < .05$; $F_2(1, 44) = 4.30, MSE = 7431, p < .05$] as was the latency difference between opaque and transparent primes. Target means after opaque, transparent, and unrelated primes were 865, 803, and 822 ms, respectively.

⁴ All correlations are reported at a two-tailed significance level. When facilitation after transparent primes was entered into separate analyses with relatedness, the values were negative [$r_{22} = -.37, -.21$, and $-.17$ for Exp. 1a, 1b, and 3, respectively]. The corresponding correlations after opaque primes did not approach significance [$r_{22} = .15, .07$, and $-.05$].

sequent correlational analyses, we partialled for semantic relatedness between prime and target.

For each target word we used the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995) to identify all words (viz., family members) derived from the base morpheme of the target word. For example, the words COMPETENCE, COMPETENT, COMPETENTLY, COMPETITION, and COMPETITIVE are some of the words derived from the base morpheme COMPETE. Their *base frequencies* (surface frequencies including inflected variants) are 135, 193, 10, 937, and 497, respectively, in the CELEX database. The sum of these base frequencies constitutes the measure *family frequency*. If these were the only words derived from COMPETE then its *family size* would be 5 (the base is not included in this count) and the family frequency would be 1772. For the 22 critical target words, following Bertram, Baayen, and Schreuder (2000), we included in the family size and family frequency counts all family members that could be construed as even partially transparent. (For example, the words COMPETITION, and COMPETITIVE but not COMPETENT are transparent with respect to the base morpheme COMPETE.) For the 22 critical target words, the transparent family size (TFAM) and transparent family frequency (TFAM freq) ranges were 1–16 and 29–2015, respectively. (The target derived from the base morpheme ACT was deleted because its family frequency exceeded 18,000.)

We used item means from Exp. 1a to compute the difference in target latencies following transparent and opaque primes and correlated that value with the number of transparent words formed from the shared base morpheme (viz., transparent family size). Because transparent family frequency counts for targets had such a large range, we partialled out the effect of family frequency so that variation across targets due to frequency could not play a role (see Baayen, Tweedie, & Schreuder, 2002). The difference between target latencies after opaque and transparent primes (i.e., O–T) could be predicted from the transparent family size of its base morpheme when transparent family frequency as well as differences in ratings of relatedness for opaque and transparent primes were partialled [$pr_{18} = .512, p < .02$]. Analogous with Experiment 1a, for the item means generated in Experiment 1b, we computed the difference in decision latencies after visually presented opaque and transparent primes and correlated this with the transparent family size measure controlled for family frequency and differences in ratings of relatedness and it was marginally significant [$pr_{18} = .410, p < .07$]. That is, with controls for the semantic relatedness between prime and target as well as a measure of target frequency, the transparency effect tended to be

greater for items such as CREATE (TFAM = 9) than for items such as COMPETE (TFAM = 5).⁵

In both experiments, the degree of facilitation after transparent primes [(UR–T)] when partialled for relatedness as well as TFAM freq was not significant [$pr_{18} = .35, p = .13$ and $pr_{18} = .30, p < .20$, respectively]. Interestingly, for transparent primes, semantic relatedness of prime and target and transparent family size of the base morpheme were negatively and nearly significantly correlated [$r_{22} = -.38, p < .08$] such that highly related prime–target pairs tended to come from smaller families. The analogous correlation for semantic relatedness with opaque family size did not approach significance, although, if anything, it was in the same direction [$r_{22} = -.11, p = .64$]. The implication of a negative correlation with TFAM is that transparency effects cannot be attributed to the degree of relatedness between particular prime–target pairs.

In conclusion, we have documented an effect of semantic transparency on morphological processing when processing time for the prime is relatively unconstrained. We interpret the effect as fundamentally morphological because its magnitude varied with TFAM, a measure of productivity defined on the cluster of words formed from a particular base morpheme. Systematically graded effects of TFAM are compatible with a mechanism that is sensitive to both semantic and orthographic similarity thereby capturing the strength of the mapping between form and meaning. Such variation arises across targets with many as opposed to few transparent or partially transparent morphological relatives.

3. Experiment 2

The goal of Experiment 2 was to contrast the effect of transparent and opaque morphological relatives on decision latencies to visual targets in the immediate priming task when primes were presented for brief SOAs. In Experiment 2, we presented visual primes for 48 ms with no mask and morphological facilitation was assessed relative to an orthographically and semantically unrelated but morphologically complex baseline. Under exposure durations that rendered effects of semantic association less reliable, we asked whether the degree of semantic transparency influenced recognition among prime–target pairs formed from a common base morpheme.

⁵ Although transparent family size and transparent family frequency tend to be highly correlated, the partial correlation of transparency (O–T) with transparent family frequency after effects of transparent family size were removed was not significant. Similarly, full family size based on transparent as well as opaque family members did not correlate with the difference in target decision latencies after opaque relative to transparent primes either for purely visual or for cross-modal presentation configurations.

3.1. Methods

3.1.1. Participants

There were 68 participants in Experiment 2. All were selected from the same population as in the previous experiment.

3.1.2. Materials

The experimental materials and design were the same as in the previous experiment.

3.1.3. Procedure

In Experiment 2, each trial began with a fixation cross (+) for 500 ms followed by blank for 50 ms. A visual prime then appeared in lowercase letters for 48 ms. A visual target in lowercase and located one line below where the prime previously had appeared followed the prime. The target remained on the computer monitor until the participant made a lexical decision response or until 3000 ms elapsed. The subsequent trial began after a 1000 ms inter-trial interval.

3.2. Results and discussion

Errors and outliers in Experiment 2 were defined in the same manner as in Experiment 1 (outliers constituted about 1% of responses). Data from one subject in Experiment 2 were eliminated. In the 48 ms SOA condition, an ANOVA revealed that the effect of prime type failed to reach significance in the decision latencies [$F_1(2, 132) = 1.40$; $F_2(2, 44) = 1.01$]. Planned comparisons showed no significant difference between the semantically transparent (733 ms) and opaque (727 ms)

conditions. In addition, the difference between the (combined) transparent and opaque conditions (730 ms) relative to the unrelated condition (747 ms) [$F_1(1, 132) = 2.55$, $MSE = 4850$, $p = .11$; $F_2(1, 44) = 1.05$, $MSE = 4033$, $p = .31$] was not significant. Nevertheless, a sign test revealed that facilitation was significant when the transparent and opaque conditions were combined and contrasted with the unrelated condition [$z = 2.06$, $p < .05$ by participants and $z = 1.5$, $p < .08$ by items].

The pattern of morphological facilitation in Experiment 2 failed to reveal an effect of semantic transparency at a short SOA and evidence of reliable morphological facilitation derived only from a sign test. Nonetheless, the magnitudes of facilitation (14–20 ms) were very similar to those reported in the Frost et al. (1997) Hebrew study. At short SOAs in English as in Hebrew, decision latencies after transparent and opaque primes were similar in magnitude.

Analogous with Experiment 1, we used item means to correlate the difference in target latencies after transparent and opaque primes (i.e., O – T) with the number of other words derived from the shared base morpheme (viz., transparent family size) and we controlled for family frequency and prime–target relatedness (see Table 3). The correlations were not significant. Further, the (non-significant) negative correlations between differences in target latencies after unrelated and related primes and transparent family size led us to speculate that when semantic processing is limited so that decisions are based primarily on form similarity, there may be *less* facilitation in large families than in small. Collectively, it appears that at a short SOA, similar dynamics underlied the processing of targets in opaque

Table 3

Differences in decision latencies relative to unrelated primes based on item means and correlations between differences and family size for Experiments 1, 2, and 3

SOA (ms)	Modality			Prime type		
	Prime	Target		UR – Transparent	UR – Opaque	O – T
Experiment 1						
At prime offset	A	V	Facilitation	26	–53	78
			TFAM cor	.47**	–.17	.51**
250	V ^a	V	Facilitation	7	–29	36
			TFAM cor	.36*	0.02	.35*
Experiment 2						
48	V	V	Facilitation	7	26	–19
			TFAM cor	–.22	–.25	–.02
Experiment 3						
83 ^b	V	V	Facilitation	34 ^c	–14 ^c	49
			TFAM cor	0.02	–.29	.40*

Note. TFAM cor, correlation with transparent family freq partialled.

^a V, visual presentation; A, auditory presentation.

^b Forward mask preceded the prime.

^c Orthographically similar unrelated control; O – T, opaque minus transparent; UR, unrelated prime.

* $p < .10$.

** $p < .05$ (two-tailed).

and transparent prime contexts and that this outcome is consistent with claims of an attenuated contribution from semantics.

3.2.1. Effects of SOA

We computed differences in visual target decision latencies after related and unrelated visual primes presented at SOAs of 250 ms (Exp. 1b) and 48 ms (Exp. 2) and combined them into one analysis. This analysis (reported in Feldman & Soltano, 1999) was informative because it allowed us to assess changes in decision latencies to the same target as a function of prime type and SOA. Results revealed a reliable interaction between prime type and SOA [$F_1(1, 132) = 5.41, MSE = 6576, p < .05$; $F_2(1, 22) = 6.04, MSE = 2878, p < .05$]. Evidently, when primes and targets were presented visually and unmasked, the influence of semantic transparency on morphological processing emerged at an SOA of 250 ms but not at an SOA of 48 ms. Stated succinctly, as SOA increased, there was greater divergence among decision latencies for targets whose primes varied along a semantic dimension of similarity.

4. Experiment 3

The failure to obtain robust facilitation after morphologically related primes in Experiment 2 could have been related to the absence of a mask or to the nature of the unrelated baseline. Therefore, in Experiment 3, we introduced a forward mask on the prime and an orthographically similar but semantically unrelated baseline. In the Hebrew studies, all word targets followed identical, morphologically related or orthographically similar primes and there were no filler trials. By contrast, only 30% of word–word trials were morphologically related in Experiments 1 and 2 and there were no identity trials. In Experiment 3, we more closely approximated the conventional forward masked procedure for Hebrew and compared the influence of opaque and transparent morphological relatives on target decision latencies.

4.1. Methods

4.1.1. Participants

There were 45 participants in Experiment 3. All were selected from the same population as in the previous experiment and all received partial credit toward a course requirement.

4.1.2. Materials

The experimental materials and design were the same as in the previous experiment with the exception that an orthographically similar word replaced the unrelated control. Following the procedure of Forster and Davis

(1984), controls were selected for maximum orthographic overlap with the target. In all but one instance, the initial syllable and the final syllable were orthographically matched to the target and only the medial portion was changed. For example, ACCEPTANCE was the orthographic control for ACCORDINGLY and ACCORDION, all of which were primes for ACCORDANCE. The mean prime length was matched and frequencies (*SD*) for the orthographic, transparent, and opaque primes were 9 (18), 32 (61), and 31 (47), respectively. All unrelated filler items from previous experiments were eliminated and 18 identity prime–target pairs were added.

4.1.3. Procedure

In Experiment 3, a visual pattern mask (#####) of 500 ms duration preceded the prime which appeared for 83 ms. The pattern mask was the same length as the prime that followed it and the inter-trial interval was 750 ms. The prime was presented in lowercase and the target was presented in uppercase and both appeared in the same place on the screen. SOA duration was based on Frost's procedure. Frost et al. (1997) used an SOA of 50 ms for words that averaged 5 letters in length. We rounded to an SOA of 83 ms for words that averaged 8.8 letters. There was no check on perceptibility of the prime.

4.2. Results and discussion

Errors and outliers constituted fewer than 2% of all responses.⁶ In the 83 ms SOA forward masked condition, the prime type ANOVAs on decision latencies failed to reach significance [$F_1(2, 88) < 1$; $F_2(2, 44) = 1.7$] but they were significant by participants with the accuracy measure [$F_1(2, 88) = 3.06, MSE = .008, p = .05$; $F_2(2, 44) = 2.25, MSE = .006, p < .12$]. Crucially, planned comparisons on the accuracy data indicated that when combined, targets after transparent and opaque primes differed relative to orthographic controls [$F_1(1, 88) = 4.34, p = .04$; $F_2(1, 44) = 4.10, p < .05$]. They did not differ from each other, however.

The forward masked procedure with orthographically similar but morphologically unrelated controls revealed significant morphological facilitation with the accuracy but not with the latency measure. The non-significant

⁶ When errors and outliers were defined in a manner similar to that of Frost (the value at 3 *SD* was substituted for latencies that were greater than 3 *SD* from the mean), means following opaque, transparent, and unrelated orthographically similar primes were 898, 879, and 908 ms, respectively. Latencies after transparent and unrelated orthographically similar primes did not differ significantly nor did latencies after opaque and unrelated orthographically similar primes. Analyses with the accuracy measure were almost identical to those reported with no replacement.

latency pattern was consistent with the accuracy measure, however. In other respects, the results were quite similar to those observed at a shorter SOA with the orthographically unrelated controls of Experiment 2. Importantly, under forward masked priming conditions with an orthographically similar but morphologically unrelated baseline, facilitation after opaque and transparent morphologically related primes did not differ. Results suggested that semantic attributes of the prime did not alter the dynamics that underlie target decision latencies at an SOA of 83 ms.

In Experiment 3, the magnitude of facilitation after transparent or opaque primes relative to the unrelated baseline could not be compared to that in other experiments because the unrelated baseline was orthographically similar to the target. Once again, however, we used item means to correlate the difference in target latencies after transparent and opaque primes with the number of other words derived from the shared base morpheme (viz., transparent family size) with effects of family frequency removed (see Table 3). The partial correlation of transparency (O–T) with family size was nearly significant [$r_{18} = .418, p = .067$]. It is interesting that even when opaque and transparent primes did not produce facilitation whose overall magnitude differed significantly, their effect on target decision latencies became progressively more distinct as family size of the target increased. We interpret the correlation as further evidence that family size influences the rate at which semantic contributions to morphological facilitation accrue.

5. General discussion

In the current study, we compared the outcomes from multiple variants of the lexical decision procedure that are known to be differentially sensitive to semantics. The primary comparison was between suffixed target decision latencies (and accuracy rates) after suffixed opaque and transparent primes formed from the same base morpheme as their target. A direct comparison of targets after opaque and transparent primes circumvented potential controversy about whether orthographically similar or dissimilar unrelated controls constitute the more appropriate baseline so as to converge on the crucial contribution of semantics to morphological processing when form similarity was controlled (Pastizzo & Feldman, this issue). In the present study, we documented a difference in decision latencies after transparent and opaque primes as well as a correlation between the difference in decision latencies after transparent and opaque primes and the transparent family size of the base morpheme.

We presented the same materials in multiple experimental contexts. In each, all primes and targets were morphologically complex forms and across experimen-

tal lists within an experiment, the same targets followed primes that were semantically transparent, semantically opaque, or unrelated. We observed a significant effect of semantic transparency on morphological processing under both cross-modal and purely visual presentation conditions at a 250 ms SOA. Crucially, at long SOAs, the magnitude of the difference in target latencies after opaque and transparent primes correlated with the number of transparent family members formed from the base morpheme. Our family size measure was defined on the number of (fully and partially) transparent forms derived from the base. What role, if any, the number or proportion of opaque family members plays still requires further empirical work. Notably, because we co-varied for semantic relatedness, the TFAM effect did not depend on the semantic relatedness between two whole word forms.

Stated generally, the outcome of the present study provides evidence consistent with the insight that the degree of systematicity in the mapping between form and meaning computed over *many* words is central to morphological facilitation in word recognition (Plaut & Gonnerman, 2000; Rueckl et al., 1997; Seidenberg and Gonnerman, 2001). For words presented in isolation, with controls for surface frequency and base morpheme frequency, we knew that the number of transparent family members correlated significantly with recognition latencies (De Jong et al., 2000) and that the number of transparent family members tended to be a better predictor of decision latencies than was the total number of family members (Bertram et al., 2000). Within the context of priming paradigms, we now have demonstrated that the dynamics within a family of transparent family members can influence the magnitude of morphological facilitation and, in particular, the effect of semantic transparency.

5.1. Failures to observe an effect of semantic transparency

At short SOAs in Experiment 2, decision latencies to transparent and opaque targets did not differ significantly and evidence of overall morphological facilitation relied on the significance of a sign test. The absence of a difference in target latencies after opaque and transparent primes with English materials in Experiments 2 and 3 replicated the composite outcome of Frost and his colleagues (1997) with Hebrew materials. The unique contribution of Experiment 3 relative to Experiment 2 derived from the correlation of TFAM with the magnitude of the transparency effect even when opaque and transparent primes produced facilitation whose magnitudes did not differ overall. As in Experiment 1, the differentiation of opaque and transparent primes became greater as family size of the base morpheme increased.

Collectively, whether or not target decision latencies after transparent and opaque forms differed in English

depended on experimental context. Contributions of semantic transparency to morphological processing did not appear at a very short SOA, with or without a mask. Because these were the same experimental conditions that typically fail to produce reliable facilitation due to semantic association, we maintain that the semantic (in)sensitivity of an experimental context imposes a fundamental constraint on the emergence of transparency effects in morphological processing. Finally, negative correlations of TFAM with facilitation (Experiments 2 and 3) imply that increases in family size impaired recognition when contributions of semantic similarity were negligible and performance depended primarily on shared form.

5.2. *What do item- and time-varying patterns of semantic transparency reveal about the lexical representation of morphology?*

Two aspects of the data from the present study have implications for our general understanding of morphological processing and the inadequacy of an account of facilitation grounded in the activation of a base morpheme shared by prime and target as implied by an account based on decomposition. The first pertains to how models of morphological facilitation might accommodate item-varying magnitudes of facilitation as implied by the correlation of facilitation with the effect of transparent family size. The second relates to the time course over which latencies after opaque and transparent forms diverge and what we can infer from time-varying semantic contributions to morphological facilitation.

In the framework of Marslen-Wilson et al. (1994), both opaque and transparent suffixed primes failed to produce facilitation but they differed with respect to the underlying mechanisms. Opaque primes were ineffective because they could not be decomposed and therefore did not access a base morpheme in common with that of their target. According to Marslen-Wilson and colleagues, although all transparent primes were decomposable, for suffixed forms presented cross-modally, the potential suffixes for a particular base morpheme inhibited each other and offset facilitation from the shared base morpheme. Crucially, graded contributions of semantics to morphological processing across targets, as emerged in the present study, are not compatible with a classic decompositional account whereby the mechanism of facilitation entails activation of a common base morpheme in prime and in target. The implication of the forgoing is that the locus of morphological facilitation cannot be restricted to activation defined over a prime and its target unless it can accommodate variation across targets that depends for example on its morphologically defined family cluster.

Finally, time- and task-varying patterns make salient the shortcomings of interpreting significant morphologi-

cal facilitation (unrelated minus related) at any single SOA as evidence of a lexical architecture, either whole word or decomposed. The magnitude of facilitation for semantically transparent morphological relatives was more stable across SOAs (250 ms vs. 48 ms) than was the pattern after opaque morphological relatives. In fact, the pattern of facilitation and inhibition after morphologically opaque forms in the present study was strikingly similar to that observed for orthographically similar but morphologically unrelated prime–target pairs such as VOWEL–VOW.⁷ Feldman (2000) reported an interaction between direction of priming and SOA. Because VOWEL–VOW type pairs showed inhibition at SOAs on the order of 250 ms and facilitation at SOAs on the order of 66 ms, she argued that orthographic facilitation at short SOAs reflected an effect of shared form with only minimal contributions of semantics but that at longer SOAs, primes were sufficiently processed so that the non-overlapping semantics of orthographically similar primes and targets slowed target recognition (see Badecker & Allen, 1999; for a similar account in Spanish). By an analogous argument, in the present study, facilitation after primes at a short SOA appeared to derive primarily from shared form although semantic influences began to emerge faster for targets from large than from small families. Stated alternatively, the long but not the short SOA priming task outcome is consistent with a linguistic distinction between morphological relatedness and semantic transparency.

In conclusion, all morphological relatives are not equivalent because opaque and transparent forms differ systematically in experimental contexts that promote semantic processing. Effects of semantic transparency that vary across experimental contexts pose a challenge to accounts that represent morphological facilitation in terms of activation of a shared base morpheme in prime and target. The most novel contribution of the present study is to extend the influence of family size into the domain of morphological facilitation such that the difference in decision latencies after opaque and transparent primes can be predicted from the transparent family size of the base morpheme. Effects of semantic transparency that vary across targets as a function of family size and cannot be attributed to the degree of semantic relatedness within a pair indicate that the locus of morphological processing extends beyond a particular target and its prime.

Simply by varying task, we have replicated with one set of English materials both the presence and the absence of transparency effects in morphological processing that have been reported previously with English (Marslen-Wilson et al., 1994) and Hebrew (Frost et al.,

⁷ In fact, by some accounts, some of the base morphemes of the opaque forms presented in the present study represented a distinct but orthographically similar (viz., homographic) unit.

1997) materials, respectively. We emphasize that cross-language differences should not be summarily dismissed, however. If differences between languages can be documented then perhaps they can be defined in terms that capture the systematicity between form and meaning. Extending the notion of morphological richness, the tendency for few or many base morphemes to enter into at least one combination (Plaut & Gonnerman, 2000), we can ask whether *average family size*, the tendency for base morphemes to enter into multiple word formations, underlies potential differences between languages.

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