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Reading Morphologically Complex Words

Some Thoughts from Masked Priming

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Much research suggests that words comprised of more than one morpheme (e.g., departure) are represented in a "decomposed" manner in the visual word recognition system, with morphologically complex words sharing representations with their stems (e.g., Rastle, Davis, Marslen-Wilson, & Tyler, 2000). In this chapter, we consider the extent to which semantic relationships influence morphological decomposition, especially with respect to those representations contacted in early visual word recognition. In two studies of visual lexical decision, we found that the recognition of stem targets (e.g., depart) was facilitated significantly and equivalently by the prior presentation of semantically transparent (e.g., departure) and semantically opaque (e.g., department) masked primes (using a 52-ms SOA). We found further that the recognition of stem targets (e.g., broth) was faster numerically when these targets were preceded by a morphemically structured semantically opaque masked prime (e.g., brother) than by a nonmorphemically structured masked prime (e.g., brothel). We believe that these results implicate the operation of a purely structural morphological segmentation system in early visual word recognition, which may enable the developing reader to capitalize upon higher-level regularities that morphology provides to the mapping between orthography and meaning (e.g., Plaut & Gonnerman, 2000).

Computational modeling has made an extraordinary contribution over the past 10 years to our understanding of the mental processes involved invisual word recognition and reading aloud, by requiring the development of explicit theories that can be measured against data from normal and impaired readers as a test of their adequacy (see Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996; Plaut, McClelland, Seidenberg, & Patterson, 1996; Zorzi, Houghton, & Butterworth, 1998). Yet for all of the advancement that the past decade has seen, a complete theory of single-word processing remains somewhat distant, with numerous commitments regarding, for example, the processing of polysyllabic and polymorphemic words, still to be made. In this chapter, we focus specifically on some of the problems that words comprised of more than one morpheme present to modellers of single-word reading. At present, none of the aforementioned computational models (that have been evaluated extensively against benchmark findings of visual word recognition and reading aloud) deals effectively with such words.[1] However, clear interest in extending our understanding of reading to polymorphemic words has been evident in recent years, with a surge of experimental work (see e.g., Frost & Grainger, 2000) accompanied by a growing desire to express hypotheses regarding the visual recognition of such words as computational simulations (e.g., Davis, van Casteren, & Marslen-Wilson, in press; Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999).

Of course, interest in the special problems posed to the reading system by polymorphemic words has not been restricted to recent years. The proposal that the reading system is comprised of a process or level of representation at which morphemes are treated somehow differently from whole words—at which whole words are "decomposed" into their constituent morphemes—dates back at least 25 years (Taft & Forster, 1975). In the years following, empirical evaluation of this general proposal became a key area of psycholinguistic research. Numerous studies have since been conducted that compare the effects of target-word frequency (e.g., the frequency of DEPARTURE) with the effects of "stem" frequency (e.g., the frequency of DEPART) on various dependent variables used in reading research (e.g., visual lexical decision latency). Such studies have demonstrated effects of stem frequency on visual lexical decision latency (e.g., Schreuder & Baayen, 1997) and fixation duration (Niswander, Pollatsek, & Rayner, 2000), indicating that at some level of the visual word recognition system, morphologically complex words may be "decomposed" and their stem constituents analyzed.[2] Similarly, numerous studies have demonstrated that the recognition of a printed target word (e.g., DEPART) is facilitated by the prior presentation of an inflectionally (e.g., DEPARTING) or derivationally related (e.g., DEPARTURE) prime (e.g., Bentin & Feldman, 1990; Drews & Zwitserlood, 1995; Stolz & Feldman, 1995). Such findings may suggest either that some operation upon the morphologically complex prime enables the activation of the target stem's representation; or that prime and target share substantially overlapping representations in the visual word recognition system.

A multitude of other conclusions that have nothing whatsoever to do with morphology could, of course, be advanced regarding these findings—and this is perhaps part of the reason that consideration of polymorphemic words in explicit (computational) theories of reading has been slow in coming. For example, Forster and Azuma (2000) have argued that nonlinguistic factors could play an important role in studies examining stem and surface frequency. Specifically, knowledge *about* morphological relationships—not those relationships themselves—may be implicated in a lexical decision mechanism. Similarly, it could be argued that priming studies may be contaminated by episodic and/or strategic factors; or indeed, may reflect types of relatedness having nothing to do with morphology, but that are typical of morphological relatives (e.g., semantic relatedness). For all of these reasons, the introduction of the masked priming technique (Forster & Davis, 1984; Forster, Davis, Schoknecht, & Carter, 1987) to the problem of morphological processing in visual word recognition has been particularly important. Because conscious appreciation of the prime can be eliminated through masking, this technique may offer a glimpse onto the word recognition system that is free of both the episodic and strategic factors that can contaminate longer-lag priming techniques (but see Bodner & Masson, 1997; Masson & Bodner, this volume) and the nonlinguistic factors that may play a role in studies of stem and surface frequency effects in the unprimed lexical decision paradigm.

Equally importantly, the masked priming technique may provide a means by which the level of representation probed can be restricted; that is, masked priming appears to capture uniquely the nature of orthographic representations and the early processes required to access those representations. Demonstrations of semantic priming under masked conditions are rarely found (see Rastle et al., 2000)—and when they are found, they are very small. (See Perea & Gotor, 1997, who reported a small but significant semantic priming effect at a prime-exposure duration of 67 ms, longer than typically used in masked priming.) As such, it should be possible, using the masked priming technique, to separate pure effects of morphological relatedness from, for example, semantic relations that are characteristic of morphological families. Indeed, using the masked priming technique, researchers have been able to demonstrate priming of targets by morphologically related primes in the absence of: (a) pure orthographic priming effects in French (Grainger, Cole, & Segui, 1991), Dutch (Drews & Zwitserlood, 1995), and English (Forster & Azuma, 2000; Forster et al., 1987; Pastizzo & Feldman, 2002; Rastle et al., 2000); (b) pure semantic priming effects in Hebrew (Frost, Forster, & Deutsch, 1997) and English (Rastle et al., 2000); and (c) the simple summation of semantic and orthographic priming effects in English (Rastle et al., 2000). In fact, morphological masked priming effects are often of the same magnitude as identity priming effects (Forster et al., 1987; Rastle et al., 2000). Such demonstrations are important for researchers interested in modeling the visual word recognition system, because they suggest rather convincingly that morphologically complex words share representations (or consist of substantially overlapping representations) with their stems at some level of the visual word recognition system. A complete theory of how polymorphemic words are recognized, of course, would have to go well beyond this—specifying (a) the exact nature of polymorphemic word representations in the visual word recognition system; and (b) what processes, if any, operate upon polymorphemic words in order to make contact with these representations. We believe that masked morphological priming may provide a useful way forward in addressing these issues.

Morphological Relationships and Lexical Organization

Islands of Regularity in the Form-Meaning Mapping. A good place to begin on the road to a theory is, of course, a consideration the conditions under which words comprised of more than one morpheme are represented in a decomposed manner (or in a manner that overlaps substantially with a stem form). A popular view regarding this issue is that decomposed representation is restricted to instances in which there is a semantically transparent relationship between a complex word and its stem (e.g., Giraudo & Grainger, 2000, 2001; Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999; Seidenberg & Gonnerman, 2000; Spencer, 1991; see also Marslen-Wilson, Tyler, Waksler, & Older, 1994 for a similar view regarding spoken word recognition). Semantically transparent complex words are those comprised of morphemic elements (stems, bound stems, affixes) such that the meaning of the complex form can be derived from the meanings of its constituents (e.g., the meaning of hunter can be derived from the meaning of hunt + er). Alternately, complex words are semantically opaque if their meanings cannot be derived from their constituents (e.g., the meaning of witness cannot be derived from the meanings of wit + ness); such words would not be stored in a decomposed manner.

This view regarding the influence of semantic transparency on morphological representation is based upon the idea that morphological relationships lend considerable structure to the mapping between orthography and meaning. Although the form-meaning mapping is predominantly arbitrary (i.e., we do not expect words that are spelled similarly to mean similar things; for instance, mink is unrelated in meaning to pink, monk, milk, and mint), morphologically complex words can form significant "islands of regularity" within that mapping (see Rastle et al., 2000, for a discussion). Regularities across the form-meaning mapping occur for morphologically complex words in two ways: (a) the meanings of stem forms are preserved in derivations of those stem forms (e.g., the meaning of dark is preserved in darkness and darkly); and (b) affix forms often alter the meanings of stems in highly predictable ways (e.g., the words darker, smarter, and faster are related to the words dark, smart, and fast in the same way). Hereafter, we review to this view as the semantic dependency hypothesis of morphological representation (after Roelofs & Baayen, 2002).

It is likely that the visual word recognition system would capitalize on the significant degree of structure that morphology provides to the relationship between orthography and meaning; and as such, this idea has been instantiated in both classical and connectionist theories of visual word recognition. For example, Plaut and Gonnerman (2000) proposed that, to the extent that regularities in the form-meaning mapping exist across the words in the lexicon, a connectionist network would develop highly similar internal (hidden unit) representations for stems and their derivations when it learns the mapping between form and meaning (see also Rueckl & Raveh, 1999; Seidenberg & Gonnerman, 2000). Similarly, in a classical interactive-activation framework, Grainger et al. (1991; see also Giraudo & Grainger, 2000, 2001) proposed that an explicit level of morphological representation (stems, bound stems, and affixes) is contacted in visual word recognition subsequent to the access of whole word representations—but only for those morphologically complex words that are also semantically transparent. Like Plaut and Gonnerman (2000), Giraudo and Grainger (2000) proposed that in the acquisition of language, readers detect the systematic co-occurrence of orthography and meaning provided by morphology; however, according to Giraudo and Grainger's (2000) theory, these regularities come to be expressed as explicit representations that act as an interface between orthographic and semantic representations.

Morphology and Orthographic Structure. A second aspect of structure brought by morphology to the visual word recognition system can be found within orthography itself: Morphological relationships constrain greatly the distribution of letter patterns in the language. Groups of letters corresponding to morphemes (affixes, bound stems, and stems) occur and reoccur, and they do so in a combinatorial way—with each morphological component reoccurring in new contexts with other reoccurring components. For example, the letters "clean" occur and reoccur through the lexicon of English words (e.g., unclean, cleanliness, cleaner, cleanly), and do so with other groups of letters that also occur and reoccur (e.g., un, ly, ness, er). If the visual word recognition system capitalizes on this aspect of structure within a lexicon, then we might expect orthographic representation itself to be organized on the basis of morphemic units, particularly those units that occur frequently. According to this proposal, the extent to which a complex surface form is decomposed is not influenced by semantic properties; rather, decomposed representation is based upon the mere occurrence of morphemic units in the input (so e.g., the word department would be treated as a complex item).

It is important to understand that, on this view, morphology exerts an influence on lexical representation irrespective not only of semantic transparency, but also of genuine morphological status (i.e., morphological relationships that are established on etymological grounds). Within this theory, all words comprised of more than one orthographic morpheme (words comprised of a morphological surface structure), whether identified linguistically as morphologically simple or complex, would be represented in a decomposed way. When discussing the representation of semantically opaque words comprised of a morphological surface structure in this work, we therefore take no account of linguistic labels. Semantically opaque words defined linguistically as morphologically complex (e.g., department) are treated no differently than semantically opaque words defined linguistically as morphologically simple (e.g., forty), as long as these words are comprised of a morphological surface structure. This decision to ignore morphological classifications established only on etymological grounds departs somewhat from the practice of other authors in the area (e.g., Longtin, Segui, & Halle, submitted; Shoolman & Andrews, this volume) who do make a distinction between semantically opaque words with an etymological morphological status (e.g., department) and words with a morphological surface structure but without an etymological morphological status (e.g., forty). Such authors refer to the former class of word as semantically-opaque and the latter class of word as pseudoaffixed (Longtin et al., submitted) or pseudocompounds (Shoolman & Andrews, this volume). We have chosen not to make this distinction here because we find it very difficult to conceive of a plausible theory of language acquisition in which a distinction between these types of words could be made.

Although the view that morphology lends structure to orthographic representation itself has not been as popular in recent years as the semantic dependency hypothesis described in the preceding, it actually formed the basis of the initial theoretical work on morphological representation in visual word recognition (Taft & Forster, 1975; see also Forster & Azuma, 2000; Taft, 1994). Based upon the finding that nonwords comprised of a bound morpheme and prefix (e.g., dejuvenate) took longer to reject in visual lexical decision than nonwords comprised of a prefix and nonstem (e.g., depertoire), Taft and Forster (1975) proposed a theory within the tradition of classical search models whereby all input strings comprised of a morphological surface structure may be subject to decomposition procedures—irrespective of their lexicality or genuine morphological status. Taft (1994) later described an interactive-activation architecture that included a sublexical level of morphemic representations—morphemic units that could be activated by any input comprising a surface morphological structure (a structure comprised of more than one morphemic unit).

Theoreticians from a connectionist perspective also have recognized the powerful role that morphological relationships in the English lexicon might play on the development of orthographic representations. Seidenberg (1987) envisaged a connectionist theory of visual word recognition in which sublexical morphemic units—in the form of coalitions of letters—emerge in the development of orthographic representation. He observed (see also Adams, 1981) that polymorphemic words are generally characterized by a trough pattern, in which higher bigram and trigram frequencies occur *within* morphemic elements than *across* morphemic boundaries, and argued that such regularity would be captured implicitly in the connection structure of any processing system able to exploit orthographic redundancy. Since the work of Seidenberg (1987), connectionist modellers have not considered in any detail this proposal that morphology exerts a purely structural influence on the development of orthographic representations; rather these modelers have focused on the regularities that morphology lends to the form-meaning mapping. However, it is worth noting that in every connectionist implementation (e.g., Davis et al., in press; Plaut & Gonnerman, 2000; Ruckl & Raveh, 1999) of the semantic-dependency hypothesis, the input presented to the network has been in a morphemically segmented form with a separate group of units representing the morphological stem and affix. It is assumed that some purely structural transformation has occurred in which morphemic units are segmented from one another, prior to the transformations that arise during the form-meaning mapping.

Although current models of morphological processing generally implement only one of the two aspects of morphological structure that we have identified, it would be curious indeed if the visual word recognition system did not capitalize on both. Specifically, we envisage a hierarchical theory of visual word recognition in which perceptual information undergoes various transformations en route to the access of meaning. In early stages, input is analyzed in a purely structural manner, segmented on the basis of frequently occurring morphemic units. If this type of structural segmentation characterises early visual word recognition, then we may expect to find evidence of it from priming techniques when prime exposure durations are very short: We would expect words comprised of more than one morphemic element to prime their stems, irrespective of semantic transparency or genuine morphological status. In this hierarchical model of visual word recognition, semantic factors would come to play an increasing role in the analysis of an input as time progresses. As such, we would expect an increasing effect of semantic transparency to emerge on morphological priming as prime exposure duration is increased. This idea—that an input comprised of morphemic elements undergoes some purely structural segmentation early in visual word recognition followed by semantic analysis—has received some support in previous research. In a study of visual lexical decision, Rastle et al. (2000) reported an effect of semantic transparency on morphological priming only at longer prime-exposure durations (i.e., over 75 ms); at very short exposure durations (i.e., 43 ms) no effect of semantic transparency on masked morphological priming was apparent. (See also Feldman & Soltano, 1999, for a similar result using a variable SOA, unmasked priming procedure.)

In the experimental work described here, we sought to explore further the idea that a purely structural segmentation based upon morphemic elements takes place in early visual word recognition. Much evidence for this view has already been obtained from studies of Hebrew readers (Frost, Deutsch, & Forster, 2000; Frost et al., 1997), where no effect of semantic transparency is found on masked morphological priming. It has been argued, however, that the morphological structure of a language may have implications for the development of the visual word recognition system; in this respect, the contrast between Hebrew, with its highly productive use of a nonconcatenative morphology—and English, with its relatively sparse use of a concatenative morphology—may be significant (see Plaut & Gonnerman, 2000, who argued that although reliable priming effects for semantically opaque words would not be expected in English, they would be predicted in "morphologically rich" languages such as Hebrew). Although we (Rastle et al., 2000) reported significant and equivalent levels of masked morphological priming for semantically transparent and semantically opaque English pairs, greater power to detect a difference between these conditions would have been afforded by a within-target comparison (e.g., comparing *departure-DEPART* with *department-DEPART*). Moreover, in that study, we were unable to distinguish statistically between priming produced in the semantically opaque morphological condition (e.g., *department-DEPART*) and a nonmorphological condition (e.g., *electrode-ELECT*); and therefore, we were unable to offer a compelling view about the reality of purely structural morphological segmentation in early English visual word recognition.[3]

For these reasons, we conducted two further masked morphological priming experiments, using within-target comparisons. In one of these experiments, we investigated the influence of semantic transparency on masked morphological priming (e.g., *departure-DEPART* versus *department-DEPART*; hereafter, the "transparency comparison"); in the other, we investigated the influence of morphemic structure on masked priming (e.g., *brother-BROTH* versus *brothel-BROTH*; hereafter, the "form comparison"). If there is a level of representation in the visual word recognition system at which words are analyzed purely on the basis of morphemic elements (irrespective of semantic transparency or genuine morphological status), then we would expect to observe an effect only of morphemic structure—and not one of semantic transparency—on masked morphological priming.

EXPERIMENT 1

Experiment 1a: The Transparency Comparison

Subjects. Forty-two students from Macquarie University participated in the Experiment. All had normal or corrected-to-normal vision, and were native speakers of Australian English. Subjects completed the experiment in exchange for course credit or a $10 payment.

Stimuli and Apparatus. Thirty-three free root targets were selected from the CELEX English database (Baayen, Piepenbrock, & van Rijn, 1993). These targets had an average frequency of 56.9/million, an average neighorhood size of 2.43, and an average length of 5.15 letters. For each target word (e.g., NUMB), three types of prime were selected: (a) a semantically transparent word with a morphological (suffixed) surface structure (e.g., numbness); (b) a semantically opaque word with a morphological (suffixed) surface structure (e.g., number); and (c) an unrelated control with a morphological (suffixed) surface structure (e.g., freedom). Primes in Experiments 1a and 1b with a "morphological surface structure" were comprised of a free root plus an orthographic ending defined in the CELEX database (Baayen et al., 1993) as a suffix (although in very few cases across Experiments 1a and 1b, perfect segmentation between free root and suffix was not possible because vowel letters are often shared between roots and affixes; for example, in the word "emergent," the letter "e" is shared between target and suffix). The stimuli are contained in Appendix 10.A.

In order to ensure that our intuitions about semantic transparency were correct, we extracted semantic relatedness values for each prime-target pair in the experimental conditions using Latent Semantic Analysis (LSA; Landauer & Dumais, 1997), and compared these statistically. LSA is a technique for extracting semantic representations of words (from which similarity can be measured) through the analysis of large amounts of written text. We calculated the similarity between pairs of prime and target vectors using the LSA web facility (*http://lsa.colorado.edu*), a measure that previously has been shown to correlate reliably with subjective ratings of semantic relatedness (Rastle et al., 2000). The vectors used were derived from a selection of texts described as "General reading up to first year of college" reduced to 300 dimensions using singular value decomposition. Similarity between pairs was measured as the cosine of the angle between the vector for the prime and the vector for the target. These similarity measures revealed significantly greater relatedness between transparent morphological primes and targets (.40) than between opaque morphological primes and targets (.08), $t(58) = 7.88$, $p < .001$.

We sought to minimize any possible influence of strategic factors by reducing the prime-target relatedness proportion to 37%, therefore, 26 pairs of unrelated words were selected as fillers. Finally, 59 word-nonword pairs were generated; nonwords were matched to word targets on length. Targets were divided into three equal lists for counterbalancing purposes; each subject saw each target, participated in all priming conditions, but saw each target only once.

In all of the experiments reported here, stimulus presentation and data recording were controlled by the DMDX software (Forster & Forster, in press) running on a Pentium II personal computer. A two-button response box was used to record lexical decisions, in which the "Yes" response button was controlled by the dominant hand. All experiments were carried out in a dim room.

Procedure. In all experiments reported here, subjects were advised that they would be seeing a series of letter strings presented one at a time, and that they would be required to decide as quickly and accurately as possible whether each letter string was a word or not a word. Subjects were told that each letter string would be preceded by a series of hash marks, but were not told of the existence of a prime stimulus. All primes were presented in lower case for 52 ms; they were preceded by a 500-ms forward mask (consisting of hash marks) and were followed immediately by a target in upper case that remained on screen until a response was made. Targets were presented in a different random order for each subject, and subjects were given 12 practice trials before the experiment.

Results. In all experiments reported here, reaction times and error rates were collected and cleaned in three ways (see Rastle et al., 2000). First, data for subjects with slow and/or error prone performance relative to the rest of the sample were excluded; in this experiment, data from four subjects were excluded because of false alarm rates (responding "Yes" to a nonword) of over 25%. Second, targets that induced error prone responding relative to the rest of the item sample were removed; in this experiment, three targets that produced error rates over 30% (PARCH, SUPPLE, and VICAR) were excluded. Finally, individual data points with outlying RTs were removed; in this experiment, there were no further outlying data points. Subject RT and error data are shown in Table 10.1; item data are presented in Appendix 10.A.

Reaction times and error rates were submitted to a mixed-design ANOVA in which prime type (three levels) was treated as a repeated factor and version (three levels) was treated as an unrepeated factor. The effect of prime type on RT was highly significant: ($F_1(2,70) = 15.14$, $p < .001$; $F_2(2,54) = 11.99$, $p < .001$). Further comparisons revealed: (a) greater priming produced by transparent morphological primes than by unrelated primes ($F_1(1,35) = 17.26$, $p < .01$; $F_2(1,27) = 25.87$, $p < .01$); (b) greater priming produced by opaque morphological primes than by unrelated primes ($F_1(1,35) = 26.85$, $p < .01$; $F_2(1,27) = 18.79$, $p < .01$); but (c) no difference in the level of priming produced by trans-

TABLE 10.1. Data from Experiments 1a and 1b

	RT (standard deviation)	Error rate
Experiment 1a		
Transparent	574 (82)	2.05%
Opaque	573 (72)	1.71%
Unrelated	614 (82)	2.98%
Experiment 1b		
Opaque	641 (100)	8.32%
Form	652 (109)	6.03%
Unrelated	659 (83)	8.64%

parent and opaque morphological primes ($F_1(1,35) < 1$; $F_2(1,27) < 1$). There were no effects of prime type on error rate ($F_1(2,70) < 1$; $F_2(2,54) < 1$).

Experiment 1b: The Form Comparison

Subjects. The same subjects tested in Experiment 1a were tested in Experiment 1b.

Stimuli and Apparatus. Thirty free root targets were selected from the CELEX English database (Baayen et al., 1993). They had an average written frequency of 115.2/million, an average neighborhood size of 2.43, and an average length of 4.5 letters. Three prime words were chosen for each of these free root targets (e.g., BROTH): (a) a semantically opaque word with surface morphological (suffixed) structure (e.g., brother); (b) a word comprised initially of the free root target plus a nonmorphological ending (e.g., brothel); and (c) an unrelated control with a surface morphological structure (e.g., brandy). "Morphological surface structure" was defined, as in Experiment 1a, by the presence of a free root and an orthographic ending defined in the CELEX database (Baayen et al., 1993) as a suffix. The stimuli are contained in Appendix 10.A.

Similarity measures of LSA vectors for primes and targets were again computed to validate our intuitions about semantic opacity, and to ensure that there were no differences in semantic relatedness across the form comparison. As in Experiment 1a, similarity was judged as the cosine of the angle between the vector for the prime and the vector for the target. Analyses revealed very low cosine measurements for both experimental conditions (surface morphological .11; form .10), and no difference between these values, $t(57) < 1$.

Although our prime conditions varied on morphological surface structure, we also ensured that they varied on bigram and trigram characteristics across the boundary between stem and affix (because it is these characteristics, not explicit morphological structure, that give rise to a componential representation in connectionist theories, for example, Seidenberg, 1987). Thus, for each experimental prime, we examined the frequency (type frequency, position nonspecific) of the bigrams and trigrams in the affix (including an end-of-word character) relative to the frequency of the bigrams and trigrams across the boundary between stem and affix. For example, the bigram affix frequency of the prime word brother was the average bigram frequency of ER and R# (where # is the end-of-word character); the bigram boundary frequency was simply the bigram frequency of HE. Similarly, the trigram affix frequency of the prime word 'brother' was simply the trigram frequency of ER#; the trigram boundary frequency was the average trigram frequency of THE and HER. We expressed these frequency values in the form of two ratios (representing bigram and trigram characterizations separately), thus: (affix frequency)/(affix frequency + boundary frequency). Ratios approaching 1.0 indicate primes with highly frequent letter combinations in the affix and highly infrequent letter combinations across the stem-affix boundary (the trough pattern). For the stimuli used in Experiment 1b, these ratios revealed that this trough pattern was more evident in the condition in which primes were comprised of a surface morphological structure (bigram .75; trigram .82) than the condition in which primes were simply formally related to their targets (bigram .66; trigram .67), $t_{bigram}(58) = 1.87$, $p = .06$; $t_{trigram}(43) = 2.76$, $p < .01$).[4]

We included 24 filler word prime-target pairs in order to achieve a relatedness proportion similar to that used in Experiment 1a (37.5%). Finally, 54 word-nonword pairs were generated; 20 of these pairs had a form relationship (e.g., *milliner-MILLIN*). As in Experiment 1a, targets were divided randomly into three lists for counterbalancing purposes. All apparatus was the same as that used in Experiment 1a.

Procedure. All procedures were identical to those used in Experiment 1a.

Results. As in Experiment 1a, RT and error data were collected and cleaned in three ways. First, eight subjects were discarded because of high error rates relative to the other subjects (above a 25% error rate on target words or nonwords). Second, two items were discarded (AMP and COLON) because of high error rates (over 30%) relative to the other items. There were no further outlying datapoints.

Subject RT and error data are included in Table 10.1, and item data are included in Appendix 10.A. These data were submitted to a mixed-design ANOVA with two factors: Prime type (three levels) was treated as a repeated factor, and version (three levels) was treated as an unrepeated factor. Although a clear numerical effect of morphological surface structure is apparent in the latency data, statistical analysis revealed no significant priming effects ($F_1(2,62) < 1$; $F_2(2,50) = 1.31$, NS). Similarly, there were no effects of priming evident in the error data ($F_1(2,64) < 1$; $F_2(2,50) = 1.03$, NS)

DISCUSSION OF EXPERIMENT 1

Two main findings emerged from Experiment 1. First, semantically transparent and semantically opaque primes (e.g., *numbness-NUMB* versus *number-NUMB*) facilitated recognition of target stems significantly, and with equal magnitude. Indeed, there was not even a numerical difference between the priming produced by transparent and opaque morphological primes in this experiment. These results replicate the findings of Rastle et al. (2000), but using a within-target comparison, and provide support for the idea that words comprised of more than one morpheme undergo some type of purely structural morphemic analysis in early visual word recognition.

However, when we examined the effect of surface morphological structure on form priming in Experiment 1b (e.g., *brother-BROTH* versus *brothel-BROTH*), no statistically significant priming effects emerged relative to those produced by unrelated controls. Although a numerical effect of morphological structure was evident (targets preceded by primes comprised of a morphological surface structure were recognized 18 ms faster than targets preceded by form controls comprised of a nonmorphological surface structure), it appears as if the variability in the data precluded significance.

EXPERIMENT 2

Experiment 2 was a replication of Experiment 1, with only one minor adjustment, conducted as a check on the validity of the pair of results revealed in that experiment. It is well known that the way in which lexical decisions are made may be affected by the other stimuli in an experiment (see Forster, 1998, for a discussion). Thus, it may be relevant that little attention was given to matching word fillers and nonword distracters across Experiments 1a and 1b, other than to ensure that the nonword distracters were orthographically and phonotactically legal. Moreover, although a significant portion of the nonword distracters in Experiment 1b were primed by formally similar words (e.g., *milliner-MILLIN*), this was not true of the nonword distracters in Experiment 1a. In Experiment 2, we sought to minimize any possibility that differential filler word or nonword distracter characteristics in Experiments 1a and 1b led to differential priming effects across the transparency and form comparisons. As such, we conducted Experiments 1a and 1b as if they were a single experiment—including in this single experiment all word fillers and nonword distracters originally in Experiments 1a and 1b. In this way, any explanation cast in terms of filler/nonword characteristics for the puzzling finding of robust facilitation effects from semantically opaque primes in Experiment 1a, but the failure to find statistically significant facilitation from such primes in Experiment 1b could be ruled out.

Subjects. Forty-two student subjects from the Macquarie University were tested, none of whom had participated in Experiment 1. All had normal or corrected-to-normal vision and were native speakers of Australian English. Subjects participated in this experiment in exchange for course credit or a payment of $10.

Stimuli, Apparatus, and Procedure. Targets, primes, word fillers, and nonword distracters were exactly those used in Experiments 1a and 1b, combined into a single stimulus set. Targets within each subexperiment were divided equally into three lists for counterbalancing purposes. All apparatus and procedures were exactly the same as in Experiment 1.

Results and Discussion. Reaction time and error data were collected and cleaned in the three ways described for Experiment 1. First, there were no outlying subjects, so none were removed. Second, data from four items (PARCH, AMP, CANDID, and COLON) were removed because of high error rates (over 33%). Finally, six outlying datapoints over 1,500 ms were excluded. Subject RT and error data are shown in Table 10.2; item data are contained in Appendix 10.A.

Data from each experiment independently were submitted to mixed-design ANOVAs with prime type (three levels) treated as a repeated factor and version (three levels) treated as an unrepeated factor.

With respect to the within-target comparison that assessed effects of semantic transparency on morphological priming (e.g., *numbness-NUMB* versus *number-NUMB*), we again found a significant effect of prime type ($F_1(2,78) = 9.11$, $p < .01$; $F_2(2,58) = 6.34$, $p < .01$). Further comparisons revealed: (a) significantly greater priming produced by semantically transparent primes than unrelated primes, ($F_1(1,39) = 15.71$, $p < .01$; $F_2(1,29) = 19.23$, $p < .01$); (b) significantly greater priming produced by semantically opaque primes than unrelated primes ($F_1(1,39) = 9.17$, $p < .01$; $F_2(1,29) = 4.96$, $p < .05$); and (c) no difference in the level of priming produced by semantically transparent and semantically opaque primes ($F_1(1,39) < 1$; $F_2(1,29) < 1$). There were no effects of prime type on the error data in this comparison ($F_1(2,78) = 1.42$, MS; $F_2(2,58) = 1.51$, NS).

With respect to the within-target comparison that assessed effects of morphological surface structure on masked priming (e.g., *brother-BROTH* versus *brothel-BROTH*), we again found no effect of prime type in the RT data ($F_1(2,78) = 2.16$, NS; $F_2(2,48) = 1.66$, NS) or in the error data ($F_1(2,78) < 1$; $F_2(2,48) < 1$). The failure to find a significant effect of morphological surface structure on masked morphological priming was again owing to the degree of variance apparent in the data. Indeed, there was no numerical difference at all between the priming produced by semantically opaque primes in the transparency comparison (e.g., *department-DEPART*) and that produced by semantically-opaque primes in the form comparison (e.g., *brother-BROTH*; 22 ms in both cases). These results replicate those observed in Experiments 1a and 1b.

TABLE 10.2. Data from Experiment 2

	RT (standard deviation)	Error
Transparency comparison		
Transparent	563 (66)	2.66%
Opaque	571 (56)	3.48%
Unrelated	593 (58)	4.63%
Form comparison		
Opaque	601 (91)	8.71%
Form	619 (86)	8.64%
Unrelated	623 (80)	7.45%

GENERAL DISCUSSION

The masked priming technique (Forster & Davis, 1984) has provided a promising avenue for exploring the representations and computations that underlie the visual recognition of polymorphemic words—a class of lexical item that has been underrepresented in the computational modeling of reading. Using this technique, much evidence has been amassed in recent years to suggest that the visual word recognition system is characterized by a process or level of representation at which morphemes play a special role (e.g., Drews & Zwitserlood, 1995; Forster et al., 1987; Frost et al., 1997; Giraudo & Grainger, 2000; Grainger et al., 1991; Rastle et al., 2000). This evidence is compelling not only because the masked priming technique should be less susceptible to the strategic and episodic factors that may contaminate other experimental paradigms (e.g., cross-modal priming: Marslen-Wilson et al., 1994; long-lag priming: Stoltz & Feldman, 1995; unprimed lexical decision: Taft & Forster, 1975), but also because it has been possible using the technique to rule out conclusively explanations for the priming effects based upon other aspects of lexical similarity (e.g., meaning and form relationships, see Rastle et al., 2000). Much of the research using the masked morphological priming technique, however, has been dedicated to establishing that there is *an* effect of morphological relatedness—that models of reading have *something* to explain that cannot be cast within existing constructs. It was our aim in this work to begin to go further than this—to use the masked morphological priming technique as a tool for uncovering the nature of the processing system that recognizes visually presented polymorphemic words.

To this end, we introduced two means by which the morphological characteristics of a language might influence the development of linguistic representation in the visual word recognition system—through the structure it provides to the otherwise arbitrary mapping between orthography and meaning, and through the structure it provides to the distribution of letter patterns in the language. We speculated that (in contrast to current theories of morphological processing that focus only on one of these elements of structure) it would be curious if our visual word recognition systems did not capitalize on both, with purely structural processing dominating in early visual word recognition and semantic influences becoming apparent as analysis of the input progresses over time. Our previous research using the masked priming technique has offered preliminary support for this view (Rastle et al., 2000; see also Feldman & Soltano, 1999).

Summary of Masked Priming Effects

In this work, we therefore sought to investigate further the view that morphology exerts a purely structural influence on the organization of orthographic representation. We examined this view by conducting two masked priming experiments in which participants made visual lexical decisions to stem targets, when these targets were preceded by masked primes sharing morphemic components with the target. In one within-target comparison, we tested whether an effect of semantic transparency on morphological priming would be observed (e.g., *departure-DEPART* versus *department-DEPART*); in another comparison, we tested whether an effect of morphological surface structure on morphological priming would be observed (e.g., *brother-BROTH* versus *brothel-BROTH*). We predicted priming in all cases in which the prime was comprised of morphemic elements, irrespective of semantic transparency. Our results offered mixed support for this prediction. In the transparency comparison we found significant and equivalent levels of target facilitation when primes were semantically transparent and semantically opaque. In the second comparison, targets were facilitated numerically by primes comprised of a morphological surface structure (to the same degree as opaque primes in the transparency comparison), but this effect reliably failed to reach statistical significance. For form related items without a morphological ending (*brothel-BROTH*) there was no evidence (either numerical or statistical) for any priming effect (see also Giraudo & Grainger, 2001, who reported no significant priming of French-derived targets in visual lexical decision by words comprised of the target stem and a nonmorphological ending, for example, *laitue-LAITIER*, relative to an unrelated control condition).

It is somewhat puzzling that semantically opaque primes with a morphological surface structure facilitated target recognition significantly in one comparison (the transparency comparison), but did not do so with sufficiently low variability to reach statistical significance in another (the form comparison). Of course, there is no *statistical* evidence to suggest that the facilitation produced by semantically opaque primes in these two comparisons differed—in fact, the *numerical* sizes of the effects in Experiment 2 were equivalent; however, some explanation for why the effects were strong and significant in one comparison, but failed to reach significance in the other comparison would be desirable.

One possibility is that the form comparison simply had less power to detect a significant effect than the transparency comparison. Although the same subject groups participated in each of these within-target comparisons, the form comparison included fewer items than the transparency comparison (30 versus 33). Moreover, error rates in the form comparisons were up to four times as high as those in the transparency comparisons, leaving fewer datapoints with which to establish a reliable effect. Unfortunately, the number of low-N targets that meet the criteria for inclusion in the form comparison is low; therefore, a more powerful manipulation would be difficult to achieve in English. We would therefore suggest that one useful way forward might be to conduct these within-target comparisons in a language other than English, which also uses a concatenative morphological system (e.g., French, German).

Another possibility is that some real difference between the items used in these two comparisons led to increased variability in data from the form comparison. Recently, a number of authors have argued that morphological family size of a simple target (the number of derived, inflectional, and compound words containing a particular stem; Schreuder & Baayen, 1997)—and more specifically, the semantic coherence of the morphological family (Ford, Marslen-Wilson, & Davis, in press)—influences visual lexical decision latency. Stems that reside in morphological families (and where the exemplars in these morphological families are semantically related) are recognized more quickly than stems that do not reside in morphological families, or stems that reside in semantically incoherent morphological families. Therefore, it is therefore of interest that targets in our transparency comparison had, by definition, at least one semantically transparent morphological family member; however, there was no requirement for targets in our form comparison to have a transparent family member.

We examined the morphological family size, and the semantic coherence of the morphological family, for targets in the transparency and form comparisons using the method described by Ford et al. (in press). Morphological family size was defined as the number of derived and compound forms containing a particular target stem, and did not differ significantly across targets in the transparency (5.6 family members) and form (4.9 family members) comparisons, $t(61) = .39$. We derived the semantic coherence of each morphological family by measuring the cosine of the angle between LSA vectors (Landauer & Dumais, 1997) for the stem and each of its family members (again obtained using the LSA web facility), and then averaging these values.[5]

Although there was no difference in family size for targets in the two conditions, the semantic coherence measure did reveal reliable differences. Targets in our transparency comparison had significantly more coherent families (average cosine .24) than targets in our form comparison (average cosine .12), $t(59) = 3.25$, $p < .01$. Furthermore, semantic coherence of the morphological family was inversely related to visual lexical decision latency: RTs for targets preceded by semantically opaque primes were reduced as semantic coherence increased (Experiment 1: $r(58) = -.36$, $p < .01$; Experiment 2: $r(58) = -.32$, $p < .01$), as were RTs for targets preceded by unrelated control primes (Experiment 1: $r(58) = -.35$, $p < .01$; Experiment 2: $r(58) = -.19$, NS). We believe that this difference in target characteristics across the transparency and form comparisons led to increased and more variable lexical decision latencies in the form comparison—rendering the numerical facilitation produced by opaque morphological primes (*brother-BROTH*) nonsignificant. If we are correct in ascribing the lack of reliable priming for opaque items in the form comparison to properties of these targets, then we may cautiously interpret our results as suggesting that recognition of stem targets is facilitated by the prior masked presentation of any morphemically structured word containing the target—irrespective of the semantic transparency or genuine morphological status of that word. This result is broadly consistent with previously published work on the recognition of English words (Feldman & Soltano, 1999; Forster & Azuma, 2000; Rastle et al., 2000; Shoolman & Andrews, this volume; but see Gonnerman & Plaut, 2000), and more recent findings regarding the recognition of French words (Longtin et al., submitted).

Morphological Segmentation and the Problem of Position Invariance

Because we did not observe any difference between transparent and opaque primes, our results suggest that there is a level of representation contacted in early visual word recognition that is structured on the basis of morphological units defined orthographically rather than semantically. This conclusion may appear surprising. Besides issues of economy, it is not immediately obvious what function such a structural segmentation system might play—especially because an orthographically determined representation may in some cases hinder access to meaning (for example, representing adder as add + er may lead to the erroneous conclusion that an adder is someone who adds; cf. baker). However, we believe that a structural morphological segmentation of written input may serve a more subtle purpose: It provides a solution to the problem of position invariance, as it applies to morphology.

One of the most fundamental challenges for modellers of visual word recognition is in developing an input-coding scheme that represents both content and order information. Although TOP and POT have completely overlapping features, the order of these features provides essential cues to meaning and must be specified. The representation of order is most often achieved in models of reading through slot-based coding (e.g., Coltheart et al., 2001; Grainger & Jacobs, 1996; Plaut et al., 1996), in which letters of the input (or in the case of Plaut et al., 1996, syllabic constituents of the input) activate position-specific units. One problem with slot-based coding is that it does not capture regularities that exist across positions of the input: Slot-based coding is not position invariant. For example, in any model that employs left-aligned slot-based input coding, orthographic representations for the words RIP, TRIP, and STRIP will bear no similarity whatsoever to each other; and orthographic representations of the words SALT and SLAT will be as similar to one another as those of the words SENT and SORT.[6] A second type of input coding scheme that overcomes some of the problems of slot-based coding is Wickelcoding (Wickelgren, 1969; see Seidenberg & McClelland, 1989, for a simulation of the orthography-phonology mapping that uses Wickelcoding), in which a word is represented as a set of letter triples (e.g., the word RIP is represented as {#RI, RIP, IP#}). Although the Wickelcode for RIP will be more similar to that of TRIP than is possible in slot-based coding schemes, C. Davis (2000) has argued that Wickelcoding ultimately suffers the same problem of a lack of position invariance as slot-based coding: for example, Wickelcodes for the words SALT and

SLAT share no overlap whatsoever. For further information, we point the reader to the excellent discussion of the problem of input coding by C. Davis (2000, this volume; see also the related discussion of the dispersion problem by Plaut et al., 1996).

Consider now the issue of position invariance for the language learner discovering morphological regularities in the form-meaning mapping (e.g., Davis et al., in press; Grainger et al., 1991; Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999). The language learner must discover that the semantically related words trust, trusty, untrustworthy, distrust have significant orthographic overlap in the form of TRUST. However, as should be apparent, this information cannot be discovered by any reading system in which the input-coding scheme lacks position invariance. For example, if orthographic input were represented from left-to-right over position-specific letter units, then the representation of the stem TRUST would be entirely dissimilar in the derived words trusty, untrustworthy, and distrust, as depicted in the following:

```
Position:  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
           t  r  u  s  t
           t  r  u  s  t  y
           d  i  s  t  r  u  s  t
           u  n  t  r  u  s  t  w  o  r  t  h  y
```

For such a system to reliably identify the orthographic overlap in these three words, the following alignment would be required:

```
Position:  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                    t  r  u  s  t
                    t  r  u  s  t  y
           d  i  s  t  r  u  s  t
                    u  n  t  r  u  s  t  w  o  r  t  h  y
```

This alignment problem is dealt with in current simulations of the form-meaning mapping (Davis et al., in press; Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999) by providing the network with an input representation that has already been morphemically segmented: A position-invariant input representation is provided by the modeler.[7]

We suggest accordingly that one of the functions of a level of representation at which input is segmented on the basis of morphemic units may be to enable the language learner to discover the morphological regularities that characterize the relationship between form and meaning. Of course, it remains possible that the language learner codes orthographic input in a positionally invariant manner (such as the spatial coding scheme proposed by C. Davis, 2000), and therefore does not require a purely structural morphemic segmentation to discover regularities in the form-meaning mapping. We acknowledge this possibility, but point out that, irrespectively, the data seem to indicate that some type of structural morphemic segmentation process is operational in the early stages of visual word recognition.

It remains a challenge for future computational modeling efforts to produce a model of this morphological segmentation system. Localist models of the adult reading system (e.g., Coltheart et al., 2001) may look toward an explicit affix identification procedure that operates upon an input string in order to activate sublexical morphological units. (See Taft, 1994, for a theory of visual word recognition which comprises a sublexical level of morphological representation; and Rastle & Coltheart, 2000, for a simple algorithm that identifies orthographic units corresponding to morphemes.) Alternatively, distributed connectionist models, in which a morphological segmentation system develops from the operation of a simple learning algorithm, may be informed by the related literature on how infants learn to segment connected speech into lexical items. Various authors have proposed that by encoding the statistical properties of phoneme sequences, infants can find words in connected speech without requiring that the boundaries between units are explicitly marked. (See Brent, 1999 for a review of these computational accounts and Jusczyk, 1999 for some associated empirical evidence from infants; see also Davis, 2002, for some recent recurrent network simulations.) A variety of mechanisms for this segmentation process have been proposed, among the simplest of which is that word boundaries are placed within low-probability biphone or triphone units (Aslin, Woodward, LaMendola, & Bever, 1996; Cairns, Shillcock, Chater, & Levy, 1997; Elman, 1990; Harrington, Watson, & Cooper, 1989). By extension to the visual domain, these mechanisms would allow the visual processing system to identify morphological units based upon simple statistics of the visual input (e.g., bigram and trigram frequencies; see Seidenberg, 1987) without morphological segmentation being present in the training set. Therefore, we might expect that an appropriately structured neural network, which learns the orthographic properties of morphologically complex words, would come to represent these words in terms of their constituent morphemes without being provided with an explicit, morphologically segmented input.

In summary, we have presented behavioral evidence that we believe is consistent with the operation of a purely structural morphological segmentation process that operates in the very early stages of visual word recognition. We have seen that the stem of a visually presented bimorphemic word is accessed rapidly, irrespective of whether the meaning of the carrier word is related to the stem in a semantically transparent or opaque manner. We believe that this rapid, visually based morphological segmentation may play an important role in allowing later stages of lexical processing to capitalize upon the regularities between form and meaning that are characteristic of morphologically related words. An important challenge in developing a fully specified computational model of the recognition of polymorphemic words is therefore to develop computationally explicit, psychologically plausible mechanisms by which this morphological segmentation can be achieved.

NOTES

1. Of these models, only the dual-route cascaded (DRC) model (Coltheart et al., 2001) even includes polymorphemic words as part of its lexicon (although this set of words is very restricted, because the model deals only with monosyllables). However, the authors of this model have yet to make any theoretical commitments regarding the processing of polymorphemic words, and these items are treated as if they were monomorphemic in the model.
2. Although the word "decomposed" was used originally to refer to an explicit segmentation of a complex word into lexical representations of the stem and affix (e.g., Taft & Forster, 1975), it can also refer, in distributed connectionist models, to the significant overlap that exists between the representation of a morphologically-complex word and that of its stem. We use the term "decomposed" in this chapter in a theory-neutral context—referring to both explicit and implicit decomposition.
3. Forster & Azuma (2000) reported significant priming across bound-stem pairs when prime exposure durations were short (e.g., submit-permit), and argued that this reflected some purely structural operation, not a level of representation mediating between form and meaning. A conclusive argument is difficult to mount on the basis of their data, however, because many of their prime-target pairs were semantically related (e.g., *survive-REVIVE*; *pronounce-ANNOUNCE*; *command-DEMAND*).
4. Because of the number of one-letter affixes in the stimulus set (for which affix trigram frequencies cannot be calculated), there are more test items included in the bigram measures than in the trigram measures.
5. Some low-frequency family members are not included in the corpus of materials from which the LSA vectors are derived. However, for most of our experimental items, the majority of family members do have LSA vectors.
6. As an aside, a number of empirical reports now demonstrate masked priming effects incompatible with position variant coding schemes, including form priming effects involving primes that are either a subset or a supraset of the target (e.g., *rip-TRIP, strip-TRIP*; see De Moor & Brysbaert, 2000) and form priming effects involving transposed letter prime-target pairs (e.g., *salt-SLAT*; see e.g., Perea & Lupker, this volume).
7. It is interesting to note that Zorzi et al. (1998), in an attempt to make use of the regularities provided by body-rime correspondences (see Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995) to the orthography-phonology mapping, presented their network with an input explicitly structured relative to the orthographic vowel (so, strong would be represented as STR ONG). Some purely structural segmentation process prior to entry to the reading system was assumed.

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APPENDIX 10.A. Stimuli and Item Data for Experiments 1 and 2

The Transparency Comparison									
	Prime Type			Experiment 1			Experiment 2		
Target	Transparent	Opaque	Unrelated	Transparent	Opaque	Unrelated	Transparent	Opaque	Unrelated
AUTHOR	authorship	authority	protection	539	560	538	532	501	540
EARN	earner	earnest	sexist	593	558	581	611	522	620
BUZZ	buzzer	buzzard	steeply	627	652	574	592	603	623
MESS	messy	message	layer	565	656	551	551	666	577
EMERGE	emergent	emergency	goodness	644	722	626	606	597	690
ACT	action	actuary	naively	577	554	510	555	474	566
INVENT	invention	inventory	curiosity	620	558	613	547	588	610
BURN	burner	burnish	sugary	579	574	524	512	553	607
ACCORD	accordance	accordion	refraction	563	576	551	525	532	617
TREAT	treatment	treaty	merciless	550	592	559	541	500	566
FRUIT	fruity	fruitful	trendy	534	579	566	509	508	591
PROPER	properly	property	buffer	573	773	719	683	641	702
PARCH	parched	parchment	escapism	—	—	—	—	—	—
ORGAN	organist	organic	sprinter	554	528	616	604	560	608
DEPART	departure	department	sweetie	539	561	654	634	543	578
SUIT	suitable	suitor	brainless	508	588	704	591	603	594
INFANT	infantile	infantry	customary	548	518	668	570	557	555
HABIT	habitual	habitat	difficulty	547	524	626	554	529	617
SWEAT	sweaty	sweater	teaser	493	576	589	506	625	513
COAST	coastal	coaster	excitedly	517	580	613	547	534	576
SECOND	secondary	secondment	pictorial	636	572	644	575	536	567
MISS	missing	missile	crabby	473	587	641	551	562	531
ACCESS	accessible	accessory	congestion	553	496	567	511	527	546
INSTALL	installation	installment	persistence	616	562	662	564	637	684
CASUAL	casually	casualty	lecturer	578	528	595	549	574	609

(Continued)

APPENDIX 10.A. Continued

The Transparency Comparison									
	Prime Type			Experiment 1			Experiment 2		
Target	Transparent	Opaque	Unrelated	Transparent	Opaque	Unrelated	Transparent	Opaque	Unrelated
DESIGN	designer	designate	goddess	540	488	566	482	503	539
MOMENT	momentary	momentous	arsonist	626	541	665	503	536	570
SUPPLE	suppleness	supplement	incidental	—	—	—	673	639	629
AUDIT	auditor	audition	workable	698	569	726	588	725	590
HOST	hostess	hostile	willowy	565	558	597	538	543	593
VICAR	vicarage	vicarious	mystical	—	—	—	590	708	698
EVENT	eventful	eventual	thinness	554	462	495	525	562	521
NUMB	numbness	number	freedom	633	604	717	610	652	617

The Form Comparison									
Target	Opaque	Form	Unrelated	Opaque	Form	Unrelated	Opaque	Form	Unrelated
AMEN	amenable	amend	lawless	715	701	653	626	632	762
AMP	ample	amplify	crater	—	—	—	—	—	—
APART	apartment	apartheid	doctorate	588	592	606	602	579	673
ARCH	archer	archaic	scenic	638	658	671	644	622	638
BROTH	brother	brothel	careful	716	746	720	664	827	741
BUTT	butter	button	kingdom	734	700	696	629	630	760
CANDID	candidate	candidacy	sculpture	758	756	738	—	—	—
CHANCE	chancery	chancellor	agreeable	529	531	615	545	620	586
COLON	colony	colonel	feature	—	—	—	—	—	—
DISC	discern	discuss	exactly	725	689	679	609	633	626
EARL	early	earlobe	finish	739	701	763	815	660	575
END	endure	endow	stuffy	620	523	625	542	544	513
EVEN	evening	eventual	mixture	644	651	533	511	526	527
FORGE	forgery	forget	tension	574	807	595	659	634	685

HEART	hearty	hearth	mileage	626	511	617	555	565	539
INTERN	internal	international	generation	738	734	701	726	648	763
JERK	jerky	jerkin	lofty	551	765	713	618	626	620
OFF	offer	office	matter	592	546	629	581	569	509
OVERT	overture	overturn	addition	660	790	678	749	693	645
PHONE	phoney	phonetic	novelist	554	580	649	513	552	563
PLAN	planet	plank	brandy	598	520	560	516	523	603
PLUM	plumage	plump	tricky	717	667	621	529	556	584
SCRAP	scraper	scrape	trader	555	563	728	600	621	664
SECRET	secretary	secrete	laughter	690	573	588	545	601	566
STUD	study	studio	total	717	734	623	664	639	632
SURGE	surgery	surgeon	shorten	585	667	799	739	770	702
TACT	tactic	tactile	monthly	649	673	793	548	725	614
TEXT	texture	textile	voltage	551	623	522	468	589	561
UNIT	unity	unite	irony	537	698	682	548	520	563
WHISK	whisker	whiskey	leaflet	692	589	736	598	615	600