LANGUAGE AND COGNITIVE PROCESSES, 2000, *15* (4/5), 507–537

Morphological and semantic effects in visual word recognition: A time-course study

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Some theories of visual word recognition postulate that there is a level of processing or representation at which morphemes are treated differently from whole words. Support for these theories has been derived from priming experiments in which the recognition of a target word is facilitated by the prior presentation of a morphologically related prime (departure-DEPART). In English, such facilitation could be due to morphological relatedness, or to some combination of the orthographic and semantic relatedness characteristic of derivationally related words. We report two sets of visual priming experiments in which the morphological, semantic, and orthographic relationships between primes and targets are varied in three SOA conditions (43 ms, 72 ms, and 230 ms). Results showed that morphological structure plays a significant role in the early visual recognition of English words that is independent of both semantic and orthographic relatedness. Findings are discussed in terms of current approaches to morphological processing.

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This work was supported by a British Academy grant awarded to the first author and an MRC programme grant awarded to the third and fourth authors. We are grateful to Ken Forster, Jonathan Grainger, and Michael Masson for their thoughtful reviews of an earlier version of this article. We are also grateful to Lianne Older for her assistance in designing the materials, to Asma Fikree and Meera Mehta for their assistance in running subjects, and to Belinda Randall for helpful discussion.

http://www.tandf.co.uk/journals/pp/01690965.html

The role of morphology in the human language processing system has become an important topic of research in the cognitive psychology of language over the past 20 years. Most fundamentally, this research has addressed whether the language processing system is characterised by a process or level of representation that is specifically morphological—a level at which morphemes are treated differently from whole words—and has exploited cross-linguistic, cross-task, and neuropsychological approaches. In the work presented here, we consider this issue specifically with respect to derivational morphology and its role within the visual word recognition system.

The priming paradigm has provided a particularly useful way by which to study the effects of morphology on language processing. It has been shown across languages that recognition of a target word (e.g., depart) is facilitated by the prior presentation of an inflectionally or derivationally related prime word (e.g., departing, departure), regardless of whether prime and target are both visually presented (e.g., Frost, Forster, & Deutsch, 1997), auditorily presented (e.g., Marslen-Wilson & Tyler, 1997, 1998; Marslen-Wilson & Zhou, 1999), or whether primes are auditorily presented and targets are visually presented (Marslen-Wilson, Tyler, Waksler, & Older, 1994). These types of results have lent support to theories which postulate access mechanisms or levels of representation dedicted to the morpheme.

At least in English, however, words which have a derivational-morphological relationship generally also have an orthographic relationship and a semantic relationship. Priming between derivationally related words could thus reflect any combination of the morphological, orthographic, or semantic similarity between primes and targets. Therefore, in studying morphological effects on visual word recognition, it has been important to find a condition in which priming effects between morphologically related items occur in the absence of priming effects between semantically and orthographically related items. The long-lag priming paradigm, in which prime and target are separated by a number of intervening items, provides such a condition. Using this paradigm, morphological priming effects have been found in the absence of semantic priming effects in Hebrew (Bentin & Feldman, 1990) and in the absence of orthographic priming effects in German (Drews & Zwitserlood, 1995) and English (Stolz & Feldman, 1995).

The masked priming paradigm (Forster & Davis, 1984) provides another avenue by which to examine morphological effects in visual word recognition. In masked priming, a prime word (e.g., glue) which cannot be consciously perceived is sandwiched between a forward mask (######) and a target (e.g., BLUE). One benefit of using the masked priming paradigm is that it eliminates the strategic and episodic components that may contaminate the long-lag priming paradigm, helping to ensure that observed effects are due to linguistic processes of interest (but see e.g., Bodner & Masson, 1997). Data regarding morphological effects in masked priming are similar to those observed when using the long-lag technique. Morphological effects in masked priming have been shown in the absence of semantic priming effects in Hebrew (Frost et al., 1997; SOA = 43 ms). They have also been demonstrated in the absence of orthographic priming effects in French (Grainger, Cole, & Segui, 1991; SOA = 64 ms) and in Dutch (Drews & Zwitserlood, 1995; SOA = 66 ms), though Masson and Isaak (1999) failed to find such effects when they examined priming of irregular inflectional morphology (kept/keep) in English using the naming task. One aim of the research reported here, then, was to determine whether effects of derivational morphology are obtained in English masked priming in the absence of priming effects for semantically and orthographically related items. Such priming effects would suggest that the English visual word recognition system incorporates a process or level of representation that encodes morphological structure, and moreover, that this information is accessed within the first moments of visual word recognition, without employing conscious or episodic components of the cognitive system.

A second aim of the present research was to examine the *nature* of morphological decomposition throughout the process of visual word recognition. One important variable that has been shown to affect morphological representation is semantic transparency. Marslen-Wilson et al. (1994) reported that in cross-modal priming, recognition of a target stem (e.g., depart) was facilitated only when a morphologically complex prime was related to the target in a semantically transparent way. No priming was observed when the prime word combined morphemic elements such that the meaning of the derived word was not transparently related to the meaning of the stem (e.g., *departure* but not *department* would prime *depart*). These results suggest that at the level of representation probed by the cross-modal priming task, semantic relationships govern morphological decomposition.

However, it is not clear whether this influence of meaning on morphological decomposition is a general fact about lexical representation, or is apparent only under experimental situations (such as those used by Marslen-Wilson et al., 1994), in which the processing of the prime is complete before presentation of the target. By varying prime-exposure duration—from conditions in which the prime is masked (e.g., Forster & Davis, 1984) to conditions in which the prime is fully visible—we sought to assess whether semantic transparency affects morphological priming throughout early visual word recognition or only at later stages of processing. This prime-duration manipulation was also intended to shed light upon other important issues regarding the temporal dynamics of visual word recognition, such as the time course of semantic activation in the word recognition process.

Therefore, in Experiment 1, we examined how the prior presentation of a prime word affected lexical decisions to target items as a function of (a) the nature of the relationship between primes and targets and (b) prime exposure duration. With respect to (a), we varied morphological, orthographic, and semantic relationships between primes and targets, so that independent effects of each property could be examined along with interaction effects. With respect to (b), the effects of priming across these dimensions of similarity were examined in each of three prime exposure duration conditions: 43 ms, 72 ms, and 230 ms. These durations were chosen (within the constraints imposed by the stimulus presentation apparatus e.g., a screen refresh rate of 14.3 ms) because they provide a range of situations in which we can measure facilitation to targets as a function of the amount of processing that has been allowed on the prime. At the two short exposure durations, explicit identification of the prime is generally not possible, though at the longer of these two durations, the presence of a prime can be detected. The longest of these durations (230 ms) was chosen because it allows conscious appreciation of the primes, yet may be so brief as to minimise strategic behaviour.

In order to carry out this work, we must be able to measure and manipulate the degree to which primes and targets are related semantically and orthographically across priming conditions. However, whilst controlling orthographic overlap across conditions can be accomplished through the use of a number of objective measures, measuring and controlling the amount of semantic overlap between primes and targets is not straightforward: there are few available measures of semantic similarity, and all are imperfect.

The approach that we took to measuring semantic relatedness between primes and targets was twofold. First, we asked subjects to rate on a 9-point scale the degree to which prime-target pairs were related in meaning. This form of relatedness judgement has the advantage of being applicable not only to synonyms (which have the same syntactic category) but also to derivationally related items in which the syntactic class differs between the stem and the derived form. However, semantic relatedness judgements are performance tasks in their own right, and at present, we have little knowledge or control over the ways in which participants execute such tasks. In an attempt to validate these relatedness judgements, we also measured semantic relatedness using Latent Semantic Analysis (LSA; Landauer & Dumais, 1997). 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. The technique used by LSA is based on generating vectors that represent the co-occurrence of words in passages of text. Since the co-occurrence window used by LSA is a whole paragraph this technique will extract representations of word meaning that are relatively independent of syntactic information. This makes LSA a suitable technique for analysis of derivational morphology where syntactic class will differ between a derivationally complex word and its stem (see Lund & Burgess, 1996 for a similar technique that does incorporate syntactic information).

EXPERIMENT 1

Method

Subjects. Seventy-two subjects between the ages of 18 and 40 participated in the experiment. All were native speakers of British English and had normal or corrected-to-normal vision. Subjects were taken from the Centre for Speech and Language research pool, and were paid five pounds for their participation.

Stimuli and apparatus. One hundred and twenty prime-target pairs were selected from the CELEX English lexical database (Baayen, Piepenbrock, & van Rijn, 1993), 24 pairs in each of five conditions: (a) morphologically, semantically, and orthographically related [(+M+S+O) e.g., departure-DEPART]; (b) morphologically and orthographically related, but semantically unrelated [(+M−S+O) e.g., apartment-APART]; (c) morphologically and orthographically unrelated, but semantically related [(−M+S−O) e.g., cello-VIOLIN]; (d) orthographically related, but morphologically and semantically unrelated [(−M−S+O) e.g., electrode-ELECT]; (e) identical (e.g., cape-CAPE). All targets were free morphemes. Stimuli are contained in Appendix A.

The morphological relationship between primes and targets was determined using the Oxford English Dictionary. Prime-target pairs in the +M−S+O condition generally bore an historical morphological relationship that is no longer apparent (cf. Marslen-Wilson et al., 1994).

Semantic relatedness was assessed by means of pretest and LSA (Landauer & Dumais, 1997). Twenty-seven subjects (who did not participate in the main experiment) rated possible prime-target pairs and unrelated filler pairs on a 9-point scale of semantic relatedness, with 9 representing "very related in meaning" and 1 representing "very unrelated in meaning". Care was taken to ensure that subjects did not use form overlap to bias their responses (by the inclusion of filler pairs that were related in form but unrelated in meaning). We chose prime-target pairs for the semantically-related conditions (+M+S+O and −M+S−O) if they were given average ratings of over 7.5; pairs were selected for the semantically unrelated conditions (+M–S+O and –M–S+O) if they were given average ratings of below 2.5.

We calculated the similarity between pairs of prime and target vectors using the LSA web facility (http://lsa.colorado.edu). The vectors used were derived from a selection of texts described as "General reading up to 1st 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 target word. These cosine measures were highly correlated with relatedness judgements obtained from participants in the pretest, $r = .665$, $p < .001$.

Despite our efforts to control semantic relatedness by selecting items from the extremes of the relatedness scale, significant differences in the semantic relatedness between primes and targets remained. Specifically, according to the pretest measure, +M+S+O pairs were significantly more related than –M+S–O pairs [8.04 vs. 7.73, $t(46) = 2.2$, $p < .05$], and +M–S+O items were significantly more related than –M–S+O items [2.47 vs. 1.73, $t(46) = 2.40$, $p < .05$]. Significant differences in relatedness between these conditions did not emerge when we considered LSA measurements of similarity. Although differences in pretest relatedness judgements were small, we attempted to account for them statistically in the analyses of the data.

Unrelated control primes were selected for each of the 120 target words. Control primes were morphologically and semantically unrelated to targets, and had the same number of letters as related primes. Control primes and targets did not share any letters in the same position. Sixty unrelated prime-target pairs (e.g., coast-LION) were included as fillers to reduce the proportion of related prime-target pairs in the experiment to 30%.

Targets were matched across the five conditions as closely as possible for number of letters, number of syllables, frequency, and neighbourhood size. Average values for each of these variables across the five conditions are shown in Table 1. There were no significant differences across the five conditions for any of the variables [frequency, $F(4, 115) = 0.32$; number of letters, $F(4, 115) = 1.62$; number of syllables, $F(4, 115) = 0.78$; neighbourhood size, $F(4, 115) = 1.22$].

One hundred and eighty prime-nonword target pairs were created. All nonword targets were pronounceable. Twenty-four of the nonword targets were primed with an identical nonword prime (e.g., slint-SLINT), just as was the case for word items. A further 24 of the nonword targets were primed by words containing the embedded nonword target (e.g., banter-BANT), as was the case for morphologically related word items. The remainder of the nonword targets were primed with orthographically unrelated words.

TABLE 1
Stimulus characteristics in Experiment 1

Condition	*No. Letters*	*No. Syllables*	*Frequency*	N
+M+S+O (departure-DEPART)	5.17	1.38	24.38	4.79
+M–S+O (apartment-APART)	5.12	1.54	34.92	4.62
–M+S–O (cello-VIOLIN)	5.12	1.42	30.58	6.42
–M–S+O (electrode-ELECT)	4.50	1.33	30.62	7.50
ID (church-CHURCH)	4.79	1.54	39.29	4.71

Note: M, morphological; S, semantic; O, orthographic.

In total, there were 360 prime-target pairs, 180 of which were word targets and 180 of which were nonword targets. Target items were divided into two lists of 60 items each. For half of the subjects, targets in the first list were preceded by their related prime words and targets in the second list were preceded by their unrelated prime words. For the other half of the subjects, targets in the second list were preceded by their related prime words and targets in the first list were preceded by their unrelated prime words.

Stimulus presentation and data recording was controlled by the DMASTR software running on a 386 personal computer. A two-button response box was used to record lexical decisions, in which the YES reponse button was controlled by the dominant hand.

Procedure. Twenty-four subjects were assigned to each of the three SOA conditions. Within each SOA condition, subjects were divided randomly into two equal groups, each group receiving one of the two lists of prime-target pairings described above.

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 as accurately as possible whether each letter string was a word or not a word. Those subjects in the two short SOA conditions 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. Those subjects in the long SOA condition were told that each letter string would be preceded by a series of hash marks followed by a briefly presented word in lower case. All targets were in upper case and all primes were in lower case. Subjects were seated approximately 16 inches from the computer monitor and were instructed to keep their hands on the response box at all times to encourage quick responding. They were given 12 practice trials before beginning the experiment.

Results

Reaction time and error data were collected and cleaned in several ways. First, two subjects were excluded, one from the shortest SOA condition because of an average target RT of over 800 ms, and another from the longest SOA condition because of a false positive rate of over 20%. Second, complete target data for all SOA conditions were plotted and outlying RTs were removed; in total, 39 data points over 1400 ms (0.24% of the data) were removed. Finally, average error rates for each item across all SOA conditions were examined, and data from those items with error rates over 25% were excluded; this phase of the data cleaning procedure excluded data from three target items—*deter*, *gorge*, and *lanky*. Complete item data are presented in Appendix A.

Data were then analysed in a mixed-design analysis of variance (ANOVA) with four factors—SOA (three levels), condition (five levels), list (two levels), and priming (two levels). In the by-subjects analysis, condition and priming were treated as repeated factors; SOA and list were treated as unrepeated factors. In the by-items analysis, priming and SOA were treated as repeated factors; condition and list were treated as unrepeated factors. Latency and error data by subjects are shown in Table 2.

Since in this experiment we were interested specifically in priming, we report here only those effects concerning the priming variable itself and its interaction with the other variables manipulated in the study. The main effect of priming was significant both by subjects, $F(1, 64) = 67.18$, $p < .001$, $MSE = 1507.83$, and by items, $F(1,107) = 48.08$, $p < .001$, $MSE = 2066.32$, as lexical decisions were made more rapidly when words

TABLE 2
Latency and error data for Experiment 1, by subjects

		SOA		
Condition		*43 ms*	*72 ms*	*230 ms*
+M+S+O	Primed	561 (3.26%)	539 (1.74%)	568 (1.45%)
	Unprimed	607 (2.57%)	600 (5.62%)	613 (3.66%)
+M–S+O	Primed	582 (3.69%)	577 (2.87%)	654 (4.26%)
	Unprimed	617 (4.15%)	593 (3.60%)	639 (2.24%)
–M+S–O	Primed	602 (3.97%)	556 (3.13%)	586 (2.17%)
	Unprimed	605 (2.90%)	575 (1.74%)	613 (2.54%)
–M–S+O	Primed	594 (5.24%)	571 (9.82%)	632 (7.39%)
	Unprimed	613 (3.46%)	586 (4.77%)	611 (3.10%)
ID	Primed	559 (5.37%)	541 (1.52%)	564 (1.98%)
	Unprimed	601 (7.38%)	571 (6.22%)	606 (2.60%)

were primed with related words than when they were primed with unrelated controls. This main effect of priming was qualified by an interaction with condition by subjects, $F(4, 256) = 10.62$, $p < .001$, $MSE = 1218.02$, and by items, $F(4, 107) = 7.17$, $p < .001$, $MSE = 2066.32$, because the effect of priming was not equivalent across the five similarity conditions. Finally, this two-way interaction between priming and condition was qualified by a three-way interaction between priming, condition, and SOA by subjects, $F(8, 256) = 2.78$, $p < .01$, $MSE = 1218.02$, and by items, $F(8, 214) = 2.94$, $p < .01$, $MSE = 1258.82$, as variations in the amount of priming across the condition variable were not constant across all SOA conditions.

The nature of the interaction between priming, condition, and SOA is shown in Figure 1, which plots the amount of priming (target RT when preceded by an unrelated prime – target RT when preceded by a related prime) across condition and SOA, with asterisks denoting statistically significant priming effects.

We investigated this three-way interaction statistically by carrying out a series of planned comparisons, the results of which were as follows:

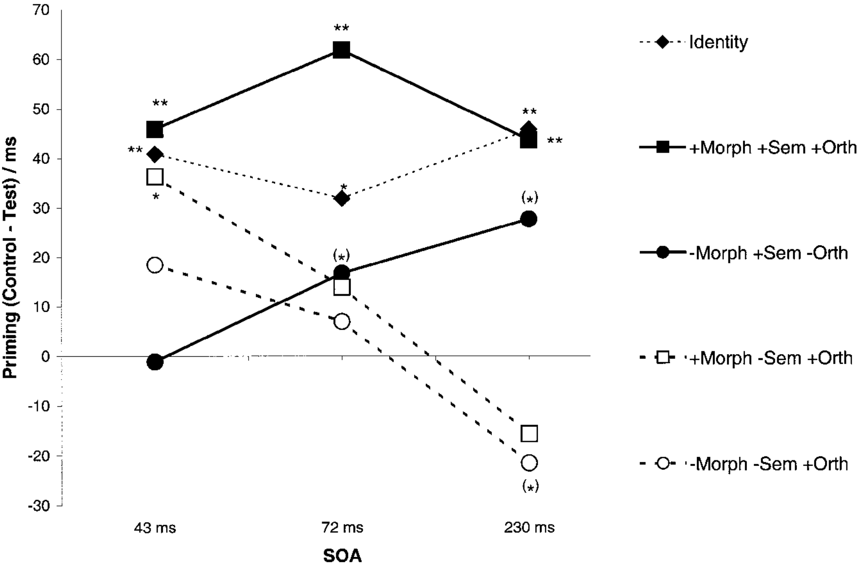

Figure 1. Priming effects in Experiment 1 as a function of relatedness condition and SOA, by items. Double asterisks indicate significance at the $p < .01$ level for both subject and item analyses; single asterisks indicate significance at the $p < .05$ level for both subject and item analyses; asterisks in parentheses indicate significance either by subjects or by items only.

(a) Robust priming effects emerged for the transparent-derived (+M+S+O) and identity conditions [$F_1(1, 64) = 101.57$, $p < .0001$, $MSE = 1336.57$; $F_2(1, 43) = 95.66$, $p < .0001$, $MSE = 1507.12$]. Priming effects for these conditions were statistically equivalent, and did not vary across SOA.

(b) Greater priming effects emerged for transparent-derived (+M+S+O) pairs than for semantically related (–M+S–O) pairs [$F_1(1, 64) = 15.48$, $p < .001$, $MSE = 1313.68$; $F_2(1, 44) = 14.81$, $p < .001$, $MSE = 1582.96$]; this effect did not vary reliably across SOA. When controlling for the small but significant difference in semantic relatedness that characterised this comparison (with the use of analysis of covariance), the interaction between priming and condition remained for prime exposure durations of 43 ms, [$F_2(1, 43) = 11.81$, $p < .01$, $MSE = 2567.36$], and 72 ms, [$F_2(1, 43) = 6.61$, $p < .05$, $MSE = 2035.18$].

(c) Similarly, greater priming effects emerged for +M+S+O pairs than for form controls (–M–S+O) [$F_1(1, 64) = 25.93$, $p < .001$, $MSE = 1422.87$; $F_2(1, 43) = 30.25$, $p < .001$, $MSE = 1393.94$]; this effect did not vary reliably across SOA.

(d) The amount of priming in the two morphologically related conditions varied as a function of the semantic relationship between prime and target, such that transparent (+M+S+O) pairs produced more priming than opaque (+M–S+O) pairs [$F_1(1, 64) = 23.57$, $p < .001$, $MSE = 1098.54$; $F_2(1, 43) = 7.64$, $p < .01$, $MSE = 2930.92$]. This variation in priming across condition tended to vary across SOA, such that the amount of priming in the +M–S+O condition decreased relative to the amount of priming in the +M+S+O condition as prime duration increased [$F_1(2, 64) = 3.44$, $p = .038$, $MSE = 1098.54$; $F_2(2, 86) = 2.90$, $p = .06$, $MSE = 1381.07$].

(e) Priming in the opaque-derived (+M–S+O) condition could not be distinguished statistically from priming in the form-related (–M–S+O) condition (both Fs < 1). However, the amount of priming in both conditions decreased as prime duration increased [$F_1(2, 64) = 8.84$, $p < .001$, $MSE = 1455.31$; $F_2(2, 84) = 9.84$, $p < .001$, $MSE = 1344.70$].

Error data were analysed in the same way as were the latency data. Global mixed-design ANOVAs showed no main effect of priming either by subjects or by items, both Fs < 1. However, a condition by priming interaction did emerge in the by-subjects analysis, $F(4, 256) = 6.23$, $p < .001$, $MSE = .0032$, and in the by-items analysis, $F(4, 107) = 5.00$, $p < .01$, $MSE = .0039$, reflecting the fact that the effect of priming was not stable across condition. There were no other effects of the priming variable in the error analysis.

We investigated the nature of the condition by priming interaction in the error data by conducting a series of five planned comparisons in each SOA condition. As in the latency data, in each SOA condition, we compared error rates for primed items against error rates for unprimed items, in each condition. The interaction between priming and condition was caused largely by significant inhibitory effects in the form-related (–M–S+O) condition and significant facilitatory effects in the (+M+S+O) condition. Because there was no interaction between SOA, priming, and condition, we did not conduct further planned comparison tests on the error data.

Discussion

One aim of this experiment was to examine whether the masked priming paradigm provides a situation in which effects of English derivational morphology can be observed in the absence of semantic effects and orthographic effects. Another aim was to investigate the nature of morphological decomposition by formulating a detailed picture of the time course of orthographic, morphological, and semantic activation in visual word recognition.

With respect to the first aim, we found clear and consistent priming effects for semantically transparent derived forms and their stems across all of the SOA conditions. These effects were significantly greater than effects of semantic relatedness and effects of orthographic relatedness, and indeed did not differ statistically at any point from identity priming effects (see Forster, Davis, Schoknecht, & Carter, 1987, for a similar result using inflectionally related pairs). Thus, these results are consistent with accounts by which morphemically structured representations play a role in visual word recognition.

Less clear are the data concerning our second aim, which was to investigate the nature of morphological decomposition through the visual word recognition process. While robust priming effects for semantically transparent morphologically complex words emerged (consistent with the theoretical position set forth by Marslen-Wilson et al., 1994, regarding the nature of morphological representation), significant priming effects also emerged for semantically opaque morphologically complex items (+M–S+O) in the shortest SOA condition. These data may indicate the existence of morphemically structured orthographic representations which are not governed by semantic transparency (see also Frost, Deutsch, & Forster, in press, who argue that a morphologically constrained, rule-governed parsing algorithm operates in the early stages of visual word recognition). Priming effects due to overlap in these orthographic representations may be revealed at short SOAs, but will be cancelled at longer SOAs, where the non-transparent semantic relationships for these pairs play a more important role.

The statistical data concerning priming for semantically opaque items at the shortest SOA condition are not clearcut, however. Although the planned comparison which assessed the significance of priming in that condition yielded a significant result (while priming for form-only related pairs did not, see Figure 1), we were unable to distinguish statistically between this condition and the form-related condition (−M−S+O). Further research is currently underway to determine whether in short SOA masked priming, facilitation for semantically opaque complex items can be distinguished from priming for orthographically related items which have no morphological relationship.

Finally, the data from this set of experiments bear upon a number of current issues regarding the time course of semantic and orthographic information in visual word recognition. First, we did not observe significant effects of semantic priming in the short SOA conditions. Indeed, semantic priming effects became apparent only when primes were clearly visible (SOA = 230 ms), and even then were statistically only marginal. Frost et al. (1997) also failed to find semantic priming effects at short SOAs in their work on Hebrew. However, given Perea and Gotor's (1997) recent report of semantic priming effects using the masked priming paradigm (SOA = 67 ms) in Spanish, there remains some way to go before time course information about semantic activation is fully understood. We also observed non-significant effects of orthographic priming (e.g., electrode-ELECT), which tended toward inhibition at long SOAs, particularly in the error data. These data are broadly consistent with data from Grainger et al. (1991) which also showed inhibitory effects of orthographically related word primes on target recognition in French. The ways in which these time-course effects of semantics, morphology, and orthography might be interpreted will be considered in the General Discussion.

EXPERIMENT 2

In Experiment 1, we demonstrated that effects of English derivational morphology occur in the masked priming paradigm in the absence of independent effects of semantics and form. These results are consistent with previous results from masked priming reported in Hebrew (Frost et al., 1997), French (Grainger et al., 1991), Dutch, and German (Drews & Zwisterlood, 1995), all of which seem to imply that the visual word recognition system is characterised by a process or level of representation at which morphemes are treated differently from whole words.

There is another possibility, however. It might be the case that morphological priming effects are not the result of some process or level of representation that is specifically morphological, but rather are due to *summed* effects of similarity in meaning and form. That is, it may be the case that a non-significant semantic priming effect added to a non-significant orthographic priming effect is sufficient to produce the robust priming effects characteristic of morphologically related, semantically transparent items (see Gonnerman, 1999, for a similar argument). The purpose of Experiment 2 was to investigate this possibility.

A complication arises immediately in trying to assess whether effects which appear morphological are actually summed effects of semantic and orthographic relatedness: the set of English words which are not morphologically related, yet share meaning and form is extremely limited. Indeed, words which share meaning and form are almost without exception morphologically related as well. Instances can be found, however, in which the mapping between form and meaning does not appear to be entirely arbitrary (see e.g., Marchand, 1969, pp. 397–428), and these may provide a source of word pairs that are related in form and meaning without a morphological component. Onomatopoeic words (e.g., bang, clang) provide the clearest example of a non-arbitrary link between form and meaning. For these items, the whole sound-structure of the word conveys its meaning.

Subtler instances of a non-arbitrary relationship between form and meaning can be found in portmanteau words and phonaesthemes. Portmanteaus are a type of word whose form and meaning is derived by the combination of two or more distinct forms (e.g., smoke + fog = smog; breakfast + lunch = brunch), so that the meaning of the new item can be obtained, in part, from the meaning of two blended forms (for examples of portmanteaus see the poem Jabberwocky by Lewis Carroll, 1872/1970). Thus, there will be an idiosyncratic relationship in both form and meaning between a portmanteau word and each of its constituents (e.g., brunch-lunch and brunch-breakfast).

Clusters of semantically related words can also be identified which share only some components of their sound structure (e.g., *gl*itter, *gl*isten, *gl*ass, *gl*eam; *sn*out, *sn*ort, *sn*eeze, *sn*iffle); such words are known as phonaesthemes. Speculative accounts of why particular form patterns are paired with particular meanings have been proposed (e.g., sn- words pertain to the nose because of the shape of the mouth and nose during their pronunciation). However, while the relationship between form and meaning for these sets of words is strong, it is also unsystematic. While pairs of phonaesthemes will be related in both form and meaning (e.g., snort-sneeze), this form-meaning relationship may have more exceptions than consistent exemplars (e.g., snail, snake, snatch, snow do not pertain to the nose). Shared components of phonaesthemes (e.g., sn-) are also unlikely to generalise to new forms.

For Experiment 2, we developed a set of items which do not have a synchronic morphological relationship, yet share orthographic and semantic properties. This set of items was comprised of portmanteau words and phonaesthemes, as well as other pairs which, although not clearly categorised in either class, also share an idiosyncratic relationship between meaning and form. It included some pairs of words which shared onsets (e.g., nose-nostril) and some which shared codas (e.g., fondle-handle).

In summary, we compared priming effects across the same three SOA conditions used in Experiment 1 (43 ms, 72 ms, and 230 ms) for morphologically, semantically, and orthographically related items [(+M+S+O) e.g., adaptable-ADAPTER], semantically and orthographically related items [(–M+S+O) e.g., screech-SCREAM], semantically related items [(–M+S–O) e.g., pygmy-DWARF], orthographically related items [(–M–S+O) e.g., typhoid-TYPHOON], and identical items (e.g., church-CHURCH). If morphological information plays a role in visual word recognition over and above a simple addition of semantic and orthographic information, then we would expect greater priming for morphologically related items than for semantically and orthographically related items. Moreoever, we expected to observe the same effects across time for semantically related pairs and for orthographically related pairs—namely, semantic priming occurring only in longer SOA conditions and orthographic effects tending toward inhibition in longer SOA conditions—as we observed in Experiment 1.

Method

Subjects. Seventy-four subjects who met the characteristics described in Experiment 1 participated in the experiment. Twenty-six of these subjects were tested in the short (43 ms) SOA condition, and twenty-four subjects were tested in each of the other (72 ms and 230 ms) SOA conditions. None of the subjects participated in Experiment 1.

Stimuli. One hundred and fifty-six prime-target pairs were chosen from the CELEX database of English wordforms (Baayen et al., 1993) which were grouped into five conditions: (a) morphologically, orthographically, and semantically related (+M+S+O) e.g., adaptable-ADAPTER, *N* = 30; (b) orthographically and semantically related, but morphologically unrelated (–M+S+O) e.g., screech-SCREAM, *N* = 30; (c) semantically related, but morphologically and orthographically unrelated (–M+S–O) e.g., pygmy-DWARF, *N* = 32; (d) orthographically related, but semantically and morphologically unrelated (–M–S+O) e.g., typhoid-TYPHOON, $N = 32$; (e) identical e.g., church-CHURCH, $N = 32$. Stimuli are contained in Appendix B.

Semantic relatedness was assessed by means of pretest and LSA (Landauer & Dumais, 1997). Prime-target pairs selected for the semantically related conditions (+M+S+O, –M+S+O, and –M+S–O) were given average ratings by a further 14 subjects (who did not participate in the main experiment) of over 7.0 on a 9-point scale with 9 representing "very related in meaning". Those pairs selected for the condition in which pairs had only an orthographic relationship (–M–S+O) received an average rating of 1.4 on the 9-point scale, with 1 representing "very unrelated in meaning". The extent to which primes and targets were judged as semantically related did not differ significantly across any of the three "semantically related" conditions (+M+S+O: 7.38; –M+S+O: 7.41; –M+S–O: 7.56, $F < 1$). Similarly ratings obtained by calculating the cosine of the angle contained between 300-dimensional prime and target vectors from the LSA comparison facility (http://lsa.colorado.edu) were broadly consistent with those obtained via pretest, $r = .262$, $p < .05$. Like the similarity ratings produced by human subjects, the LSA similarity measurements showed no differences across the three "semantically related" conditions, $F(2, 70) = 2.30$, $p > .10$.

We endeavoured to select items such that the nature of the form relationship in the three +O conditions was equivalent. Whereas orthographically related primes and targets in Experiment 1 always shared beginnings (e.g., electrode-ELECT), the scarcity of –M+S+O items in the set of English words required us to select two types of items for inclusion in Experiment 2: items which shared beginnings (e.g., nose-NOSTRIL) and items which shared endings (e.g., fondle-HANDLE). As such, the +M+S+O and –M–S+O conditions also included items which shared beginnings (e.g., sadly-SADNESS; dominate-DOMINO) and items which shared endings (e.g., remount-DISMOUNT; ferret-CLARET). Matching constraints also required that we use primes and targets in the +M+S+O condition which were both derivationally complex (e.g., sadly-SADNESS), unlike Experiment 1 in which we used complex primes and target stems (e.g., sadly-SAD).

Orthographic relatedness between primes and targets was measured as the average proportion of concatenative letters in the prime also in the target and vice versa, relative to word length; this measure produced a rating of 1.0 for identical pairs and 0.0 for entirely unrelated pairs. For example, the pair adaptable-ADAPTER shares five concatenative letters, so the proportion overlap was calculated as $(5/9 + 5/7)/2$. Proportion overlap calculations for the four non-identity conditions were 0.62 for the morphologically related items, 0.63 for the semantically and orthographically related items, 0.00 for the semantically related items, and 0.63 for the orthographically related items.

Targets across the five conditions were matched as closely as possible on a number of variables including frequency, length, and neighbourhood size. Average values for these variables across the five conditions are displayed in Table 3. Despite our efforts in matching target items on these variables, a significant difference on length, $F(4, 151) = 2.84, p < .05, MSE = 1.22$, remained. Therefore, we treated length as a covariate in the analyses of the data.

Control primes for each of the 156 target words were created that bore no morphological, semantic, or orthographic relationship to the target, and had an equal number of letters to the related primes. Seventy-eight additional prime-target pairs which did not have any morphological, semantic, or orthographic relationship were created as fillers so as to reduce the relatedness proportion in the experiment to 33%.

Two hundred and thirty-four prime-nonword target pairs were created for the lexical decision task. All nonword targets were primed with words. Since subjects saw 62 word prime-target pairs that had an orthographic relationship, 62 of the nonword prime-target pairs also had an orthographic relationship (e.g., lunatic-LUNARD). The remainder of the nonword target items were primed with orthographically unrelated words.

In total, there were 468 prime-target pairs, 234 of which were word targets and 234 of which were nonword targets. Target items were divided into two lists of 78 items each. Details regarding counterbalancing procedures and stimulus presentation/data recording apparatus are described in Experiment 1.

Procedure. Twenty-six subjects were tested in the short SOA condition (43 ms), and 24 subjects were tested in each of the other SOA conditions (72 ms and 230 ms). All other procedural details regarding this Experiment were the same as in Experiment 1.

TABLE 3

Stimulus characteristics in Experiment 2

Condition	*Frequency*	*N*	*No. letters*
+M+S+O (adapter-ADAPTABLE)	7.33	1.27	6.83
–M+S+O (screech-SCREAM)	7.07	1.70	6.00
–M+S–O (cello-VIOLIN)	18.06	3.34	6.06
–M–S+O (typhoid-TYPHOON)	18.38	2.22	6.38
ID (church-CHURCH)	16.59	2.21	6.16

Note: M, morphological; S, semantic; O, orthographic.

Results

Data were collected and cleaned in several ways. First, six subjects were removed for slow or error-prone responses relative to the other subjects: two subjects were removed (one from the middle SOA condition and one from the long SOA condition) for error rates on target items of over 20%; two subjects were removed (both from the short SOA) for false positive rates of over 15%; and two subjects were removed (one from the short SOA and one from the middle SOA) for average nonword RTs of over 1000 ms. Second, complete target data for all SOA conditions were plotted and outlying RTs were removed; in total, 77 data points over 1600 ms (0.38% of the data) were removed.[1] Finally, data from six target items which produced average error rates of over 35% were excluded: these items were *stiffish*, *sprig*, *coerce*, *redo*, *mingy*, and *pooch*. Complete item data are presented in Appendix B.

Data were then analysed in a mixed-design ANOVA with four factors—condition, priming, list, and SOA. In the by-subjects analysis, condition and priming were treated as repeated factors whilst list and SOA were treated as unrepeated factors. In the by-items analysis, priming and SOA were treated as repeated factors whilst list and condition were treated as unrepeated factors. Length was treated as a covariate in the by-items analysis. Subject means for the latency and error data are shown in Table 4.

TABLE 4
Latency and error data for Experiment 1, by subjects

		SOA		
Condition		*43 ms*	*72 ms*	*230 ms*
+M+S+O	Primed	651 (6.78%)	666 (7.14%)	690 (5.26%)
	Unprimed	695 (6.52%)	697 (11.50%)	728 (11.00%)
−M+S+O	Primed	635 (8.09%)	645 (10.82%)	684 (8.22%)
	Unprimed	650 (7.27%)	649 (13.73%)	718 (10.00%)
−M+S−O	Primed	616 (6.61%)	625 (8.00%)	635 (5.39%)
	Unprimed	617 (5.09%)	625 (9.32%)	663 (5.17%)
−M−S+O	Primed	626 (5.57%)	643 (8.09%)	683 (5.65%)
	Unprimed	618 (6.00%)	629 (6.55%)	682 (5.52%)
ID	Primed	568 (1.57%)	550 (1.96%)	582 (2.17%)
	Unprimed	621 (4.13%)	603 (3.59%)	637 (3.26%)

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[1] Reaction times in this experiment were generally longer than were those in Experiment 1. Since application of the RT cutoff used in Experiment 1 (1400 ms) would have been too severe, we used in Experiment 2 a cutoff of 1600 ms, in an attempt to discard approximately the same percentage of data points.

Since again we were interested specifically in priming effects, we report only those main effects and interactions with the priming variable. The ANOVA showed a main effect of priming both by subjects, $F(1, 62) = 39.61$, $p < .001$, $MSE = 2157.94$, and by items, $F(1, 139) = 33.82$, $p < .001$, $MSE = 3510.30$. This main effect of priming was qualified, however, by an interaction between priming and condition, both by subjects, $F(4, 248) = 12.48$, $p < .001$, $MSE = 1629.61$, and by items, $F(4, 139) = 9.76$, $p < .001$, $MSE = 3510.30$, since the amount of priming in the experiment varied as a function of condition. This priming by condition interaction was not qualified by a three-way interaction between priming, condition, and SOA, both Fs < 1.

The nature of the priming by condition interaction is apparent in Figure 2 which plots priming effects in each condition across SOA, with asterisks denoting statistically significant priming effects.

We were particularly interested in whether morphological priming effects could be the result of a simple addition of semantic and orthographic priming effects, and consequently, whether target recognition would be facilitated to the same degree when primes shared meaning and orthography with targets as when primes also shared a morphological

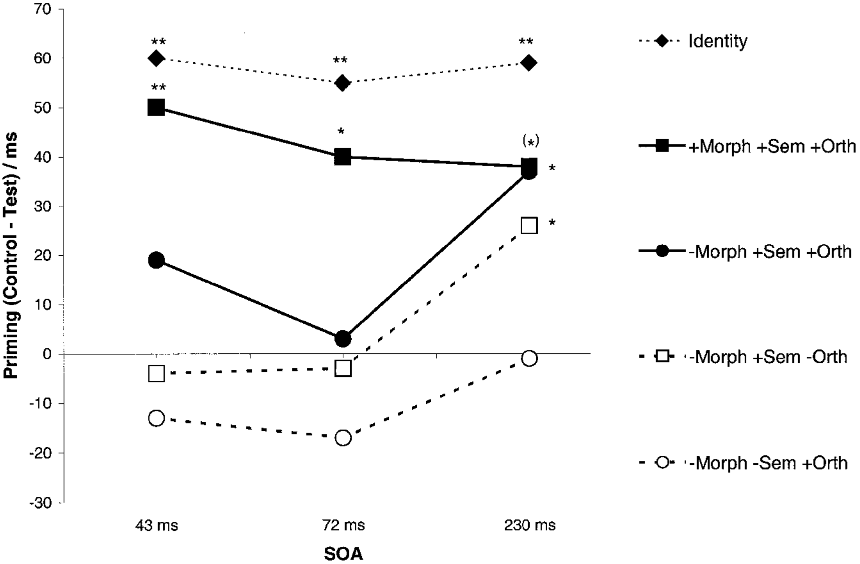

Figure 2. Priming effects in Experiment 2 as a function of relatedness condition and SOA, by items. Double asterisks indicate significance at the $p < .01$ level for both subject and item analyses; single asterisks indicate significance at the $p < .05$ level for both subject and item analyses; asterisks in parentheses indicate significance either by subjects or by items only.

relationship with targets. An inspection of the priming effects reported in Figure 2 suggest that (–M+S+O) pairs produced priming effects similar to (–M+S–O) pairs; both of these types of relationship produced priming effects only in the long SOA condition, not in the shorter SOA conditions. Pairs with a transparent morphological relationship (+M+S+O), however, produced significant priming effects in all SOA conditions.

Planned comparisons confirmed that in the two short SOA conditions, –M+S+O pairs produced effects more like –M+S–O pairs than +M+S+O pairs. In these SOA conditions, priming effects for –M+S+O pairs did not differ significantly from priming effects for –M+S–O pairs, (F_1 = 1.06; $F_2 < 1$), but *did* differ significantly from priming effects for +M+S+O pairs, [$F_1(1, 41) = 4.98$, $p < .05$, $MSE = 1781.40$; $F_2(1, 51) = 6.02$, $p = .018$, $MSE = 2769.88$].

Posthoc analyses were carried out to determine whether the amount of priming in the +O conditions (+M+S+O, –M+S+O, –M–S+O) varied as a function of whether the orthographically related segment was at the beginning or end of the word (e.g., beginning: *happi*ly-*happi*ness, *domin*ate-*domin*o; end: pre*heat*-re*heat*, di*rect*-cor*rect*). Analyses revealed no effects of this variable on priming in any of the relatedness or SOA conditions (all Fs < 1.20).

Error analyses were conducted in the same way as were the latency analyses. A main effect of priming emerged in the error analysis by subjects, $F(1, 62) = 5.24$, $p < .05$, $MSE = .0042$, but failed to reach significance in the by-items analysis, $F < 1$. Neither the interaction between condition and priming, nor the interaction between SOA, condition, and priming reached significance in either the by-subjects or the by-items analysis. Because the main effect of priming was marginal and because there were no interactions between priming and any of the other factors, we did not conduct further analyses on the error data.

Discussion

In Experiment 2, we replicated and extended findings from our first experiment. Once again, we observed morphological priming effects—this time with transparent derivationally complex primes *and* targets—in the absence of semantic priming effects and in the absence of orthographic priming effects in short SOA conditions. We also observed semantic priming effects only when primes were consciously appreciated, and a total absence of orthographic priming effects throughout all SOA conditions. Furthermore, we have extended our findings to exclude the possibility that the morphological priming observed in Experiment 1 was due to a *simple addition* of semantic and orthographic effects. Here, we have shown that in short SOA conditions, morphological priming effects are observed over and above priming effects for targets which share only a semantic and an orthographic relationship with their primes. In the following section we will discuss the implications of this pattern of results for accounts of morphological representation and processing.

GENERAL DISCUSSION

We have reported priming effects of English derivational morphology in masked conditions that cannot be attributed to semantic similarity, orthographic similarity, or a simple summation of semantic and orthographic similarity. These results suggest that the English visual word recognition system is characterised by a process or level of representation at which morphemes are treated differently from whole words. Here, we discuss how these results might be accommodated within two approaches to theorising about the nature of the language system—a "localist" approach built around the concept of the lexical entry and a distributed, connectionist approach.

The classical approach

A popular approach to derivational morphology across languages has been one in which knowledge is represented explicitly in a system of interconnected lexical nodes (e.g., Marslen-Wilson et al., 1994; Schreuder & Baayen, 1995; Taft, 1994; Taft & Forster, 1975). The theory we will focus on here (Marslen-Wilson et al., 1994) is concerned in particular with the role of morphological and semantic relationships in determining the properties of lexical representations. Marslen-Wilson et al. (1994) proposed that derivational morphological relationships are stored explicitly so that words like *punishment* and *punish* share the same lexical stem, the abstract morpheme {punish}. However, this shared representation applies only to morphologically related items that also share meaning. Words like *department*, although formed out of two morphemes, would not be lexically decomposed into a stem and an affix since the stem *depart*, is not transparently semantically related to the complex word: {depart} + {ment} does not yield the correct meaning for *department*.

Within this theory, the pattern of data that we have reported—specifically, early priming effects for identical pairs and for transparent morphologically related pairs accompanied by later semantic priming and orthographic interference effects—can be interpreted as the result of events which occur, respectively, *within* lexical entries and *between* lexical entries. We believe that effects in masked priming occur when primes and targets share overlapping representations (e.g., Frost et al., 1997, though see Masson & Isaak, 1999, for arguments favouring a nonlexical locus for masked priming effects). Thus, those prime-target pairs which share the same lexical stem, and therefore have overlapping lexical entries, such as the +M+S+O pairs in Experiments 1 and 2, should show significant facilitation in masked priming, while pairs which do not share a lexical stem will show priming effects (facilitatory or inhibitory) only at later stages of visual word recognition. Consistent with this conceptualisation, we found robust priming effects at short SOAs for morphologically complex items which bore a semantically transparent relation and for the identical pairs.

Of course, if further research confirms the existence of priming effects for semantically opaque complex items (e.g., department-DEPART) at short SOAs, then some augmentation of the Marslen-Wilson et al. (1994) theory may be required. On that account, it is not clear what the locus of these priming effects might be, since according to that theory morphologically related but semantically opaque items do not share a common stem and hence do not have overlapping lexical representations.

The connectionist approach

Another theoretical approach that has been fruitfully applied to simulating a number of aspects of the language system is parallel distributed processing, or connectionism. Linguistic processing, by this approach, consists of quasi-regular mappings between different domains of representation. These mappings are typically simulated in a distributed system of simple processing units joined by weighted connections trained using a standard learning algorithm such as back-propagation (e.g., Rumelhart, Hinton, & Williams, 1986). Connectionist models have been applied in theorising about the quasi-regular mapping that exists between the phonology of verb stems and past-tenses in English (MacWhinney & Leinbach, 1991; Plunkett & Marchman, 1991, 1993; Rumelhart & McClelland, 1986). These accounts suggest that a single system is capable of learning both regular and irregular forms of inflectional morphology—though these single mechanism accounts remain controversial (Pinker & Prince, 1988; Prasada & Pinker, 1993).

In a connectionist account of derivational morphology, however, the regularities that are of interest exist in the mapping from form to meaning (see Plaut & Gonnerman, this issue; Rueckl, Mikolinski, Raveh, Miner & Mars, 1997). Although this form-meaning mapping is predominantly arbitrary, semantically transparent derived words form *islands of regularity*, since the meaning of a stem such as “dark” is preserved in derivationally related words such as “darkness” or “darkly”. In learning the form-meaning mapping, a connectionist network will develop highly similar internal representations for stems and semantically transparent derived words (see the discussion of componential and non-componential attractors in Plaut, McClelland, Seidenberg, and Patterson, 1996, pp. 82–91, and also Davis, Marslen-Wilson, and Hare, 1996, for an equivalent demonstration in the context of inflectional morphology). Differences in the lexical representation of semantically transparent and opaque derived forms will therefore arise as an emergent property of a system mapping from form to meaning. If priming effects are diagnostic of overlapping representations for the prime and target word then this distributed account would predict that greater facilitation be observed for semantically transparent items than for semantically opaque words (as observed in our study and also by Marslen-Wilson et al., 1994).[2]

If morphological priming effects arise through these overlapping internal representations (see Plaut & Gonnerman, this issue; Rueckl et al., 1997), one might expect equivalent priming effects for pairs of words which share a corresponding degree of semantic and orthographic overlap, such as the screech-SCREAM pairs used in Experiment 2. It might then be argued that the clear failure to find priming for those types of items in the presence of priming for derivationally related items poses a challenge to the connectionist approach.

However, in our view, such an argument is based upon a misunderstanding of the computational properties of connectionist models. Even though word pairs like screech-SCREAM or brunch-LUNCH share form and meaning, we would argue that a network would not develop overlapping internal representations for these pairs to the same degree as for semantically transparent derivational pairs. Rather, the consistency of the form-meaning mapping across *all* words in the language-user's vocabulary must be considered to make predictions regarding the connectionist account.

In the case of phonaesthemes such as screech-SCREAM, for example, there are only a small number of words that share a consistent form-meaning pairing ("scritch" being perhaps the only example in the Oxford English Dictionary) while there will be many more items that have the same form but lack the core meaning of the phonaestheme (screen, screw, script, etc.). Similarly, for portmanteaus like "brunch" there are only two other words that share any form and meaning—i.e., the specific pair of words out of which the portmanteau is formed (in this case breakfast and lunch). Other items that have similar forms are unlikely to be at all related in meaning to brunch (e.g., brunch, crunch, hunch or brain, branch, break).

In contrast, for morphologically complex words, the relationship between form and meaning is much more consistent. For an example

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[2] A more difficult problem may be to simulate priming effects for semantically opaque words at short SOA conditions which are attenuated at longer SOAs—if that pattern of data (which was suggested in this work) proves reliable.

stem from our experimental materials (clean), there are many semantically transparent words that can be derived by adding either a suffix (cleaner, cleanly, cleanness), a prefix (reclean, unclean), or both (uncleanness)—and typically very few semantically opaque forms.

Since a “critical mass” of words sharing a consistent form-meaning mapping is required to allow the development of overlapping internal representations in a distributed connectionist network (cf. Plunkett & Marchman, 1993), we would not expect equivalent priming effects for pairs that share an idiosyncratic relationship between form and meaning as for transparent, morphologically related words that typically have a large family of consistent exemplars. Thus, while the results of our Experiment 2 have falsified an account of morphological priming based upon a simple addition of semantic and orthographic effects, it should be clear from the previous discussion that they do not rule out a connectionist approach.

However, current connectionist simulations of phenomena in the processing of derivational morphology (see for instance, Rueckl et al., 1997; Plaut & Gonnerman, this issue) are limited in both the number and type of morphologically related forms that can be processed. Until more sophisticated models are implemented which can accurately capture the statistical structure of the language, connectionism can represent only an approach to morphology. Greater theoretical sophistication must go hand in hand with larger scale simulations in order to evaluate the utility of the connectionist approach with respect to English derivational morphology.

Concluding remarks

In summary, in the two sets of experiments reported here, we have shown that effects of English derivational morphology cannot be reduced to semantic effects, orthographic effects, or a simple summation of semantic and orthographic effects. This finding therefore constitutes strong evidence in support of an account in which a morphologically structured level of representation plays an important role in the word recognition process. We have speculated on how classical and connectionist approaches might accommodate the findings that we have presented, and consider that the results presented here are compatible with either framework.

One point should be especially clear from this discussion and from the claims of others (see e.g., Frost et al., in press) regarding the utility of these approaches to theoretical psycholinguistics. There now exist clearly defined empirical phenomena across languages suggesting that morphology plays a role in the visual word recognition system. Despite their successes in the monosyllabic and generally monomorphemic domains, the major computational models of visual word recognition and reading aloud (e.g., Coltheart, Curtis, Atkins, & Haller, 1993; Plaut et al., 1996; Zorzi, Houghton, & Butterworth, 1998) have, as yet, very little to say about these phenomena. Work dedicated to extending each of these models into the domain of morphologically complex words is required not only to enlighten our understanding of morphological effects of the type reported here and to stimulate further empirical work, but also to help us to evaluate the viability of these different approaches to theorising about the nature of the language system.

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APPENDIX A

			SOA 1 *43 ms*		*SOA 2* *72 ms*		*SOA 3* *230 ms*	
Condition	*Target*	*Prime*	*Test*	*Con*	*Test*	*Con*	*Test*	*Con*
+M+S+O	vague	vagueness	576	562	619	632	610	627
+M+S+O	bleak	bleakly	543	668	588	625	598	691
+M+S+O	quick	quickly	517	544	586	528	538	560
+M+S+O	blunt	bluntly	636	684	644	606	655	585
+M+S+O	sad	sadness	536	603	517	557	496	594
+M+S+O	prison	prisoner	567	613	499	625	568	571
+M+S+O	farm	farmer	530	592	486	555	521	587
+M+S+O	sleep	sleepless	565	523	535	544	497	660
+M+S+O	fate	fateful	563	604	614	480	584	570
+M+S+O	cease	ceaseless	673	668	634	718	659	688
+M+S+O	blame	blameless	541	545	576	597	551	682
+M+S+O	bake	baker	525	649	613	610	559	651
+M+S+O	hunt	hunter	559	684	503	629	523	574
+M+S+O	swim	swimmer	546	636	494	578	628	633
+M+S+O	yellow	yellowish	530	594	490	609	604	549
+M+S+O	punish	punishable	565	601	543	667	535	591
+M+S+O	starve	starvation	592	605	495	585	641	657
+M+S+O	paint	painter	518	595	516	609	507	597
+M+S+O	dance	dancer	531	529	485	549	528	604
+M+S+O	discover	discovery	634	636	464	638	584	606
+M+S+O	confirm	confirmation	535	615	518	626	578	636
+M+S+O	depend	dependent	559	586	548	629	578	582
+M+S+O	rebel	rebellious	574	581	496	636	553	598
+M+S+O	select	selection	547	647	490	609	545	595
+M– S+O	audit	audition	649	600	674	612	732	712
+M– S+O	casual	casualty	614	579	591	548	626	581
+M– S+O	compete	competence	707	668	694	551	737	595
+M– S+O	design	designate	529	563	545	531	598	593
+M– S+O	list	listless	598	604	592	498	595	575
+M– S+O	organ	organise	594	559	592	607	638	658
+M– S+O	ration	rational	671	592	647	607	730	752
+M– S+O	seed	seedy	518	552	510	555	515	570
+M– S+O	virtue	virtual	552	616	658	597	705	757
+M– S+O	wit	witness	576	674	647	603	783	649
+M– S+O	crank	cranky	556	813	562	686	720	770
+M– S+O	blaze	blazer	566	572	579	524	694	678
+M– S+O	depart	department	564	573	511	600	605	620
+M– S+O	apart	apartment	631	726	680	704	651	694
+M– S+O	awe	awful	586	631	588	655	599	621
+M– S+O	fruit	fruitful	540	665	509	632	637	555

+M–S+O	author	authorise	525	564	491	670	684	657
+M–S+O	hard	hardly	519	532	504	583	520	531
+M–S+O	import	important	593	638	566	585	681	595
+M–S+O	create	creature	587	609	607	546	743	615
+M–S+O	patron	patronise	571	627	556	601	755	635
+M–S+O	court	courteous	629	649	538	565	594	617
+M–S+O	base	basement	506	612	495	600	576	729
–M+S–O	wealth	fortune	536	570	608	574	563	625
–M+S–O	profit	gain	669	664	572	619	595	610
–M+S–O	boss	chief	557	560	533	495	562	532
–M+S–O	ascend	climb	602	662	601	540	639	669
–M+S–O	wash	cleanse	545	632	517	567	532	551
–M+S–O	rule	law	624	587	557	553	552	649
–M+S–O	couch	sofa	677	570	675	596	650	588
–M+S–O	circle	ring	594	567	565	530	542	600
–M+S–O	ill	sick	591	646	620	574	558	690
–M+S–O	construct	build	622	644	593	560	562	739
–M+S–O	knock	bump	649	566	552	496	589	636
–M+S–O	battle	fight	552	585	537	520	495	586
–M+S–O	jacket	coat	553	543	500	568	535	627
–M+S–O	ban	forbid	672	566	541	671	623	675
–M+S–O	tremble	shiver	584	622	546	628	636	575
–M+S–O	honour	glory	628	628	492	557	594	550
–M+S–O	feeble	weak	722	637	656	675	644	666
–M+S–O	threat	menace	578	578	539	622	623	530
–M+S–O	scotch	whisky	630	676	528	598	607	625
–M+S–O	paper	card	567	595	511	498	494	554
–M+S–O	sob	weep	715	672	560	659	632	610
–M+S–O	pie	tart	544	575	504	521	659	530
–M+S–O	dart	arrow	583	631	578	589	551	612
–M+S–O	lane	alley	546	538	522	598	606	679
–M–S+O	elect	electrode	706	682	790	585	820	792
–M–S+O	enter	enterprise	549	551	522	520	629	557
–M–S+O	art	artery	554	566	534	571	553	606
–M–S+O	bell	belly	573	559	555	530	611	594
–M–S+O	bullet	bulletin	518	605	595	559	593	590
–M–S+O	car	cardiac	586	556	545	545	522	576
–M–S+O	tape	tapestry	547	558	584	581	495	551
–M–S+O	rub	rubber	590	577	549	582	689	669
–M–S+O	stride	strident	607	645	628	684	668	672
–M–S+O	tail	tailor	559	570	547	485	525	573
–M–S+O	stamp	stampede	573	610	645	499	585	561
–M–S+O	chap	chapter	720	703	638	654	619	630
–M–S+O	corn	corner	639	609	522	580	629	595
–M–S+O	harm	harmony	540	625	571	603	642	601
–M–S+O	mess	message	666	629	577	547	618	587
–M–S+O	sock	socket	556	590	495	561	573	561
–M–S+O	brand	brandy	535	659	645	633	645	624
–M–S+O	tent	tentacle	538	579	499	530	590	526
–M–S+O	demon	demonstrate	536	615	558	640	645	554
–M–S+O	colon	colony	682	703	606	707	779	674

–M–S+O	accord	accordion	565	627	555	604	672	635
–M–S+O	intern	international	719	659	637	680	857	787
–M–S+O	dial	dialect	631	636	519	596	604	554
ID	accent	accent	513	538	529	564	539	644
ID	beard	beard	579	527	605	543	603	625
ID	beauty	beauty	523	581	551	515	533	495
ID	block	block	554	582	520	487	576	617
ID	brain	brain	541	596	495	559	491	591
ID	breath	breath	546	551	509	517	564	563
ID	camera	camera	557	601	523	549	521	560
ID	cape	cape	547	640	624	578	532	576
ID	canal	canal	558	566	554	537	517	626
ID	cent	cent	675	753	633	673	607	739
ID	cobble	cobble	675	608	644	646	611	698
ID	metal	metal	485	521	531	529	542	600
ID	frail	frail	632	606	575	538	580	625
ID	fury	fury	575	619	546	572	593	607
ID	pocket	pocket	533	532	456	544	549	586
ID	play	play	479	581	436	533	501	543
ID	gift	gift	540	559	456	549	507	575
ID	humble	humble	619	627	515	630	642	563
ID	idol	idol	539	637	534	614	550	647
ID	inn	inn	560	677	561	596	600	624
ID	met	met	562	661	594	704	655	700
ID	messy	messy	501	586	520	585	570	577

APPENDIX B

			SOA 1 43 ms		*SOA 2 72 ms*		*SOA 3 230 ms*	
Condition	*Target*	*Prime*	*Test*	*Con*	*Test*	*Con*	*Test*	*Con*
+M+S+O	redness	reddish	611	612	593	734	628	759
+M+S+O	unset	reset	824	743	678	722	995	849
+M+S+O	coolness	coolly	642	536	644	692	703	687
+M+S+O	darkly	darkness	535	767	600	762	656	716
+M+S+O	baker	bakery	601	613	571	592	557	666
+M+S+O	falsify	falsely	666	758	807	864	705	780
+M+S+O	firmness	firmly	657	593	575	666	570	692
+M+S+O	happily	happiness	629	578	589	608	603	656
+M+S+O	huntable	hunter	597	763	714	791	777	836
+M+S+O	learnable	learner	626	669	766	694	657	791
+M+S+O	loudness	loudly	558	607	520	591	603	638
+M+S+O	paintable	painter	660	820	729	761	681	940
+M+S+O	preheat	reheat	732	743	752	842	649	776
+M+S+O	purely	purify	742	691	688	712	769	711
+M+S+O	adapter	adaptable	666	818	728	751	869	766
+M+S+O	bitterly	bitterness	727	734	722	775	719	766

+M+S+O	refold	unfold	727	770	736	710	689	870
+M+S+O	relock	unlock	713	862	798	833	646	790
+M+S+O	remount	dismount	766	833	700	746	754	832
+M+S+O	repay	prepay	651	685	637	654	672	621
+M+S+O	roughly	roughness	550	674	621	647	744	653
+M+S+O	sadly	sadness	513	615	582	566	608	568
+M+S+O	slowish	slowly	703	797	901	774	698	860
+M+S+O	snobbish	snobby	623	628	594	711	699	747
+M+S+O	swimmer	swimable	656	714	566	670	750	649
+M+S+O	toughly	toughness	686	720	583	721	752	682
+M+S+O	unable	disable	589	578	623	590	685	619
+M+S+O	cleaner	cleanly	614	741	641	590	687	646
–M+S+O	brunch	lunch	617	753	686	795	710	934
–M+S+O	bustle	hustle	678	724	580	601	805	766
–M+S+O	converge	merge	544	620	665	689	606	736
–M+S+O	crinkle	wrinkle	703	733	758	699	738	680
–M+S+O	devil	evil	505	564	539	529	521	642
–M+S+O	flood	float	488	576	607	566	543	651
–M+S+O	flutter	flurry	660	637	589	662	797	828
–M+S+O	fondle	handle	732	688	705	634	724	750
–M+S+O	freeze	frost	584	591	524	587	600	640
–M+S+O	ghost	ghoul	555	543	500	572	573	614
–M+S+O	gleam	glint	707	667	632	721	826	772
–M+S+O	groan	grumble	642	623	566	632	546	783
–M+S+O	loathe	loath	634	688	631	639	617	737
–M+S+O	mohair	hair	696	764	724	716	732	720
–M+S+O	hotel	motel	499	561	545	514	565	535
–M+S+O	nostril	nose	583	599	554	629	637	665
–M+S+O	placard	card	662	759	861	729	833	799
–M+S+O	plunge	plummet	655	659	617	691	722	644
–M+S+O	scald	scorch	765	743	793	659	701	779
–M+S+O	scrape	scratch	687	590	682	640	730	630
–M+S+O	screech	scream	760	640	775	646	787	823
–M+S+O	shelve	shelf	539	543	649	608	789	682
–M+S+O	shrivel	shrink	552	667	616	683	654	856
–M+S+O	crumple	rumple	796	727	731	716	736	733
–M+S+O	slither	slink	742	709	764	707	771	793
–M+S+O	spam	ham	657	654	605	685	719	729
–M+S+O	shimmer	glimmer	610	734	715	732	687	744
–M+S–O	pygmy	dwarf	705	753	741	671	803	721
–M+S–O	awkward	clumsy	703	662	749	731	617	663
–M+S–O	bud	flower	722	587	640	660	587	718
–M+S–O	bump	knock	658	558	597	626	633	663
–M+S–O	cancel	stop	517	552	498	527	576	634
–M+S–O	drench	soak	716	677	604	645	586	883
–M+S–O	chair	stool	558	626	652	524	523	605
–M+S–O	dominant	supreme	670	630	665	642	628	692
–M+S–O	chore	duty	683	703	674	683	687	755
–M+S–O	compost	manure	538	629	580	607	583	688
–M+S–O	corpse	mummy	702	568	689	675	627	656
–M+S–O	detergent	soap	653	689	577	734	652	623

–M+S–O	evidence	proof	551	599	628	577	546	635
–M+S–O	pursue	follow	609	663	675	747	621	716
–M+S–O	gut	bowel	614	591	624	558	554	677
–M+S–O	hare	bunny	612	655	615	692	625	704
–M+S–O	infant	child	552	569	531	596	635	568
–M+S–O	jovial	merry	702	719	705	759	696	780
–M+S–O	pledge	oath	573	594	641	634	608	631
–M+S–O	banish	deport	690	683	662	619	657	617
–M+S–O	gamble	risk	582	526	556	618	672	713
–M+S–O	scandal	gossip	532	580	536	618	610	644
–M+S–O	stomach	belly	555	527	546	529	631	549
–M+S–O	swallow	digest	571	542	592	501	589	545
–M+S–O	sweetie	lolly	778	723	819	637	806	728
–M+S–O	muzzle	gag	660	643	713	603	693	664
–M+S–O	fellow	mate	537	637	577	535	646	646
–M+S–O	corridor	passage	548	549	579	642	602	616
–M+S–O	wild	feral	568	515	517	572	627	551
–M+S–O	shrewd	canny	675	682	710	627	688	653
–M+S–O	carnival	fete	567	569	610	629	732	620
–M–S+O	aspire	aspirin	593	625	810	622	699	651
–M–S+O	batter	patter	573	559	672	619	722	619
–M–S+O	butter	button	537	543	520	595	547	672
–M–S+O	cabin	cabbage	753	612	615	610	616	663
–M–S+O	dandruff	dandy	565	623	594	641	615	848
–M–S+O	direct	correct	547	535	547	567	590	651
–M–S+O	dominate	domino	571	577	627	676	679	751
–M–S+O	elegant	elephant	779	570	637	620	673	731
–M–S+O	ferret	claret	769	727	719	700	800	846
–M–S+O	galley	gallon	722	625	544	652	807	672
–M–S+O	typhoid	typhoon	727	648	701	767	749	745
–M–S+O	lavatory	lavender	552	697	658	585	615	764
–M–S+O	lizard	wizard	543	602	616	649	648	697
–M–S+O	medley	medal	801	727	639	774	800	795
–M–S+O	memory	member	523	526	575	513	542	604
–M–S+O	terrace	grace	622	582	722	562	688	669
–M–S+O	merger	mercy	751	729	774	658	831	675
–M–S+O	tumor	tumble	706	622	756	697	844	728
–M–S+O	nimble	thimble	623	597	612	596	759	729
–M–S+O	fibre	calibre	619	598	676	686	649	645
–M–S+O	paradise	paradox	592	620	572	606	648	605
–M–S+O	remedy	remnant	553	608	611	646	673	665
–M–S+O	sarcasm	sardine	693	630	767	760	704	705
–M–S+O	scampi	scamper	661	751	763	759	650	699
–M–S+O	sentence	sentry	666	601	643	546	636	626
–M–S+O	shudder	rudder	634	627	604	648	741	687
–M–S+O	sister	fester	561	584	635	536	637	555
–M–S+O	sound	source	536	534	571	527	655	576
–M–S+O	tender	tendon	507	537	528	569	629	594
–M–S+O	drizzle	puzzle	686	640	755	653	769	645
–M–S+O	tinkle	tiny	603	735	696	593	716	688
–M–S+O	virtue	virtual	653	630	627	626	634	704

ID	honey	honey	570	496	553	522	538	563
ID	prize	prize	504	525	469	528	540	573
ID	catch	catch	509	560	503	574	492	671
ID	sword	sword	518	609	517	609	493	647
ID	yeast	yeast	493	600	490	546	561	659
ID	decay	decay	577	673	498	688	514	680
ID	drank	drank	581	808	593	666	660	792
ID	glare	glare	593	588	608	652	667	732
ID	goose	goose	524	560	523	533	507	626
ID	tango	tango	495	549	459	573	552	655
ID	prison	prison	482	577	465	631	549	592
ID	slight	slight	636	716	636	733	585	652
ID	heaven	heaven	514	556	516	547	504	650
ID	prayer	prayer	599	587	506	650	499	649
ID	basket	basket	583	617	455	531	495	645
ID	ripple	ripple	656	576	549	634	585	766
ID	beaker	beaker	699	689	568	749	794	748
ID	bellow	bellow	657	656	646	560	608	638
ID	opinion	opinion	546	604	550	574	605	622
ID	minimum	minimum	616	750	637	727	685	716
ID	uniform	uniform	502	529	564	579	551	528
ID	peasant	peasant	663	804	727	624	664	660
ID	conduct	conduct	557	572	496	534	586	563
ID	concert	concert	538	555	504	548	601	579
ID	actress	actress	541	675	520	540	560	574
ID	include	include	555	587	592	566	582	582
ID	portion	portion	524	590	628	567	605	631
ID	romance	romance	560	508	524	512	551	536
ID	nucleus	nucleus	595	730	574	869	651	674
ID	cushion	cushion	570	665	508	526	581	611
ID	massage	massage	536	667	632	525	543	598
ID	petition	petition	650	894	614	776	665	637